Waste/Circular Economy (CE) Analysis for the Enhancement of Nigeria's Nationally Determined Contribution (NDC) 2021-2025

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0.1 Acronyms

ACEF	African Clean Energy Finance
ACEN	African Circular Economy Network
ASGM	Artisanal and Small Scale Gold Mining
CCI	Clinton Climate Initiative
EU	European Union
EIA	Environmental Impact Assessment
EMS	Environmental Management System
EPR	Extended Producer Responsibility
FMOE	Federal Ministry of Environment
FMOH	Federal Ministry of Health
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft fur Internationale Zusammernarbeit GmbH
IBRD	International Bank for Reconstruction and Development
IRENA	International Renewable Energy Agency
IsDB	Islamic Development Bank
LAWMA	Lagos State Waste Management Agency
MMSD	Ministry of Mines and Steel Development
NDS	National Development Strategy
NESREA	National Environment Standards and Regulations Enforcement Agency
NIP	National Implementation Plan
PACE	Platform for Accelerating the Circular Economy
PCBs	Polychlorinated biphenyl
PCEH	Department of Pollution and Control and Environmental Health
PET	Poly Ethylene Terephthalate
PRO	Producer Responsibility Organization
POPs	Persistent organic pollutants
RGB	Recyclable Glass Bottle
NRGB	Non-Recyclable Glass Bottle
SON	Standard Organization of Nigeria
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
WB	World Bank
WEEE	Waste from Electrical and Electronic Equipment
WHO	World Health Organization

0.2 Executive Summary

Introduction

Climate change has become a serious wide-ranging issue that is currently hindering global growth and societal sustainability. Several measures have been undertaken to adapt and mitigate the resultant effects of climate change such as global warming through collaborations and initiatives by various governments and stakeholders-one of which is the 2015 Paris Agreement, which seeks to decrease global temperatures warming by reducing the amount of greenhouse gases (GHGs) released into the environment. The Nationally Determined Contributions (NDC) play a huge role in ensuring that this agreement is implemented as it outlines national plans of member nations and steps which they intend to execute to reduce GHGs in various sectors. A periodic revision of the NDCs is also required to provide updates and review activities that have been carried out. The Circular Economy (CE) is a strategy that propels a society towards generating no waste as all materials are maximally utilized in cyclic processes. It is intentionally designed and implemented to be incorporated in the production systems elongating the lifecycle of materials and phasing out the concept of 'waste' and this, in turn, leads to a reduction in GHG emissions and their impact on climate change.

This study was commissioned to analyze the impact of the CE in the waste management sector of Nigeria so that its outcome can be incorporated into the NDC revision 2021-2025. Its objectives included a review of the existing policies, regulations and projects in the country; an analysis of waste management projects highlighting the synergies and differences between circular economy -related initiatives; collection, collation and validation of relevant data for waste emissions estimation; simulation of waste and emission reductions; and the development of a list of results to be considered for the NDC revision.

Approach and Methodology

The study adopted multiple approaches to tracking Circular Economy in the waste management sectors through document reviews, engagements with relevant stakeholders in the public and private sectors, institutional surveys, data analysis and modelling.

Document review and analysis by project team of reports, publications and relevant websites of government and non-government agencies were made to identify existing waste management policies and projects from multiple stakeholders. The reviews mapped out the CE policy, legislative and institutional landscapes and activities currently in place in Nigeria to determine the CE attributes, synergies and differences of the various initiatives.

Data sets of Solid Waste Disposal Sites (SWDS) were obtained from the Federal Ministry of Environment for waste (in kg) characterized by states in Nigeria from 2007 - 2017. The data sets were further refined for consistency with the IPCC model utilized for emissions estimation from the waste sector. The data from SWDS were complemented with data obtained from other sources, namely; Population data and projections from the World Bank database; Industrial Waste data derived from GDP factored against waste generation rates. These were combined with assessments was made of the operations of the Extended Producer Responsibility (EPR) programme by a detailed questionnaire survey and interactive sessions with the Producer Responsibility Organizations (PROs) in four major waste streams, namely, Food and Beverage Alliance (FBRA), Electrical and electronics (EPRON), Plastics and Batteries (ARBR). The questionnaire utilized for the survey was designed among others, to delineate the waste reduction and emissions reduction potentials from the activities of these organizations. The data obtained from PROs were supplemented with secondary data from private sector players and the websites from donor partners and international development organizations dedicated to various waste streams. The information and data provided were validated in physical and virtual meetings with key stakeholders.

In conducting our waste emission modelling, we relied on the data sets obtained from the various identified sources. However, the primary data obtained from the Federal Ministry of Environment lacked emission factors like the fraction of Degradable Organic Carbon (DOC), it contained no DOC composition data for wood and the dataset has inadequate historical waste data for at least 50 years that are critical to accurately calculating methane emissions. In mitigating some of the gaps in the primary data source, we looked to secondary data sources to augment the activity data for modelling. To achieve this, we added new parameters like Fraction of DOC (DOCf), Methane correction factor (MCF), Half-life rate constant (k), and Wood composition data.

Municipal waste data modelling. The annual municipal solid waste (MSW) is computed as the population (millions) multiplied by the waste per capita per year (kg). Population estimates and population growth rate for Nigeria from 1960 - 20020 was obtained from the World Bank database. In estimating the population growth rate, we used the average growth rate over a rolling 10-year window to predict future population growth rate. For waste per capita modelling, Nigerians generate 0.58kg of solid waste per person per day [1]. To authenticate this secondary data source, [2] reports that the waste generation for low-income countries is 0.5 kg/capita/day. To compute the waste per capita, we evaluate 0.5 x 365.

Industrial waste modelling. Total industrial waste is computed as the gross domestic product (GDP, millions) multiplied by the waste generation rate (Gg/$m GDP/yr). To make GDP projections for the years 2020 - 2030, we used a recurrent neural network (RNN) deep learning model. RNNs are developed to solve learning problems where information about the past (i.e., past instants/events) are linked to making future predictions [3]. In this case, the model learns the underlying statistical structure of past GDP values to predict future GDPs. For waste generation rate, we calculate it as one-fifth of the total municipal solid waste (MSW) divided by the GDP for year at time t.

For Solid Waste Disposal Site (SWDS), we report estimates for methane (CH_4) from solid waste disposal sites (SWDS) as part of carbon accounting from the waste sector in Nigeria from 1960 2030. Various methods exist for estimating CH_4 emissions from SWDS. These methods are included in the First Order Decay (FOD) methods. In it, we assess three tiers for estimating CH_4 emissions from SWDS. Where in Tier 1, factors for estimating CH_4 emissions are mainly based on IPCC default activity data and default parameters. In Tier 2, emission accounting requires good quality country-specific activity data along but also allow for the use of some default parameters. And in Tier 3, estimations require the use of good quality country-specific activity data with either nationally developed key parameter or measurements derived from country-specific parameters. We choose Tier 2 because of our ability to collect and estimate good quality country-specific activity data on historical and current waste disposal.

Tier 2 emission estimate was therefore conducted using the IPCC FOD method with default parameters and country-specific activity data. The FOD method assumes that degradable organic carbon (DOC) in SWDS decays slowly over time forming CH_4 and carbon dioxide CO_2 in the process [4]. The method also assumes that emissions from CH_4 and CO_2 in SWDS are higher in the first few decades after waste is deposited and as time goes on, there is a steady decline in emissions because the degradable carbon in the waste is consumed by bacteria responsible for decay.

Results

Policy & Institutional Analysis. The outcome of the review of the CE policy and institutional landscape showed that the Nigerian legislation related to waste management had embedded circular economy procedures in policies such as the National Policy on Plastic Waste Management (2020) and National Policy on the Environment (2016). Also, out of the 33 environmental regulations outlined on the NESREA website excluding the Nigerian Constitution, 27 of them are waste related with 23 of these having circular economy features. The Institutional Architecture of the Waste Management sector was also highlighted giving details of the roles of various stakeholders in government, private sector, donor agencies and the NDC Development Partners. A robust organizational and institution for waste management exist across the three levels of government in Nigeria with a wide latitude for public private partnership (PPP).

Analysis of the waste management initiatives showed the existence of circular economy features in some existing projects, most of which are concentrated in the Lagos State axis. The Federal Government in collaboration with some State Governments has also initiated some circular-economy related waste management initiatives in the health, plastic, briquette, metal scrap, and sawmill sectors with mixed outcomes as some are working, and others are uncompleted or dysfunctional due to a range of issues. A thriving federal government private sector partnership in waste recycling and reduction with significant potential to bridge the circularity gap is the EPR-PRO arrangement along four major waste streams (Food & Beverage, Plastics, E-Waste and Batteries). Their waste recycling activities are presently in their infancy having been only established in 2018. The present level of circularity in the food and beverage sector is estimated at 10% and projected to rise to 30% in 2025 when they hope to have a national coverage in their operations. The circularity level for the Battery waste stream in the country is currently estimated at 80%, although the bulk of these are 'dirty' recyclers (with recycling processes that pollute the environment) in the informal sector. Clean Battery is recycling is associated with the PRO in Battery waste stream and large concerns such as Ibeto Factory. They are account for about 10% of recycling in the sector. The Battery PRO have their presence currently in Lagos and Ogun States and hope to have a nationwide coverage in 2025 with an ambition to attain 100% recycling in the sector. Lagos State Government through various PPP schemes have initiated circular CE related projects encompassing the processing, recycling and reduction of a wide range of waste streams. Development partners and donor agencies are also involved in waste management projects though most of these are targeted at capacity building for circular groups to drive the circular economy process and address the waste challenge at their point of generation. Private Sector initiatives are also in existence with a focus on the retrieval and recycling of waste items already generated by consumers.

Emission Estimation. The results of the FOD model in estimating CH_4 emissions from SWDS in Nigeria from 1960 2030 reports the estimated amounts of waste deposited in SWDS from municipal solid waste (MSW) and industrial categories annually from 1960 – 2030. It also reports the amount of CH_4 emitted from SWDS annually from 1960 – 2030 and provides information on the CH_4 emission from harvested wood products (HWP), and HWP carbon (C), long- term stored in SWDS. Regarding the amount of waste deposited in SWDS, our results show that in 1961, 4,977 Gg of MSW was estimated to be deposited in SWDS. Whereas, in 2020, 30,914 Gg of MSW was estimated to be deposited. We observed that there was a 521% increase in the amount of MSW deposited in SWDS within a 60-year interval from 1960 to 2020. We estimate that in the years 2021 and 2030, 35,854 Gg and 45,471 Gg of MSW will be deposited at SWDS, respectively.

The period between 2021 - 2030 shows a projected percentage increase of 28.51% of waste deposited in SWDS in Nigeria. For industrial waste deposited, our results shows that there has been an increase in the amount of industrial waste deposited during the 60-year period. Further, we observed that there was a 430% increase in the amount of Industrial waste deposited in SWDS within a 60 year interval from 1960 2020. We estimate that in the years 2021 and 2030, 9,453 Gg and 12,182 Gg of industrial waste will be deposited at SWDS, respectively. Coming to the annual CH_4 emissions from SWDS, using the FOD model, we estimated the amount of CH_4 emitted in 1961 was 77 Gg. Our results show that in 2020, 2,622 Gg of CH_4 was estimated to be generated and emitted in SWDS. Regarding CH_4 emissions from harvested wood products HWP, our results from the IPCC FOD model shows that from 1961 – 2020, estimated CH_4 emissions for garden had a percentage increase of 3265% within the 60-year interval. We observed that year 1971 - 1980 experienced a huge drop in percentage increase (47.37%) compared to the 10-year interval (1961 - 1970) before (451.52%).

Regarding biological treatment of solid waste in Nigeria, it is observed that Municipal Solid Waste Management is generally a challenge for developing countries like Nigeria due to a rapid increase in urban population among other challenges. We have been unable to run a model for the biological treatment of solid waste for Nigeria because the data simply does not exist. With respect to open burning of waste, it is the most common form of getting rid of waste in Nigeria [5]. Like other types of combustion, open burning is a major source of greenhouse gas emission. N_2O is largely emitted during open burning, hence, the need to estimate the N_2O emissions from open burning in Nigeria. Due to limited country-specific data, we used IPCC default values to generate N_2O emissions estimates for Nigeria from 1960-2020. We also projected the N_2O emissions from 2021 2030 (IPCC Guidelines Vol5 Ch5 p5.22, Table 5.6). The method used to estimate the CO_2 emissions from the amount of waste open burned is centred on an estimation of the fossil carbon contained in the waste burned, then multiplied by the oxidation factor, and then by converting amount of fossil carbon oxidised to CO_2.

To estimate CO_2 emissions from open burning of waste in Nigeria, the Tier 2a level was carried out because open burning is used as a key source of waste disposal in Nigeria. Due to a lack of data and default parameters for specific categories, only the CO_2 emissions from the open burning of paper, plastics and textiles in Nigeria were calculated. Our results depict that the estimated total amount of municipal solid waste open-burned was 301583.59 Gg in 1960. Whereas in 2020 the total amount of municipal solid waste open burned was 1599031.15 Gg. This shows there was a 430.21% increase in the total amount of municipal solid waste open-burned in Nigeria within a 60-year interval from 1960-2020.

Our results show the net N_2O emissions for open-burned waste was 45.24 Gg in 1960. Whereas in 2020 the net emission was 239.86 Gg. This shows there was a 430.21% increase in the net N_2O emissions from open-burned waste in Nigeria within a 60-year interval from 1960 to 2020. Our results show the net CO_2 emissions for open-burned waste in 1960 was 115.46 Gg, whereas, in 2020 the net CO_2 emission was 717.05 Gg. This shows that within the 60-year interval (1961 2020), there was a 521.02% increase in the total CO_2 emissions from open-burned waste in Nigeria.

Wastewater treatment and discharge is considered. Wastewater is any water that has been negatively affected in quality due to human activities [6]. Wastewater is a major source and contributor of CH_4 especially when treated or disposed anaerobically. The safe disposal of wastewater is still a major problem in Nigeria [7]. The chief factor in determining the potential of CH_4 generation of wastewater is the amount of degradable organic material present in the wastewater. This is done by using the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) parameters to measure the organic content of the wastewater. Our results show that in 1960, the net CH_4 emission was 126.65 Gg. In 2020, it is estimated that 640.73 Gg of CH_4 was emitted. We observed that there was a 405.91% increase in the net CH_4 emission totals for wastewater within a 60-year interval from 1961 to 2020.

In conducting waste data modelling, we considered the amount of E-Waste deposited. E-Wastes are unwanted electronic products that are not working or near the end of their useful life [8]. Computers, stereos, TVs, and copiers, and fax machines are most used electronic products. To estimate the total amounts of E-waste generated in Nigeria, a data model was built. Using this model, we were able to project the amounts of E-waste that will be generated from 2021 - 2030. We observed that year 1960 - 1970 recorded a percentage change of 38.40%. In 1960, the estimated amount of E-waste generated was 54.77 Gg, and within the next 20 years, the amount of E-waste generated had doubled, with the estimated amount 110.02 Gg in 1980. The highest percentage change per 10-year interval was in 1981- 1990 with a percentage increase of 38.82%.

For amount of medical waste deposited, we observed that year 1960 - 1970 recorded a percentage change of 15.44%. In 1960, the estimated amount of medical waste generated was 20.26 Gg. In 2020, the amount of medical waste generated was 131.89 Gg. The highest percentage change per 10 year interval was in 2011 2020 with a percentage increase of 30.99%.

In considering the amount of battery waste deposited, we found out that due to the rise of technological advancement and transportation in Africa, there is immense growth in the demand for lead batteries in developing countries. One component of vehicles that are often replaced are Lead acid battery [9]. In Nigeria, lead acid batteries (LAB) are used in automobile vehicles, motor bikes and lorries [10]. In the country, heavy metal contamination, around the informal ULAB recycling centers is a serious public health problem. To estimate the total amounts of battery waste deposited in Nigeria, data supplied from the Federal Ministry of Nigeria on Generation of ULAB and annual generation rate for ULAB batteries each year was used to build the data model. We observed that year 1960 1970 recorded a percentage change of 55.10%. In 1960, the estimated amount of ULAB waste generated was 24.75 Gg. In 2020, the amount of batteries waste (ULAB) generated was 322.98 Gg. In considering plastics waste, we observed that the year 1960 - 1970 recorded a percentage change of 21.60%. In 1960, the estimated amount of plastic waste deposited was 746.55 Gg. In 2020, the amount of Plastic waste deposited was 4637.1 Gg.

Emission Reduction Estimation. In conducting our waste emission reduction models, we considered organic waste reduction in terms of the amount of organic waste reduced from the environment due to recycling. In estimating the waste reduction, [11] we found the percentage of recycled organic waste weighted every two years from 2011 to 2022 (i.e. [2011-2013], [2014-2016] ... [2020-2022]) with a random stride of .1. To estimate organic waste reduction from 2023 to 2030, we projected that 13.82% of organic waste will be recycled. For plastics waste emission reduction, research reports that [12] 1000 tonnes (i.e., 0.9 Gigagrams) per annum of plastics are recycled.

Emission Reduction Consideration for NDC Revision. It has been shown that significant reduction in waste and emissions can be achieved between 2023 and 2030 if Nigeria achieves a recycling rate of at least 13.82%. However, there may be varying percentages in some sectors due to their peculiarities like e-waste (60%), batteries (80%), medical waste (16.9%) while plastics and organic waste can be set at least on the reference value of 13.82%. These reductions within this period will lead to a decrease in waste quantities in organic waste (4,000Gg), plastic waste (8,000Gg), e-waste (1,315Gg), battery (2,150Gg) and medical waste (400Gg). There will also be corresponding emissions reduction of 100Gg in organic waste and 2,667Gg in plastic waste within this period as well as e-waste, batteries and medical waste leading to an overall reduction in emissions as part of the circular economy contributions to emission reductions. However, the emission reduction data from the e-waste, batteries and medical waste in addition to other sectors on interest can be obtained along with their environmental implications when further research is carried out as an extension of this project.

These targets can be achieved by a nationwide strategy involving the revamping of non-operational existing facilities, installing new recycling plants, transitioning informal sector players to the formal sector, effective enforcement of legislation, capacity building and providing access to funds.

Chapter 1

Introduction

The United Framework Convention on Climate Change (UNFCCC) (2019) has identified climate change as the greatest challenge to sustainable development all over the world and its adverse effects are felt in various communities. It is therefore pertinent to act quickly and put an end to factors contributing to climate change while addressing its consequences on the environment. The United Nations Conference on Sustainable Development which took place in June 2012 at Rio de Janeiro developed a set of robust guidelines after a series of consultations with stakeholders from all over the world. These guidelines which consisted of 17 interdependent goals to attain global sustainability, known as Sustainable Development Goals (SDGs), were proposed in July 2014 to the United Nations General Assembly Open Working Group (OWG) to be achieved from 2015 to 2030.

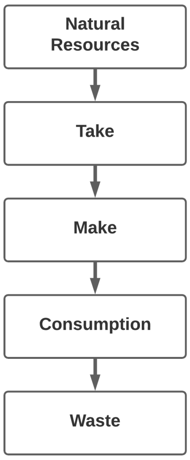
The SDGs were also made at the same time with the 2015 COP21Paris Climate Conference and 2015 Sendai Framework for Disaster Risk Reduction in Japan, which also formulated a set of guidelines and targets to reduce carbon emissions and tackle climate change issues and natural disasters.

In 2015, the Paris Agreement was created as the outcome of a meeting between 196 countries with the aim of developing a pathway to sustainable growth for the world and to reduce global warming by 1.5 to 2 degrees Celsius above pre-industrial limits. The stakeholders committed to long term goals of increasing climate resilience and adaptation measures to climate change challenges, reduce greenhouse gas emissions in such a way that it does not hinder agricultural outputs, and continuously support the financing of these goals.

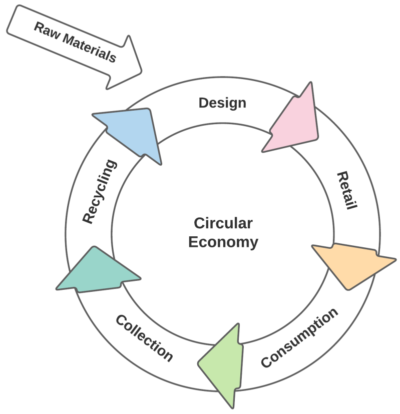
The Nationally Determined Contributions (NDCs) are central to the achievement of these objectives as they consist of proactive plans to be carried out by each nation in order to reduce its national emissions and enhance climate change adaption. The Article 4 and paragraph 2 of the Paris Agreement states that each member was to develop, manage and fully implement their own successive NDCs. As such, member countries were expected to create national mitigation plans which were to be developed and disseminated to highlight their respective climate actions to take place after 2020. These plans were then to be used collectively as an indicator to measure the status of the Paris Agreement goals, quicken the attainment of the maximum threshold of GHGs as quickly as possible, and catalyze the utilization of modern technological solutions.

The bulk of GHG gases (62%) are emitted from production systems while the remaining

(38%) are released into the environment during the logistics and utilization of goods and amenities. An increase in production over the years has compounded climate change as the demand for materials has greatly increased by 300% since 1970 and future projections of up to 200% by 2050 have been made if no measures are put it place (UNFCCC, 2019). Rethinking the modes of material production and consumption of goods and services in way that are socially, economically and ecologically sustainable necessitates a shift from linear to circular economy (see Figure 1.1a & 1.1b).



(a) Linear Economy



(b) Circular Economy.

Figure 1.1: Schematic Diagram of Linear and Circular Economy (End of Waste Foundation, 2021).

Circular economy processes aim to achieve zero waste in the lifecycle of materials thereby minimizing GHG emissions as low as possible. The Ellen-MacArthur Foundation (2013) gives a modern definition of the concept as "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models." It is an economic system with an intention to 'design out' waste from a product's lifecycle by continuously utilizing materials as long as possible after which they are eventually used to replenish the environment. Manufacturing is carried out with materials which can be recovered, reused and repaired instead of being discarded after a single use as it is the norm in a linear economy which is currently in use by many societies in the world.

Circularizing the waste sector and Revision of the Nationally Determined Contributions (NDCs)

The NDC is one of the measures put in place by countries to achieve climate resilient growth, and there has been a rising interest in Circular Economy (CE) initiatives which can foster this growth among governments and key stakeholders in the African landscape, with the African Development Bank working with its regional members to achieve this.

Key benefits of implementing circular economy strategies are its significant potentials to decrease current greenhouse gas emissions by up to 50% and reduction in the amount of materials, energy and waste used during production. The NDC highlights CO2 emission targets based on the population and economic growth of the country as well as various scenarios depending on the level of commitment it made. Nigeria is working towards emissions targets of 2 tonnes of CO2 emissions per capita and 0.491kg of CO2 emissions per GDP which are to be achieved by 2030.

The similarities in NDC targets and CE strategies becomes more evident by this, making it compelling to include CE measures in the ongoing NDC Revision as part of national climate actions. To fully understand this impact, an assessment is required to be carried out detailing current circular economy related policies, initiatives and proposals with a focus on the waste management sector which would enable a synergy of key stakeholders to develop common goals. In a bid to raise its climate ambitions, the Federal Government of Nigeria has decided to revise the NDC to incorporate the waste and water sectors. The African Development Bank (AfDB), responsive to this initiative is partnering with the Federal Government of Nigeria through the Federal Ministry of Environment and the Department of Climate Change to support the incorporation of CE in the waste sector in enhancing NDC (2021-2025). This study focused on the situational analysis of waste management and circular economy strategies for revising the NDC is the outcome of the support provided.

Terms of Reference

This analysis will examine the circular economy status and priorities for Nigeria as it is applicable to waste sectors to constitute the basis for enhancing the NDC. The understated TOR reflects the tasks:

1. Review existing policies, laws, regulations and projects in the country and other activities undertaken by the development partners, including UNEP, NESREA, the Dutch Consulate, NCEWG, NCCRP, etc
    - Identify synergies and differences between CE targets in separate initiatives
    - Identify the positive attributes, compile key findings or results to be achieved
2. Identify circular economy and waste management results to be considered for the revised NDC.
    - Assessment, analysis and validating extant waste management data and that which is available in other databases to undertake a conservative emission estimation from the waste sector. Coordinating with existing initiatives (NCCRP, NCEWG, EU, Dutch Consulate/RVO, etc.), to identify existing data sources and waste/CE emission projections where available will be required.
    - Collect project waste /CE emission data and simulate emission reduction targets for the revised NDC period (based on best available data on preliminary results) through the assessment, analysis and validating extant waste management data.
    - Develop a proposed list of results to be achieved or considered for the revised NDC

Chapter 2

Study Approach and Methodology

The study adopted multiple approaches to tracking Circular Economy in the waste management sectors through document reviews, engagements with relevant stakeholders in the public and private sectors, institutional surveys, data analysis and modeling.

Document review and analysis by project team of reports, publications and relevant websites of government and non-government agencies were made to identify existing waste management policies and projects from multiple stakeholders. The stakeholders comprised the Federal Ministry of Environment and the NDC Revision Partnership, NESREA, NCEWG, NCCRP, National Bureau of Statistics, UNEP, UNIDO, The Dutch Consulate, the Extended Producer Responsibility (EPR) through the Producer Responsibility Organization (PROs), Private Sector Stakeholders and several others. The reviews mapped out the CE policy, legislative and institutional landscapes and activities currently in place in Nigeria to determine the CE attributes, synergies and differences of the various initiatives.

Data sets of Solid Waste Disposal Sites (SWDS) were obtained from the Federal Ministry of Environment for waste (in kg) characterized by states in Nigeria from 2007 - 2017. The data contained the waste breakdown per different waste types/material. The data sets were further refined for consistency with the IPCC model utilized for emissions estimation from the waste sector. These were combined with assessments was made of the operations of the Extended Producer Responsibility (EPR) programme by a detailed survey of the Producer Responsibility Organizations (PROs) in four major waste streams, namely, Food and Beverage Alliance (FBRA), Electrical and electronics (EPRON), Plastics and Batteries (ARBR). The questionnaire utilized for the survey was designed among others to delineate the waste reduction and emissions reduction potentials from the activities of these organizations. The data obtained from PROs were supplemented with secondary data from private sector players and the websites from donor partners and international development organizations dedicated to various waste streams.

The PROs guided by the questionnaire designed to elicit information on the activities from their respective organizations, made presentations in a virtual meeting to multiple stakeholders hosted by the National Circular Economy Working Group (NCEWG) for feedbacks and further refinements in the data on their activities. The presentation from the PROs were on a range of issues such as, the Annual waste estimates generated in the country in the past 5 years; Estimated percentages presently recycled formally and informally, including geographical spread & reasons; Their Organisation's present activities nationwide, which are circular economy-related; Sectoral changes which have taken place as a result of the EPR program; National projection of Circular Economy measures hoped to be accomplished in their respective sectors; and Recommendations on requirements needed to speed the circular economy transition process in the various waste streams.

A data validation meeting with key stakeholders of NDC Partnership and the Federal Ministry of Environment was also carried out to validate available waste data.

The application of Material Flow Analysis (MFA) technique as an additional method to carry out waste generation projections using parameters such as quantities of imports, exports, and production and consumption data amounts of products in the officially recognized national solid waste categories were considered, but the acquisition of such data proved to be problematic and cumbersome to obtain given the limited time available for the study, thus the technique was shelved for a future research.

The outputs from the analysis and simulation of waste emissions and emissions reduction are utilized to highlight opportunities for including the circular economy analysis for enhancing the NDC revision for 2021 – 2025.

2.1 Emission Data Modelling Approaches

This section will discuss our methodology in preparing the data set obtained from the Federal Ministry of Environment for modelling. Further, we will discuss some of the gaps in the data. We will then discuss the steps we took to mitigate the data gaps by augmenting from secondary data sources and building data models to refine and enrich the data to build a Tier 2 IPCC FOD model.

2.1.1 The Federal Ministry of Environment Datasets

The Federal Ministry of Environment provided datasets for waste (in kg) characterized by states in Nigeria from 2007 - 2017. The activity data contained the waste breakdown per different waste types/material. The waste types included paper (10%), plastics (15%), metal (5%), organic waste (8%), textiles (4%), vegetables (45%), glass (5%), fines (5%) and others (3%). The Ministry's dataset provided population information for all the states for the given time frame. Also, the dataset computed annual waste per capita estimates for each state from 2007 - 2017. In calculating waste per capita, the dataset pegged the amount of solid waste generated per person per day to 0.5.

Limitations of the Primary dataset. To calculate methane (CH_4) emissions from SWDS using a Tier 2 IPCC FOD model, we need to mainly have high-quality country-specific activity data for at least 50 years in addition to country-specific emission if and where possible. As such, the primary data provided by the Federal Ministry of Environment had the following limitations.

- Lack of emission factors such as, the fraction of DOC which decomposes (DOC_f), methane correction factor (MCF) and the half-life rate constant (k).
- No degradable organic carbon (DOC) composition data for wood.

- The dataset lacked adequate historical waste data for at least 50 years that are critical to calculate accurate methane (CH_4) emissions.

Secondary data sources. To mitigate some of the gaps in the primary data source, we looked to secondary data sources to augment the activity data for modelling. To this end, we added the following parameters to the data set.

- Fraction of DOC (DOC_f): (Yusuf, et al., 2019 [13]).
- Methane correction factor (MCF): (IPCC 2006 defaults, [4]).
- Half-life rate constant (k): (IPCC 2006 defaults, [4]).
- Wood composition data: (IPCC 2006 defaults, [4]).

Yusuf, et al, [13] gives the value of 0.77 as the fraction of degradable organic carbon which decomposes (DOC_f). For other data gaps, we settled for the 2006 IPCC regional defaults.

2.1.2 Activity Data Refinements

Data standardization. From the Federal Ministry of Environment primary data source, we mapped the following data categories to the IPCC FOD municipal solid waste (MSW) compositions as seen in Table 2.1. In computing methane (CH_4) emissions using the FOD model, the waste types composition must sum to 100%.

However, since we obtained the composition for wood from IPCC defaults, whereas other waste types were from the primary data source, we standardized the dataset to sum to 100%. Table 2.1 shows the original percentages and the standardized percentages used in computing the emission model.

Primary data categories	MSW compositions	Percentages (%)	Standardized Percentages (%)
Organic waste	Food	8	7.6
Vegetables	Garden	45	43.1
Paper	Paper	10	9.6
Wood	Wood	4.4	4.2
Textiles	Textile	4	3.8
No data available (Default)	Nappies	0	0
Other inert waste (glass, metal, plastics, others, fines)	Plastic	33	31.6

Table 2.1: Map from primary data categories to MSW compositions.

2.1.3 Municipal Waste Data Modelling

The annual municipal solid waste (MSW) is computed as the population (millions) multiplied by the waste per capita per year (kg) as shown in Equation 2.3. Since waste per capita is in kg, we divide by 1000000 to get the values in gigagrams (Gg).

$$MSW_t = (P \cdot W)/1000000 \tag{2.1}$$

where:

- MSW_t = total annual municipal solid waste at time t.
- P = population (millions).
- W = waste per capita (kg/cap/yr).

Population modelling. Population estimates and population growth rate for Nigeria from 1960 - 20020 was obtained from the World Bank database [14]. To estimate the population growth rate, we used the average growth rate over a rolling 10-year window to predict future population growth rate. This is shown in the Equation below.

$$Pg_t = \sum_{i=1}^{10} Pg_{t-i}$$

where:

- Pg_t = population growth at time t.
- Pg_{t-i} = population growth at t instances in the past controlled by parameter i.

With the estimate of the population growth rate for year t, we use the population projection formula to estimate the population at time t. This equation is expressed in Equation 2.2.

$$N_t = Pe^{rt} \tag{2.2}$$

where,

- N_t - the number of people at time t.
- P - the population at the beginning time t.
- e - the base of the natural logarithms (2.71828).
- r - the rate of increase (natural increase divided by 100).
- t - represents the time period involved.

Waste per capita modelling. Nigerians generate 0.58kg of solid waste per person per day [1]. To corroborate this secondary data source, [2] reports that the waste generation for low income countries is 0.5 kg/capita/day. To compute the waste per capita, we evaluate $0.5 \cdot 365$.

2.1.4 Industrial Waste Data Modelling

Total industrial waste (TIW_t) is computed as the gross domestic product (GDP, millions) multiplied by the waste generation rate (Gg/$m GDP/yr).

$$TIW_t = GDP_t \cdot Wgr_t \tag{2.3}$$

where:

- TIW_t = total industrial waste at year t.
- GDP_t = gross domestic product (GDP, millions) at year t.
- Wgr_t = waste generation rate (Gg/$m GDP/yr) at year t.

GDP modelling using recurrent neural networks. GDP data for Nigeria from 1960 - 2019 was obtained from the World Bank database [15]. To make GDP projections for the years 2020 to 2030 we used a recurrent neural network (RNN) deep learning model. RNNs are developed to solve learning problems where information about the past (i.e., past instants/events) are directly linked to making future predictions [3]. In the case of modelling GDP estimates, the model learns the underlying statistical structure of past GDP values to predict future GDPs. In particular, we use a special type of RNN architecture called the Long Short-Term Memory (LSTM). LSTM is efficient for capturing long-term dependencies across long-running time instants. LSTMs are trained using a special optimization algorithm called backpropagation through time (BPTT). The reader is directed to [3] to learn more about recurrent neural networks.

In training a machine learning or deep learning model, the goal is for the model to generalize to unseen or out-of-sample examples. Hence, the model should minimize the error on the test set. To have a proper evaluation, we split our dataset into a training set and a test set. The LSTM model is trained on the training set and evaluated on the test set. Figure 2.1 illustrates the performance of our model on the hold-out testing examples. We can visually see that the model predictions approximate the true values.

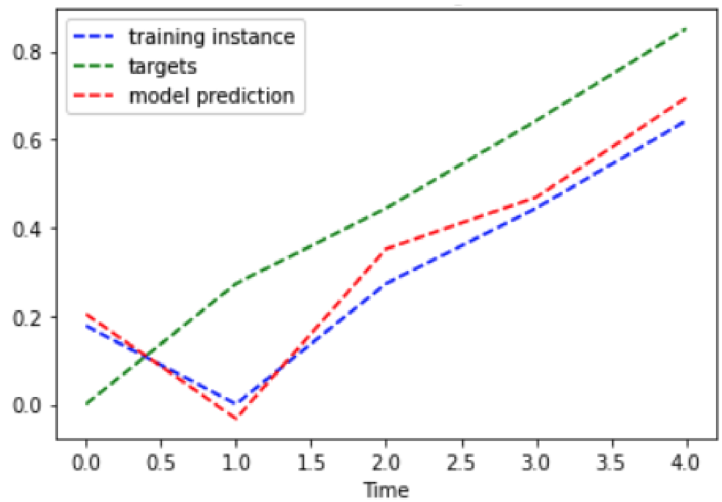


Figure 2.1: LSTM model testing.

The LSTM model is then used to predict GDP from 2020 - 2030. Figure 2.2 show a graph of the original GDP sequences (in blue) and the predicted sequences (in red).

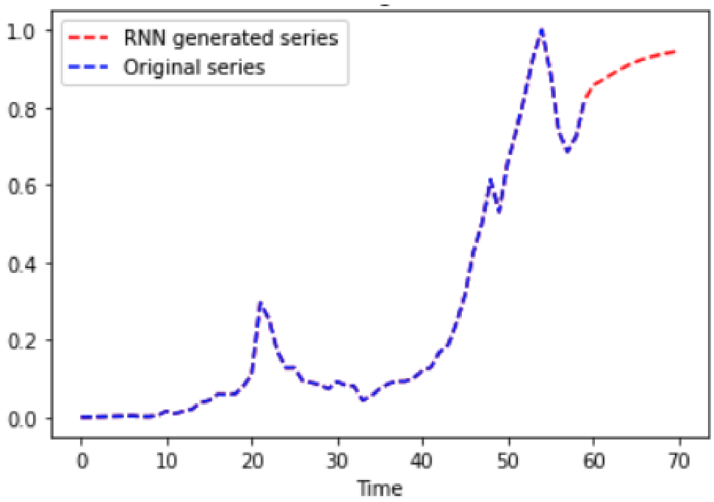


Figure 2.2: Original GDP sequence (in blue) and the predicted LSTM GDP (in red).

Waste generation rate. The waste generation rate is calculated as one-fifth of the total municipal solid waste (MSW) divided by the GDP for year at time t. The formula is formally defined in Equation 2.4.

$$Wgr_t = ((1/5) \cdot MSW_t)/GDP_t \tag{2.4}$$

where:

- Wgr_t = waste generation rate at time, t.
- MSW_t = municipal solid waste (MSW) at time, t.
- GDP_t = gross domestic product (GDP) at time, t.

2.2 Waste Reduction Methodology

This section is about calculating how much waste is reduced based on the utilization of circular economy activities over particular periods.

Having used the IPCC model to calculate the total waste generated and the corresponding emissions released from 1960 to 2030 in the previous section, a similar approach can be used to generate the amount of waste processed by circular activities such as recycling, refurbishment, repurposing, remanufacture etc so that the waste materials can be utilized. These circular activities reduce the amount of waste materials which are sent to MSWDS and other landfills thereby leading to a reduction of emissions from those sites.

Thus the amount of waste which is processed for further use instead being discarded into landfills is known as 'Waste Reduced' and the process in this context is known as 'Waste Reduction'.

2.2.1 Total Recycled Waste for Nigeria

The simulated data model in the previous section spans a period of 1960-2030 but this research will only undertake a waste reduction analysis from various years where data has been made available up until 2030. This is because circular economy measures have been implemented at various times for various waste streams. Also, these measures are still in the process of being formalized and regulated in Nigeria, and presently there is a dearth of verifiable data of formal and informal circular activities.

This research would be making some assumptions regarding the waste data estimations:

Assumption 1. The percentage of waste recycled in Nigeria in the period 2000-2016 is constant and 2% less than that of 2017-2022.

Assumption 2. The EPR programme and other circular economy projects were initiated between 2017 and 2022, hence the degree of circularity in 2017-2022 is be higher than the previous period of 2017-2022.

Assumption 3. Nigeria will attain a higher degree of circularity in 2023-2030 than previous years based on the implementation of Nigeria's Circular Economy Road Map and Action Plan from 2023 onward which further increases the percentage of waste reduced.

Present (Total waste reduced in 2017-2022 and their corresponding emissions). This was obtained first and used as a reference to deduce past and present waste data and emissions.

1. First, the 2020 percentage of waste recycled for various waste streams were calculated based on data collected for specific identified waste streams.
2. The average of these percentages of waste recycled was obtained.
3. The average percentage was then multiplied by the total waste generated for 2020 to obtain total waste recycled in 2020.
4. This average percentage was also used to obtain total waste recycled for each year 2018-2022 by multiplying the average percentage by the total waste generated in each year.

Past (Total waste reduced in 2000-2016 and their corresponding emissions).

1. The average percentage of waste recycled for the 2018-2022 period was reduced by 2% to obtain a new percentage of waste recycled. This was done to reflect the fewer circular economy activities which took place within 2000-2016.
2. The new percentage of waste recycled was then multiplied by the total amount of waste generated by each year 2000-2016 to obtain an estimated amount of total waste recycled for each year.

Future (Total waste reduced in 2023-2030 and their corresponding emissions) This indicates projected statistics of the country's reduced waste and its corresponding emissions. Lagos was used as an ambitious reference point for Nigeria because it had the most circular economy projects in the country. In Lagos, only 13% of its waste is recycled [16].

Assumption 4. The amount of waste generated in Lagos is 6.3% of the total waste generated in Nigeria based on 2017 FMOE Solid Waste data [17].

Assumption 5. In the period 2023-2030, Lagos doubles its recycled waste rate to 26%, and the rest of the country achieves 13% recycled rate (similar to Lagos currently).

This implies that 26% of 6.3% of the waste generated (W) represents recycled waste in Lagos. And 13% of 93.7% of the waste generated (W) represents recycled waste for the rest of the country. Adding these two together will give: (0.26 x 0.063)W + (0.13 x 0.937)W = 0.01638W + 0.12181W = 0.13819W = 13.82% of total waste will be the amount of recycled waste.

Assumption 6. In the period 2023-2030, not less than 13.82% of the total waste in Nigeria will be recycled.

Multiplying this percentage by the total waste generated will give the total waste recycled for each particular year between 2023 and 2030. The corresponding emissions can then be obtained from the IPCC model. Therefore, for each year between 2021 and 2030, we can have:

1. Amount of total waste generated (Twg) and its emissions in a year i.e. pre-circular activities or business-as-usual.
2. Amount of total waste recycled (Twr) & its emissions in a year i.e. emissions prevented.
3. Amount of new total waste generated (Twn) & its emissions i.e. post-circular activities, where Twn = Twg - Twr

2.2.2 Recycled Waste for Various Waste Streams

This section highlights the methodology to obtain the amount of recycled waste for various identified waste streams.

Assumption 7. For a period highlighting recycled data estimates, the initial year of the recycled data estimates will be taken to be five years before the year the data was published to cater for earlier years in which circular economy activities had already been taking place.

1. Plastic Waste:
    - 1960-2030 Waste Generated and Emissions: The simulated model already has the estimated quantity of plastic waste generated in each year for this period.

- 2016-2022 Waste Recycled and Emissions: For each year in this period, the estimated amount of plastic recycled = 13,000 tonnes/annum [18] + 10% total plastic packaging waste generated/annum [19]

- 2023-2030 Waste Recycled and Emissions: For each year in this period, the amount of plastic recycled was calculated to approximately 13.82% of total plastic waste generated/ annum.

2. Lead Acid Battery Waste:

   - 2016-2030 Waste Generated and Emissions: The simulated model already has the estimated quantity of lead acid battery waste generated in each year for this period.

   - 2016-2030 Waste Recycled and Emissions: For each year in this period, the approximate battery waste recycled per annum was calculated to be 80% of battery waste generated annually [20].

3. E-waste:

   - 2006-2030 Waste Generated and Emissions: The simulated model already has the estimated quantity of e-waste generated in each year for this period.

   - 2014-2030 Waste Recycled and Emissions: The e- waste recycled per annum is approximately 500,000 tonnes [21]. The percentage of e-waste recycled per annum was obtained as 500,000 tonnes divided by total e-waste generated in 2019. This percentage was then multiplied by the total quantity of e-waste generated annually to obtain the estimated total quantity of e-waste recycled annually during 2014-2030.

4. Medical Waste:

   - 2015-2030 Waste Generated and Emissions: The simulated model already has the estimated quantity of medical waste generated in each year for this period.

   - 2016-2022 Waste Incinerated and Emissions: Medical waste incinerated per annum was taken to be approximately 5,500 tonnes [18] for all the seven years.

   - 2023-2030 Waste Incinerated and Emissions: 13.82% of medical waste generated for each year was calculated to give the amount of medical waste incinerated in 2023-2030.

5. Organic Waste:

   - 2008-2030 Waste Generated and Emissions: The simulated model already has the estimated quantity of organic waste generated in each year for this period.

   - 2011-2022 Waste Recycled and Emissions: Organic waste recycled per annum was taken to be approximately 600 tonnes [11] for the years within the period.

   - 2023-2030 Waste Recycled and Emissions: 13.82% organic waste was multiplied by the total amount of organic waste generated for each year to give the approximate amount of organic waste recycled in 2023-2030.

Chapter 3

Circular Economy Policy, Legal, and Institutional Landscape in the Waste Management Sectors in Nigeria

This chapter provides a review of the existing national policies, laws, and regulations in relation to waste management and the circular economy concept. An assessment of the projects being undertaken by the NDC development partners and other waste stakeholders in the country has also been carried out to highlight key findings, identify synergies and differences between CE targets in separate initiatives, and to also highlight their positive CE attributes.

3.1 History of Environmental Policy Framework in Nigeria

As a result of the Koko toxic disaster in 1987, the Federal Government formulated the Harmful Waste Decree 42 in 1988 which led to the formation of the Federal Environmental Protection Agency (FEPA) by Decree 58 of 1988 and amended Decree 59 of 1992 (FMOE, 2020). The Federal Ministry of Environment was then formed in 1999 from the combination of FEPA and departments in various Ministries, and it was given the mandate to undertake the environmental protection and conservation of Nigeria's natural resources as a national development effort. Subsequently, the National Environmental Standards and Regulations Enforcement Agency (NESREA) - a Parastatal of the Federal Ministry of Environment was established in 2007. This was to fill the gap of the absence of enabling laws to enforce environmental compliance, and became the precursor of several other environmental policies and legislations for waste management.

3.2 Waste Management Policy and Legislative Framework

Policies, legislations and rules to support waste management processes have been put in place in Nigeria. These are implemented by NESREA which works with various stakeholders to develop a more sustainable environment.

3.2.1 Waste Management Policies

The existing key policies which support Waste Management have been briefly described below:

1. **National Policy on Environmental Sanitation (2005):** This is a policy developed with the objective of ensuring a clean and healthy environment by utilizing efficient, sustainable and cost-effective measures to enhance public health and well-being according to national objectives. It addresses key areas of sanitations including solid and medical waste, food hygiene, faeces and sewage, markets, water, schools, drainage, animal husbandry, corpses, plants control and sanitation education. It is part of the country's National Development Strategy (NDS) and it aims to work with statutory stakeholders and guidelines in these areas. The waste related feature of this policy is the drive to ensure the sanitation of the environment which involves the proper management of waste that has been generated.

2. **National Policy on Chemical Management (2010):** This policy was created to protect the environment and its constituents by properly managing the production, handling and disposal of chemicals within the country. It also highlights resources and infrastructure and activities which will be utilized to develop guidelines for chemical safety and waste management, create inventories for tracing chemicals throughout their lifetime, and undertake the impact assessment of chemicals in the locality of their operations. The waste related feature of this policy is the proper management of chemical and hazardous waste to prevent their uncontrolled and untreated release into the atmosphere.

3. **National Healthcare Waste Policy (2013):** This policy was developed and enforced by the Ministry of Environment to ensure the safe handling and disposal of Health Care Waste (HCW) generated from health organizations. It aimed to encourage healthcare waste management best practices in all health care institutions in Nigeria using standards set by the World Health Organization (WHO), international conventions, the Constitution of the Federal Republic of Nigeria, and other related Nigerian Regulations and Acts to provide guidance and aid its implementation. The policy has waste related features as it involves the collection, transportation and treatment of healthcare waste in a bid to keep up with universally acceptable waste management standards.

4. **National Policy on Environment (2016):** This policy deals with the management of environmental resources providing policy statements for sustainable development in different sections of the economy and is reflective of the recent international treaties and conventions the country is now a part of. Also, recent issues such climate change, water resources at borders, environmental conflicts, genetically modified organisms and bio-safety have also been addressed in this policy. Section 5 and subsection 5.2 of this policy focuses on waste with the Government undertaking policy statements on applying waste management-related national laws and regulations; enforcing standards for sanitary facilities for waste disposal in both rural and urban areas; management of all major land waste disposal sites; regulating and sustainably managing toxic, hazardous and radioactive wastes with emphasis on those prohibited; and quickening the establishment of sustainable waste management facilities.

5. **National Policy on Solid Waste Management (2018):** The establishment of this policy is to create a sustainable waste management process for all stakeholders. It is aimed to enhance the cleanliness of the environment; improve the well-being of the populace; decrease the huge stacks of solid waste disposed indiscriminately which caused public health issues; aid the establishment of waste management facilities; enhance the participation of private investors in the waste sector; incorporate the concept of reuse, reduce, recycle and recovery of waste materials; protect environmental resources; adopt international best practices; ensure the country keeps to its commitments made in international treaties and agreements; and utilize economic opportunities in the waste management process. It outlines the roles of various solid waste management stakeholders giving clarity on their functions in the system. Another function of the policy is to serve as a tool which supports the fight against trans-boundary waste disposal as it can be used in conjunction with other guidelines and synergy of national, regional and international waste management networks. The policy also grouped solid waste into the following categories, namely; Household, Industrial, Electronic (e-waste), Special bulk, Agricultural, Marine Liter, Medical, Used tyres, End-of-life vehicles, Unserviceable fridges and freezers, Used batteries, and Construction/asbestos wastes.

   The policy hinges on the '5Rs' (reduce, repair, reuse, recycle, recover) in a 'waste management hierarchy' at all levels of government and communities and the policy gives a detailed account of how these measures will be used to achieve the desired results.

6. **National Policy on Plastic Waste Management (2020):** This national policy encourages the sustainable utilization of plastic products throughout their lifecycle. Its objective is to protect environmental resources and stimulate an energy-efficient circular plastics economy thereby improving the conservation of the natural resources through processes which involve the sustainable creation and utilization of plastics according to national sustainable development objectives with specified targets and timelines.

3.2.2 Waste Management Regulations

Waste management regulations among others include: Constitution of the Federal Republic of Nigeria (1999): This is the supreme law in Nigeria which describes the framework for the government and the separation of powers. Chapter II of the constitution states that the government shall enhance and undertake the environmental protection of the Nigerian airspace, land and water .

1. **National Environmental Protection (Pollution Abatement in Industries and Facilities Generating Wastes) Regulations S.I.9 of 1991 (2004):** These proposes a threshold of substances released as waste by Nigerian industries and regulates the waste management of these substances including licensing for discharges, regulation of air emissions and standard of fuel used by these factories.

2. **National Environmental Protection Management of Solid and Hazardous Waste Regulations S.I.15 of 1991 (2013):** These regulations guide the use of solid and hazardous waste stating the roles of the government establishments, the duties of the industries, and guidelines to disposing hazardous waste.

3. **Environmental Impact Assessment Act of 1992:** This statute gives guidelines, activities and processes to assess the potential of undertaking an environmental impact assessment of some particular projects.
4. **Nigeria Sectoral Guidelines for EIA (1995):** These assist the EIA process for different sectors and offer guidance on the scope, content and impacts as a result of the sector-specific procedures.
5. The Harmful Wastes Special Criminal Provision Act No42 of 1988 (1998): These regulations places a ban on all processes that involve harmful waste substances including the buying and selling of such items, their movement, and storage.
6. **The National Guidelines and Standards for Environmental Pollution control in Nigeria:** These provide regulations for six areas of environmental pollution control: effluent limitations; water quality for industrial uses; industrial emission limitations; noise exposure limitations; management of solid and hazardous waste; and pollution reduction in industries.
7. **The National Oil Spill Detection and Response Agency Act 2006 (NOSDRA Act):** This Acts gives NOSDRA the responsibility of spearheading the management of crude oil accidents in the country. It places a requirement on polluting parties to report oil accidents within 24 hours of the incident with a daily penalty for non-reporting of such accidents. The Act also requires that any person in default of the provision shall be subject to a fine for each day of failure to report the incident
8. **The National Environmental Standards and Regulations Enforcement Agency Act, 2007 (NESREA Act):** This Act was enabled the creation of NESREA which was given the mandate to enforce all Nigerian environmental laws, policies, standards and regulations. In addition to this, NESREA has the mandate to localize and enforce the environmental commitments made by the country in international agreements, conventions and treaties.
9. **National Environmental (Sanitation and Wastes Control) Regulations, S.I No.28 of 2009:** These guidelines provide a legal foundation for the incorporation of sustainable and eco-friendly methods in the waste sector.
10. **National Environmental (Permitting and Licensing System) Regulations, S. I. No. 29, 2009:** These guidelines aid the administration of environmental laws, regulations and standards in all sectors, economies and locations of the Nigerian landscape.
11. **National Environmental (Mining and Processing of Coal, Ores and Industrial Minerals) Regulations, S.I. No 31, 2009:** These guidelines aim to reduce the adverse effects of effluents from the mining and treatment of minerals, coal and ores.
12. **National Environmental (Ozone Layer Protection) Regulations, S. I. No. 32, 2009:** The provisions of these regulations aim to ban the manufacture, utilization, and business of ozone-depleting materials.
13. **Merchant Shipping Act, 2007 (2013):** This is a statute which supports the registration, licensing and branding of shipping vessels in Nigeria. It also supports the prohibition of dangerous materials carried by ships and the prevention of the

indiscriminate release of waste by the ships.

14. **National Environmental (Food, Beverages and Tobacco Sector) Regulations, S. I. No. 33, 2009:** The activities and processes of the food, beverages and tobacco industries are guided by these regulations which also strives reduce to pollution from their effluents.
15. **National Environmental (Textile, Wearing Apparel, Leather and Footwear Industry) Regulations, S. I. No. 34, 2009:** These regulations drive the reduction of pollution and effluents from the processes and activities of the textile, wearing apparel, leather and footwear sector in Nigeria.
16. **National Environmental (Chemicals, Pharmaceuticals, Soap and Detergent Manufacturing Industries) Regulations, S. I. No. 36, 2009:** This sector is regulated by these guidelines to reduce and eliminate pollution from all processes and operations that have negative consequences on the Nigerian environment.
17. **National Environmental (Base Metals, Iron and Steel Manufacturing/Recycling Industries) Regulations, S. I. No. 14, 2011:** These guidelines seek to eliminate and reduce the impact of the effluents from all processes of this sector on the environment in Nigeria.
18. **National Environmental (Control of Bush/Forest Fire and Open Burning) Regulations, S. I. No. 15, 2011:** The aim of these guidelines is to eliminate and reduce the destruction of the environment through fires and also the burning of any items which may have an adverse impact on the ecosystem leading to a release of polluting substances.
19. **National Environmental (Domestic and Industrial Plastic, Rubber and Foam Sector) Regulations, S. I. No. 17, 2011:** These guidelines seek to eliminate and reduce the effluents released as a result of processes in this sector of the country.
20. **National Environmental (Construction Sector) Regulations, S. I. No. 19, 2011:** The aim of these guidelines is to eliminate and reduce the effluents released as a result of processes in the construction, decommissioning and demolition sector of the country.
21. **National Environmental (Non-Metallic Minerals Manufacturing Industries Sector) Regulations, S. I. No. 21, 2011:** These guidelines seek to eliminate and reduce the adverse impacts as a result of processes in this sector of Nigeria.
22. **National Environmental (Electrical/Electronic Sector) Regulations, S. I. No 23, 2011:** The aim of these guidelines is to eliminate and reduce the adverse impacts as a result of processes, activities and the use of new and old equipment in the Electrical/Electronic Sector.
23. **National Environmental (Pulp and Paper, Wood and Wood Products) Regulations, S. I. No 34, 2013:** These guidelines aim to eliminate and reduce pollution from all processes in this sector of the country.
24. **National Environmental (Motor Vehicle and Miscellaneous Assembly) Regulations, S. I. No 35, 2013:** These guidelines drive the elimination and reduction of effluents and wastes from all processes of the Motor Vehicle (MV) and

Miscellaneous Assembly sector. They encompass new, used and end-of-life vehicles in Nigeria.

25. **National Environmental (Air Quality Control) Regulations, S. I. No 64, 2014:** These regulations assist in the management of processes that impact on the air quality of the country and its corresponding impact on all the beneficiaries of the environment.
26. **National Environmental (Hazardous Chemicals and Pesticides) Regulations, S. I. No 65, 2014:** These guidelines assist the implementation of sustainable agricultural practices and also safeguard the environment from the adverse effects of hazardous chemicals, pesticides and other agriculturally related substances.
27. **National Environmental (Energy Sector) Regulations, S. I. No 63, 2014:** These are guidelines for the energy sector which aims to increase the sustainable use of energy resources, enhance energy efficiency, as well as eliminating and reducing environmental pollution while contributing to the country's growth and development.

3.3 Institutional Architecture

The goals of waste management policies and regulations in Nigeria are to be attained through a collaborative effort of various stakeholders and organizations who work according to legal, administrative and regulatory guidelines. Nigeria operates a three tier structure of public governance. The institutional structures for waste management in the public sector are derived from the constitution of the federal republic of Nigeria which explicitly defines the responsibilities of the various tiers of government (The Federal Government, The 36 States structure, and the 774 Local Government Areas) in the management of the environment. The thirty six states of Nigeria have for instance, created environmental regulations and standards supported by their own state laws to aid the management and disposal of solid waste.The Local Governments have the constitutional responsibility for municipal solid waste management and disposal in Nigeria.

The institutional landscape for waste management highlighted in this section goes beyond the public sector and includes the private sector, civil society organizations, development partners and communities.

3.3.1 Federal Government

1. **The Legislative Arm of Government:** This is Federal Legislature which consists of the Senate Committee on Environment and House Committee on Environment both of which have the mandate to legislate and make laws guiding effective and sustainable waste management practices in Nigeria.
2. **The Judiciary Arm of Government:** This arm of government has the mandate for the interpretation of principles, protocols, rules and legislations. It also prosecutes offenders of waste management legislation.
3. **The Executive Arm of Government:** The Federal Government of Nigeria has the responsibility of developing institutional frameworks for solid waste management which it carries out through the Federal Ministry of Environment.

(a) **Federal Ministry of Environment:** This is the government body responsible for the development of policy regulations, standards and guidelines for waste management in Nigeria. It also support state and local government in the implementation of national waste management strategies and policies through:

   i. **National Environmental Standards, Regulation and Enforcement Agency (NESREA):** This is the regulatory and enforcement agency under the Federal Ministry of Environment. It assists the Federal and State Governments to monitor and implement waste management policies, enforce legislation, monitors and evaluates waste management related activities, domesticate the conditions of international treaties and agreements in which the country has entered into, and enhance the achievement of sustainable development objectives.

   ii. **National Steering Committee On Plastic Waste Management (NSCPWM):** This comprises of the Honorable Minister of Environment as its head with representatives from the Federal Ministries of Agriculture and Rural Development, Industry, Trade and Investment, Environment, Nigerian Maritime Administration and Safety Agency (NIMASA), National Inland Waterways Authority (NIWA), State Inland Waterways, Health, and Labour, as well as one representative from each State Ministry of Environment, Manufacturers Association of Nigeria, academia, Research Institutions, Professional Bodies and Civil Society Organizations. This committee has been set up to advise government on issues such as capacity building, strategies, initiatives; setting targets to ensure the proper implementation of the National Policy on Plastic Waste Management; and collect reports and recommendations for the Technical Coordinating Committee.

(b) **Technical Coordinating Committee (TCC):** This is part of the NSCPWM consisting of one representative of each participating agency and organization. This committee will give counsel to the NSCPWM on sustainable waste management procedures.

3.3.2 State Government

1. State Governments: The various State Governments in Nigeria are expected to create special purpose technical agencies and provide waste management infrastructure. They are also expected to work with their various Ministries of Environment to create State Waste Management agencies, develop a State Waste Management Master Plan and implement strategies which would manage waste within the State using sustainable means.

2. State Ministries of Environment: These are established to uphold environmental legislation and enforce regulations within the state. They also ensure that environmental, social, health, and safety requirements have been fulfilled before the creation of waste management infrastructures within the state.

3. State Environmental Protection Agencies: These agencies create State Waste Management policies using the national guidelines, regulate solid waste management

in the states, establish tax regimes to serve as a detriment to increased usage of landfill sites and lead towards waste-to-wealth initiatives so as to reduce GHG emissions, collection of liquid and solid waste, implementation of sanitation and waste management initiatives of the state, and monitoring and evaluation of solid waste management.

4. State Waste Management Authorities: These agencies have the primary mandate to manage waste management processes in the state and shall undertake or approve the collection of waste, ensure commercial provision to the state and local governments, manage waste collection contractors and franchises, liaise with the State Ministry of Environment to develop and enforce state waste management policies, create a waste management database, create awareness on sustainable waste management practices, encourage private sector stakeholders across the waste management value chain.

3.3.3 Local Government

Local Government Authorities (LGAs): The LGAs are expected to work within the remit of the Local Government jurisdiction. They are to implement policy guidelines on Solid Waste Management; develop a LGA waste management plan to run every 5 years; enforce sanitary regulations; incorporate stakeholders from the private sector, NGOs and CBOs to implement the reuse, reduction and recycling of waste materials thereby reducing waste; The Local Governments are in addition responsible for creating awareness on waste management processes; recruitment and capacity building for provision of quality service; and create empowerment schemes in waste management.

3.3.4 Civil Societies Organizations, NGOs, CBOs

The organizations are interested in contributing toward achieving sustainable waste management objectives. They create programs on informing and educating the populace on waste management processes and practices mediate between the government and private sector. They also aid waste separation and recovery at the household and community level, and enhance the formation of waste management CBOs.

3.3.5 Private Sector

The stakeholders here are those who partake in the waste management process to make profit. They are to be licensed where applicable by the relevant authorities and are to use sustainable waste management methods based on National Policy, Guidelines and Plans as a minimum standard for operation.

Stakeholders who are in this category are also to follow guidelines for the Extended Producer Responsibility (EPR) program and should focus on eco-friendly packaging and products to enhance their reusability and recyclability. They are also to carry out waste audits according to laid down Federal and State regulations.

3.3.6 International Organisations/ Donor Agencies

These are foreign affiliated organizations which have interests in collaborating with other stakeholders in the waste management process. They can work Government to provide instruments which stimulates entrepreneurial growth in the waste management sector and also undertake community participatory schemes for awareness and capacity building. Sometimes, these organizations also work with other stakeholders to aid the government in giving consent and commitments to international treaties and agreements.

3.4 Waste Management Initiatives of Development Partners

The NDC Development Partners are organizations working with the Federal Ministry of Environment on the revision of the NDC with respect to the waste sector, and they include the African Development Bank (AfDB), United Nations Development Program (UNDP under its Climate Promise Initiative), United Nations Industrial Development Organization (UNIDO), the GIZ, Islamic Development Bank (IsDB), the Dutch Consulate, the United Kingdom (UK) Government, International Renewable Energy Agency (IRENA), and 2050 Pathways.

In addition to the development partners, there are several initiatives which engage in sustainable waste management activities to complement the efforts of the Local and State Governments in Nigeria. The details of some of these initiatives is given in 4.2.

Chapter 4

Circular Economy Analysis of Nigeria's Waste Management Regimes

This chapter of the report analyzes the waste management initiatives and activities undertaken in various parts of the country to highlight the level of circularity incorporated into the projects.

Nigeria has developed policies and legislation to address waste management related challenges is a party to international agreements in recognition of the need to effectively incorporate global best practices and sustainable solutions. Part of these goals is to increase efficiencies by maximizing the value of materials and reduce waste.

4.1 Waste Reduction: Circular Economy R-Framework

In order to facilitate the circularization of an economy and reduce the amount of waste generated, techniques known as R-strategies have been proposed which consists of numbered R definitions that depict certain sustainability measures. These strategies vary from 3Rs (reduce, reuse, recycle) to 10Rs (reduce, reuse, recycle , recover, redesign, re-manufacture, refuse, rethink and refurbish) frameworks. It is common in various frameworks that low R-values depict high circularity while high R-values are reflective of low circularity.

In Table 4.1, the 10 R-framework which is a hybrid of R-strategies developed by [22]and [23] highlights a list of circular economy indicators which can be undertaken across the lifecycle of a project.

Smart Product Use and Manufacture.	R0 - Refuse	Make product redundant by abandoning its function or by offering the same function with radically different product.
	R1 - Rethink	Make product's use more intensive (e.g. through sharing products, or by putting multi-functional products in the market).
	R2 - Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.
Extend lifespan of products and its parts.	R3 - Reuse	Re-use by another consumer of discarded product which is still in good condition and fulfills its original function.
	R4 - Repair	Repair and maintenance of defective product so it can be used with its original function.
	R5 - Refurbish	Restore an old product and bring it up to date.
	R6 - Remanufacture	Use parts of discarded products in a new product with the same function.
	R7 - Repurpose	Use discarded products or its parts in a new product with a different function.
Useful application of materials.	R8 - Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality.
	R9 - Recover	Incineration of materials with energy recovery.

Table 4.1: R-Framework Strategy (Source: [24]

The analysis of the waste management legislation and initiatives was carried out using this framework as a tool to measure the degree of circularity as shown in Tables A.1 - A.2 in the Appendix.

4.1.1 Waste Reduction: EPR Program

The Extended Producer Responsibility (EPR) program implemented by NESREA involves the use and management of materials according to circular economy guidelines. The manufacturers become responsible for the complete life-cycle of their products ensuring that products are made efficiently and then subsequently recycled and reused instead of being disposed using 'take-back' or 'buy-back' schemes to facilitate the process.

The stakeholders involved in the EPR programmes are highlighted in Figure 4.1 and they include the regulator (NESREA), producers, PROs, recyclers, collectors, and the

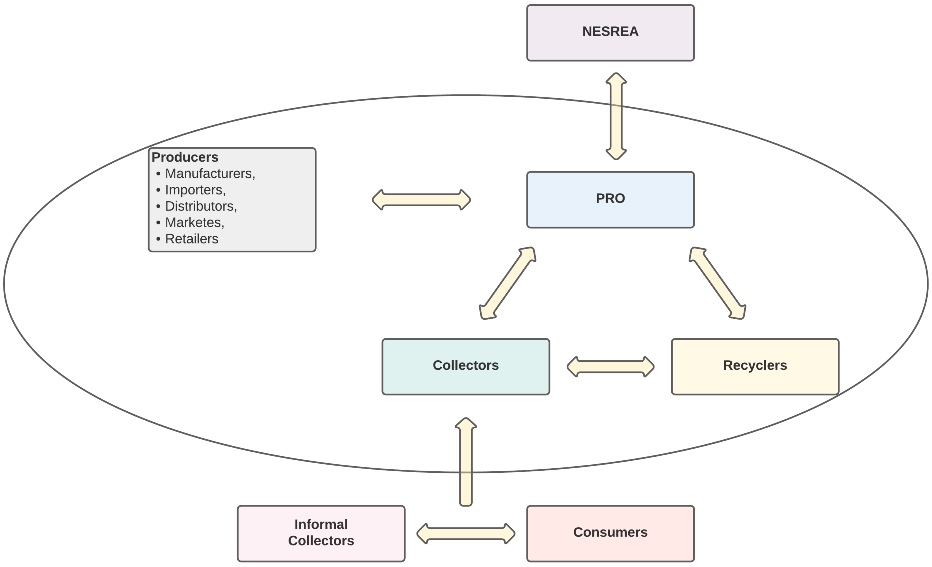


Figure 4.1: EPR implementation framework in Nigeria [25]; [26]
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consumers.

1. The Producer is the creator of the product which may include the brand owner, manufacturer, filler franchisee, distributor, retailer or first importer of the product who engages in the sales and distribution of the product. They are responsible for the lifecycle of the product before and after its use by the consumer.

2. The Producer Responsibility Organization (PRO) is a group which has been formed to assist producers in managing the waste retrieval process which usually involves creating awareness, collection, storage, and logistics. Producers in similar sectors can collaborate to assign the responsibility and initiate take-back schemes or stewardship programmes. Some PROs are FBRA, REDIN, and ARBR.

3. Recycler: This is an individual, group or body which reprocesses the collected waste to become a raw material for the original product or for other alternative uses. The recycler may work with producer to reuse the waste material or repurpose/remanufacture the original product.

4. The Collector is a party which retrieves waste from consumers for storage and recycling. The collector receives waste at designated locations knowledgeable to the consumers in a safe and responsible manner or moves from place to place and picking them up at the point of waste generation. The EPR model is illustrate below showing interactions between various stakeholders.

Presently the EPR program focuses on four streams – Food & Beverages, Electrical Electronic, Plastics and Batteries, with the waste produced from these streams currently managed by three PROs: the Food and Beverages Recycling Alliance (FBRA), E-Waste Producer Responsibility Organization of Nigeria (EPRON), and Alliance for Responsible Battery Recyclers (ARBR).

Food and Beverage Recycling Alliance (FBRA)

This is a collaborative platform established in 2013 by four companies to recycle used food and beverage packaging and plastic waste. Presently its members include some of the biggest food and beverage companies in Nigeria such as the Coca-Cola Nigeria Limited/Nigerian Bottling Company Limited, Nestle Nigeria PLC, Nigerian Breweries PLC, Seven-Up Bottling Company, Guinness Nigeria Plc, International Breweries, International Distillers, Tulip Cocoa, Prima Corporation Limited, DOW Chemicals, Tetra Pak West Africa, The LaCasera Company Limited, Engee PET Manufacturing Company Limited, Omnik Limited, UAC Foods Limited and Unilever Nigeria Plc.

It undertakes awareness, engagement with stakeholders, promote safe and sustainable waste management practices, collect post-consumer packaging waste and recycle this waste. The Alliance also collects packaging wastes with the aid of Recycle Points, West-AfricaENRG and Chanja Datti and other organizations. Key partners of the organization include the Lagos State Waste Management Agency (LAWMA), Delta State Ministry of Environment, Circular Economy Innovative Partnership (CEIP), Nigeria Circular Economy Working Group (NCEWG), Federal Competition and Consumer Protection Commission (FCCPC) Taskforce on Sustainable Consumption and Nigerian Maritime Administration and Safety Agency (NIMASA) Taskforce on Marine Litter.

The products which make up the plastic packaging waste stream are varied depending on their uses. Though the quantity of plastic waste has increased with time, the various components which make up these waste have fluctuated. Table 4.2 below shows the quantity of beverage plastic packaging waste generated between 2013 and 2018.

Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018e**
PET Waste Quantities (tonnes)	1,773,372	1,894,157	2,048,534	2,140,701	2,242,500	2,369,627

Table 4.2: Quantity of Beverage Plastic Packaging Waste Generated (tonnes)

A further analysis of these quantities illustrated in Figure 4.11 show the different components which make up this waste with Returnable Glass Bottles (RGB) at 81-86%, Non-Returnable Glass Bottles (NRGB) at 7-8%, PET making 2-6% of the composition within this period and other plastics at 4-5%.

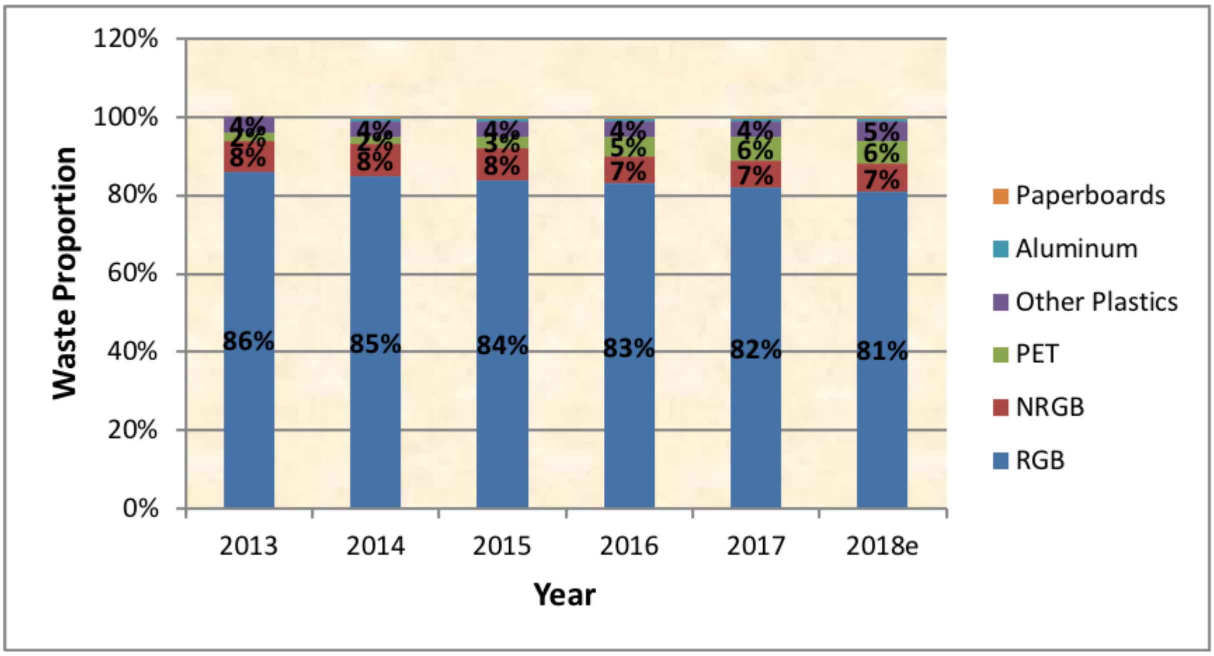

Figure 4.2: Total beverage packaging waste [27]

Polyethylene terephthalate (PET) bottles have become popularly used and its share in the packaging waste sector has steadily grown over the years as highlighted in Table 4.3.

Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
PET Waste Quantities (tonnes)	70,838	99,557	132,439	149,240	179,248	229,020	301,600	322,580	373,768

Table 4.3: Actual and Projected PET Waste Quantities Generated between 2015-2023

On further analysis of the PET waste stream, various organizations which utilize PET as a raw material for their products as well as their corresponding proportions were highlighted in Figure 4.3 showing Coca cola and 7Up as the main PET consumers with Nestle and Nigerian Breweries also among the top companies with a high PET demand.

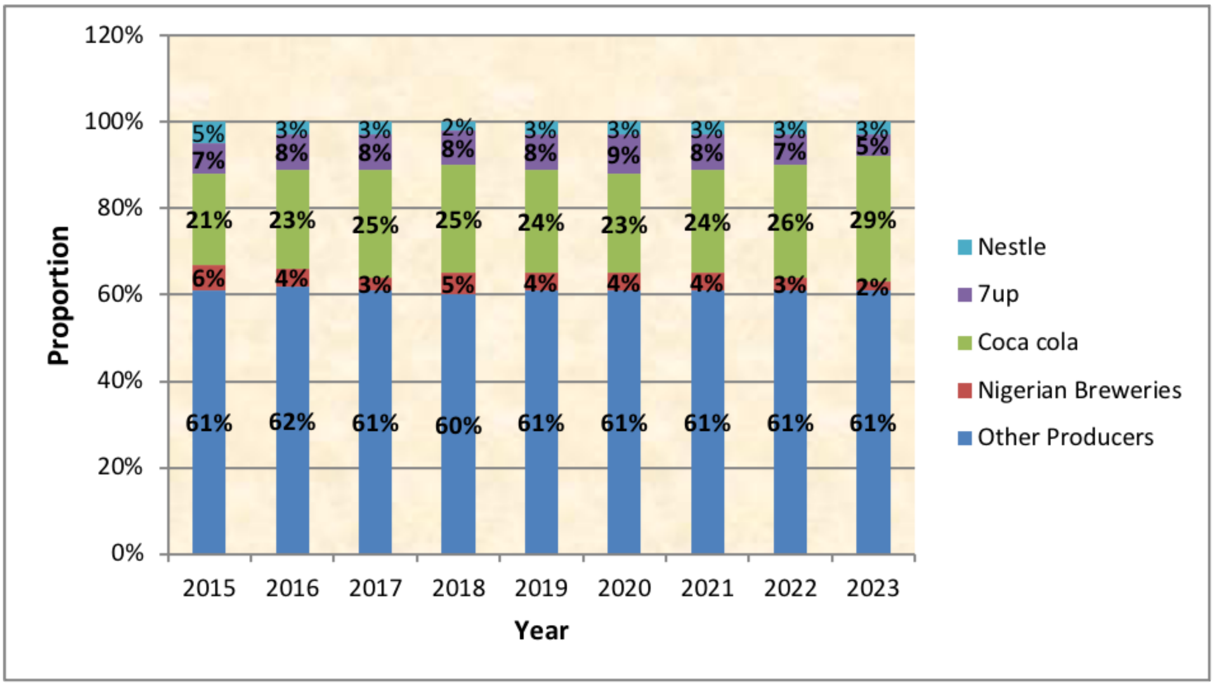

Figure 4.3: Beverage plastic packaging waste trend of Key Organizations from 2015 to 2023 [27]

After use, plastic products are usually indiscriminately disposed off in the environment but there has been a growing awareness of circular practices and activities by various initiatives as shown in Figure 4.4. There has been a rapid rise in the amount of plastics collected and recycled with a 97.8% increase in plastic waste in 2019 and 88.4% increase in 2020.

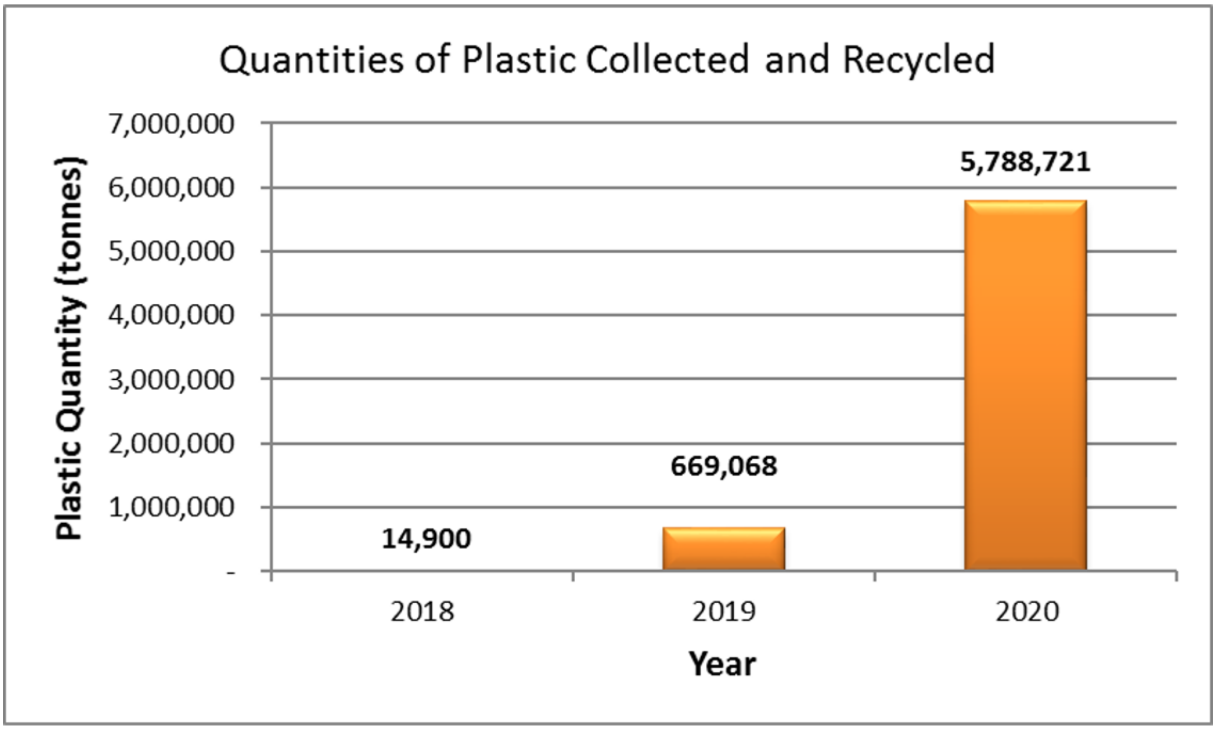

Figure 4.4: Recycled Plastic Quantities in 2018-2020 [19]

FBRA intends to cover all the Nigerian states by 2025 and recycle at least 30-50% of packaging materials by then representing an increase from 10% in 2021 [19].

In 2020, FBRA is recycled only 10% of the 185,558 tonnes of the packaged plastic waste in the country but they hope to increase this percentage to 30-50% by 2025 when the organisation covers all states in the country [19]. Key challenges which are required to be surmounted before this place are access to funding, provision of incentives to recycling schemes, creating enabling environments for stakeholders to thrive, infrastructural development, increased membership, and awareness and patronage of their activities.

E-Waste Producer Responsibility Organization of Nigeria (EPRON)

EPRON was established in May 2019 consisting of electrical and electronic producers in Nigeria for the purpose of efficiently managing Waste Electrical and Electronic waste (WEEE). It presently has a membership of thirty eight organizations including MTN Nigeria, Slot Systems Limited, Mitsumi Nigeria Ltd SPL Business Solutions Ltd, Technology Distributions Ltd and other electronic related specialists. It also has collaborations with the Department of Pollution Control, Federal Ministry of Environment, Federal Ministry of Science and Technology, Federal Competition and Consumer Protection Commission (FCCPC), Standard Organization of Nigeria (SON), Nigeria Custom Service (NCS), Nigeria Communication Commission (NCC), Sustainability Centre of the Lagos Business School(LBS), Chemistry Department of University of Ibadan (UI), The WEEE Forum, United Nation Industrial Development Organization (UNIDO), United Nation Environment (UNEP). In addition to these, EPRON is partnering with Hinckley E-waste Recycling and E-Terra Technologies Limited in Lagos to recycle, refurbish and delete data from electronic waste. The estimated amount of e-waste generated in Nigeria between 2014 and 2019 is illustrated Figure 4.5 showing the gradual increase on e-waste and depicting a steady consumption in electrical and electronic products.

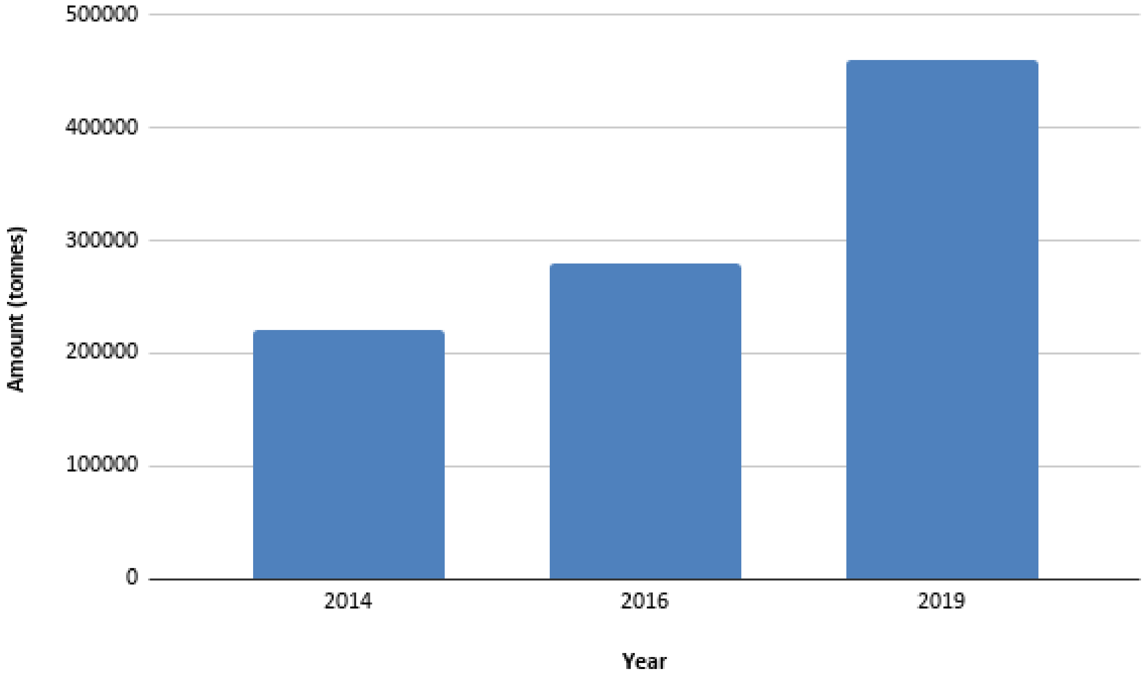

Figure 4.5: National E-waste Generation Rate [28]

Major e-waste recyclers in Nigeria such as E-terra technologies, Hinckley Recycling and the Initiates and the quantities of waste they have processed over the last two years have been highlighted in Figure 4.6.

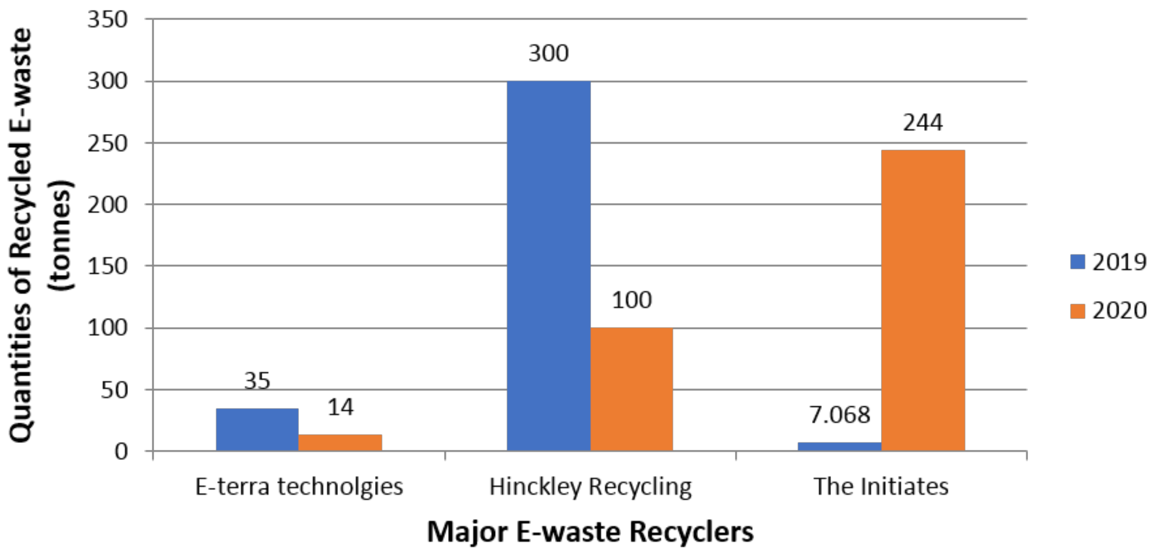

Figure 4.6: Quantities of E-waste processed by Nigeria's Major Recyclers in 2019-2020 [29]

EPRON is also anticipating covering the whole country by 2024 in which it will recycle a tentative amount of 5% of WEEE [29].

Key challenges EPRON would require assistance to meet its targets include the development and implementation of an enforcement plan, facilitate the transition of informal sector members to the formal mainstream, development and implementation of recycling standards, the influencing of Original Equipment Manufacturers (OEMs) on their channel partners, research to obtain data on consumer behaviour and trends, funding, technical assistance and awareness of their activities.

Alliance for Responsible Battery Recyclers (ARBR)

The ARBR focuses on recycling used lead acid batteries and engages in the collection, storage and transportation of these batteries to prevent to the release of dangerous substances into the environment. It also undertakes a buy-back process and creates awareness on its activities as well as establishing up-to-date and eco-friendly battery recycling plants in Nigeria. The Alliance currently has 13 members and has partnerships with Recycling and Economic Development Initiative (REDIN), Waste Battery Recyclers Association of Nigeria (WBRAN), the Renewable Energy Association of Nigeria (REAN), International Lead Association (ILA), Africa Mini-Grid Developers Association (AMDA), Association of Licensed Telecommunications Operators of Nigeria (ALTON), Nigeria Circular Economy Working Group (NCEWG), Basel Convention Center for Africa (BCCC-Africa), Heinrich Boll Foundation, Abuja-Nigeria and the Rural Electrification Agency (REA).

Lead acid batteries are a source of power making them a vital component in the production chain. 95% of lead acid batteries in use in Nigeria are imported while approximately 80% of battery waste are collected and recycled. Figure 4.7 highlights the quantities of battery products and their various entry and exit points in the market.

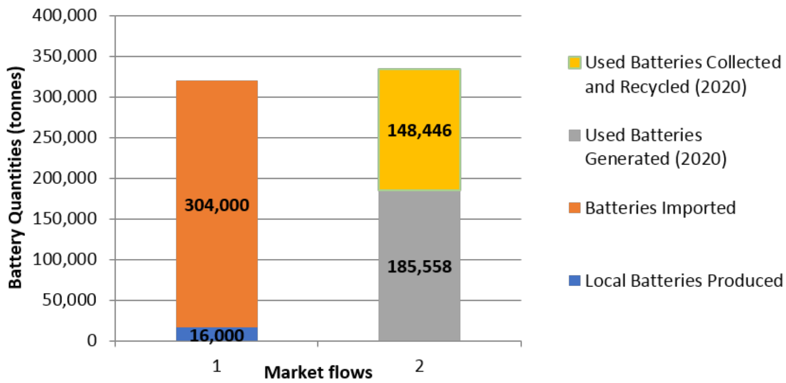

Figure 4.7: Battery Quantities showing Market Inflows (1) and Outflows (2) [30]

The various sectors in the Nigerian economy utilize batteries based on their energy requirements and an increased production. Table 4.4 highlights the battery use by sectors and Figure 4.7 illustrates the proportions used by these sectors.

Sector	Number of batteries
Automotive	5,900,000
Power Generators	4,600,000
Telecoms	367,644
Solar Backup	100,000
Total	10,967,644

Table 4.4: Quantity of lead acid batteries used in various sectors [30]

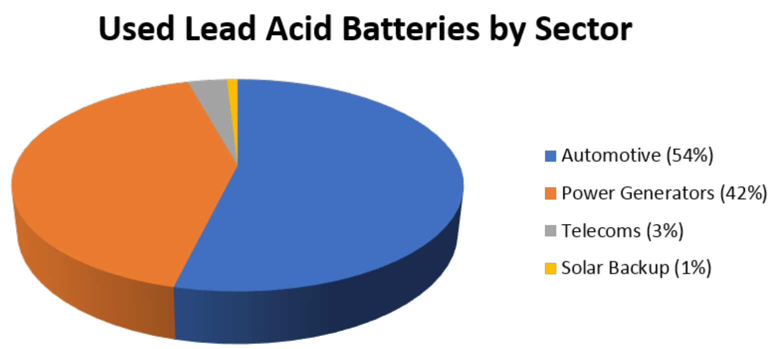

Figure 4.8: Sectoral Use for Lead Acid Batteries (Source: [31]

The recycling of lead acid batteries is cost intensive and requires special skills to safely dispose of the sulfuric acid and decouple the battery parts for reuse. Figure 4.9 outlines the cyclic stages of this process from collection of used batteries from the customers to the purchase of new batteries made of recycled parts.

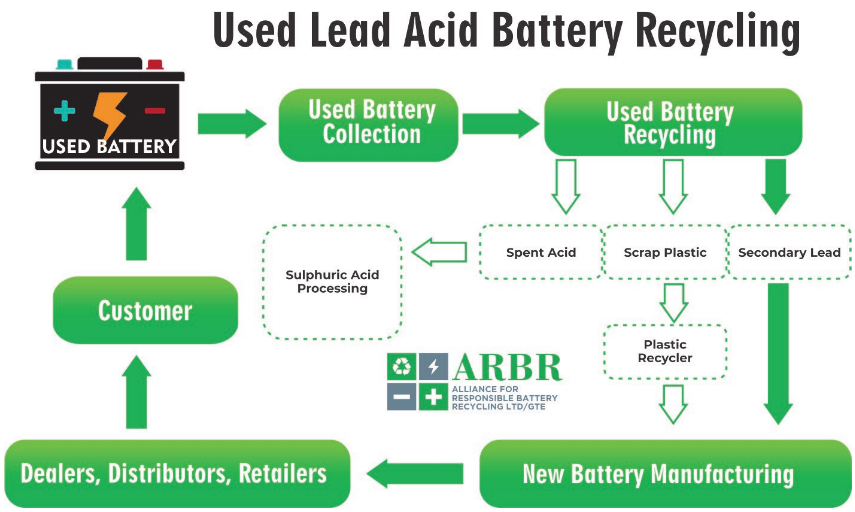

Figure 4.9: The Battery Recycling Process [**aarbr**]

ARBR hopes to have a representative in all states in Nigeria by the fourth quarter of 2022 and will support the informal sector through WBRAN to facilitate the proper collection and recycling of at least 40% of all used batteries in Nigeria. This will be an equivalent of 3 million used batteries weighing up to 75,000 tonnes in the first year of collaboration and will anticipate a 100% increase between 2 and 3 years afterwards [30]. A diagram highlighting the stakeholder details of the EPR PROs is illustrated in Figure 4.10.

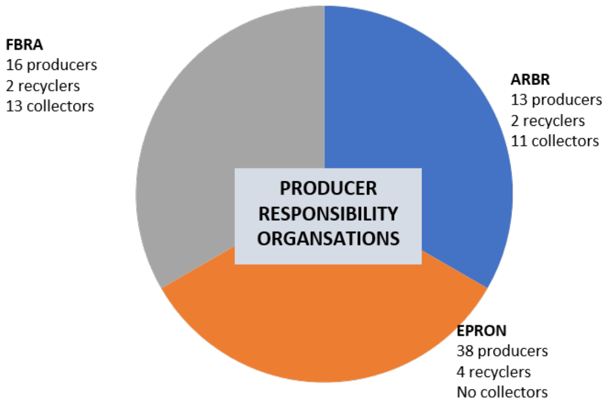

Figure 4.10: Stakeholders of Producer Responsibility Organization (PROs) of the Nigeria EPR Program.

Eighty percent (80%) of lead acid batteries are recycled though about 70% are carried out by the informal sector. Presently, ARBR have recyclers in only 2 states in the country. Union Autoparts Manufacturing Company Limited, a subsidiary of the Ibeto Group has environmentally friendly facilities to recycle 250,000 tonnes per annum. ARBR hopes to rapidly expand to cover the whole nation by 2026. They intend to achieve this by aiding the transition of informal recycling operators to the formal sector, upgrading their facilities to environmentally clean technological processes. ARBR also requires the creation, implementation and enforcement of battery policies and regulations, technical assistance, funding and awareness/patronage.

4.2 Circular Economy Analysis of the Waste Management Legislation

The waste management policies and regulations identified in Chapter 3 of this report were assessed and tabulated (Appendix A.1 & A.2) highlighting circular economy features and indicators. It was observed that the National Policy on Solid Waste Management and National Policy on Plastic Waste Management (see Figure 4.11) have clearly outlined circular measures to reduce the generation of solid waste and plastics compared to other polices which have no clear links with the circular economy.

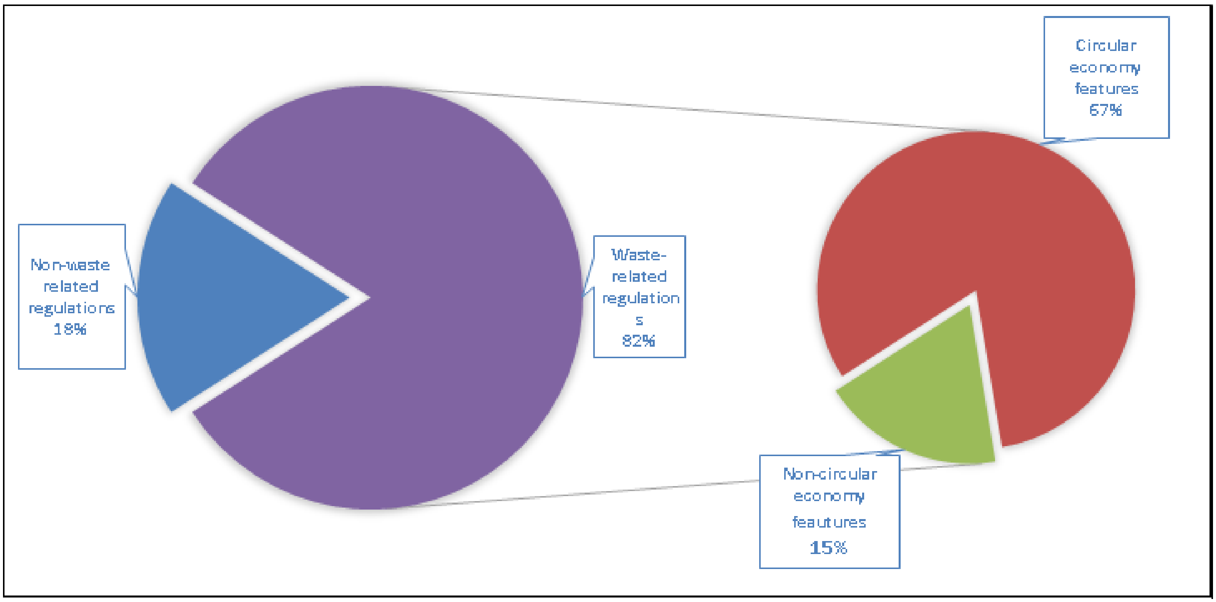

Figure 4.11: Nigerian Environmental Regulations.

Also, a combination of low and high R-values depict waste related policies comprising of both proactive and reactive circularity approaches as part of the nation's waste management policies. However, most of the regulations have lower R-values implying higher circularity tendencies compared to the policies and therefore prioritize the development of sustainable materials and increased efficiencies of waste processes ahead of utilizing already used and discarded materials for varied purposes, reproduction and recycling.

4.3 Circular Economy Analysis of Various Waste Management Initiatives

From the analysis of the government affiliated waste management projects which were tabulated in Table 4.6, it was shown that the initiatives were a combination of proactive and reactive circular measures addressing potential and existing challenges of waste management. Synergies include Government collaborations with stakeholders such as NCEWG, UNIDO, UNEP, ACEF, GEF, WB, IsDB, EU, CCI, USEPA, World Bank/IBRD, UNITAR. The analysis also highlighted a strained relationship on some projects between the Federal and some State Governments where projects were initiated by the former and handed over to the latter. Issues such as contractual commitments, absence of basic amenities, and a lack of proper communication has led to some projects becoming dormant. These synergies need to be improved with roles clarified in order to resuscitate those projects.

The initiatives of the African Development Bank (AfDB) including a description, stakeholders involved, circular economy attributes and the status of the initiative have been highlighted in Table 4.5. The AfDB have partnered with stakeholders within and outside the African continent to develop programs and form circular economy groups which address the whole spectrum of the circular economy features.

S/n	Title of Initiative	Description	Location	Project Timeframe	Other Partners	Circular Economy Features	Status
1	NDC Revision	Revision of 2021-2025 NDC	Nigeria	2021	FMOE, UNDP, UNIDO, the GIZ, IsDB, UK Government, IRENA, 2050 Pathways	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7-Repurpose • R8-Recycle • R9-Recover	Ongoing
2	Nigeria Circular Economy Working Group (NCEWG)	Working Group consisting of stakeholders from the government and various sectors to facilitate the drive for the implementation of the circular economy in Nigeria	Nigeria	N/A	AfDB, UNDP, World bank Group, EU, IsDB, Kingdom of Netherlands, CEIP, ACEN,		Ongoing
3	African Circular Economy Alliance (ACEA)	Steer the African continent towards a circular economy by developing the necessary legal and regulatory frameworks, and creating awareness	Africa	N/A	Governments of Cote d'Ivoire, Ghana, Rwanda and South Africa; other strategic partners include the ACEN, GEF, Government of Finland, PACE, UNEP, and World Economic Forum.		Ongoing
4	Nigeria Circular Economy Program	Incorporate circular economy activities into nation's economy	Nigeria	2021-2030	Members of NCEWG, UNIDO, UNEP, ACEF, GEF, WB, IsDB, EU and other partners.		Ongoing

Table 4.5: Initiatives Promoted by African Development Bank (AfDB)

The Federal Government through the Ministry of Environment has established waste management projects in some states of the federation as highlighted in Table 4.6 and these facilities process different waste streams for various purposes. These projects were initiated between 2008-2010 with the aim of processing different waste streams ranging from plastics, medical waste, and scrap metal; in addition to briquette facilities but most of these projects are not in operation due to number of challenges. Stakeholders include the State Governments, the Ecological Fund Officer and the Federal Ministry of Health. An Integrated Waste Management Scheme nationwide has also be developed but the facilities are yet to be installed in the selected states. The EPR Programme is an initiative developed by the FMOE and enforced by NESREA whereby manufacturers are mandated to manage waste reduction process. The current waste streams covered by the programme include those from the food and beverage, electrical/electronics, and batteries sectors. The details of the EPR programme have been summarized in Table 4.7.

The Lagos State Government has also been actively developing waste management projects in collaboration with PPPs and these projects have been tabulated in Table 4.8. Common features of the projects include the recycling of waste and recovery of energy currently taking place at various sites across the state which involve processing different waste streams. Waste streams which are processed include organic waste, medical waste, plastic, compost and general waste recycling. Foreign and local stakeholders have also partnered with Lagos State to sustainably manage its waste but there is a concentration of foreign donors in the Integrated Waste Management Initiatives compared to other initiatives. All projects are currently in operation.

There are Foreign Development Partners and Donor Agencies working together with other stakeholders to facilitate sustainable waste management processes through different projects. These have been highlighted in Table 4.9 describing the activities, locations, duration, circular economy features and status. The highlighted projects are currently ongoing and were initiated from 2014. Stakeholders of these projects are governments, donor agencies, and the private sector. It can be noted that fewer stakeholders were involved in initiatives which addressed specific waste streams compared to a higher number of stakeholders in projects with far reaching effects and cover a broad range of circular economy features. These initiatives have focused on the implementation and planning processes of circular economy activities with the formation of groups which would drive these processes in a bid to address waste generation at their sources. There is however a focus on the creation of circular economy groups and in ad- dressing the release of PCBs into the environment which may be at the expense of reactive measures which tackle waste which has already been indiscriminately disposed.

A circular analysis of major private sector driven waste management initiatives was also carried out with their details highlighted in Table 4.10 describing project activities and circular economy features. Though the waste streams the initiatives focused on are on e-waste, compost, plastics and packaging, and solid waste, it was noted 90% of these initiatives are based in Lagos. The Earthcare facility is the largest organic fertilizer in West Africa utilizing organic waste as its raw materials. Project ReflexNG with Dow Chemicals as its principal stakeholder is one of the largest plastic recycling initiatives in the country with an objective to recycle 300 million plastic water satchets. The Initiates Recycling Initiative is an e-waste processing facility located in Rivers State which is one of the largest e-waste recyclers in Nigeria. All initiatives are currently in operation.

S/n	Title of Initiative	Description	Locations	Project Timeframe	Other partners	Circular Economy Features	Status
1	National Plastic Recycling Program	Installation of Plastic Recycling Machine (pelletizer) across the country at 26 designated centers installed with 1000kg/cycle machines in 2008 and 2012	FCT, Ogun, Oyo, Osun, Ekiti, Niger, Taraba, Katsina, Kano, Yobe, Benue, Jigawa, Kaduna, Imo, Azare, Bauchi, Anambra, Kwara, Borno, Kebbi;, Rivers, Bayelsa, Sokoto, Delta; Calabar, Ebonyi	2008-date	Ecological Fund Office, State Governments in Nigeria	• R6 - Remanufacture • R7-Repurpose • R8-Recycle	3 handed over to State Governments, others are dysfunctional due to uncompleted buildings, lack of basic amenities etc
2	National Hospital Intervention Scheme	Installation of 23 biomedical waste incinerators with 100kg/hr capacity at Federal Medical Institutions in various parts of the country to dispose of medical wastes	Lagos, Kwara, Ondo, FCT, Kaduna , Kano, Gombe, Osun, Enugu, Anambra, Akwa Ibom, Bayelsa, Cross River, Rivers, Benue, Sokoto, Zamfara, Kogi, Nasarawa, Bauchi	2009-date	FMOE, FMOH	R9-Recover	10 installations completed and handed over to the Federal Medical Institute Agency; others ongoing and awaiting installations
3	National Scrap Metal Recycling and Recovery Programme	Installation of scrap metal recovery and recycling facilities with capacity of processing 2 tonnes/hr for abandoned vehicles at 3 locations	Kaduna, Rivers and Sokoto;	2010-date	State Governments	• R6 - Remanufacture • R7-Repurpose • R8-Recycle	Rivers State Government in PPP management; Kaduna and Sokoto yet to be completed
4	Briquette Plants	Installation of briquette equipment at 4 locations nationwide	Delta, Lagos, Benue, Cross River	2010-date	State Governments	R9-Recover	• Delta-operational • Lagos- managed by LAWMA • Cross River and Benue-yet to be completed

Table 4.6: Initiatives Executed by the Federal Government of Nigeria

S/n	Title of Initiative	Description	Locations	Project Timeframe	Foreign Stakeholders	Circular Economy Features	Status
1	Extended Producer Responsibility (EPR)	Implementation of initiative whereby manufacturers are mandated to manage waste reduction process with current emphasis on food and beverage, electrical/-electronics, and batteries	Country wide	2018-date	Producers, PROs (FBRA, ARBR, EPRON) Recyclers, Collectors, Consumers.	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7-Repurpose • R8-Recycle • R9-Recover	Ongoing

Table 4.7: The Public Private Partnership (EPR Programme in Nigeria)

S/n	Title of Initiative	Description	Other Partners	Circular Economy Features	Status
1	Integrated Waste Management Initiatives	It consists of a Waste Containerization Strategy, Intermediate Waste Disposal Facilities (TLS), a Medical Waste Treatment Plant in Oshodi, a Nylon Buyback Programme, a Waste-to-Wealth Compost Plant in Ikorodu, a Landfill Waste to Energy (WTE) Olusosun which has a Landfill Gas Capturing Facility, Biogas Plant for WTE using market waste	UNEP, CCI, USEPA, World Bank/IBRD, local investors and financial institutions	• R8-Recycle • R9-Recover	Ongoing
2	Integrated Solid Waste Management Facility	Waste facilities at Epe and Methane Gas Capture and Utilization Project at Abule –Egba and Solous Landfills. It will utilize three landfill sites for the gas capture and will also incorporate nylon/plastic recycling facility as well as construction and demolition waste services.	CCI	• R8-Recycle • R9-Recover	Ongoing
3	Recycling Bank	The recycling bank encourages the collection and processing of certain kinds of waste at locations for recycling in various parts of Lagos.		R8-Recycle	Ongoing
4	Blue Box Recycling Initiative	Promotes greater segregation of waste	Private sector	R8-Recycle	Ongoing

Table 4.8: Lagos State Waste Management PPP Initiatives

S/n	Title of Initiative	Description	Locations	Project Timeframe	Foreign Stakeholders	Circular Economy Features	Status
1	NDC Revision	Revision of 2021-2025 NDC	Nigeria	2021	FMOE, UNDP, UNIDO, the GIZ, IsDB, UK Government, IRENA, 2050 Pathways	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7-Repurpose • R8-Recycle • R9-Recover	Ongoing
2	Nigeria Circular Economy Working Group (NCEWG)	Working Group consisting of stakeholders from the government and various sectors to facilitate the drive for the implementation of the circular economy in Nigeria	Nigeria	N/A	AfDB, UNDP, World bank Group, EU, IsDB, Kingdom of Netherlands, CEIP, ACEN	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7-Repurpose • R8-Recycle • R9-Recover	Ongoing
3	African Circular Economy Alliance (ACEA)	Steer the African continent towards a circular economy by developing the necessary legal and regulatory frameworks, and creating awareness	Africa	N/A	Governments of Cote d'Ivoire, Ghana, Rwanda and South Africa; other strategic partners include the ACEN, GEF, Government of Finland, PACE, UNEP, and World Economic Forum.		
4	Nigeria Circular Economy Program	Incorporate circular economy activities into nation's economy	Nigeria	2021-2030	Members of NCEWG, UNIDO, UNEP, ACEF, GEF, WB, IsDB, EU and other partners.		

5	National Action Plan on Mercury in the Nigerian Artisanal and Small Scale Gold Mining Sector	Strengthen capacity of Nigeria as a result of Minamata Convention	Nigeria	2016-Date	UNEP, FMOE, WHO, GEF Trust Fund, UNIDO	• R0-Refuse • R1-Rethink • R2-Reduce	Ongoing
6	Minamata Convention Initial Assessment	Project to check level of preparedness of Nigeria based on Minamata Convention	Nigeria	2014-Date	FMOE and UNITAR, GEF Trust Fund	• R0-Refuse • R1-Rethink • R2-Reduce	Ongoing
7	Environmentally Sound Management and Disposal of PCBs	Reduce the exposure of polychlorinated biphenyl (PCBs) on the Nigerian populace	Nigeria	2017-date	FMOE, GEF	• R0-Refuse • R1-Rethink • R2-Reduce	Ongoing

Table 4.9: Waste Management Initiatives of Foreign Development Partners and Donors

S/n	Title of Initiative	Primary Stakeholder of Initiative	Brief Description	Location	Project timeframe	Other partners	Circular Economy Indicators	Status
1	Earthcare Waste –to-Wealth Composting Plant	Earthcare Nigeria Limited (ENL)	Commissioned to produce 200,000 metric tons of fertilizer per annum from 1,500 metric tons of waste daily. Currently operational but collecting only 600 the tonnes of organic waste daily due to logistics issues. It is the largest commercial producer of organic fertilizer in West Africa.	Odogunyan farm settlement, Ikorodu Local Government Council of Lagos State	2009-Date	N/A	• R8-Recycle • R9-Recover	Ongoing
2	West Africa ENRG Materials Recovery Facility (MRF)	West Africa Engrg	Conversion of non-recyclable waste materials into electricity using patented technology. It also recovers valuable materials such as plastic, metal and paper and aims to reduce landfills. It employs approximately 600 people of which 72% are women and 95% from the local community.	Igando, Lagos State	2015-Date	N/A	• R7-Repurpose • R8-Recycle • R9-Recover	Ongoing
3	Lafarge Geocycle	Lafarge Africa	Professional waste management services division of Larfarge Africa catering for wastes from various sectors and converting plastic and other waste to fuel sources for use in its kilns.	Lagos, Ogun, Kano	N/A	N/A	• R8-Recycle • R9-Recover	Ongoing
4	E-terra Technologies Recycling	E-Terra Technologies Ltd	Recycling of e-waste and data destruction	Lagos State	N/A	N/A	• R4-Repair • R5-Refurbish • R6-Remanufacture • R7-Repurpose • R8-Recycle • R9-Recover	Ongoing
5	Hinckley E-waste Recycling	Hinckley Group Nigeria	Recycling of e-waste and data destruction. In 2012, it processed more than 2,000 waste products.	Lagos State	N/A	N/A	• R4-Repair • R5-Refurbish • R6-Remanufacture • R7-Repurpose • R8-Recycle	Ongoing

Continued on next page

Table 4.10 – continued from previous page

S/n	Title of Initiative	Primary Stakeholder of Initiative	Brief Description	Location	Project time-frame	Other partners	Circular Economy Indicators	Status
6	Wecyclers and Recyclers Recycling Schemes	Wecyclers and Recyclers Recycling Companies	Purchase of plastic waste and then reselling to off-takers using mobile applications. These initiatives have collected between 1000- 1,500 tonnes of plastic waste yearly with 70% of this waste consisting of valuable PET bottlers.	Lagos State	N/A	N/A	• R7-Repurpose • R8-Recycle	Ongoing
7	Alkem Recycling	Alkem Nigeria Limited	Processes plastic waste bottles to raw materials used in manufacturing roofing sheets, pillows, textiles, sofas, mattresses, building insulation and the textile etc	Lagos State	N/A	Coca-cola, Nigerian Bottling Company	• R6-Remanufacture • R7-Repurpose • R8-Recycle	Ongoing
8	Engee PET Recycling	Engee PET Manufacturing Company	Recycle plastic PET bottles into eco-friendly PET raw materials (resin)	Lagos State, Ogun State	2014-Date	N/A	• R6-Remanufacture • R7-Repurpose • R8-Recycle	Ongoing
9	Project ReflexNG	Dow Chemicals	Plastic waste can be exchanged for cash, call credits and provisions. It has a target of recycling 300 million plastic water satchets by employing over 200 registered waste collectors and encourages the use of recycled plastic resins as an alternative to plastic use.	Lagos State	2020-Date	Omnik Ltd, Recycle Points Ltd, Lagos Business School	• R6-Remanufacture • R7-Repurpose • R8-Recycle	Ongoing
10	Initiates Recycling Initiatives	Initiates Plc	E-waste processing, decontamination, industrial cleaning and municipal waste management	Rivers State	N/A	N/A	• R8-Recycle • R9-Recover	Ongoing

Table 4.10: Private Sector Waste Management Initiatives

4.4 POPs and Mercury Emissions

Persistent Organic Pollutants and mercury are hazardous chemicals released from some materials into the environment affecting human health, wildlife, and surroundings as well as faraway locations as these substances can travel far from where they are released. Sources such as electrical and electronic products, industrial processes, and agricultural chemicals are all sources of POP and mercury, and they cannot be reused, re-purposed and recycled. This implies that a sustainable solution to reducing hazardous waste would be to prevent their uses. Certain initiatives by UNIDO, UNDP and GEF as delineated in Table 4.9 have been carried out in Nigeria to build capacity, identify polluted sites and work towards meeting the commitments made at the Stockholm and Minamata Conventions.

The constituents' materials of common electrical and electronic devices and gadgets are shown in Table 4.11. Some devices can be seen to contain multiple polluting materials which are hazardous.

Electrical/ Electronic component	**Materials/ Pollutant**
Computers	Lead, mercury, cadmium and beryllium
Batteries	Cadmium, cobalt, lead, lithium, mercury, nickel, silver and zinc
Mobile phones	Lithium, copper, tin, cobalt, indium, antimony, silver, gold, and palladium
Photocopiers	Mercury, selenium
Circuit Boards	Silver, lead, copper, cadmium, brominated flame proofing agent, PCBs (polychlorinated biphenyls) and arsenic
Light Emitting Diodes (LEDs)	Arsenic
Cathode ray tubes	Cadmium, lead
Liquid Crystal Displays	Mercury

Table 4.11: Electronic components and their Materials (Source: Omole et al, 2015)

These polluting materials can lead to health ailments both in the short and long term. Their health effects are illustrated in Table 4.12.

Materials	**Effect on human health**
Antimony	Severe skin problems
Cadmium	Damage to kidney and bone structure, elevated blood pressure. Cadmium is a carcinogen.
Lead	Short term exposure can initially cause malaise, muscle pain and headache. Long term exposure can lead to irreversible damage to the nervous system, particularly in children
Mercury	Short term exposure can initially cause lung damage, nausea, diarrhoea, skin rashes, and high blood pressure. Long term exposure damages the central nervous system and kidneys.
Nonylphenol	Damages sperm function and deoxyribonucleic acid (DNA).
Polybrominated diphenyl ether	Affects immune system, interferes with growth hormones, sexual development and brain development. Children exposed to this display increased risk of thyroid disease and neurobehavioral disease.
Polychlorinated biphenyls	Suppresses immune system, damages liver and nervous system, promotes cancer, causes behavioural changes, and damages male and female reproductive system.
Polychlorinated naphthalene	Can impact skin, liver, nervous and reproductive system.
Triphenyl phosphate	Contact dermatitis, endocrine disruptor.

Table 4.12: WEEE Materials and their effect on Human Health (Source: Kumar et al., 2017; Grant et al., 2013)

Chapter 5

Waste Emission Modelling

5.1 Solid Waste Disposal Sites (SWDS)

This chapter reports estimating methane (CH_4) from solid waste disposal sites (SWDS) as part of carbon accounting from the Waste sector in Nigeria from 1960 - 2030. [32] reports that "methane (CH_4) produced at SWDS contributes about 3 - 4% to the annual global anthropogenic GHG emissions". Also, [33, 34] reports that by mass, methane (CH_4) has 21 times the global warming potential of carbon dioxide (CO_2) over a 100-year time frame. In following the IPCC guidelines for carbon accounting, the First Order Decay (FOD) model is used to estimate methane (CH_4) emissions from SWDS as it produces more accurate estimates of annual emissions [4, 35].

Various methods exist for estimating methane (CH_4) emissions from SWDS. These methods include first order decay methods such as the Netherlands Organization for Applied Scientific Research (TNO) model [36], LandGEM [37, 38], Gassim [39], Afvalzorg [40], and IPCC [4]), and zero order decay methods such as the German EPER and France EPER models [35, 40, 41].

Section 5.1.1 will discuss the rationale for using IPCC's First Order Decay (FOD) method. It will discuss the three tiers to estimate Methane (CH_4) emissions from SWDS using the FOD method and our choice of country-specific activity data and default parameters for the FOD emission model. Section 2.1 will discuss the data acquisition from primary and secondary sources. It will explain our approach to data modelling for developing a consistent time series using recurrent neural networks (RNNs) to calculate results for previous years that are not in the primary or secondary data sources. Section 5.1.7 will discuss the results from the FOD model in estimating Methane (CH_4) emissions from SWDS in Nigeria from 1960 - 2030.

The emission model we selected for estimating methane (CH_4) from SWDS is the IPCC First Order Decay (FOD) method. This method's choice is based on the fact that we are estimating the total methane emission from landfill sites in Nigeria for both municipal and industrial waste for the years 1960 - 2030. [40] reports that a first-order degradation model is sufficiently accurate to estimate methane emissions from landfills for an entire nation. We know that FOD methods may not be the most accurate in estimating emissions from individual landfills [40], however, when estimating annual methane emissions for all national dumps, the emissions estimates will "statistically counterbalance" each other [40].

We expect this to be the case for Nigeria.

5.1.1 The IPCC First Order Decay (FOD) method

The FOD method assumes that degradable organic carbon (DOC) in solid waste disposal sites (SWDS) decays slowly over time forming methane (CH_4) and carbon dioxide (CO_2) in the process [4]. Further, the FOD method assumes that emissions from methane (CH_4) and carbon dioxide (CO_2) in SWDS are higher in the first few decades after waste is deposited. As time goes on, there is a steady decline in emissions because the degradable carbon in the waste is consumed by bacteria responsible for decay [4]. Different types of waste have varying half-lives (i.e. the time taken to degrade) from a few years to several decades, or longer [4].

To the end, the FOD model requires data for at least 50 years to achieve an acceptably accurate result [4]. For this emission accounting effort, we used primary data from the Nigerian Federal Ministry of Environment to build a model to estimate data for the missing periods from 1960 - 2030, spanning a total of 70 years. Details on the data modelling approach are covered in Section 2.1.

5.1.2 Tiers for estimating methane (CH_4) emissions from SWDS

To estimate methane (CH_4) emissions from SWDS, they are three (3) tiers which are employed based on the available granularity of country-specific data:

- **Tier 1.** In Tier 1, the factors for estimating methane (CH_4) emissions are mainly based on IPCC default activity data and default parameters.
- **Tier 2.** Tier 2 emission accounting requires good quality country-specific activity data along but also allow for the use of some default parameters.
- **Tier 3.** Tier 3 estimations require the use of good quality country-specific activity data with either nationally developed key parameter or measurements derived from country-specific parameters.

On Using Tier 2 for emission accounting. The accounting results in this report use the Tier 2 method for estimating methane (CH_4) emissions from SWDS in Nigeria from 1960 - 2030. We choose Tier 2 because we can collect and estimate good quality country-specific activity data on historical and current waste disposal. Hence, we can do a Tier 2 emission estimate using the IPCC FOD method with default parameters and country-specific activity data.

On the spreadsheet model. We use the IPCC spreadsheet for estimating methane (CH_4) emissions from solid waste disposal sites in Nigeria. The IPCC FOD spreadsheet model calculates accurate methane (CH_4) emissions from SWDS and reflects the degradation rate of wastes in a landfill [42]. The spreadsheet model simplifies calculating methane (CH_4) emissions from SWDS as the FOD method's algorithm is already pre-computed in the cells. What remains is to input the default parameters and country-specific activity data for the time-frames under consideration.

5.1.3 On Methane Generation

Methane (CH_4) is generated in SWDS as a result of degradation of organic material under anaerobic conditions. The amount of methane (CH_4)generated from waste in a certain year will decrease gradually throughout the following decades. The FOD model is built on an exponential factor that describes the fraction of degradable material that is degraded into (CH_4) and (CO_2) each year [4].

A primary input to the FOD model is the amount of degradable organic matter (DOC_m) in waste disposed into SWDS. Degradable organic matter (DOC_m), is estimated based on information on disposal of different waste categories (municipal solid waste (MSW), sludge, industrial and other waste) and the different waste types/material (food, paper, wood, textiles, plastics and other inert, etc.) included in these categories. So, the basis for estimating the methane (CH_4) emissions from SWDS is to calculate the amount of Decomposable Degradable Organic Carbon ($DDOC_m$). The formula for calculating ($DDOC_m$) is shown in Equation 5.1 [4].

$$DDOC_m = W \cdot DOC \cdot DOC_f \cdot MCF \tag{5.1}$$

where,

- $DDOC_m$ = mass of decomposable DOC deposited, Gg.
- W = mass of waste deposited, Gg.
- DOC = degradable organic carbon in the year of deposition, fraction, Gg C/Gg waste.
- DOC_f = fraction of DOC that decomposes under anaerobic conditions.
- MCF = CH_4 correction factor for aerobic decomposition in the year of deposition (fraction) under aerobic conditions (prior to the conditions becoming anaerobic) in the SWDS.

Equation 5.1 is pre-computed in the IPCC spreadsheet model.

5.1.4 First Order Decay (FOD)

With the first-order decay reaction, the amount of waste product is proportionate to reactive material. Hence the year the waste was deposited in the SWDS is unrelated to the amount of methane (CH_4) produced each year. The total mass of the current decomposing material on the site is what is necessary. Therefore, if the amount of decomposing material at the beginning of the year is known, every year can be considered the first year in the estimation method. The first-order calculations can be done using two simple equations with the decay reaction starting on the 1st of January the year after deposition [4]. Equation 5.2 shows the Decomposable Degradable Organic Carbon ($DDOC_m$) accumulated in the SWDS at the end of year T. Equation 5.2 is substituted into Equation 5.3 to show the ($DDOC_m$) decomposed at the end of year T.

$$DDOC_m a_T = DDOC_m d_T + (DDOC_m a_{T-1} \cdot e^- k) \tag{5.2}$$

$$DDOC_m \ decomp_T = DDOC_m a_{T-1} \cdot (1 - e^- k) \tag{5.3}$$

where:

- T = inventory year.
- $DDOC_m a_T$ = DDOCm accumulated in the SWDS at the end of year T, Gg.
- $DDOC_m a_{T-1}$ = DDOCm accumulated in the SWDS at the end of year (T-1), Gg.
- $DDOC_m d_T$ = DDOCm deposited into the SWDS in year T, Gg.
- $DDOC_m \ decomp_T$ = DDOCm decomposed in the SWDS in year T, Gg.
- k = reaction constant, k = $ln(2)/t1/2(y-1)$.
- $t1/2$ = half-life time (y).

Using Equation 5.3, we then calculate the estimated amount of methane (CH_4) formed from decomposable material by multiplying the methane (CH_4) fraction in generated landfill gas and the methane/ carbon CH_4/C molecular weight ratio (see Equation 5.4).

$$CH_4 \ generated_T = DDOC_m \ decomp_T \cdot F \cdot 16/12 \tag{5.4}$$

where:

- $CH_4 \ generated_T$ = amount of CH4 generated from decomposable material.
- $DDOC_m \ decomp_T$ = DDOCm decomposed in year T, Gg.
- F = fraction of CH4, by volume, in generated landfill gas (fraction).
- 16/12 = molecular weight ratio $CH4/C$ (ratio).

For more detailed information on the IPCC FOD method the reader is directed to [4], [43] and [44].

5.1.5 The IPCC Spreadsheet Waste Model

The IPCC spreadsheet waste model provides two options for estimating emissions from municipal solid waste (MSW) based on the granularity of activity data available. The options are:

- **A multi-phase model:** This model is based on the composition of waste data for each type of degradable waste material (food, garden and park waste, paper and cardboard, wood, textiles, etc.).
- **A single-phase model:** This model is based on bulk waste (MSW).

In building the FOD model for Nigeria from 1960 to 2030, we used the multi-phase model approach and entered activity data for each type of degradable waste material. The spreadsheet model was adapted for our Tier 2 approach to methane (CH_4) emission modelling in SWDS.

5.1.6 Emission Factors and Parameters

Degradable organic carbon (DOC). Degradable organic carbon (DOC) is the organic carbon in waste that is accessible to biochemical decomposition, and should be expressed as Gg C per Gg waste [4].

Methane correction factor (MCF). The methane (CH_4) correction factor (MCF) accounts for the fact that unmanaged SWDS produce less methane (CH_4) from a given amount of waste than anaerobic managed SWDS [4]. The default values for MCF used in estimating our FOD model is shown in Table 5.1.

Type of Site	**Methane Correction Factor (MCF) Default Values**
Managed – anaerobic	1.0
Managed – semi-aerobic	0.5
Unmanaged – deep (>5 m waste) and /or high water table	0.8
Unmanaged – shallow (<5 m waste)	0.4
Uncategorised SWDS	0.6

Table 5.1: SWDS classification and methane correction factors (MCF).

Half-life. The half-life value, $t_1/2$ is the time taken for the degradable organic matter (DOCm) in waste disposed into SWDS to decay to half its initial mass. In the FOD model, the reaction constant k is used [4].

Table 5.2 shows the selected degradable organic carbon (DOC) and half-life inputs. The values for degradable organic carbon (DOC) are country-specific values from the Nigerian Federal Ministry of Environment. However, the DOC for wood and straw is an IPCC default. On the other hand, all the rate constants (k) are IPCC regional defaults for the tropical climate Zone (moist and wet).

	DOC (Degradable organic carbon) (weight fraction, wet basis)	**Methane generation rate constant (k) (years-1)**
Food waste	0.08	0.4
Garden	0.45	0.4
Paper	0.1	0.07
Wood and straw	0.43	0.035
Textiles	0.4	0.07
Disposable nappies	0.24	0.1
Sewage sludge	0.05	0.4
Bulk MSW	0	0.09
Industrial waste	0.15	0.09

Table 5.2: Selected DOC and half-life inputs.

Fraction of degradable organic carbon which decomposes (DOC_f). The Fraction of degradable organic carbon which decomposes (DOC_f). is an estimate of the fraction of carbon that is ultimately degraded and released from SWDS, and reflects the fact that some degradable organic carbon does not degrade, or degrades very slowly, under anaerobic conditions in the SWDS. The DOC_f for Nigeria is 0.77 [13].

5.1.7 Results and Discussion

In this section we will discuss the results of the FOD model in estimating methane (CH_4) emissions from SWDS in Nigeria from 1960 - 2030. The results will be reported in this order.

1. Section 5.1.7 reports the estimated amounts of waste deposited in SWDS from municipal solid waste (MSW) and industrial categories annually from 1960 - 2030. In reporting the amount of MSW, we will show the breakdown of waste deposited yearly from the different waste types/material. The waste types/ materials under consideration are food, garden, paper, wood, textile, plastics and other inert.

2. Section 5.1.7 reports the amount of methane (CH_4) emitted from SWDS annually from 1960 - 2030. In this report, the reader will observe that our results provides the break-down of methane (CH_4) emission from specific waste types of municipal solid waste (MSW). In addition, we will show the estimated amount of methane (CH_4) emitted from industrial waste for the same time period. Further, we will show the total methane (CH_4) emission annually for Nigeria from 1960 - 2030.

3. Section 5.1.7 provides information on the methane (CH_4) emission from harvested wood products (HWP), and HWP carbon (C), long-term stored in SWDS.

Amount of Waste Deposited in SWDS

This section accounts for the estimated amount of municipal solid waste (MSW) deposited in SWDS annually from 1960 – 2020 and also the projections of waste from 2021 - 2030 (see Appendix B.3 for full results). From Figure 5.1, our results show that in 1961, 4,977 Gg of MSW was estimated to be deposited in SWDS. Whereas, in 2020, 30,914 Gg of MSW was estimated to be deposited. We observed that there was a 521% increase in the amount of MSW deposited in SWDS within a 60-year interval from 1960 to 2020. Further, we observed that the 10-year interval between 1971 and 1980 showed a33.77% increase in the amount of MSW deposited at SWDS. The interval between 1971 and 1980 is the highest percentage per 10-year window from 1960 to 2020. Table 5.3 shows the percentage change per 10 years from 1960 to 2020.

Further, we used our activity data projections with the FOD model to provide estimates of the amount of MSW that will be deposited at SWDS for the year 2021 to 2030. We estimate that in the years 2021 and 2030, 35,854 Gg and 45,471 Gg of MSW will be deposited at SWDS respectively. The time period between 2021 to 2030 shows a projected percentage increase of 28.51% of waste deposited in SWDS in Nigeria. This projection will account for the second highest percentage increase over 10 years since 1971 to 1980.

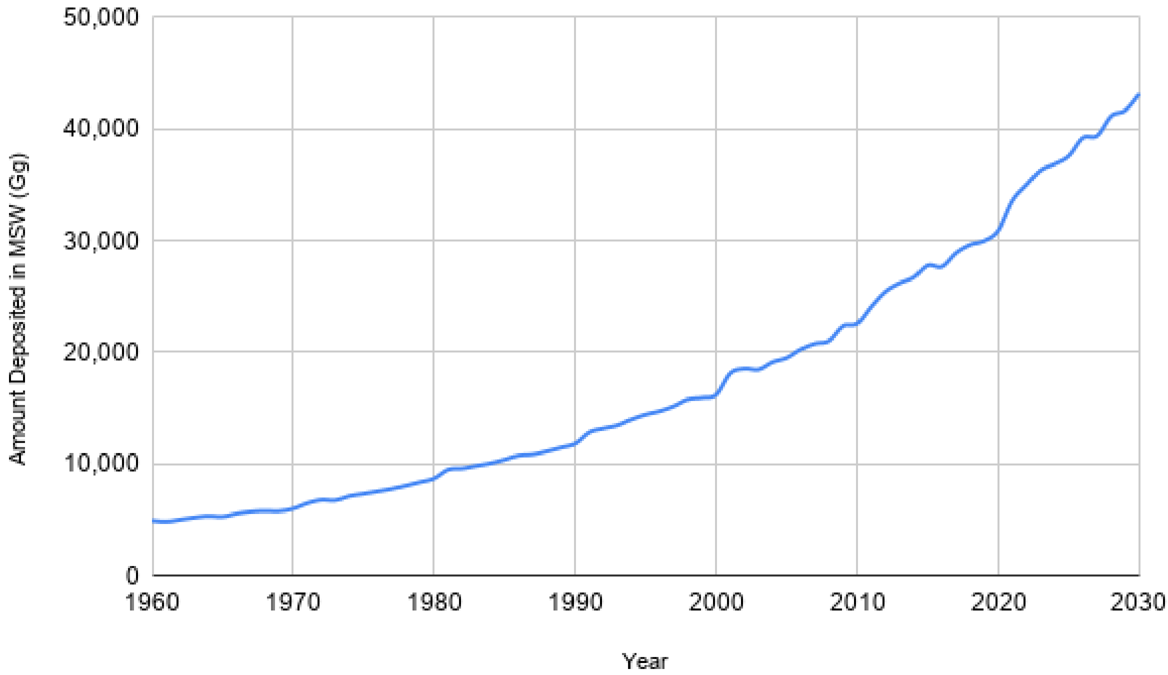

Figure 5.1: Amount of MSW deposited in SWDS.

Time Intervals (years)	**Percentage change** (%)
1960 - 1970	21.60%
1971 - 1980	33.77%
1981 - 1990	24.41%
1991 - 2000	26.13%
2001 - 2010	24.47%
2011 - 2020	28.24%

Table 5.3: Percentage change per 10 years for the amount of MSW deposited in SWDS from 1961 to 2020.

Industrial Waste. This section accounts for the amount of industrial waste deposited in SWDS annually from 1960 – 2020.

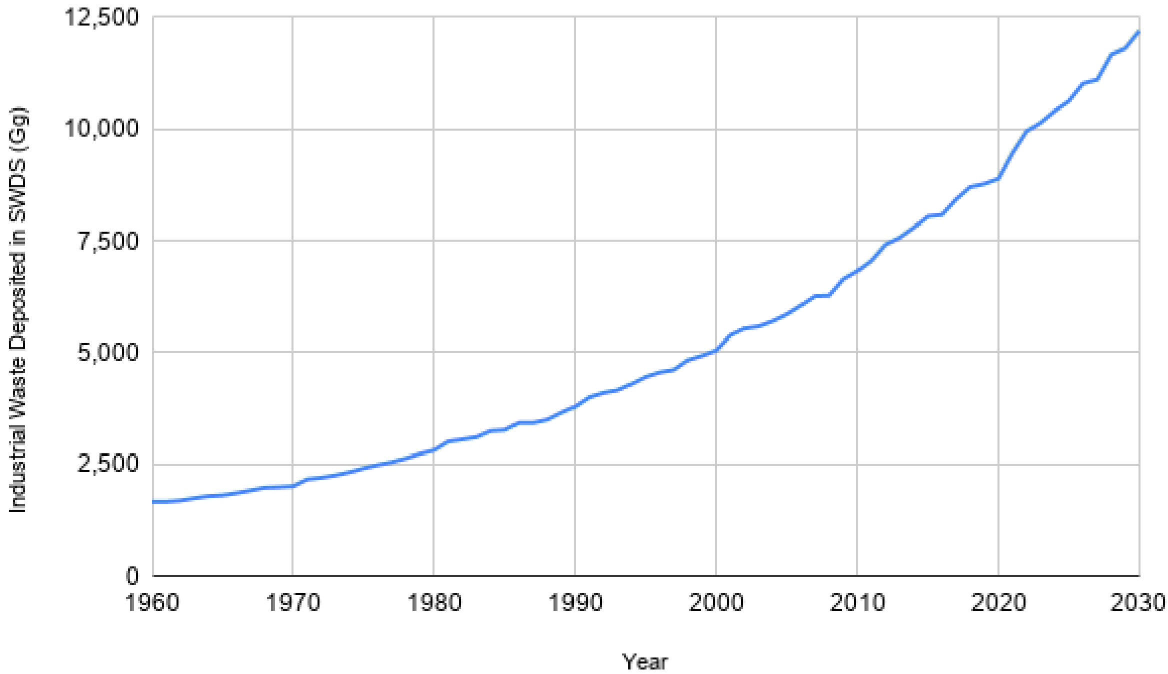

Figure 5.2: Amount of Industrial waste deposited in SWDS.

Figure 5.2 shows that there has been an increase in the amount of industrial waste deposited during the 60-year period. Further, we observed that there was a 430% increase in the amount of Industrial waste deposited in SWDS within a 60-year interval from 1960 to 2020. Further, we observed that the 10-year interval between 1971 and 1980 showed a 29.78% increase in the amount of waste deposited at SWDS. Table 5.4 shows that the interval between 1971 and 1980 is the highest percentage per 10-year window from 1960 to 2020. Also, we used the model to project the amount of industrial waste that will be deposited into SWDS from year 2021 to 2030. We estimate that in the years 2021 and 2030, 9,453 Gg and 12,182 Gg of industrial waste will be deposited at SWDS respectively. The time period between 2021 to 2030 shows a projected percentage increase of 28.87% of waste deposited in SWDS in Nigeria. This projection will account for the second highest percentage increase over 10 years since 1971 to 1980.

Time Intervals (years)	**Percentage change (%)**
1960 - 1970	20.66%
1971 - 1980	29.78%
1981 - 1990	23.91%
1991 - 2000	26.10%
2001 - 2010	26.58%
2011 - 2020	25.91%

Table 5.4: Percentage change per 10 years for the amount of Industrial waste deposited in SWDS from 1961 to 2020.

Annual Methane Emission from SWDS

This section reports the annual methane emissions from SWDS from 1960 to 2030. Using the FOD model, we estimated the amount of methane emitted in 1961 was 77 Gg. From Figure 5.3, our results show that in 2020, 2,622 Gg of methane was estimated to be generated and emitted in SWDS (see Appendix B.4 for full results). We observed that there was an increase of 3305.19% in the methane being emitted from SWDS within the 60-year interval from 1961 to 2020. Further, we observed that the 10-year interval between 1961 and 1970 recorded the highest percentage increase of 278.6% per 10-year window from 1961 to 2020. Table 5.5 shows the full 10-year interval results from 1961 to 2020. We also observed that since 1961 – 1970, the percentage increase per 10-year interval has steadily decreased up till 2020.

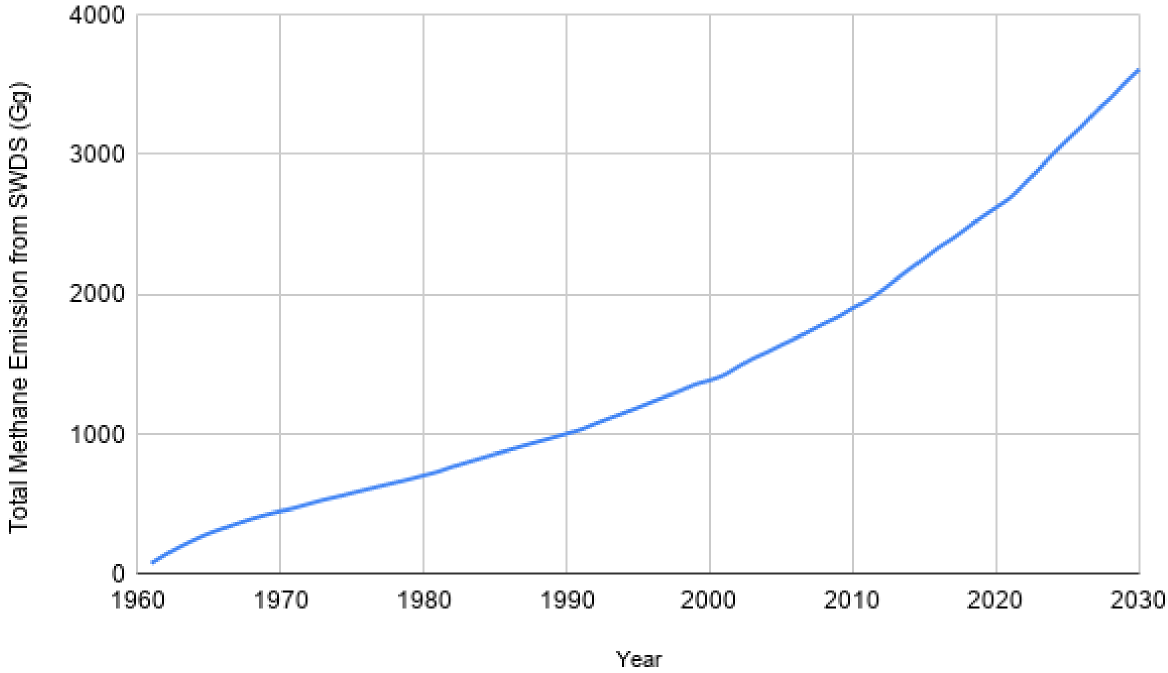

Figure 5.3: Annual methane emissions from SWDS from 1961 to 2030.

Further, using the FOD model, we estimated the amount of methane that will be emitted at SWDS for the year 2021 to 2030. In 2021, it is estimated that 2,693 Gg of methane will be emitted and in 2030, 3,610 Gg of methane is estimated to be emitted SWDS. The time period between 2021 to 2030 shows a projected percentage increase of 34.05% of methane emitted in SWDS in Nigeria.

Time Intervals (years)	Percentage change (%)
1961 - 1970	484.42%
1971 - 1980	48.95%
1981 - 1990	36.97%
1991 - 2000	33.91%
2001 - 2010	33.64%
2011 - 2020	33.84%

Table 5.5: Percentage change per 10 years for Methane Emissions in SWDS from 1961 to 2020.

Methane emission from harvested wood products (HWP)

This section accounts for methane emissions from Harvested Wood Products (HWP) – Garden, Paper and Wood from SWDS from 1961-2020. This section also accounts for the projections of Methane emissions for HWP from 2021 – 2030 (see Appendix B.5 for full results).

Results from the IPCC FOD model shows that from 1961 – 2020, estimated methane emissions for Garden had a percentage increase of 3265% within the 60-year interval. In Table 5.6, with values for Garden, we observed that year 1971 to 1980 experienced a huge drop in percentage increase (47.37%) compared to the 10-year interval(1961-1970) before (451.52%). Results also show that there is a decrease in the percentage increase of the estimated methane being emitted from Garden from 1971 to 2020(see Table 5.6).

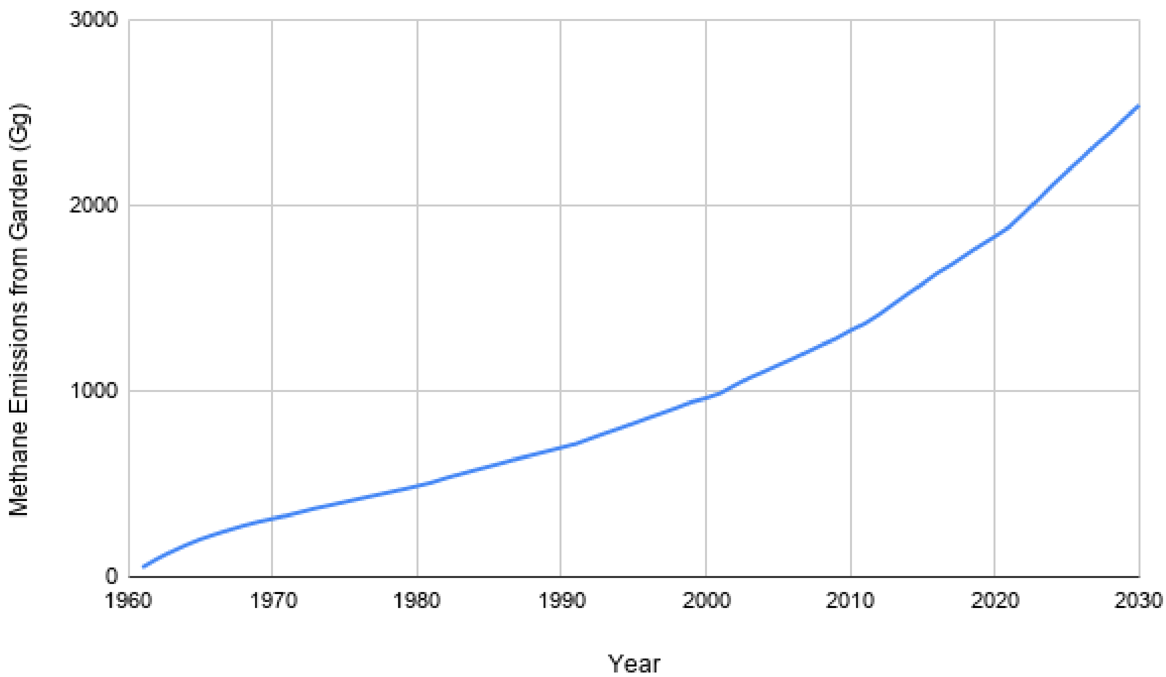

Figure 5.4: Methane Emissions from Garden (Gg) from 1961 to 2030.

Results also show that Paper had an increase of 6248% in the methane emissions from 1961- 2020, a 60-year interval. We see from Table 5.6, from 1961 to 1970, Methane emissions from Paper registered a 716.30% increase but in the next 10-year interval, 1971 to 1980, there was a percentage increase of methane emissions by 71.36%. The results in Table 5.6 for Paper in also show that there was a steady decrease in the percentage increase of Methane being emitted from Garden from 1971 to 2010.

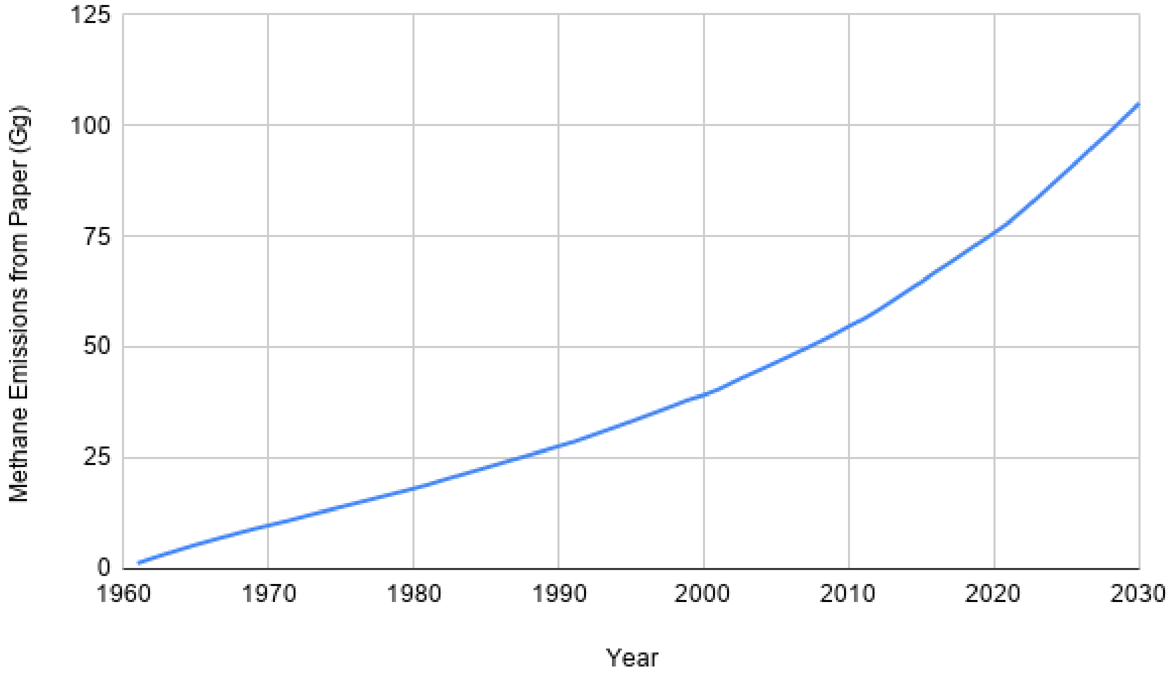

Figure 5.5: Methane Emissions from Paper (Gg) from 1961 to 2030.

The results for Wood from Table 5.6 showed that the percentage increase for methane emissions from HWP (wood) decreased for every 10-year interval in the 60-year interval.

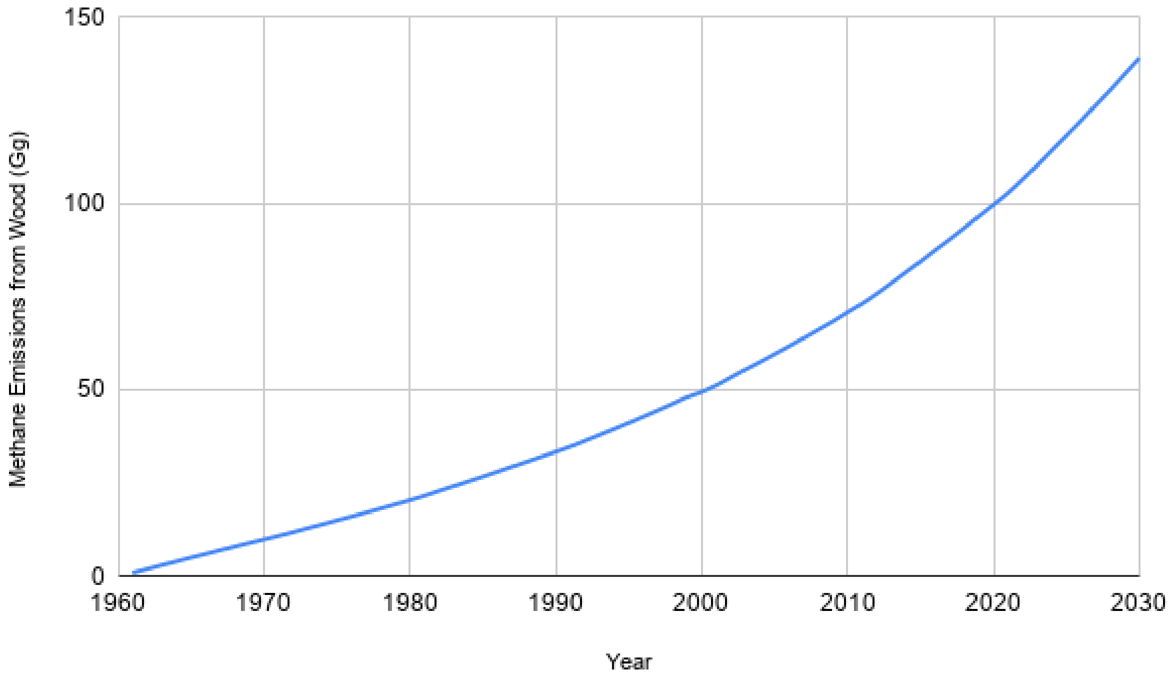

Figure 5.6: Methane Emissions from Wood (Gg) from 1961 to 2030.

Further, we observed from Table 5.6 that from 1961 to 1970, Garden, paper and wood had the highest percentages per 10-year window from 1961 to 2020 of methane emissions.

The time period between 2021 to 2030 shows a projected percentage increase of methane emissions for HWP for Nigeria (see Appendix B.5). Results show a percentage increase in methane emissions of 34.63% for Garden, 34.43% for Paper and 35.15% for Wood.

Time Intervals (years)	**Percentage change (%)**		
	Garden	**Paper**	**Wood**
1961 - 1970	451.52%	716.30%	835.59%
1971 - 1980	47.37%	71.36%	87.73%.
1981 - 1990	36.69%	45.67%	54.41%
1991 - 2000	34.11%	37.09%	42.01%
2001 - 2010	34.02%	35.25%	38.17%
2011 - 2020	34.29%	34.58%	36.11%

Table 5.6: Percentage change per 10 years for Methane Emissions from Harvested Wood Products (HWP) from 1961 to 2020.

5.2 Biological Treatment of Solid Waste

The biological treatment of municipal solid waste which includes domestic waste, industrial waste and institutional waste involves two main processes of composting and anaerobic digestion of organic waste. Composting is an aerobic process of the controlled decomposing raw organic materials using microorganisms in the presence of oxygen to break them down into simpler organic/inorganic forms. Anaerobic digestion of organic waste involves the controlled breakdown of organic matter in the absence of oxygen. What makes these processes unique is the emission of methane (CH4) and nitrous oxide (N2O) as by-products. Methane is flammable and can be used as an energy source, making it a potential as a renewable energy source.

In this model, we seek to estimate the emission of CH4 and N2O from biological treatment of solid waste in Nigeria. At this junction, it must be stated that Municipal Solid Waste Management is generally a challenge for developing countries like Nigeria for various reasons. Firstly, the amount of municipal solid waste has exponentially increased due to rapid increase in urban population in Nigeria. Secondly, lack of adequate technology has posed a challenge to waste treatment and disposal. Lastly, inefficient enforcement of relevant regulations adds to the problems for waste management in Nigeria [45]).

Due to the above, we have been unable to run a model for the biological treatment of solid waste for Nigeria because the data simply does not exist. For instance, composting of municipal solid waste in Nigeria has largely failed in various regions of the country mainly because of lack of funds and mismanagement of the site [46].

5.3 Open Burning of Waste

The challenge of efficient waste management is Nigeria has been a chronic issue. As is common with less developed countries, waste management remains an unresolved matter that deserves ample attention. In the case of Nigeria, the main blocks of solid waste management are attributed to high population, poverty, and urbanization growth rates together with a weak and underfunded infrastructure [47].

The most common form of getting rid of waste in Nigeria is open burning or refuse in residential areas and at illegal dump sites [5]. Open burning of waste is the combustion of waste materials like wood, paper, plastics, textile, rubber, waste oils etc. in open dumps or in nature where smoke and other emissions are released directly into the atmosphere. This waste management practice is used in many developing countries while in developed countries, open burning of waste may either be strictly regulated, or otherwise occur more frequently in rural areas than in urban areas. Open burning is commonly practiced in Nigeria [48].

Like other types of combustion open burning is a major source of greenhouse gas emission. The CO_2 emissions from combustion of MSW will also be estimated.

5.3.1 N_2O Emission from Open Burning

During a controlled burning method like incineration, the N_2O emitted from the burning of nitrogen rich waste leather is minimized in the facility. However, in the case of open burning which is uncontrolled N_2O emission in large undocumented portions is inevitable. Hence, the need to estimate the N_2O emissions from open burning in Nigeria. According to the IPCC guidelines for calculating estimate of N_2O emissions, there are 3 tiers that can be used.

For the first tier, we could simply estimate the N_2O emission by the amount of waste burned and a default emission factor provided by the guideline. The emission factors are simply the amount of N_2O emitted by the weight of the waste burned openly (Cite). The amount of waste burned can be determined by obtaining the country-specific data. However, if this is not available, then surveys and expert judgement can be used for the estimates. We would not be going with the first-tier method because we have some data to be used for the estimates.

For the third-tier system, site-specific data would be used to run the estimates. It is the most detailed and accurate approach for making emission estimations. It uses data on a plant-plant bases. This would be possible where ample data is available because of proper waste management structures in place. However, such is not the case for Nigeria. We will be using the second-tier system which is like the first tier except that we would use country-specific data to make our estimations. To estimate N_2O emissions from open burning, we would use the equation below:

$$N_2O \text{ Emissions } = \sum_i (IW_i \cdot EF_i) \cdot 10^{-6}$$

Where:

- N_2O Emissions $=$ N_2O emissions in inventory year, Gg/yr.
- Iw_i $=$ amount of open-burned waste of type i , Gg/yr.
- EF_i $=$ N_2O emission factor (kg N_2O/Gg of waste) for waste of type i.
- 10-6 $=$ conversion from kilogram to gigagram.
- i $=$ category or type of waste incinerated/open-burned, specified as follows:
  - MSW: municipal solid waste,
  - ISW: industrial solid waste,
  - HW: hazardous waste,
  - CW: clinical waste,
  - SS: sewage sludge, others (that must be specified)

Due to limited country-specific data, we used IPCC default values to generate N_2O emissions estimates for Nigeria from 1960 - 2020. We also projected the N_2O emissions from 2021-2030 (IPCC Guidelines Vol5 Ch5 p5.22, Table 5.6).

5.3.2 CO_2 Emissions from Open Burning

The method used to estimate the CO_2 emissions from the amount of waste open burned is centred on an estimation of the fossil carbon contained in the waste burned, then multiplied by the oxidation factor, and then by converting amount of fossil carbon oxidised to CO_2.

The activity data required for estimating the CO_2 emissions are the amount and composition of waste open-burned, the dry matter content, the total carbon content, the fossil carbon fraction and the oxidation factor.

The equation used to estimate the CO_2 emitted from open burning is outlined below.

$$CO_2 \text{ Emissions } = MSW \cdot \sum_j (WF_j \cdot dm_j \cdot CF_j \cdot FCF_j \cdot OF_j) \cdot 44/12$$

where,

- CO_2 Emissions = CO_2 emissions in inventory year, Gg/yr.
- MSW = total amount of municipal solid waste as wet weight incinerated or open-burned, Gg/yr.
- WF_j = fraction of waste type/material of component j in the MSW (as wet weight incinerated or open-burned).
- dm_j = dry matter content in the component j of the MSW incinerated or open-burned, (fraction)
- CF_j = fraction of carbon in the dry matter (i.e., carbon content) of component j
- FCF_j = fraction of fossil carbon in the total carbon of component j
- OF_j = oxidation factor, (fraction)
- 44/12 = conversion factor from C to CO_2

with:

$$\sum_j WF_j = 1$$

- j = component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste.

There are three tiers that could be applied when estimating CO_2 emissions from open burning of waste (depending on the amount of data available).

Tier 1. In Tier 1, the factors used in estimating CO_2 methods are mainly based on the IPCC default parameters and data. In this tier, data on the amount of waste open burned is essential. This tier is suitable when CO_2 emissions from open burning is not a key category.

Tier 2. Tier 2 involves the use of country specific activity data for waste generation, composition and waste management. Tier 2 is divided into 2 categories:

- Tier 2a: this demands the use of country specific data for waste composition and then IPCC default values can be used for the other parameters.
- Tier 2b: this demands the use of country specific data on the amount of waste open burned by waste type or MSW composition, and the other emission factors such as the dry matter content, carbon content, fossil carbon fraction and oxidation factor.

Tier 3 In Tier 3, this requires the use of plant-specific data in-order to estimate CO_2 emissions from waste incineration

To estimate CO_2 emissions from open burning of waste in Nigeria, the tier 2a level was carried out because open burning is used as a key source of waste disposal in Nigeria (cite).

Due to a lack of data and default parameters for specific categories, only the CO_2 emissions from the open burning of paper, plastics and textiles in Nigeria were calculated.

5.3.3 Results

In this section, we will discuss the results of estimating N2O and CO2 emissions from Open burning in Nigeria from 1960 - 2030. The results will be reported in this order.

- Estimates of the total amounts of MSW Open burned from 1960 - 2020 and the projected estimates of MSW to be open burned from 2021 - 2030.
- Nitrous Oxide (N_2O) Emissions from MSW open burned from 1960 - 2030
- Carbon Dixode (CO_2) Emmissions from (Plastics, Textiles and Paper) MSW open burned from 1960 - 2030

Total Amount of MSW Open-burned

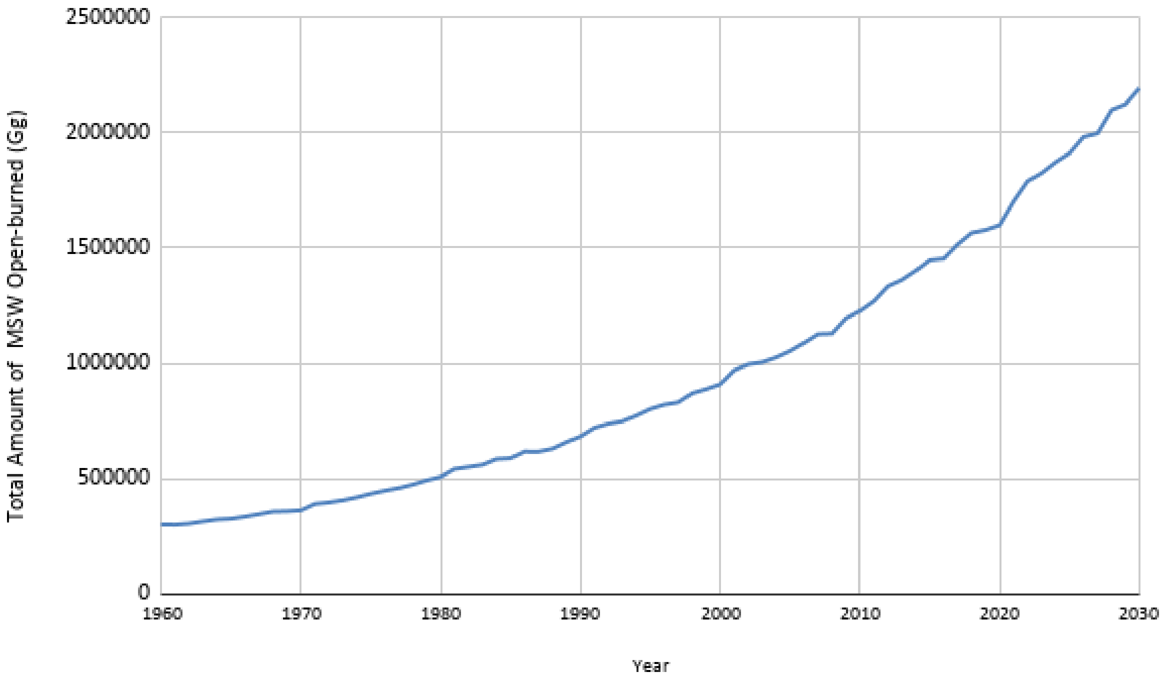

Figure 5.7: Total Amount of MSW Open Burned 1960 to 2030.

In Figure 5.4 above, our results depict that the estimated total amount of municipal solid waste open-burned was 301583.59 Gg in 1960. Whereas in 2020 the total amount of municipal solid waste open burned was 1599031.15 Gg. This shows there was a 430.21% increase in the total amount of municipal solid waste open-burned in Nigeria within a 60-year interval from 1960 to 2020. We also observe that the turn of the decade of 2001 has the highest amount of MSW open burned 969597.57 Gg. While the turn of the decade of 2011 has the lowest amount of MSW open burned of 1270165.22 Gg. In 2021, it is projected that the total amount of MSW open-burned will be 1701618.73 Gg and in 2030, it is projected that the total amount of MSW open-burned will be 2192725.69 Gg. Table 5.7 shows the percentage change per 10 years from 1960 to 2020.

Time Intervals (years)	Percentage change (%)
1960 - 1970	20.63%
1971 - 1980	29.83%
1981 - 1990	25.92%
1991 - 2000	26.11%
2001 - 2010	26.60%
2011 - 2020	25.89%

Table 5.7: Percentage change per 10 years for Total Amount of MSW Open burned from 1960 to 2020.

In Table 5.7, we observe that the year interval of 1971 – 1980 recorded the highest percentage increase per 10-year interval from 1960 – 2020. The lowest percentage increase for the total amount of MSW open-burned in Nigeria was in 1960 – 1970. From the results, we observe that from 1960 – 2020, there was a 430.21% increase for the 60-year time interval. Results also show that the projected amount of total MSW open-burned in Nigeria for 2021 – 2030 will see a percentage increase of a 28.87%.

Nitrous Oxide (N_2O Emissions from MSW Open burned

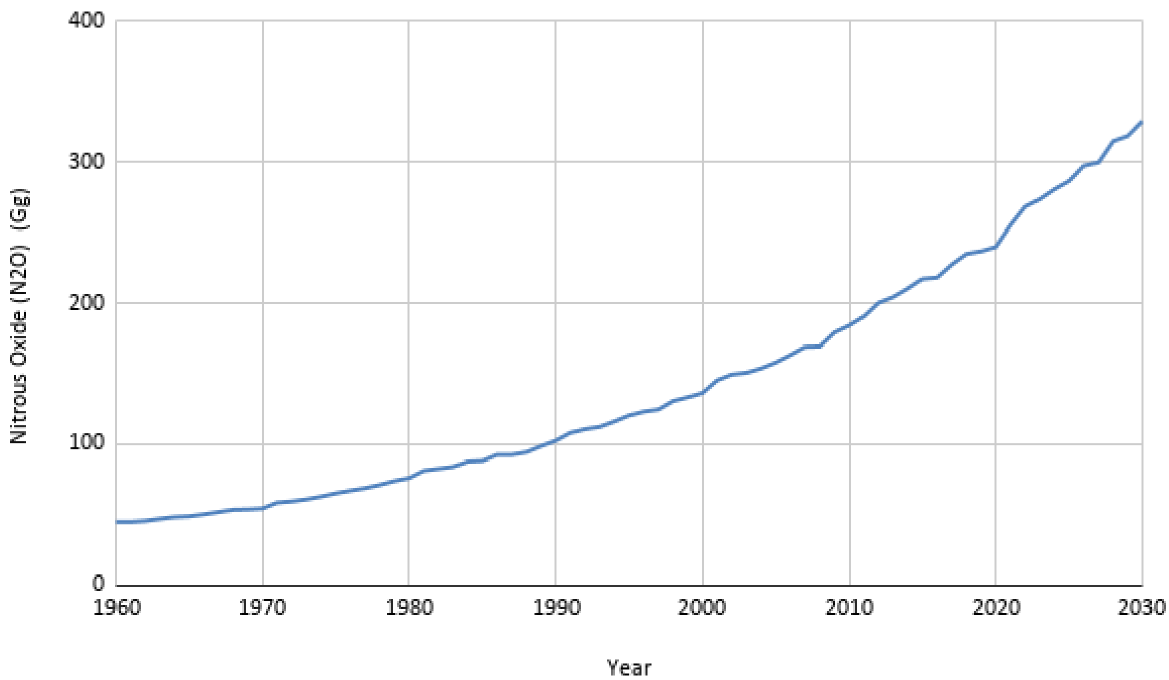

Figure 5.8: Total Nitrous Oxide (N_2O) for Open Burning from 1960 to 2030.

In Figure 5.8 above, our results show the net N_2O emissions for open-burned waste was 45.24 Gg in 1960. Whereas in 2020 the net N_2O emission was 239.86 Gg. This shows there was a 430.21% increase in the net N_2O emissions from open-burned waste in Nigeria within a 60-year interval from 1960 to 2020. In 2021, it is projected that the net N_2O emissions for open-burned waste will be 255.23 Gg and in 2030, it is projected that the net N_2O emissions for open-burned waste will be 328.90 Gg.

Table 5.8 shows the percentage change per 10 years from 1961 to 2020.

Time Intervals (years)	**Percentage change** (%)
1960 - 1970	20.63%
1971 - 1980	29.83%
1981 - 1990	25.92%
1991 - 2000	26.11%
2001 - 2010	26.60%
2011 - 2020	25.89%

Table 5.8: Percentage change per 10 years for Nitrous Oxide (N_2O) Emissions from Open burning from 1960 to 2020.

In Table 5.8, we observe that the year interval of 1971 – 1980 recorded the highest percentage increase per 10-year interval from 1960 – 2020. The lowest percentage increase for the net N_2O emissions for open-burned waste in Nigeria was in 1960 – 1970. From the results, we observe that from 1960 – 2020, there was a 430.21% increase for the 60-year time interval. Results also show that the projected amount of the net N_2O emissions for open-burned waste in Nigeria for 2021-2030 will see a percentage increase of a 28.87%.

Carbon Dioxide (CO_2) Emissions from MSW Open burned

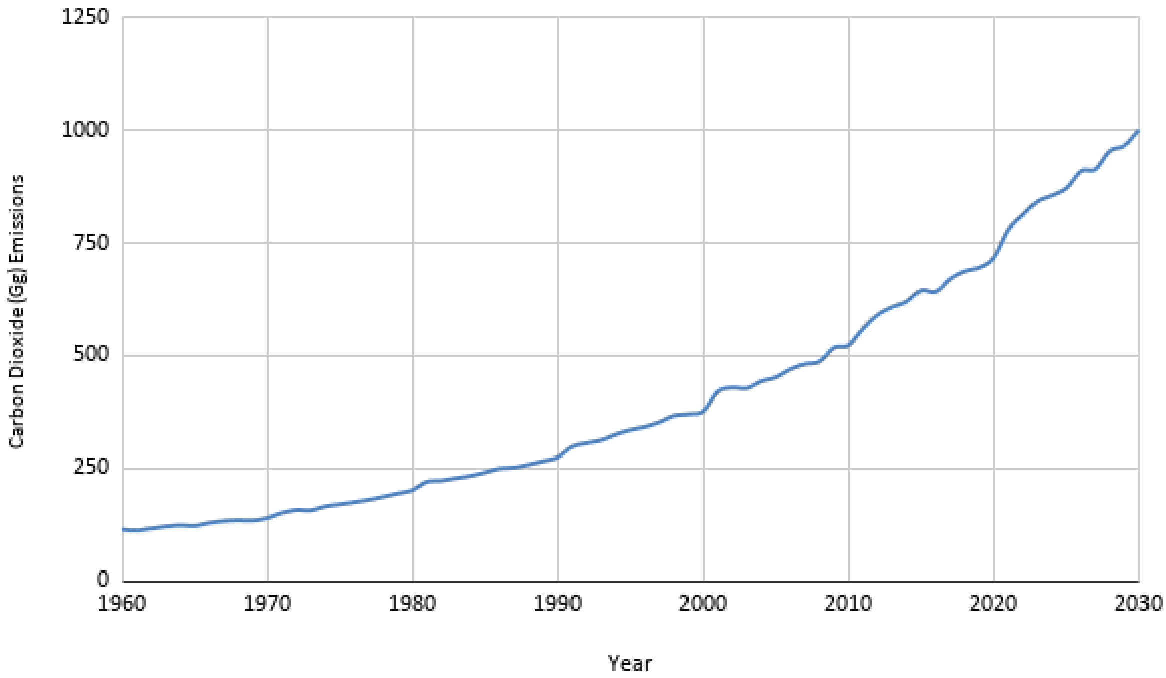

Figure 5.9: Carbon Dioxide (CO_2) Emissions for Open Burning from 1960 to 2030.

In Figure 5.9 above, our results show the net CO_2 emissions for open-burned waste in 1960 was 115.46 Gg. Whereas in 2020 the net CO_2 emission was 717.05 Gg. This shows that within the 60-year interval (1961 to 2020), there was a 521.02% increase in the total CO_2 emissions from open-burned waste in Nigeria . In 2021, it is projected that total CO_2 emissions for open-burned waste will be 778.64 Gg and in 2030, it is projected that the net CO_2 emissions for open-burned waste will be 1000.64 Gg.

Time Intervals (years)	**Percentage change** (%)
1960 - 1970	21.55%
1971 - 1980	33.76%
1981 - 1990	24.41%
1991 - 2000	26.15%
2001 - 2010	26.48%
2011 - 2020	28.27%

Table 5.9: Percentage change per 10 years for Carbon Dioxide (CO_2) Emissions from Open burning from 1960 to 2020.

In Table 5.9, we observe that the year interval of 1971 – 1980 recorded the highest percentage increase per 10-year interval from 1960 – 2020. The lowest percentage increase for the net CO_2 emissions for open-burned waste in Nigeria was in 1960 – 1970. From the results, we observe that from 1960 – 2020, there was a 521.02% increase for the

60-year time interval. Results also show that the projected amount of the net CO_2 emissions for open-burned waste in Nigeria for 2021 - 2030 will see a percentage increase of a 28.51%.

5.4 Wastewater Treatment and Discharge

Wastewater is any water that has been negatively affected in quality due to human activities [6]. Wastewater is a major source and contributor of methane (CH_4) especially when treated or disposed anaerobically (IPCC 2006 Guideline, Vol6 Ch6 p). Wastewater can also be a source of nitrous oxide (N_2O) and Carbon dioxide (CO_2) emissions. CO_2 from wastewater are not to be included because according to the IPCC Guidelines (IPCC Vol6 Ch6) because CO_2 are from biogenic origin and therefore cannot be included in the national total emissions, therefore emissions from CO_2 was not included in this report. In addition, due to insufficient activity data, and country specific data needed to run the model, N_2O emissions from wastewater was not modelled.

Wastewater is produced from a range of domestic, commercial and industrial sources and wastewater could be collected, stored in sewers (closed or open), dumped in a body of water such as rivers, lakes and estuaries (IPCC 2006 Guideline, Vol6 Ch6 p6.10). Also wastewater could be collected and treated, and it could also be uncollected - in open pits/latrines (IPCC 2006 Guideline, Vol6 Ch6). The amount of CH_4 production is mainly determined by the quantity of degradable organic material in the wastewater, the temperature of the environment and the type of treatment method used. (IPCC 2006 Guideline, Vol6 Ch6).

Domestic wastewater is usually derived from residential sources - for example, waster from food preparation, cleaning, laundry, and waster from personal hygiene [49]. Also, based on the source, domestic wastewater can be considered as black water or greywater. Blackwater consists mainly of human excreta, including urine and fecal sludge, while greywater includes wastewater from the kitchen and bathing [49].

According to [7], the safe disposal of wastewater is still a major problem in Nigeria and this could lead to groundwater pollution and environmental pollution [7].

The chief factor in determining the potential of CH_4 generation of wastewater is the amount of degradable organic material present in the wastewater (IPCC 2006 Guideline, Vol6 Ch6). This is done by by using the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) parameters to measure the organic content of the wastewater (IPCC 2006 Guideline, Vol6 Ch6).

5.4.1 Domestic Wastewater

According to the IPCC guidelines Vol6 Ch6) BOD is more regularly reported for domestic wastewater, and COD is primarily used for industrial wastewater. Therefore, the BOD parameters and values was used to estimate the degradable organic component present in domestic wastewater.

To estimate the total organically degradable carbon in wastewater (TOW), equation 6.3 in the IPCC guideline, Vol. 6 Ch6 p6.11 was used.

$$TOW = P * BOD * 0.001 * I * 365$$

- TOW = total organics in wastewater in inventory year, kg BOD/yr.
- P = country population in inventory year, (person).
- BOD = country-specific per capita BOD in inventory year, g/person/day.
- 0.001 = conversion from grams BOD to kg BOD .
- I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00).

Population from the 6 geopolitical regions in Nigeria from 2007 **(National Bureau of Statistics)** was imputed into the Domestic wastewater (TOW) model.

The BOD was based on the IPCC default for Africa from Table 6.4 (IPCC 2006 Guideline, Vol6 Ch6 p6.14). The default value (37) was multiplied by $0.001 * 365$ to get the (kg BOD/cap/yr) - 13.505 (see Table 5.10).

The correction factor used in modelling is based on the IPCC default for additional uncollected industrial BOD discharged into sewers. The default for uncollected was selected because majority of wastewater in Nigeria end up in Septic tanks, Latrines and River discharge [50].

Region/City	**Pop (2007)** (P)	**Degradable organic component** (BOD) (kg BOD/cap/yr)	**Correction factor** (I)	**Organically degradable material** (TOW) (kg BOD/yr)
North Central	21,090,977	13.505	1	284833644.4
North East	15,294,773	13.505	1	206555909.4
North West	37,043,992	13.505	1	500279112
South East	16,881,110	13.505	1	227979390.6
South south	21,716,324	13.505	1	293278955.6
South West	28,629,692	13.505	1	386643990.5
Total				1899571002

Table 5.10: Estimating TOW - Organically Degradable Material

The spreadsheet model, using the equation above calculates the TOW for Nigeria.

To estimate the CH_4 emission factor for each domestic wastewater treatment/discharge pathway or system used in Nigeria, equation 6.2 from the IPCC Guidelines Vol6 Ch6 p6.12 was used (spreadsheet). Domestic pathway systems identified and in use in Nigeria are Stagnant sewer, Latrine, Septic system, Sea, Rivers and Lakes (First Biennial Update Report (BUR1) of the Federal Republic of Nigeria).

$$EF_j = B_o \cdot MCF_j$$

where:

- EF_J = emission factor, kg CH_4/kg BOD.
- j = each treatment/discharge pathway or system.
- B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD.
- MCF_j = methane correction factor (fraction).

Due to the absence of National Data, Default values for Maximum Methane producing capacity- B_O (0.6kg CH_4/kg BOD) was used. Default Values from Table 6.3 IPCC Guidelines Vol6 Ch6 p6.13 was used to for the Methane Correction Factor (MCF_j) for each treatment system.

Type of Treatment /discharge	**Maximum Methane producing capacity-BO Maximum [kg CH4/ kg BOD] (A)**	**Methane correction factor for each treatment system – MCFj (B)**	**Emission Factor [kg CH4/kg BOD] (AxB)**
Stagnant sewer	0.6	0.5	0.30
Latrine, wet climate	0.6	0.7	0.42
Septic System	0.6	0.5	0.30
Sea, river and lakes	0.6	0.1	0.06

To estimate methane (CH_4) emissions from domestic wastewater, the equation is as follows:

$$CH_4 \text{ Emissions } = \left[\sum_{i,j}(U_i \cdot T_{i,j} \cdot EF_j)\right](TOW - S) - R$$

Where:

- CH_4 Emissions = CH_4 emissions in inventory year, kg CH4/yr.
- TOW = total organics in wastewater in inventory year, kg BOD/yr.
- S = organic component removed as sludge in inventory year, kg BOD/yr.
- U_i = fraction of population in income group i in inventory year.
- $T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, j, for each income group fraction i in inventory year.
- i = income group: rural, urban high income and urban low income.
- j = each treatment/discharge pathway or system.
- EF_j = emission factor, kg CH_4 / kg BOD.

- R = amount of CH_4 recovered in inventory year, kg CH_4/yr.

Due to lack of country specific data, IPCC defaults values for Nigeria to generate methane emissions for Nigeria from 1960-2020 and also project methane emissions from 2021 - 2030 (IPCC Guidelines Vol6 Ch6 p6.16 Table 6.5).

5.4.2 Industrial Wastewater

According to IPCC, Industrial wastewater can be treated on site or released into domestic sewer systems. In Nigeria, industries and private or commercial facilities such as hotels and hospitals are mandated by the law to treat their wastewater to a specified quality before discharge [50]). In Nigeria, wastewater treatment before discharge or re-use by these facilities is completely non-existent or inadequately done [50]. This is because most industries in Nigeria lack effective waste treatment plants, hence they release their wastewater into domestic wastewater discharge pathways without proper treatment, and often releasing wastewater into the closest water body or sewers [50].

Due to the almost completely non existent or inadequate treatment of industrial wastewater and lack of country specific industry sector data from government authorities, industrial organisations, or industrial experts in Nigeria, methane emissions from Industrial wastewater was impossible calculate. However, during the calculations of methane emissions from domestic wastewater, it was taken into account that industrial wastewater is being deposited into domestic wastewater discharge pathways. Therefore the correction factor for additional industrial BOD discharged into sewers was in place to account for the industrial wastewater being deposited in Domestic wastewater pathways.

5.4.3 Results and Discussion

In this section we will discuss the results of the Wastewater model in estimating methane (CH_4) emissions from Wastewater Treatment and Discharge in Nigeria from 1960 - 2030.

Methane Emissions from Wastewater

From Figure 5.10, our results show that in 1960, the net methane (CH_4) emission was 126.65 Gg. Whereas, in 2020, it is estimated that 640.73 Gg of methane was emitted. We observed that there was a 405.91% increase in the net methane emission totals for wastewater within a 60-year interval from 1961 to 2020. Further, we observed that the 10-year interval between 1981 and 1990 showed a 21.99% increase in Total Methane Emissions. This is the lowest percentage increase per 10 year interval from 1960 to 2020 (see Table 5.11). The interval between 1971 and 1980 is the highest percentage of Methane emissions increase per 10-year window from 1960 to 2020. Table 5.11 shows the percentage change per 10 years from 1960 to 2020.

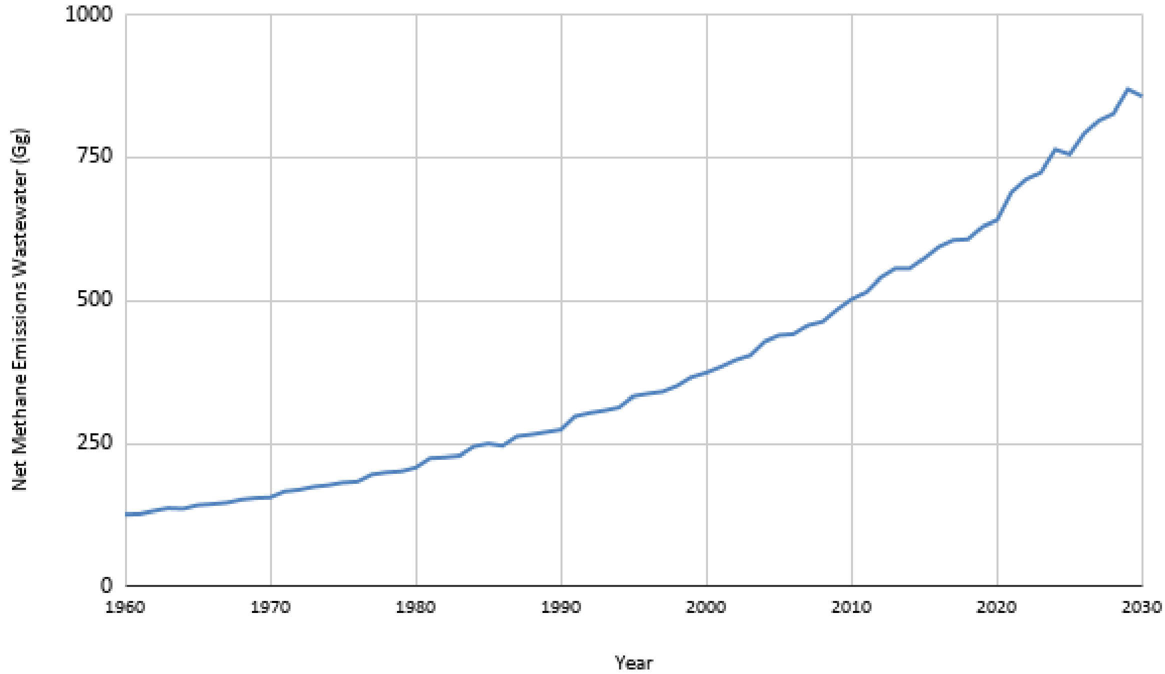

Figure 5.10: Annual methane emissions for wastewater from 1960 to 2030.

Time Intervals (years)	**Percentage change** (%)
1960 - 1970	23.17%
1971 - 1980	25.16%
1981 - 1990	21.99%
1991 - 2000	25.40%
2001 - 2010	30.75%
2011 - 2020	24.39%

Table 5.11: Percentage change per 10 years for Methane Emissions from Wastewater from 1960 to 2020.

Further, wastewater model, we estimated the amount of methane that will be emitted from domestic wastewater for the year 2021 to 2030. In 2021, it is estimated that 689.9 Gg of methane will be emitted and in 2030, an estimate of 856.98 Gg of methane will be emitted from wastewater. The time period between 2021 to 2030 shows a projected percentage increase of 24.22% of methane emitted from wastewater in Nigeria.

Chapter 6

Waste Data Modelling

6.1 E-Waste: Amount of Deposited Waste

E-wastes are unwanted electronic products that are not working or near the end of their useful life [8]. Computers, stereos, TVs, copiers, and fax machines are most commonly used electronic products. Many of these products are discarded, reused, refurbished, or recycled [51].

According to the UN [52], approximately, 100,000 people work in the informal e-waste recycling sector in Nigeria, gathering and disassembling electronics by hand to retrieve the viable components.

In Nigeria, the national consumption of electrical and electronic devices is rapidly on rise, henceforth, leading to rapidly growing e-waste volumes [53] in the country. This has resulted in the dumping of e-waste in open dumpsites across the country [54]. There, e-waste is susceptible to spontaneous burning and fosters the release of persistent organic pollutants into the environment. N_2O is one of the major gases associated to the open burning of e-waste [54].

6.1.1 E-waste Data Model

To estimate the total amounts of E-waste generated in Nigeria, a data model was built. Also, using this model, we were able to project the amounts of E-waste that will be generated from 2021 - 2030.

We used population estimates from our data models and with the e-waste generated (kg/per capita) data provided by the Federal Ministry [55], the Total amount of E-waste generated for Nigeria from 1960 - 2030 was calculated. Below, we discuss the results of the Data model.

6.1.2 Results and Discussion

In this section, we will discuss the results of the E-waste data model and the amount of e-waste generated from 1960 to 2020. This section will also display the estimated projection of E-waste deposited for 2021 - 2030.

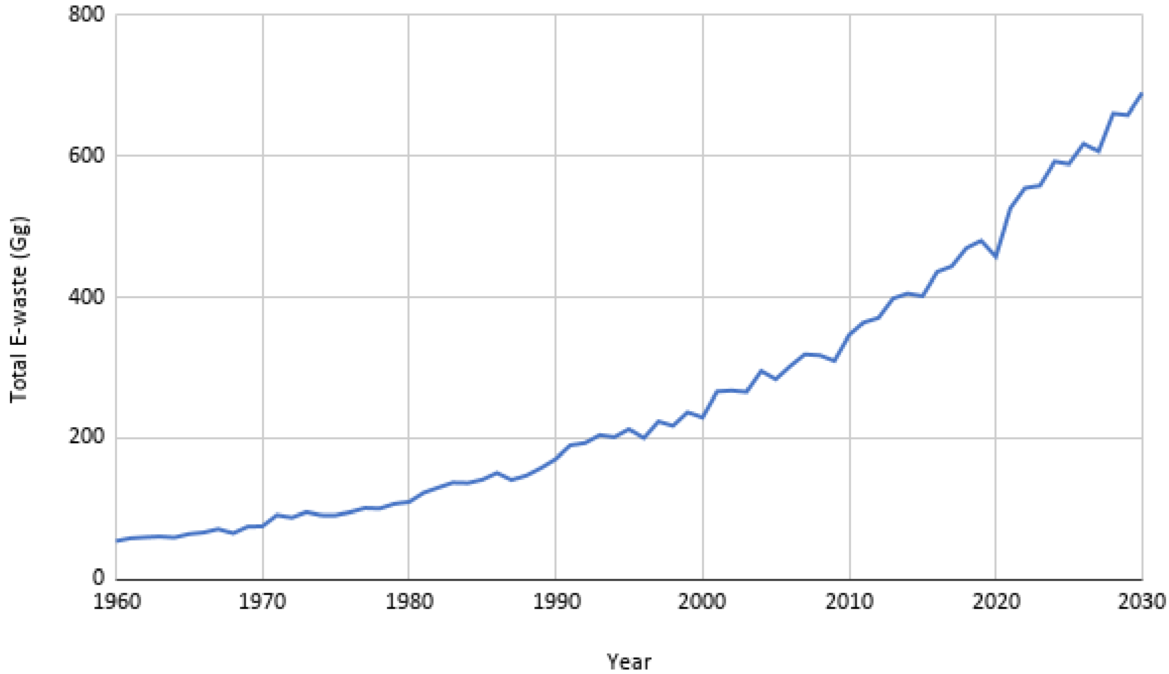

Figure 6.1: Total E-waste Deposited from 1961 to 2030.

In Table 6.1, we observed that year 1960 - 1970 recorded a percentage change of 38.40%. In 1960, the estimated amount of E-waste generated was 54.77 Gg, and within the next 20 years, the amount of E-waste generated had doubled, with the estimated amount 110.02 Gg in 1980. The highest percentage change per 10 year interval was in 1981 - 1990 with a percentage increase of 38.82%. The lowest percentage increase for the amount of e-waste generated in Nigeria was in 1960 - 1970 (see Table 6.1). From the results, we observe that from 1960 - 2020, there was a 677.16% increase for the 60 year time interval. Also, results show that the projected amounts of waste for 2021 -2030 will record a percentage increase of 31.06%, which is an increase of 5.5% from the previous 10 year interval (2011-2020).

Time intervals	**Percentage change %**
1960 - 1970	38.40%
1971 - 1980	20.13%
1981 - 1990	38.82%
1991 - 2000	20.82%
2001 - 2010	29.91%
2011 - 2020	25.56%

Table 6.1: Percentage change per 10 years for National Amounts of E-waste Generated from 1961 to 2020.

6.2 Medical Waste: Amount of Deposited Waste

Medical waste is defined as any solid waste that is produced in the diagnosis and treatment of humans and animals [56]. Medical wastes are generated from hospitals and clinics, medical laboratories and doctor offices [56]. Medical waste management in Nigeria is a serious issue and it poses potential risks and hazards to the environment [57].

The burning and burial of medical waste is a very common practice in hospitals in Nigeria [56]. Medical waste should be separate from municipal waste, but in Nigeria, medical wastes are still handled and deposited together with municipal waste [57].

6.2.1 Medical Waste Data Model

To estimate the total amounts of Medical waste generated in Nigeria, data supplied from the federal ministry of Nigeria (National Healthcare Waste Management Plan) was used in building the medical waste data model. The total national average of waste was used. Along with that, the number of hospital beds in Nigeria and population estimates from our data models was used to estimate the total amount of medical waste generated for Nigeria from 1960 - 2020 and projected medical waste for 2021 - 2030. Below are the results of the Data model.

6.2.2 Results and Discussion

In this section, we will discuss the results of the Medical waste data model and the amount of Medical Waste generated from 1960 to 2020. This section will also display the estimated projection of Medical waste to be generated in 2021 - 2030.

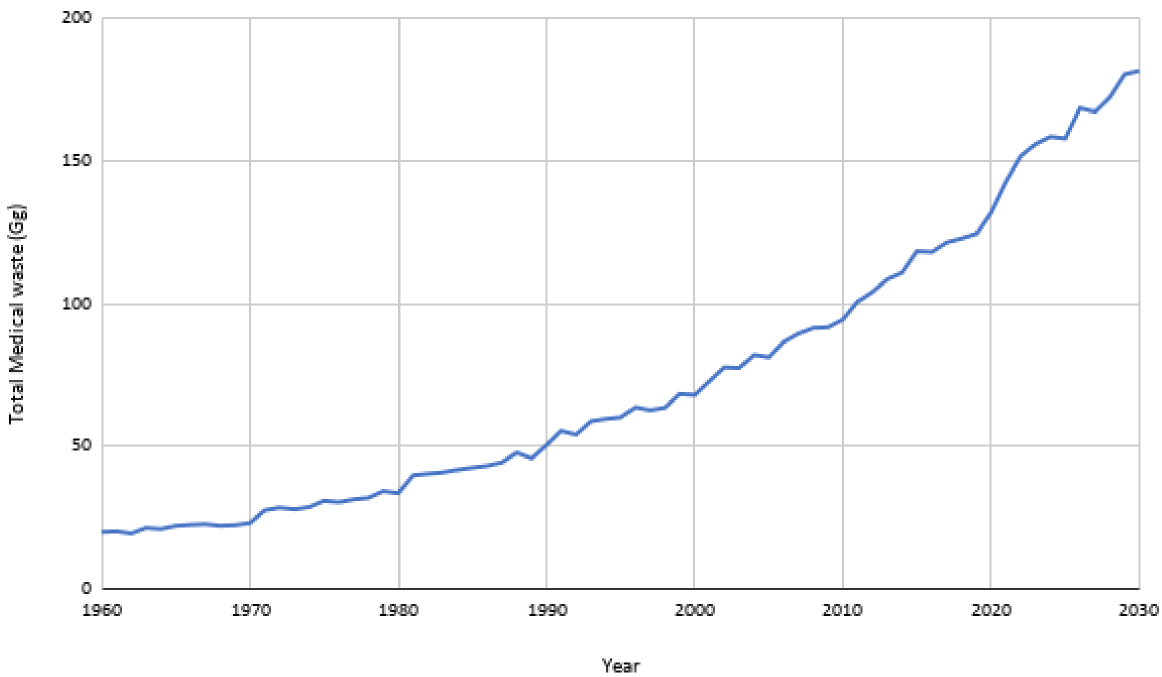

Figure 6.2: Total Medical Waste generated from 1961 to 2030.

In Table 6.2, we observed that year 1960 - 1970 recorded a percentage change of 15.44%. In 1960, the estimated amount of medical waste generated was 20.26 Gg. In 2020, the amount of medical waste generated was 131.89 Gg. The highest percentage change per 10 year interval was in 2011 - 2020 with a percentage increase of 30.99%. The lowest percentage increase for the amount of medical waste generated in Nigeria was in 1961 - 1970, (see Table 6.2). From the results, we observe that from 1961 - 2020, there was a 550.85% increase for the 60 year time interval. Also, results show that the projected amounts of waste for 2021 -2030 will record a percentage increase of 27.09%. In 2030, Nigeria is estimated to generate 181.26 Gg of medical waste.

Time intervals	**Percentage change %**
1960 - 1970	15.44%
1971 - 1980	21.70%
1981 - 1990	26.29%
1991 - 2000	22.54%
2001 - 2010	29.44%
2011 - 2020	30.99%

Table 6.2: Percentage change per 10 years for National Amounts of Medical Waste Generated from 1961 to 2020.

6.3 Batteries: Amount of Deposited Waste

Over the few decades, due to the rise in the development of communication technological advancement and transportation in Africa, there is immense growth in the demand for lead batteries in developing countries [58]

When these devices get to their end-of-life, they are either landfilled, recycled, or openly disposed of in the environment [9]. One component of vehicles that are often replaced are Lead acid battery [9]. In Nigeria, lead acid batteries (LAB) are used in automobile vehicles, motor bikes and lorries [10].

In Nigeria, heavy metal contamination, around the informal ULAB recycling centers is a serious public health problem [59]. When lead batteries reach their end of life, the pose a risk to the environment and the people if not disposed properly or well managed [9].

Incompetent production and recycling procedures of used lead acid batteries (ULAB) can release release tons of lead and fumes are released into the environment [59]. In developing countries like Nigeria, where there is a lack of regulation on used lead acid batteries, there are devastating lead epidemics, most of which are unreported [58].

6.3.1 Batteries Waste Data Model

To estimate the total amounts of Battery waste deposited in Nigeria, data supplied from the federal ministry of Nigeria on Generation of ULAB and annual generation rate for ULAB batteries in a given year was used to build the data model. The Proportion of LAB is generated relative to the population (%) and then with that, we were able get the estimated total ULAB generated in Nigeria from 1960 - 2030.

6.3.2 Results and Discussion

In this section, we will discuss the results of the Batteries waste data model and the amount of ULAB generated from 1960-2020. This section will also display the estimated projection of battery waste to be deposited for 2021 - 2030. Figure 6.3 shows the amounts of ULAB generated in Nigeria from 1960 - 2030.

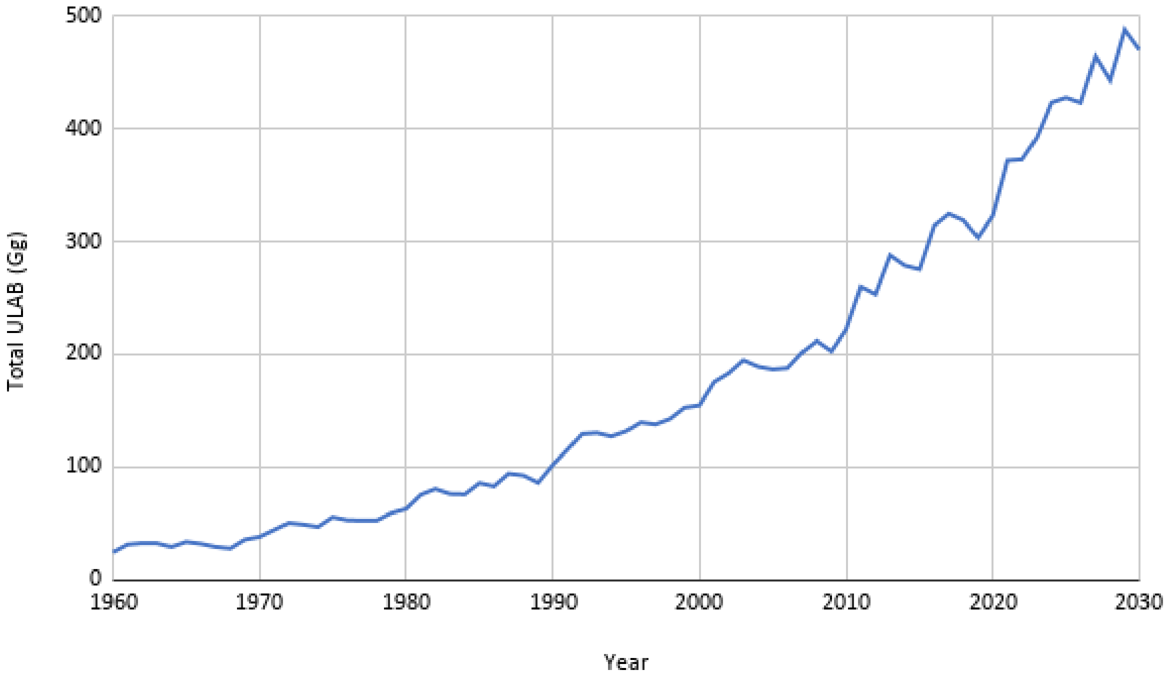

Figure 6.3: Total ULAB (Gg) generated from 1960-2030

In Table 6.3, we observed that year 1960 - 1970 recorded a percentage change of 55.10%. In 1960, the estimated amount of ULAB waste generated was 24.75 Gg. In 2020, the amount of batteries waste (ULAB) generated was 322.98 Gg. The highest percentage change per 10 year interval was in 1960 - 1970 with a percentage increase of 55.10%. From the results, we observe that from 1960 - 2020, there was a 1204.79% increase for the 60 year time interval. Also, results show that the projected amounts of waste for 2021 -2030 will record a percentage increase of 26.37%. In 2030, Nigeria is estimated to generate 469.66 Gg of battery waste.

Time intervals	Percentage change %
1960 - 1970	55.10%
1971 - 1980	42.20%
1981 - 1990	34.63%
1991 - 2000	34.06%
2001 - 2010	26.37%
2011 - 2020	24.23%

Table 6.3: Percentage change per 10 years for National Amounts of Battery Waste Generated from 1961 to 2020.

6.4 Plastics: Amount of Deposited Waste

Combating plastic waste pollution is not just a problem in Nigeria but it has become a global environment challenge [60]. Plastic waste management has become one of Nigeria's greatest challenges [60].

The manufacturing and production of plastics continually keep increasing as its production increased per year with 13 million tons of plastics produced between the year 2015 and 2016 [60]. It is estimated that fifty percent of the plastic products are single-use plastic products and therefore will be thrown away after use [60].

Combined with the poor management of waste in Nigeria, it is very common to observe that a large number of plastic waste products are not collected, and they are carelessly disposed in unsuitable and inaccessible areas [60]. The common practices in Nigeria comprises of plastic bottles and containers being thrown on the ground, thrown out of cars, thrown into gutters littering the environment and consequently causing polluting [60]. In this section, we estimated the amounts of plastic waste deposited in Nigeria from 1960- 2020. We also estimated the projected amounts of plastic wastes to be deposited in 2021 - 2030.

6.4.1 Plastics Waste Data Model

To estimate the total amounts of plastic waste deposited in Nigeria, data supplied from the Federal Ministry of Environment on environmental waste from 2007 - 2017 on plastic waste was used in building this estimation model. The amount of MSW was extracted from MSW modelling estimates. The data from the Federal Ministry of Environment showed that waste composition of MSW and using the percentage of plastics in MSW, we were able to generate the amounts of plastics deposited in MSW from 1960 - 2030. In the next section, we will discuss the results from the plastic data model.

6.4.2 Results and Discussion

In this section, we will discuss the results of the Plastic waste data model and the amount of plastics deposited from 1960-2020. This section will also display the estimated projection of battery waste to be deposited for 2021 - 2030. Figure 6.4 shows the amounts of plastic deposited in Nigeria from 1960 - 2030.

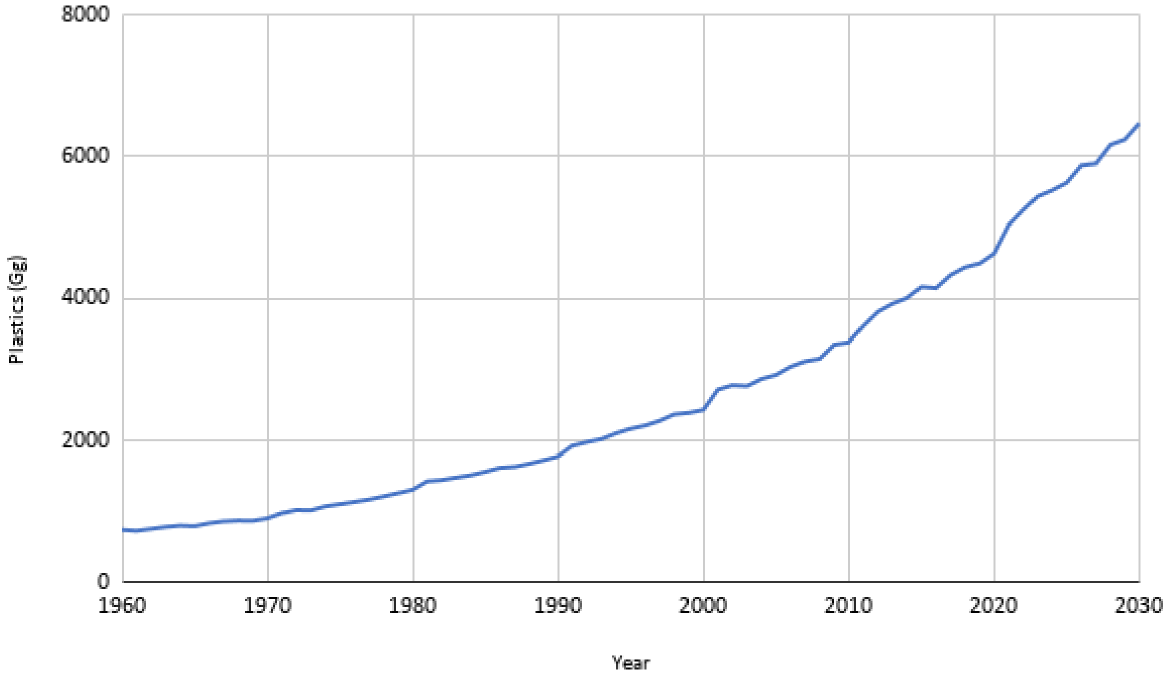

Figure 6.4: Total Amounts of Plastic waste (Gg) deposited from 1960-2030

In Table 6.4, we observed that year 1960 - 1970 recorded a percentage change of 21.60%. In 1960, the estimated amount of plastic waste deposited was 746.55 Gg. In 2020, the amount of Plastic waste deposited was 4637.1 Gg. The highest percentage change per 10 year interval was in 19671 - 1980 with a percentage increase of 33.77%. Results also show that the projected amounts of plastic waste to be deposited in the year 2021 is 5035.95 Gg and the percentage increase from year 2021 - 2030 will be 28.51%. In 2030, Nigeria is estimated to deposit 6471.75 Gg of plastic waste.

Time intervals	**Percentage change %**
1960 - 1970	21.60%
1971 - 1980	33.77%
1981 - 1990	24.41%
1991 - 2000	26.13%
2001 - 2010	24.47%
2011 - 2020	28.24%

Table 6.4: Percentage change per 10 years for National Amounts of Plastic Waste Generated from 1961 to 2020.

Chapter 7

Waste/ Emission Reduction Models

7.1 Organic Waste and Emission Reduction

Organic Waste Reduction. In this section, we shall consider the amount of organic waste reduced from the Environment from the effects of recycling. [11] reports that the organic waste recycled from 2020 to 2022 is 600 tonnes per annum (this amounts to 0.054 Gigagrams).

In estimating the waste reduction, we the found the percentage of recycled organic waste weighted every two years from 2011 to 2022 (i.e. [2011-2013], [2014-2016] ... [2020-2022]) with a random stride of .1.

The result in Table 7.1 show that there was a negligible decreased in organic waste due to recycling with an average percent change of 0.02%. By Table 7.1, the potential Methane (CH_4) emission is also negligible.

Year	Organic Waste (Gg)	Percent of recycled waste (%)	Organic Waste Recycled (Gg)	Reduction in Organic Waste (Gg)	Percentage change (%)
2011	1,928	0.0181	0.3485	1,928	-0.000181
2012	2,035	0.0184	0.3739	2,035	-0.000184
2013	2,095	0.0183	0.3843	2,095	-0.000183
2014	2,137	0.0209	0.446	2,137	-0.000209
2015	2,222	0.0195	0.4325	2,222	-0.000195
2016	2,213	0.0201	0.4456	2,213	-0.000201
2017	2,310	0.0213	0.4925	2,310	-0.000213
2018	2,369	0.0215	0.5105	2,368	-0.000215
2019	2,398	0.0228	0.5474	2,397	-0.000228
2020	2,473	0.0231	0.5701	2,472	-0.000231
2021	2,686	0.0239	0.6431	2,685	-0.000239
2022	2,798	0.0243	0.6787	2,797	-0.000243

Table 7.1: Waste Reduction from 2011 to 2022.

To estimate organic waste reduction from 2023 to 2030, we projected that 13.82% of organic waste will be incinerated. The practice of recycling is a more controlled method of managing waste disposal leading to reduced emissions. Figure 7.1 shows the amount of organic waste in the business-as-usual (BAU) scenario (in blue) and the waste reduction due to recycling (in orange).

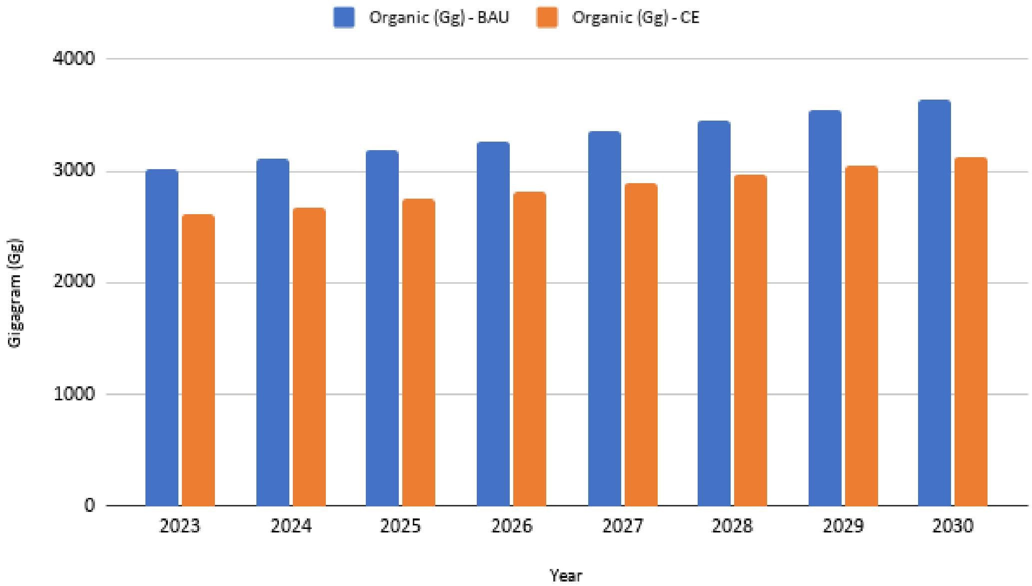

Figure 7.1: Organic waste reduction from 2023 to 2030.

Organic Emission Reduction. Consequently, the amount of Emission from CH_4 (shown in Figure 7.2) shows a reduction across the time frames from 2023 to 2029.

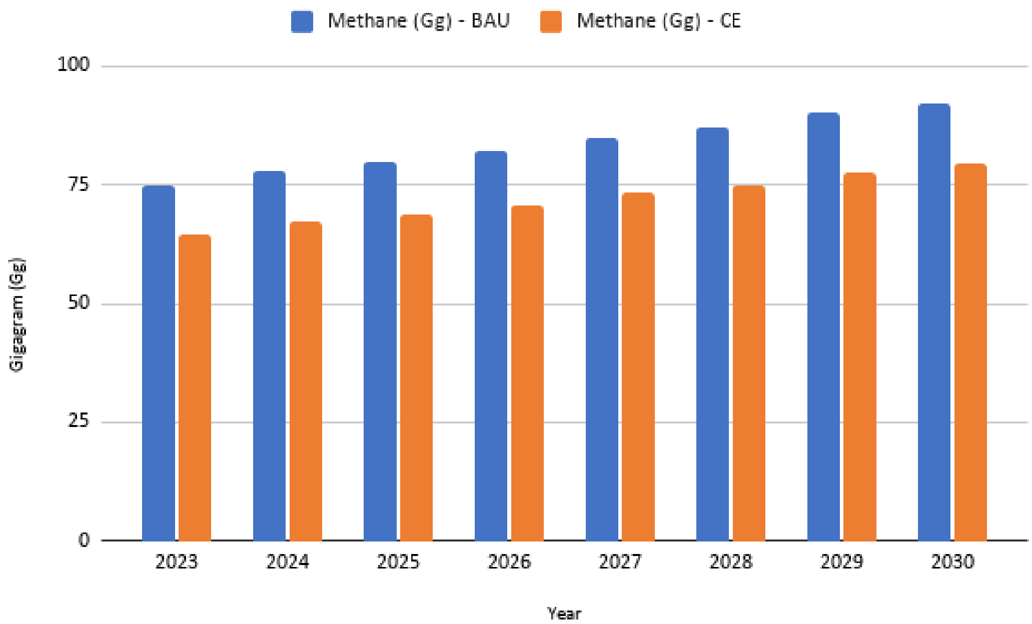

Figure 7.2: Organic waste emission reduction from 2023 to 2030.

7.2 Plastics Waste and Emission Reduction

In this section, we estimate the reduction in plastic waste and the corresponding reduction in GHG emissions from recycling activities.

Research from [12] report that 1000 tonnes (i.e. 0.9 Gigagrams) per annum of plastics are recycled. [17] reports that upwards of 12,000 tonnes (i.e. 10.89 Gigagrams) of plastics per annum are recycled. Also, [12] about 10% of plastic waste is recycled per annum.

Information on recycling activities in Nigeria are used to estimate the reduction in plastic waste from 2020 - 2022. The results are shown in Table 7.2. From the results, we observed that an average of 10% of plastic waste are reduced due to recycling. The corresponding emission reduction is shown in Table 7.2.

Year	Plastics (15% of MSW) (Gg)	Recycled Plastic (Gg)	Reduction in Plastic Waste (Gg)	Percent Change (%)	Methane (Gg)	New Methane Emission (Gg)
2020	4637.1	475.51	4161.59	-0.10254	2,198	1,973
2021	5035.95	515.39	4520.56	-0.10234	2,258	2,027
2022	5247.15	536.512	4710.64	-0.10225	2,345	2,105

Table 7.2: Reduction in plastic waste from 2020 to 2022.

To estimate the reduction in plastics waste and the corresponding reduction in emissions from 2023 - 2030, we projected that up to 13.82% of plastics will be recycled. The results of waste reduction from plastics are shown in Figure 7.3.

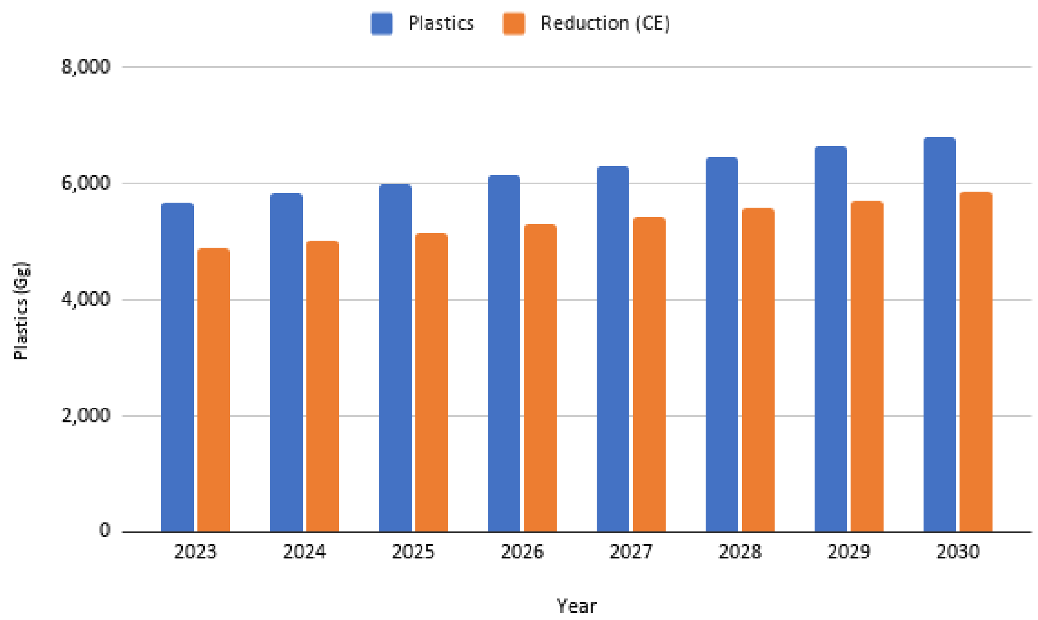

Figure 7.3: Plastic waste reduction from 2023 to 2030.

Figure 7.4 compares the methane emission from plastics under BAU scenario against emission under projected plastic recycling regimes.

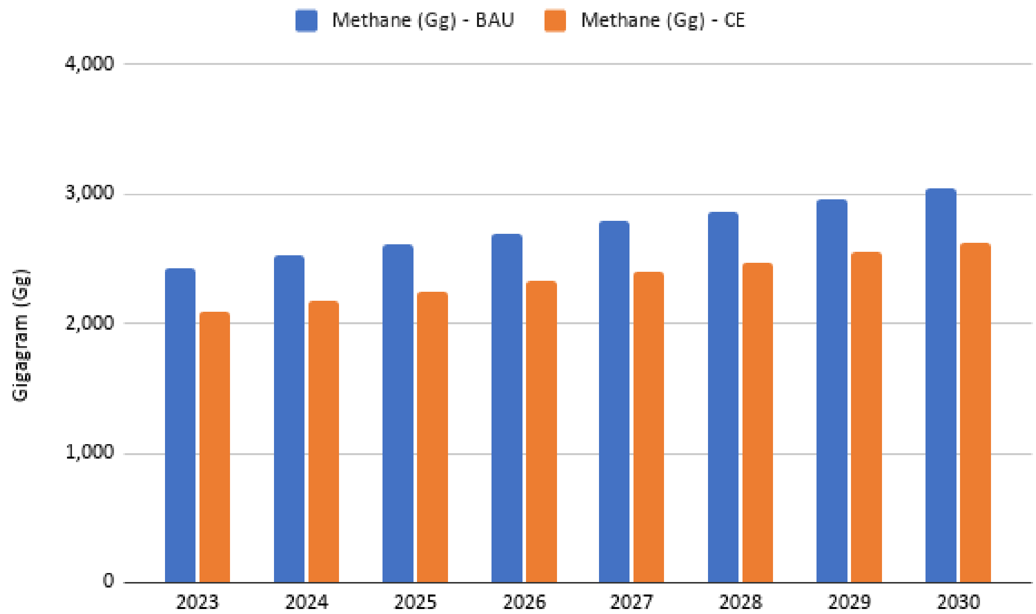

Figure 7.4: Plastic waste emission reduction from 2023 to 2030.

7.3 Medical Waste Reduction

In estimating the reduction in medical waste from 2020 to 2022, the Federal Ministry of Environment [17] reports that 5,500 tonnes (i.e. 4.99 Gigagrams) of medical waste are incinerated annually. We used this figure to find the proportion of Medical waste incinerated in 2020 with respect to population, which was then used to approximate the reduction in medical waste. The results of our approximations are shown in Table 7.3

Year	**Total Medical Waste (Gg)**	**Amount of Waste Incinerated**	**Reduction in Medical Waste**
2016	111.12	4.38	106.74
2017	114.06	4.49	109.56
2018	117.04	4.61	112.43
2019	120.09	4.74	115.35
2020	123.18	4.86	118.32
2021	126.51	4.99	121.52
2022	129.91	5.13	124.79

Table 7.3: Reduction in medical waste from 2016 to 2022.

To estimate medical waste reduction from 2023 - 2030, we projected that 16.9% will be incinerated. The results of our reduction estimates where we compare the BAU scenario and the scenario under circular economy schemes are shown in Figure 7.5.

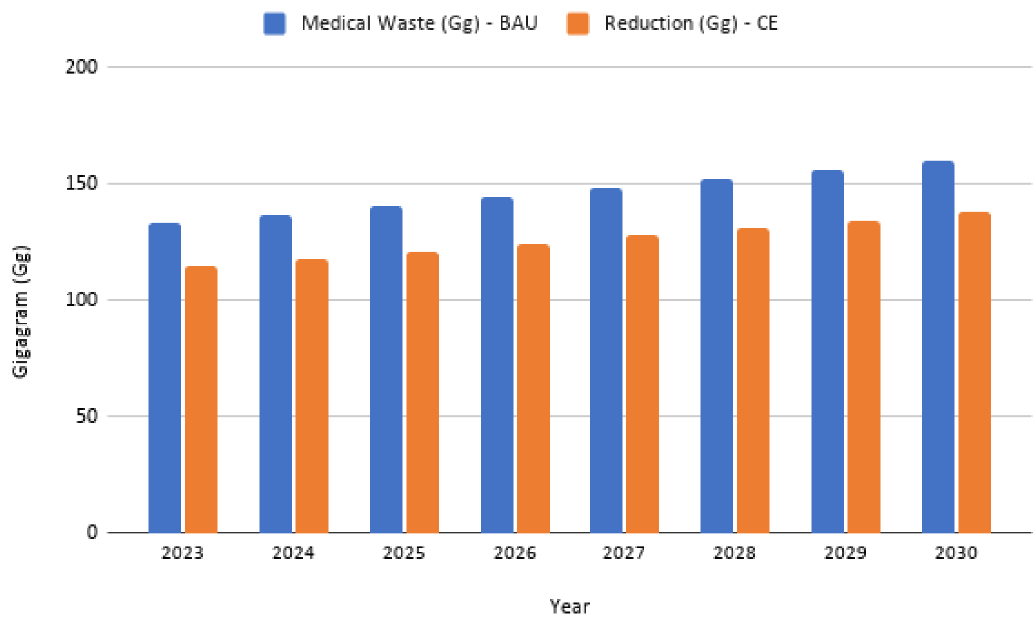

Figure 7.5: Medical waste emission reduction from 2023 to 2030.

7.4 E-Waste Reduction

The United Nations Environment Programme [61] reports that about 500,000 tonnes (i.e. 453.72 Gg) of e-waste was recycled in 2019. We then used the proportion of e-waste recycled to the total e-waste to estimate the approximate reduction in e-waste from 2014 to 2030. The results of our model is shown in Table 7.4.

Year	Total E-waste (Gg)	Reduction in E-waste (Gg)
2014	405.7312746	7.457546538
2015	416.6161304	7.657615706
2016	427.7086647	7.86150211
2017	439.0086153	8.069200932
2018	450.511902	8.280637173
2019	462.2162777	8.495769533
2020	474.1210547	8.71458537
2021	486.911636	8.949682739
2022	500.0232729	9.190681273
2023	513.4557361	9.437576758
2024	527.2178956	9.690532227
2025	541.3191558	9.949720539
2026	555.775074	10.21542764
2027	570.6030369	10.48797312
2028	585.8225125	10.7677148
2029	601.4553365	11.05505403
2030	617.5260398	11.3504417

Table 7.4: Reduction in E-waste from 2014 to 2030.

7.5 Battery Waste Reduction

To model the projected reduction in battery waste, i.e. Unused lead acid batteries (ULAB), [31] reports that 80% of battery waste generated annually will be recycled. We then used the proportion of ULAB recycled to the total ULAB waste to estimate the approximate reduction in ULAB from 2016 to 2030. The summary of our results are shown in Table 7.5.

Year	**Total ULAB (Gg)**	**Reduction in ULAB waste (Gg)**
2016	254.8312191	50.96624383
2017	261.563793	52.31275861
2018	268.4175157	53.68350314
2019	275.3910483	55.07820967
2020	282.4839812	56.49679624
2021	290.1046812	58.02093624
2022	297.9166679	59.58333359
2023	305.9198048	61.18396096
2024	314.1193765	62.8238753
2025	322.5209864	64.50419727
2026	331.1339034	66.22678068
2027	339.9684868	67.99369736
2028	349.0363356	69.80726713
2029	358.3504598	71.67009196
2030	367.9254749	73.58509497

Table 7.5: Reduction in ULAB waste from 2016 to 2030.

Chapter 8

Results & Recommendations for NDC Revision

The analysis of the results of the waste management legislation and institutional architecture, and the circular economy analysis of the waste management regimes bring to fore many issues which need to be addressed to ensure circular economy activities would thrive in the Nigerian landscape and yield the desired results. Based on the research carried out, a list of general and specific recommendations developed for consideration for the NDC revision are outlined below:

General Recommendations:

1. Undertake studies to obtain waste data from various waste streams to enable proper planning of resources in address waste management challenges
2. Develop policies for various key waste streams that would support their waste management and facilitate sustainable practices in their sectors.
3. Revise existing policies and regulations with the aim of updating them with circular economy processes where applicable.
4. Resuscitate dysfunctional waste management projects nationwide and complete unfinished installations to increase the amount of waste processed for recycling. This includes existing facilities installed to process plastics, scrap metal, compost, biogas, animal feed etc. but are presently non-operational.
5. Other sectors of the economy should be incorporated into the Extended Producer Responsibility (EPR) programme to increase the impact of circular economy measures in the Nigerian economy.
6. Establishment of institutional waste management regulators for each waste stream which would work with existing ones to effectively cater for waste management enforcement.
7. Increase support to waste related arms of the enforcement agencies with increased funding, technical expertise, personnel and up-to-date equipment to adequately manage waste management stakeholders and processes.
8. Facilitate the speedy conversion of waste processors in the informal sector of various

waste streams to the formal sector, and encouraging them with incentives such as start-up capital, capacity building, grants etc.

9. Development of industry-specific circular economy standards, procedures and guidelines to aid circular economy goals in each industry and sector.

10. Encourage inter-sector collaborations regarding materials which can be repurposed and remanufactured, and processes which can be replicated in a sustainable manner.

11. Develop feasibility studies for the waste management of different work streams to attract local and international investors.

12. Develop and implement a Unified Waste Management Strategy for the purpose of a continuous synergy between government agencies and regulators where their strategic roles are clear and non-ambiguous.

13. Establish Research Centers in higher institutions to produce indigenous circular economy solutions and develop sector-specific processes. This will increase circularity adoption, improve resiliency and reduce waste generation for key sectors which generate very large volumes of waste.

14. Develop a waste management inventory for various waste streams to properly undertake monitoring and evaluation of circular economy processes.

15. Periodically review existing policies, regulations and guidelines to ensure that they are still relevant in the present times and incorporate the best circular economy practices available.

16. Increase the awareness of environmental, health and socio-economic implications of unsustainable waste management practices at various schools and institutions.

17. The management and enforcement of waste practices in the agricultural sector should be carried out by leaders in various communities of the Nigerian society.

18. An assessment should be made nationwide at designated populated areas to obtain the technical and economic feasibility of incorporating biogas from organic waste for use in electricity generation.

19. There should be a coordinated investment in nationwide waste-to-wealth initiatives in the value chain of various waste streams which would build capacity, create jobs, establish new businesses, upscale small enterprises, promote gender equality, and ensure wealth penetration in rural and urban areas.

20. Resuscitating non-operational Integrated Waste Management Facilities nationwide while completing the unfinished project installations.

21. Ensure that the 26 facilities of the Plastic Recycling Program are fully operational and any dysfunctional ones resuscitated with basic amenities provided.

22. More producers should also be enjoined to participate in the EPR programme to ensure full compliance in various sectors

23. Proper enforcement on all stakeholders should be in carried out by strengthening the enforcement and regulatory institutions.

24. PPP projects should also be encouraged across the country with stakeholders sharing responsibilities and benefits.
25. Ensure that the 23 medical incinerators and facilities in the National Hospital Intervention Scheme are fully operational with properly trained staff using the equipment.
26. Establish more medical waste processing facilities across the country in urban and rural areas.
27. Technical assistance and access to funds should also be provided to develop recycling facilities.

Specific Recommendations:

1. **Organic Waste:** From the results of the model, if approximately 13.82% of organic waste is recycled in Nigeria between 2023-2030, the quantity of waste generated will reduce by approximately 4,000Gg, and the quantity of methane emissions generated will also reduce by approximately 100Gg in the period. Therefore a target of not less than 13.82% recycled organic waste would reduce methane emissions by not less than 100 Gg and this can be achieved and exceeded by resuscitating dysfunctional Integrated Waste Management Facilities nationwide while completing the unfinished project installations. A policy on Organic Waste Management and its proper enforcement would also help the nation achieve this.
2. **Plastic Waste:** From the results of the model, if approximately 13.82% of plastic waste is recycled in Nigeria between 2023-2030, the quantity of waste generated will reduce by approximately 8,000Gg and the quantity of methane emissions generated will reduce by approximately 2,667Gg in the period. This implies that if not less than 13.82% of plastic is recycled, then not less than 2,667Gg. Of methane emissions would be reduced. This target can be reached and surpassed if the dysfunctional facilities of the Plastic Recycling Program are resuscitated and basic amenities provided. More producers should also be enjoined to participate in the EPR programme and a proper enforcement on all stakeholders should be in carried out. PPP projects should also be encouraged across the country with stakeholders sharing responsibilities and benefits.
3. **Medical Waste:** From the results of the model, if approximately 16.9% of medical waste is incinerated in Nigeria between 2023-2030, the quantity of waste generated will reduce by approximately 400Gg and this can be attained by ensuring that all existing medical incinerators and facilities in the National Hospital Intervention Scheme are operational with properly trained staff using the equipment. More installations should also be carried out across the country in urban and rural areas.
4. **E-Waste:** Also from the model, if an estimation of 60% of e-waste is recycled in Nigeria between 2023-2030 based on the results obtained, the quantity of waste generated will reduce by approximately 1,315 Gg within this period. This can be achieved by facilitating and increasing the number of e-waste recyclers' nationwide and establishing PPP facilities in various states. The Members of the informal sector should also be encouraged and trained to transition to the formal sector before proper enforcement is carried out. Technical assistance and access to funds should also be provided to develop recycling facilities.
5. **Battery Waste:** From the results of the model, if approximately 80% of batteries

waste is recycled in Nigeria between 2023-2030, the quantity of waste generated will reduce by approximately 2,150Gg. This target is already being achieved but majority of recycling activities are carried out by the informal sector. These members of the informal sector should be encouraged to transition to the formal sector and encouraged with incentives such as training, funds and other factors of productions so they can expand and upscale their operations.

Environmental, Health and Socio-Economic Impact of Certain Waste Streams

Plastic waste. When plastics are disposed of indiscriminately, it leads to an increase in landfill sites and GHGs emissions. The African Development Bank (2018) stated that annually: 17 million barrels of oil are used in plastic production, 500 billion plastic bags are used, 13 million tons of plastic is released into the ocean and 100,000 marine organisms die due to plastic materials. A demand for more plastic products leads to a demand for more fossil fuels and associated GHG emissions. Some plastic waste management techniques such as incineration, gasification etc also release harmful substances such as dioxins, mercury, lead, furans, acid gases and other toxic materials into the environment which are harmful to the ecosystem. The common health hazards of these emissions include damage to the nervous and reproductive systems, cancer, leukemia and genetic defects for people working or residing close to plastic production sites; carcinogenic, growth or hormonal ailments for people who work in product management and packaging; sicknesses associated with polluted air, soil, water, food substances in areas where incineration takes place and possible clogging of toxins in human and animal tissues (CIEL, 2019). Plastic Value Chain: Opportunities also exist in all parts of the country in the plastic value chain due to the huge demand for plastic based products ranging from material specialists and designers of alternative raw materials and systems, and producers; to waste collectors, sorting/separators, recyclers, reproducers etc. Circular economy activities initiate the rethinking of product and raw material designs before production, and the reuse, repurposing, remanufacturing and recycling of plastic materials already in the consumption space.

E-waste. The unsustainable processing of e-waste using methods such as decoupling, leaching of metals from electronic boars and burning which can lead to the release of dioxins and polybrominated diphenyl ethers (PBDEs) into the environment. These can travel to other locations where they eventually settle and adversely affect wildlife and plants. Some WEEE consists of hazardous materials including mercury and Persistent Organic Pollutants (POPs) which if not discarded properly may pollute the environment and cause health issues. A breakdown of these substances and their health implications has been made in Tables 4.41 and Table 4.42. The PCBs highlighted in the Table 4.41 are a part of the POP group which has been addressed by the Stockholm Convention on Persistent Organic Pollutants which was adopted in 2001 but entered into force in 2004. Value Chain: The e-waste sector has a potential to generate employment due to the reuse and recovery of valuable materials from electronics as the ILO (2019) states that approximately 100,000 persons work in the Nigerian informal waste sector. As circularity is incorporated nationwide, this will lead to a demand for more collectors and recyclers as well as an increased formalization of this sector which will enhance health and safety measures, and proper implementation of regulations thereby making it more appealing and conducive for more women work in.

Organic waste. A large proportion of solid waste generated is made up of organic and vegetable waste therefore a reduction in this waste stream will lead to a significant reduction in resultant GHG emissions. In the business-as-usual scenario, a large amount of organic waste would also require large portions of useful land damaging its associated ecosystem in the process. Unsustainable organic waste practices can lead to the spread of infectious diseases and also attract disease vectors such as rats, flies and other animals. Wet organic waste undergoes decomposition releasing unhygienic foul smells, and sometime fermentation which enhances the increase of harmful pathogens. Improper handling too can lead to infections and serious ailments if not addressed in time. However, it also has some benefits if properly harnessed. Organic waste can be used to make compost for growing crops as an alternative to chemical based fertilizers, while clean organic waste can be used to feed animals. Biogas can also be produced for use as heating gas and to generate electricity for domestic, commercial and industrial uses. Therefore investment into this sector would generate power, create jobs, contribute to agriculture, enhance sustainable practice, and increase healthy living.

Batteries waste. Lead acid batteries are made up of metallic lead, lead dioxide, lead sulfate and sulfuric acid with the electrodes made of minor proportions of metals like tin, antimony, calcium. Cadmium, lead and sulfuric acid are toxic and can pollute surface and groundwater sources when improperly disposed of and are part of landfill sites, and emit toxins into the atmosphere when incinerated in the open. Lead also causes damage to the yet-to-be developed brains of infants of 5 years old and below leading to sensory, mental and physical damage to their bodies (UNICEF, 2020). Using water from these sources becomes dangerous to humans, animals and plants. Inhaling toxins can lead to sicknesses and exposure to lead can lead to brain damage, kidney defects and hearing problems. Contact with other metals over a long period may also lead to asthma, headaches, asthma, reduced IQ and cancer. Approximately 85% of lead material is used in the manufacture of lead batteries and about 100% can be easily recovered and recycled continuously making it ideal for circular processes (Leblanc, 2018). This therefore makes the sustainable recycling of lead from batteries economically attractive as the lead and casing can be reused. Lead acid batteries are in high demand in various sectors such as the transportation, renewable energy, generators, telecommunications etc. Approximately 65 persons are required to work in a recycling plant while about 20 workers are required in a collection facility. A battery plant in every state of Nigeria will provide jobs for at least 3,000 individuals. This implies that there are economic opportunities in the battery value chain involving the sales, operation, maintenance and sustainable recycling of batteries.

Medical waste. The World Health Organization (2018) states that 85% of medical waste is generic waste while the remaining 15% is harmful. Dioxins, furans and small substances are emitted into the environment when burnt, treated, and disposed of, and this waste is destructive to human, animal and plant life. Health effects include the likelihood of infections, cuts, exposure to radiation and hazardous materials, chemical injuries, polluted air, and wounds associated with burning waste. Proper medical waste management practices is essential in reducing the overall cost of healthcare in communities and the larger society by reducing susceptibility to diseases, ensuring a clean atmosphere, avoiding pollution of soils and water sources, and preventing disease vectors all carried out so as to safeguard the surrounding ecosystem.

Sawmill waste. The emitted pollutants associated with saw mill activity are bark and wood rubbish, chemicals used for wood treatment such as Biochemical Oxygen on Demand (BOD), Chemical Oxygen on Demand (COD), toxic chemicals; oils, heavy metals, alkaline effluents and leachates. These can also adversely affect surrounding water bodies where the saw mill factories are situated by riverine areas and wood wastes are gathered close to the rivers (Fagbenro, 2018). The health effects due to sawmill waste include various ailments caused by toxic substances, harmful emissions into the air and polluted water. Circular activities such as waste reduction and recycling of the sawmill waste into compost and fiberboard can be carried out to reduce their environmental and health impacts and also create jobs in the process.

Appendices

Appendix A

Circular Economy Analysis

S/n	Policies	Circular Economy Features	Circular Economy Indicators
1	National Policy on Environmental Sanitation (2005)	Policy Section 6.2.2.3: Minimize waste amounts at source by: • i) Reuse of discarded items • ii) Recycle items like bottles, glass, metals, paper, plastic and biodegradable matter	• R3-Reuse • R8-Recycle
2	National Policy on Chemical Management (2010)	Policy Section 3.3.3: • i) Refuse to utilize dangerous chemicals • ii) Cleaner production of chemicals	R0-Refuse • R1-Rethink
3	National Healthcare Waste Policy (2013)	Policy Section 3.0: • i) Minimize amount of health waste by applying sustainable procurement guidelines and transportation	R2 – Reduce
4	National Policy on Environment (2016)	Policy Section 5.1 (Policy Statement): • i) Promote waste to wealth' projects at various levels	R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9–Recover
5	National Policy on Solid Waste Management (2018)	Policy Section 5.2: • i) Separation of recyclable and biomedical waste • Policy Section 5.5.7: • i) EPR principle	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
6	National Policy on Plastic Waste Management (2020)	Policy Section 3.1: • i) States and Local Governments are to use a waste hierarchy which promotes a circular economy • ii) Make available various streams for easy waste separation • iii)Establishment of plastic collection and recycling centers nationwide	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover

Table A.1: Circular Economy Analysis of the Nigerian Waste Related Policies

S/n	National Waste Management Related Regulations	Circular Economy Features	Circular Economy Indicators
1	National Environmental Protection (Pollution Abatement in Industries and Facilities Generating Wastes) Regulations S.I.9 of 1991 (2004)	• i) Ensure high quality of technologies/fuel • ii) Reduction in the amount of waste generated	• R1-Rethink • R2-Reduce
2	National Environmental Protection Management of Solid and Hazardous Waste Regulations S.I.15 of 1991 (2013)	• i) Refuse to use hazardous materials • ii) Seek alternatives to hazardous waste materials • iii) Reduction in the amount of waste generated • iv) Recycling of solid waste	• R0-Refuse • R1-Rethink • R2-Reduce • R8–Recycle
3	Environmental Impact Assessment Act of 1992	• i) Increases project efficiency • ii) Reduction in the amount of materials used and waste generated	• R1-Rethink • R2-Reduce
4	Nigeria Sectoral Guidelines for EIA (1995)	• i) Increases project efficiency • ii) Reduction in the amount of waste generated	• R1-Rethink • R2-Reduce
5	The Harmful Wastes Special Criminal Provision Act No. 42 of 1988 (1998)	• i) Refuse to use harmful materials in production process • ii) Seek alternatives to harmful wastes	• R0-Refuse • R1-Rethink
6	The National Guidelines and Standards for Environmental Pollution control in Nigeria	• i) Increase standards and alternatives to hazardous wastes • ii) Reduction in the amount of waste generated	• R1-Rethink • R2-Reduce
7	The National Oil Spill Detection and Response Agency Act 2006 (NOSDRA Act)	• i) Develop sustainable technologies and improve existing processes and standards	• R1-Rethink
8	The National Environmental Standards and Regulations Enforcement Agency Act, 2007 (NESREA Act)	• i) Enforcement of waste management legislation and development of sustainable initiatives	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
9	National Environmental (Sanitation and Wastes Control) Regulations, S.I No.28 of 2009	• i) Reduction in the amount of waste generated • ii) Recycling of solid waste	• R2-Reduce • R8–Recycle
10	National Environmental (Permitting and Licensing System) Regulations, S. I. No. 29, 2009	• i) Increase efficiency of operations • ii) Reduction in the amount of materials used and waste generated	• R1-Rethink • R2-Reduce
11	National Environmental (Mining and Processing of Coal, Ores and Industrial Minerals) Regulations, S.I. No 31, 2009	• i) Increase efficiency of operations • ii) Reduction in the amount of materials used and waste generated	• R1-Rethink • R2-Reduce
12	National Environmental (Ozone Layer Protection) Regulations, S. I. No. 32, 2009	• i) Increase efficiency of operations • ii) Reduction in the amount of materials used and waste emitted	• R1-Rethink • R2-Reduce

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Table A.2 – continued from previous page

S/n	National Waste Management Related Regulations	Circular Economy Features	Circular Economy Indicators
13	Merchant Shipping Act, 2007 (2013).	• i) Refuse to use unsustainable waste practices • ii) Increase efficiency of shipping waste processes and seek alternatives to dangerous raw materials by manufacturers	• R0–Refuse • R1-Rethink
14	National Environmental (Food, Beverages and Tobacco Sector) Regulations, S. I. No. 33, 2009	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
15	National Environmental (Textile, Wearing Apparel, Leather and Footwear Industry) Regulations, S. I. No. 34, 2009	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
16	National Environmental (Chemicals, Pharmaceuticals, Soap and Detergent Manufacturing Industries) Regulations, S. I. No. 36, 2009	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
17	National Environmental (Base Metals, Iron and Steel Manufacturing/Recycling Industries) Regulations, S. I. No. 14, 2011	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
18	National Environmental (Control of Bush/Forest Fire and Open Burning) Regulations, S. I. No. 15, 2011	• i) Refuse to use unsustainable land management techniques • ii) Seek sustainable methods of land management practices to prevent the release of GHGs into the atmosphere	• R0-Refuse • R1-Rethink
19	National Environmental (Domestic and Industrial Plastic, Rubber and Foam Sector) Regulations, S. I. No. 17, 2011	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover

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Table A.2 – continued from previous page

S/n	National Waste Management Related Regulations	Circular Economy Features	Circular Economy Indicators
20	National Environmental (Construction Sector) Regulations, S. I. No. 19, 2011	• i) Increase efficiency of construction operations • ii) Reduction in the amount of materials used and waste emitted	• R1-Rethink • R2-Reduce
21	National Environmental (Non-Metallic Minerals Manufacturing Industries Sector) Regulations, S. I. No. 21, 2011	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
22	National Environmental (Electrical/Electronic Sector) Regulations, S. I. No 23, 2011	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
23	National Environmental (Pulp and Paper, Wood and Wood Products) Regulations, S. I. No 34, 2013	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
24	National Environmental (Motor Vehicle and Miscellaneous Assembly) Regulations, S. I. No 35, 2013	• i) Sustainable measures such as circular economy strategies	• R0-Refuse • R1-Rethink • R2-Reduce • R3-Reuse • R4-Repair • R5-Refurbish • R6-Remanufacture • R7–Repurpose • R8–Recycle • R9-Recover
25	National Environmental (Air Quality Control) Regulations, S. I. No 64, 2014:	• i) Develop alternative processes to air polluting activities • ii) Reduction of effluents released into the atmosphere	• R1-Rethink • R2-Reduce
26	National Environmental (Hazardous Chemicals and Pesticides) Regulations, S. I. No 65, 2014	• i) Refuse to use hazardous materials • ii) Utilize sustainable agricultural practices and seek alternatives to hazardous chemicals • iii) Reduction of effluents released into the atmosphere	• R0-Refuse • R1-Rethink • R2-Reduce
27	National Environmental (Energy Sector) Regulations, S. I. No 63, 2014	• i) Develop more efficient eco-friendly energy delivery services	• R1-Rethink

Table A.2: Circular Economy Analysis of the Nigerian Waste Related Regulations

Appendix B

Results from Solid Waste Disposal Sites (SWDS)

Table B.1: Municipal solid waste (MSW) activity data.

Year	Population	Waste per capita	Total MSW	% to SWDS	Composition of waste going to solid waste disposal sites							Total
					Food	Garden	Paper	Wood	Textile	Nappies	Plastics, other inert	
	millions	kg/cap/yr	Gg	%	%	%	%	%	%	%	%	(=100%)
1960	45138458	0.000185592	8377.336697	59%	8%	43%	10%	4%	4%	0%	31%	100%
1961	46063563	0.000181616	8365.880058	58%	8%	43%	10%	4%	4%	0%	31%	100%
1962	47029822	0.000180628	8494.902688	60%	8%	43%	10%	4%	4%	0%	31%	100%
1963	48032934	0.000182363	8759.429943	60%	8%	43%	10%	4%	4%	0%	31%	100%
1964	49066760	0.000183255	8991.729104	60%	8%	43%	10%	4%	4%	0%	31%	100%
1965	50127921	0.00018126	9086.18696	59%	8%	43%	10%	4%	4%	0%	31%	100%
1966	51217973	0.000182356	9339.904684	60%	8%	43%	10%	4%	4%	0%	31%	100%
1967	52342233	0.000184107	9636.571491	60%	8%	43%	10%	4%	4%	0%	31%	100%
1968	53506196	0.00018587	9945.196651	59%	8%	43%	10%	4%	4%	0%	31%	100%
1969	54717039	0.000182721	9997.952083	58%	8%	43%	10%	4%	4%	0%	31%	100%
1970	55982144	0.000180513	10105.50476	60%	8%	43%	10%	4%	4%	0%	31%	100%
1971	57296983	0.000189846	10877.60303	60%	8%	43%	10%	4%	4%	0%	31%	100%
1972	58665808	0.000188356	11050.05693	62%	8%	43%	10%	4%	4%	0%	31%	100%
1973	60114625	0.000188263	11317.35965	60%	8%	43%	10%	4%	4%	0%	31%	100%
1974	61677177	0.000189318	11676.5998	61%	8%	43%	10%	4%	4%	0%	31%	100%
1975	63374298	0.000191001	12104.55429	61%	8%	43%	10%	4%	4%	0%	31%	100%
1976	65221378	0.000191187	12469.4796	61%	8%	43%	10%	4%	4%	0%	31%	100%
1977	67203128	0.000190273	12786.94077	61%	8%	43%	10%	4%	4%	0%	31%	100%
1978	69271917	0.000190796	13216.80468	61%	8%	43%	10%	4%	4%	0%	31%	100%
1979	71361131	0.000192304	13723.03094	61%	8%	43%	10%	4%	4%	0%	31%	100%
1980	73423633	0.000192336	14122.00788	62%	8%	43%	10%	4%	4%	0%	31%	100%
1981	75440502	0.000199961	15085.15822	63%	8%	43%	10%	4%	4%	0%	31%	100%
1982	77427546	0.000198015	15331.81552	63%	8%	43%	10%	4%	4%	0%	31%	100%
1983	79414840	0.000196277	15587.30655	63%	8%	43%	10%	4%	4%	0%	31%	100%
1984	81448755	0.000199845	16277.12644	62%	8%	43%	10%	4%	4%	0%	31%	100%
1985	83562785	0.000195945	16373.70991	64%	8%	43%	10%	4%	4%	0%	31%	100%
1986	85766399	0.00020024	17173.86374	63%	8%	43%	10%	4%	4%	0%	31%	100%
1987	88048032	0.000195005	17169.80648	63%	8%	43%	10%	4%	4%	0%	31%	100%
1988	90395271	0.000193747	17513.81257	64%	8%	43%	10%	4%	4%	0%	31%	100%
1989	92788027	0.000197232	18300.76814	63%	8%	43%	10%	4%	4%	0%	31%	100%
1990	95212450	0.000199503	18995.16941	62%	8%	43%	10%	4%	4%	0%	31%	100%
1991	97667632	0.000205126	20034.17068	64%	8%	43%	10%	4%	4%	0%	31%	100%
1992	100161710	0.000204858	20518.92759	64%	8%	43%	10%	4%	4%	0%	31%	100%
1993	102700753	0.000202743	20821.85877	65%	8%	43%	10%	4%	4%	0%	31%	100%
1994	105293700	0.000204396	21521.61111	65%	8%	43%	10%	4%	4%	0%	31%	100%

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Table B.1 – continued from previous page

Year	Population	Waste per capita	Total MSW	% to SWDS	Composition of waste going to solid waste disposal sites: Food	Garden	Paper	Wood	Textile	Nappies	Plastics, other inert	Total
	millions	kg/cap/yr	Gg	%	%	%	%	%	%	%	%	(=100%)
1995	107948335	0.000206675	22310.22214	65%	8%	43%	10%	4%	4%	0%	31%	100%
1996	110668794	0.000206216	22821.67602	65%	8%	43%	10%	4%	4%	0%	31%	100%
1997	113457663	0.000203568	23096.34954	66%	8%	43%	10%	4%	4%	0%	31%	100%
1998	116319759	0.000208026	24197.53419	65%	8%	43%	10%	4%	4%	0%	31%	100%
1999	119260063	0.00020703	24690.41084	65%	8%	43%	10%	4%	4%	0%	31%	100%
2000	122283850	0.000206607	25264.6994	64%	8%	43%	10%	4%	4%	0%	31%	100%
2001	125394046	0.000214789	26933.26175	67%	8%	43%	10%	4%	4%	0%	31%	100%
2002	128596076	0.000215291	27685.5778	67%	8%	43%	10%	4%	4%	0%	31%	100%
2003	131900631	0.000211722	27926.2654	66%	8%	43%	10%	4%	4%	0%	31%	100%
2004	135320422	0.000210647	28504.84093	67%	8%	43%	10%	4%	4%	0%	31%	100%
2005	138865016	0.000210795	29272.05105	67%	8%	43%	10%	4%	4%	0%	31%	100%
2006	142538308	0.000212233	30251.33272	67%	8%	43%	10%	4%	4%	0%	31%	100%
2007	146339977	0.000213926	31305.92592	66%	8%	43%	10%	4%	4%	0%	31%	100%
2008	150269623	0.000208763	31370.73731	67%	8%	43%	10%	4%	4%	0%	31%	100%
2009	154324933	0.000215083	33192.66956	67%	8%	43%	10%	4%	4%	0%	31%	100%
2010	158503197	0.000215119	34097.04924	66%	8%	43%	10%	4%	4%	0%	31%	100%
2011	162805071	0.000216715	35282.30096	68%	8%	43%	10%	4%	4%	0%	31%	100%
2012	167228767	0.000221698	37074.28319	69%	8%	43%	10%	4%	4%	0%	31%	100%
2013	171765769	0.000220262	37833.47181	69%	8%	43%	10%	4%	4%	0%	31%	100%
2014	176404902	0.000220806	38951.26079	69%	8%	43%	10%	4%	4%	0%	31%	100%
2015	181137448	0.000222008	40213.96256	69%	8%	43%	10%	4%	4%	0%	31%	100%
2016	185960289	0.000217232	40396.5255	68%	8%	43%	10%	4%	4%	0%	31%	100%
2017	190873311	0.000220584	42103.59843	69%	8%	43%	10%	4%	4%	0%	31%	100%
2018	195874740	0.000221984	43481.05828	68%	8%	43%	10%	4%	4%	0%	31%	100%
2019	200963599	0.000218171	43844.42936	68%	8%	43%	10%	4%	4%	0%	31%	100%
2020	206139589	0.000215473	44417.51566	70%	8%	43%	10%	4%	4%	0%	31%	100%
2021	211700711.3	0.000223274	47267.26461	71%	8%	43%	10%	4%	4%	0%	31%	100%
2022	217401423	0.000228587	49695.13908	70%	8%	43%	10%	4%	4%	0%	31%	100%
2023	223241624.4	0.00022704	50684.7784	72%	8%	43%	10%	4%	4%	0%	31%	100%
2024	229225172	0.000226789	51985.74753	71%	8%	43%	10%	4%	4%	0%	31%	100%
2025	235356154.7	0.000225481	53068.34112	71%	8%	43%	10%	4%	4%	0%	31%	100%
2026	241641336.5	0.000227704	55022.69889	71%	8%	43%	10%	4%	4%	0%	31%	100%
2027	248088276.9	0.000223634	55480.97372	71%	8%	43%	10%	4%	4%	0%	31%	100%
2028	254705440.2	0.000228831	58284.50059	71%	8%	43%	10%	4%	4%	0%	31%	100%
2029	261502320.2	0.000225481	58963.80466	71%	8%	43%	10%	4%	4%	0%	31%	100%
2030	268489582.5	0.000226858	60909.00971	71%	8%	43%	10%	4%	4%	0%	31%	100%

Table B.2: Industrial waste activity data.

Year	GDP	Waste generation rate	Total industrial waste	% to SWDS	Total to SWDS
	$ millions	Gg/$m GDP/yr	Gg	%	Gg
1960	4,196	0.399301082	1675.467339	100%	1675.467339
1961	4467	0.374563692	1673.176012	100%	1673.176012
1962	4909	0.346095037	1698.980538	100%	1698.980538
1963	5165	0.339184122	1751.885989	100%	1751.885989
1964	5553	0.323851219	1798.345821	100%	1798.345821
1965	5874	0.309369662	1817.237392	100%	1817.237392
1966	6367	0.293384787	1867.980937	100%	1867.980937
1967	5203	0.370423659	1927.314298	100%	1927.314298
1968	5201	0.382434018	1989.03933	100%	1989.03933
1969	6634	0.301415498	1999.590417	100%	1999.590417
1970	12546	0.161095246	2021.100952	100%	2021.100952
1971	9182	0.236933196	2175.520607	100%	2175.520607
1972	12274	0.180056329	2210.011386	100%	2210.011386
1973	15163	0.149275996	2263.471929	100%	2263.471929
1974	24847	0.093988005	2335.319959	100%	2335.319959
1975	27779	0.087148956	2420.910858	100%	2420.910858
1976	36309	0.068685337	2493.895919	100%	2493.895919
1977	36035	0.070969562	2557.388155	100%	2557.388155
1978	36528	0.072365334	2643.360935	100%	2643.360935
1979	47260	0.058074613	2744.606187	100%	2744.606187
1980	64202	0.043992424	2824.401575	100%	2824.401575
1981	164475	0.018343406	3017.031644	100%	3017.031644
1982	142769	0.021477794	3066.363104	100%	3066.363104
1983	97095	0.032107331	3117.46131	100%	3117.46131
1984	73484	0.044301144	3255.425289	100%	3255.425289
1985	73746	0.04440569	3274.741981	100%	3274.741981
1986	54806	0.062671473	3434.772747	100%	3434.772747
1987	52676	0.065190244	3433.961296	100%	3433.961296
1988	49648	0.070551936	3502.762514	100%	3502.762514
1989	44003	0.083179638	3660.153628	100%	3660.153628
1990	54036	0.070305609	3799.033882	100%	3799.033882
1991	49118	0.081575678	4006.834136	100%	4006.834136
1992	47795	0.085862235	4103.785517	100%	4103.785517
1993	27752	0.150056636	4164.371753	100%	4164.371753
1994	33833	0.1272226	4304.322221	100%	4304.322221
1995	44062	0.101267406	4462.044427	100%	4462.044427
1996	51076	0.089363599	4564.335205	100%	4564.335205
1997	54458	0.084822614	4619.269908	100%	4619.269908
1998	54604	0.088629163	4839.506837	100%	4839.506837
1999	59373	0.083170501	4938.082169	100%	4938.082169
2000	69449	0.072757561	5052.939879	100%	5052.939879
2001	74030	0.072763101	5386.652349	100%	5386.652349
2002	95386	0.058049562	5537.11556	100%	5537.11556
2003	104912	0.053237505	5585.253079	100%	5585.253079
2004	136386	0.041800245	5700.968187	100%	5700.968187
2005	176134	0.033238388	5854.41021	100%	5854.41021
2006	236104	0.02562543	6050.266544	100%	6050.266544
2007	275626	0.022716236	6261.185184	100%	6261.185184
2008	337036	0.01861566	6274.147461	100%	6274.147461
2009	291880	0.022744052	6638.533913	100%	6638.533913
2010	361457	0.018866448	6819.409847	100%	6819.409847
2011	404994	0.017423617	7056.460192	100%	7056.460192
2012	455502	0.016278428	7414.856637	100%	7414.856637
2013	508693	0.014874776	7566.694362	100%	7566.694362
2014	546676	0.014250218	7790.252158	100%	7790.252158
2015	486803	0.016521658	8042.792511	100%	8042.792511
2016	404650	0.019966156	8079.3051	100%	8079.3051
2017	375746	0.02241067	8420.719687	100%	8420.719687
2018	397190	0.021894337	8696.211657	100%	8696.211657
2019	448120	0.019568164	8768.885871	100%	8768.885871

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Table B.2 – continued from previous page

Year	GDP	Waste generation rate	Total industrial waste	% to SWDS	Total to SWDS
	$ millions	Gg/$m GDP/yr	Gg	%	Gg
2020	469136	0.01893588	8883.503132	100%	8883.503132
2021	476219	0.019851062	9453.452923	100%	9453.452923
2022	483074	0.020574545	9939.027816	100%	9939.027816
2023	490357	0.020672603	10136.95568	100%	10136.95568
2024	496789	0.020928703	10397.14951	100%	10397.14951
2025	502046	0.021140828	10613.66822	100%	10613.66822
2026	506304	0.021735044	11004.53978	100%	11004.53978
2027	509779	0.021766677	11096.19474	100%	11096.19474
2028	512618	0.022739935	11656.90012	100%	11656.90012
2029	514929	0.022901722	11792.76093	100%	11792.76093
2030	516802	0.023571507	12181.80194	100%	12181.80194

Table B.3: Amounts deposited in SWDS.

	Amounts deposited in SWDS							
Year	Food	Garden	Paper	Wood	Textile	Deposited MSW	Inert	Industrial
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
1960	398	2,140	488	199	199	4,977	1,543	1,675
1961	390	2,099	478	195	195	4,881	1,513	1,673
1962	405	2,176	496	202	202	5,061	1,569	1,699
1963	419	2,254	514	210	210	5,243	1,625	1,752
1964	430	2,312	527	215	215	5,376	1,667	1,798
1965	426	2,288	521	213	213	5,321	1,650	1,817
1966	448	2,406	548	224	224	5,596	1,735	1,868
1967	462	2,483	566	231	231	5,774	1,790	1,927
1968	468	2,514	573	234	234	5,847	1,813	1,989
1969	466	2,505	571	233	233	5,825	1,806	2,000
1970	484	2,602	593	242	242	6,052	1,876	2,021
1971	522	2,808	640	261	261	6,530	2,024	2,176
1972	546	2,934	669	273	273	6,824	2,115	2,210
1973	543	2,921	666	272	272	6,792	2,106	2,263
1974	573	3,082	702	287	287	7,167	2,222	2,335
1975	590	3,169	722	295	295	7,370	2,285	2,421
1976	607	3,262	743	303	303	7,585	2,351	2,494
1977	624	3,356	765	312	312	7,806	2,420	2,557
1978	648	3,481	793	324	324	8,096	2,510	2,643
1979	673	3,616	824	336	336	8,408	2,607	2,745
1980	699	3,756	856	349	349	8,735	2,708	2,824
1981	762	4,097	934	381	381	9,528	2,954	3,017
1982	771	4,144	945	386	386	9,638	2,988	3,066
1983	790	4,245	967	395	395	9,871	3,060	3,117
1984	808	4,341	989	404	404	10,094	3,129	3,255
1985	833	4,479	1,021	417	417	10,416	3,229	3,275
1986	863	4,638	1,057	431	431	10,786	3,344	3,435
1987	871	4,680	1,067	435	435	10,885	3,374	3,434
1988	894	4,803	1,095	447	447	11,171	3,463	3,503
1989	920	4,945	1,127	460	460	11,499	3,565	3,660
1990	948	5,097	1,162	474	474	11,854	3,675	3,799
1991	1,029	5,533	1,261	515	515	12,868	3,989	4,007
1992	1,057	5,680	1,295	528	528	13,210	4,095	4,104
1993	1,079	5,801	1,322	540	540	13,492	4,182	4,164
1994	1,122	6,032	1,375	561	561	14,029	4,349	4,304
1995	1,157	6,218	1,417	578	578	14,459	4,482	4,462
1996	1,181	6,346	1,446	590	590	14,759	4,575	4,564
1997	1,216	6,536	1,490	608	608	15,201	4,712	4,619
1998	1,265	6,797	1,549	632	632	15,807	4,900	4,840
1999	1,276	6,859	1,563	638	638	15,951	4,945	4,938
2000	1,298	6,979	1,591	649	649	16,230	5,031	5,053
2001	1,451	7,798	1,777	725	725	18,136	5,622	5,387

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Table B.3 – continued from previous page

Year	Amounts deposited in SWDS							
	Food	Garden	Paper	Wood	Textile	Deposited MSW	Inert	Industrial
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
2002	1,483	7,974	1,817	742	742	18,543	5,748	5,537
2003	1,478	7,944	1,811	739	739	18,475	5,727	5,585
2004	1,532	8,233	1,876	766	766	19,146	5,935	5,701
2005	1,561	8,393	1,913	781	781	19,518	6,050	5,854
2006	1,623	8,722	1,988	811	811	20,284	6,288	6,050
2007	1,663	8,940	2,037	832	832	20,791	6,445	6,261
2008	1,683	9,045	2,061	841	841	21,034	6,521	6,274
2009	1,788	9,612	2,191	894	894	22,353	6,929	6,639
2010	1,806	9,707	2,212	903	903	22,574	6,998	6,819
2011	1,928	10,366	2,362	964	964	24,106	7,473	7,056
2012	2,035	10,938	2,493	1,017	1,017	25,436	7,885	7,415
2013	2,095	11,259	2,566	1,047	1,047	26,184	8,117	7,567
2014	2,137	11,487	2,618	1,069	1,069	26,713	8,281	7,790
2015	2,222	11,944	2,722	1,111	1,111	27,777	8,611	8,043
2016	2,213	11,894	2,711	1,106	1,106	27,660	8,575	8,079
2017	2,310	12,417	2,830	1,155	1,155	28,878	8,952	8,421
2018	2,369	12,732	2,902	1,184	1,184	29,609	9,179	8,696
2019	2,398	12,890	2,938	1,199	1,199	29,976	9,293	8,769
2020	2,473	13,293	3,030	1,237	1,237	30,914	9,583	8,884
2021	2,686	14,436	3,290	1,343	1,343	33,573	10,407	9,453
2022	2,798	15,042	3,428	1,399	1,399	34,981	10,844	9,939
2023	2,902	15,597	3,555	1,451	1,451	36,271	11,244	10,137
2024	2,948	15,844	3,611	1,474	1,474	36,846	11,422	10,397
2025	3,005	16,150	3,681	1,502	1,502	37,558	11,643	10,614
2026	3,134	16,843	3,839	1,567	1,567	39,169	12,142	11,005
2027	3,148	16,923	3,857	1,574	1,574	39,356	12,200	11,096
2028	3,290	17,683	4,030	1,645	1,645	41,122	12,748	11,657
2029	3,329	17,895	4,078	1,665	1,665	41,615	12,901	11,793
2030	3,452	18,552	4,228	1,726	1,726	43,145	13,375	12,182

Table B.4: Methane generated in Nigeria (1960 - 2030).

Methane generated									
Year	Food	Garden	Paper	Wood	Textile	Industrial	Total	Methane recovery	**Methane emission**
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
1960	0	0	0	0	0	0	0	0	0
1961	4	54	1	1	2	14	77	0	77
1962	6	99	2	2	4	27	140	0	140
1963	8	139	3	3	5	37	196	0	196
1964	9	175	4	4	7	46	246	0	246
1965	10	206	5	5	9	55	291	0	291
1966	11	232	6	6	10	62	328	0	328
1967	12	257	7	7	12	68	363	0	363
1968	12	280	8	8	13	74	396	0	396
1969	13	301	9	9	15	80	425	0	425
1970	13	317	10	10	16	84	450	0	450
1971	13	334	11	11	17	89	474	0	474
1972	14	353	11	12	19	93	502	0	502
1973	15	373	12	13	20	98	530	0	530
1974	15	389	13	14	21	102	554	0	554
1975	15	406	14	15	23	106	580	0	580
1976	16	424	15	16	24	110	605	0	605
1977	17	440	16	17	25	115	630	0	630
1978	17	457	16	18	27	119	654	0	654
1979	18	474	17	19	28	123	679	0	679
1980	18	492	18	21	29	127	706	0	706
1981	19	511	19	22	31	132	733	0	733
1982	20	535	20	23	33	137	768	0	768

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Table B.4 – continued from previous page

	Methane generated								
Year	Food	Garden	Paper	Wood	Textile	Industrial	Total	Methane recovery	**Methane emission**
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
1983	21	557	21	24	34	142	799	0	799
1984	21	578	22	26	36	147	829	0	829
1985	22	598	23	27	37	152	859	0	859
1986	23	619	24	28	39	156	888	0	888
1987	23	640	25	29	40	161	919	0	919
1988	24	659	26	31	42	166	947	0	947
1989	25	678	27	32	43	170	975	0	975
1990	25	698	28	33	45	175	1,004	0	1,004
1991	26	719	29	35	47	180	1,035	0	1,035
1992	27	747	30	36	48	187	1,076	0	1,076
1993	28	775	31	38	50	193	1,115	0	1,115
1994	29	802	32	40	52	198	1,153	0	1,153
1995	30	830	33	41	54	204	1,193	0	1,193
1996	31	858	34	43	56	211	1,234	0	1,234
1997	32	886	36	45	58	217	1,274	0	1,274
1998	33	914	37	46	60	223	1,313	0	1,313
1999	34	944	38	48	62	230	1,357	0	1,357
2000	35	971	39	50	64	236	1,396	10	1,386
2001	36	997	41	52	66	243	1,434	10	1,424
2002	38	1,040	42	54	69	251	1,494	10	1,484
2003	40	1,080	44	56	72	260	1,551	10	1,541
2004	41	1,113	45	58	74	267	1,598	10	1,588
2005	42	1,149	47	60	76	274	1,649	10	1,639
2006	43	1,183	48	62	79	282	1,697	10	1,687
2007	44	1,220	50	64	82	290	1,750	10	1,740
2008	46	1,257	52	67	84	298	1,803	10	1,793
2009	47	1,291	53	69	87	306	1,852	10	1,842
2010	48	1,334	55	71	90	315	1,913	10	1,903
2011	50	1,372	57	74	92	325	1,969	10	1,959
2012	52	1,422	59	76	96	335	2,038	10	2,028
2013	54	1,478	61	79	99	346	2,117	10	2,107
2014	56	1,534	63	82	103	357	2,194	10	2,184
2015	58	1,586	65	85	106	368	2,269	10	2,259
2016	60	1,642	67	88	110	380	2,347	10	2,337
2017	61	1,688	69	91	113	390	2,413	10	2,403
2018	63	1,741	72	94	117	402	2,488	10	2,478
2019	65	1,793	74	97	121	414	2,563	10	2,553
2020	66	1,841	76	100	124	424	2,632	10	2,622
2021	68	1,891	78	103	128	435	2,703	10	2,693
2022	71	1,963	81	107	132	448	2,803	10	2,793
2023	75	2,039	84	111	137	464	2,909	10	2,899
2024	78	2,117	87	115	142	478	3,017	10	3,007
2025	80	2,190	90	119	147	493	3,118	10	3,108
2026	82	2,259	93	123	152	507	3,215	10	3,205
2027	85	2,334	96	127	157	523	3,322	10	3,312
2028	87	2,400	99	131	162	536	3,415	10	3,405
2029	90	2,475	102	135	167	553	3,522	10	3,512
2030	92	2,544	105	139	172	568	3,620	10	3,610

Table B.5: Information on methane emission from HWP, and HWP C long-term stored in SWDS.

	Long-term stored C			Long term stored C accumulated			CH4 generated			CH4 emitted		
Year	Garden C	Paper C	Wood C	Garden C	Paper C	Wood C	Garden	Paper	Wood	Garden	Paper	Wood
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
1960	156	8	14	156	8	14	0	0	0	0	0	0
1961	153	8	14	309	16	27	54	1	1	54	1	1
1962	159	8	14	468	24	42	99	2	2	99	2	2
1963	164	8	15	633	32	56	139	3	3	139	3	3
1964	169	9	15	801	41	71	175	4	4	175	4	4
1965	167	8	15	968	49	86	206	5	5	206	5	5
1966	176	9	16	1,144	58	102	232	6	6	232	6	6
1967	181	9	16	1,325	67	118	257	7	7	257	7	7
1968	183	9	16	1,508	76	134	280	8	8	280	8	8
1969	183	9	16	1,691	86	150	301	9	9	301	9	9
1970	190	10	17	1,881	95	167	317	10	10	317	10	10
1971	205	10	18	2,086	106	185	334	11	11	334	11	11
1972	214	11	19	2,300	116	204	353	11	12	353	11	12
1973	213	11	19	2,513	127	223	373	12	13	373	12	13
1974	225	11	20	2,738	139	243	389	13	14	389	13	14
1975	231	12	21	2,969	150	264	406	14	15	406	14	15
1976	238	12	21	3,207	162	285	424	15	16	424	15	16
1977	245	12	22	3,452	175	307	440	16	17	440	16	17
1978	254	13	23	3,706	188	329	457	16	18	457	16	18
1979	264	13	23	3,970	201	353	474	17	19	474	17	19
1980	274	14	24	4,244	215	377	492	18	21	492	18	21
1981	299	15	27	4,543	230	404	511	19	22	511	19	22
1982	302	15	27	4,846	245	431	535	20	23	535	20	23
1983	310	16	28	5,155	261	458	557	21	24	557	21	24
1984	317	16	28	5,472	277	486	578	22	26	578	22	26
1985	327	17	29	5,799	294	515	598	23	27	598	23	27
1986	338	17	30	6,137	311	546	619	24	28	619	24	28
1987	342	17	30	6,479	328	576	640	25	29	640	25	29
1988	350	18	31	6,829	346	607	659	26	31	659	26	31
1989	361	18	32	7,190	364	639	678	27	32	678	27	32
1990	372	19	33	7,562	383	672	698	28	33	698	28	33
1991	404	20	36	7,966	403	708	719	29	35	719	29	35
1992	414	21	37	8,380	424	745	747	30	36	747	30	36
1993	423	21	38	8,803	446	783	775	31	38	775	31	38
1994	440	22	39	9,244	468	822	802	32	40	802	32	40

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Table B.5 – continued from previous page

Year	Long-term stored C			Long term stored C accumulated			CH4 generated			CH4 emitted		
	Garden C	Paper C	Wood C	Garden C	Paper C	Wood C	Garden	Paper	Wood	Garden	Paper	Wood
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
1995	454	23	40	9,697	491	862	830	33	41	830	33	41
1996	463	23	41	10,160	515	903	858	34	43	858	34	43
1997	477	24	42	10,637	539	946	886	36	45	886	36	45
1998	496	25	44	11,133	564	990	914	37	46	914	37	46
1999	500	25	44	11,634	589	1,034	944	38	48	944	38	48
2000	509	26	45	12,143	615	1,079	971	39	50	964	39	49
2001	569	29	51	12,712	644	1,130	997	41	52	990	40	51
2002	582	29	52	13,294	673	1,182	1,040	42	54	1,033	42	53
2003	580	29	52	13,873	703	1,233	1,080	44	56	1,073	44	55
2004	601	30	53	14,474	733	1,287	1,113	45	58	1,107	45	58
2005	612	31	54	15,087	764	1,341	1,149	47	60	1,142	47	60
2006	636	32	57	15,723	796	1,398	1,183	48	62	1,176	48	62
2007	652	33	58	16,375	829	1,456	1,220	50	64	1,213	50	64
2008	660	33	59	17,035	863	1,514	1,257	52	67	1,250	51	66
2009	701	36	62	17,737	898	1,577	1,291	53	69	1,284	53	68
2010	708	36	63	18,445	934	1,640	1,334	55	71	1,327	55	71
2011	756	38	67	19,201	972	1,707	1,372	57	74	1,365	56	73
2012	798	40	71	19,999	1,013	1,778	1,422	59	76	1,415	58	76
2013	822	42	73	20,821	1,054	1,851	1,478	61	79	1,471	60	79
2014	838	42	75	21,659	1,097	1,925	1,534	63	82	1,527	63	82
2015	872	44	77	22,531	1,141	2,003	1,586	65	85	1,579	65	84
2016	868	44	77	23,398	1,185	2,080	1,642	67	88	1,635	67	87
2017	906	46	81	24,305	1,231	2,160	1,688	69	91	1,681	69	90
2018	929	47	83	25,234	1,278	2,243	1,741	72	94	1,734	71	93
2019	941	48	84	26,174	1,326	2,327	1,793	74	97	1,786	74	97
2020	970	49	86	27,144	1,375	2,413	1,841	76	100	1,834	76	100
2021	1,053	53	94	28,197	1,428	2,506	1,891	78	103	1,884	78	103
2022	1,098	56	98	29,295	1,484	2,604	1,963	81	107	1,956	81	106
2023	1,138	58	101	30,433	1,541	2,705	2,039	84	111	2,032	84	110
2024	1,156	59	103	31,589	1,600	2,808	2,117	87	115	2,110	87	114
2025	1,178	60	105	32,768	1,660	2,913	2,190	90	119	2,183	90	118
2026	1,229	62	109	33,997	1,722	3,022	2,259	93	123	2,252	93	122
2027	1,235	63	110	35,231	1,784	3,132	2,334	96	127	2,327	96	126
2028	1,290	65	115	36,522	1,850	3,246	2,400	99	131	2,393	99	130
2029	1,306	66	116	37,827	1,916	3,362	2,475	102	135	2,468	102	135
2030	1,354	69	120	39,181	1,984	3,483	2,544	105	139	2,537	105	139

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