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

Final Report

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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. The 2015 Paris Agreement seeks to decrease global temperature 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. It outlines national plans of member nations and steps 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 in the production systems elongating the lifecycle of materials and phasing out the concept of 'waste'. 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 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.

We obtained Solid Waste Disposal Sites (SWDS) datasets 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.

We also obtained datasets from assessments of the operations of the Extended Producer Responsibility (EPR) programme through a detailed questionnaire survey and interactive sessions with the Producer Responsibility Organizations (PROs) in four major waste streams, namely, Food and Beverage Alliance (FBRA), E-waste Producer Responsibility Organization of Nigeria (EPRON), Alliance for Responsible Battery Recyclers (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 0.5kg/capita/day. To compute the waste per capita, we evaluate 0.5 x365.

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 our current neural network (RNN) deep learning model. RNNs are developed to solve learning problems where information about the past (i.e. past instants/events) is 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 allows 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 parameters 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. Also, four policies and ten regulations were found to be key waste legislation that is influential to the emissions of greenhouse gases. 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 institutional framework for waste management exists 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 report 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 from1960–2030 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, 2,578Gg of MSW was estimated to be deposited in SWDS. Whereas in 2020, 17,510Gg of MSW was estimated to be deposited. We observed that there was a 619.7% 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, 20,213Gg and 25,653Gg of MSW will be deposited at SWDS, respectively. The period between 2021-2030 shows a projected percentage increase of 26.91% of waste deposited in SWDS in Nigeria.

For industrial waste deposited, our results show 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 519.31% increase in the amount of Industrial waste deposited in SWDS within a 60-year interval from 1960 to 2020. We estimate that in the years 2021 and 2030, 6,768Gg and 8,741Gg 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 462Gg CO2- eq. Our results show that in 2020, 18,564Gg CO2-eq of CH_4 was 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 3920% within the 60-year interval.

Regarding the 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 emissions. 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 the amount of fossil carbon oxidized 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 301583.59Gg in 1960. Whereas in 2020, the total amount of municipal solid waste open burned was 1599031.15Gg. 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 112.34Gg in 1960, whereas in 2020, the net emission was 595.64Gg. 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 56.37Gg, whereas, in 2020, the net CO_2 emission was 406.11Gg. This shows that within the 60-year interval (1961-2020), there was a 620.48% 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 2659.65Gg CO2-eq. In 2020, it was estimated that 13455.33Gg CO2-eq 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 the most used electronic products. To estimate the total amounts of E-waste generated in Nigeria, a data model was built. Using this model, the estimated amount of E-waste generated in 1960 was 54.77Gg, and by 2020, this figure had increased by 677.16% over the 60 year time interval. From the projected results, e-waste is projected to rise by 31.06% between 2021 and 2030.

For the amount of medical waste deposited, the estimated amount of medical waste generated in 1960 was 20.26Gg, while in 2020, the amount was 131.89Gg. Based on the model, the projected amounts of medical waste in 2030 is 181.26Gg representing an increase of 27.09% from 2021.

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 is Lead-acid battery [9]. In Nigeria, lead-acid batteries (LAB) are used in automobile vehicles, motorbikes, and lorries [10]. In the country, heavy metal contamination around the informal ULAB recycling centres 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 the Generation of ULAB and the annual generation rate for ULAB batteries each year was used to build the data model. In 1960, the estimated amount of ULAB waste generated was 24.75Gg while it was 322.98Gg in 2020, highlighting an increase of 1204.79% over the 60 year time interval. Based on the projected results, ULAB waste is projected to rise by 26.37% between 2021 and 2030, generating approximately 469.66Gg of battery waste in 2030.

In considering plastics waste, we observed the estimated amount of plastic waste deposited in 1960 was 746.55Gg while it was 4637.1Gg in 2020. The projected amounts of plastic waste to be deposited in the year 2021 was found to be 5035.95Gg, increasing by 28.51% to 6471.75Gg in 2030.

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 7.47% of organic waste will be recycled, which will result in approximately 10% annual reduction in methane emissions within the same period. For plastics waste emission reduction, research reports that [12] 1000 tonnes (i.e. 0.9 Gigagrams) per annum of plastics are recycled. A projection of 7.47% plastic waste to be recycled per annum will lead to a corresponding decrease of approximately 20% annual reduction in methane emissions within the same period.

Emission Reduction Consideration for NDC Revision. It has been shown that a significant reduction in waste and emissions can be achieved between 2023 and 2030 if Nigeria achieves a recycling rate of at least 7.47%. However, there may be varying percentages in some sectors due to their peculiarities, like batteries (80%), whose current recycling percentage is similar to the projected recycled percentage. These reductions within this period will lead to a decrease in the quantities and emissions of the analyzed waste streams, with the most significant projections being organic waste (4,000 Gg) and plastic waste (8,000 Gg) reductions leading to corresponding emissions reduction of approximately 10% and 20% respectively within the period 2023-2030.

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.

Recommendations were also made based on General Policy and Governance Structure; Specific Waste Streams such as organic waste, plastic waste, e-waste, battery waste, medical waste; Waste Management Practices such as open burning and landfills; and the Extended Producer Responsibility (EPR) – Producer Responsibility Organization (PRO).

Chapter 1

Introduction

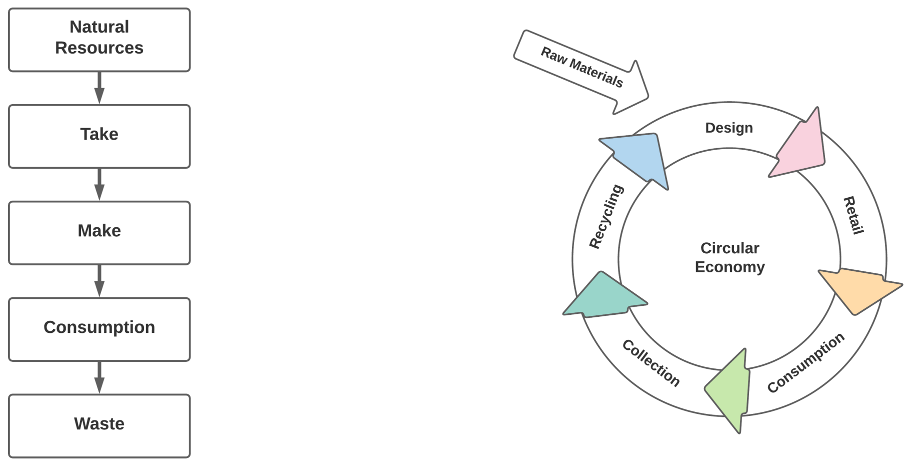
The United Framework Convention on Climate Change (UNFCCC) (2019) has identified climate change as the greatest challenge to sustainable development worldwide, and its adverse effects are felt in various communities. Therefore, it is pertinent to act quickly and end contributing factors contributing to climate change while addressing its consequences on the environment. The United Nations Conference on Sustainable Development, which took place in June 2012 in 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 simultaneously as 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 to develop a pathway to sustainable growth for the world and 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 achieving these objectives. They consist of proactive plans to be carried out by each nation to reduce its national emissions and enhance climate change adaption. 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, and the remaining (38%) are released into the environment during the logistics and utilization of goods and amenities. Increased production over the years has compounded climate change as the demand for materials has dramatically increased by 300% since 1970, and future projections of up to 200% by 2050 have been made if no measures are put in place (UNFCCC, 2019). Rethinking the modes of material production and consumption of goods and services in a way that is socially, economically and ecologically sustainable necessitates a shift from linear to a 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 that can be recovered, reused and repaired instead of being discarded after a single use as it is the norm in a linear economy that 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. There has been a rising interest in Circular Economy (CE) initiatives that 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 potential to decrease current greenhouse gas emissions by up to 50% and reduce the number of materials, energy, and waste used during production. The NDC highlights CO_2 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 CO_2 emissions per capita and 0.491kg of CO_2 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 must be carried out detailing current circular economy-related policies, initiatives, and proposals focusing on the waste management sector, which would enable a synergy of key stakeholders to develop common goals. 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 as 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 modelling.

Document review and analysis by a 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.

We obtained Solid Waste Disposal Sites (SWDS) datasets 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/materials. We further refined the datasets for consistency with the IPCC model utilized for emissions estimation from the waste sector.

We also obtained datasets from assessments of the operations of the Extended Producer Responsibility (EPR) programme through a detailed survey of the Producer Responsibility Organizations (PROs) in four major waste streams, namely, Food and Beverage Alliance (FBRA), E-waste Producer Responsibility Organization of Nigeria (EPRON), Alliance for Responsible Battery Recyclers (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. We supplemented the data obtained from PROs 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 the 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. However, 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 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/materials. 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 calculating 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 the 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 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 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 model aims 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.

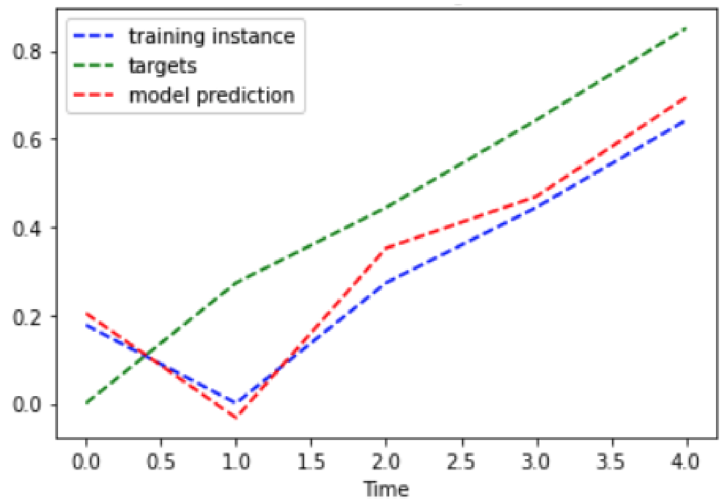


Figure 2.1: LSTM model testing.

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).

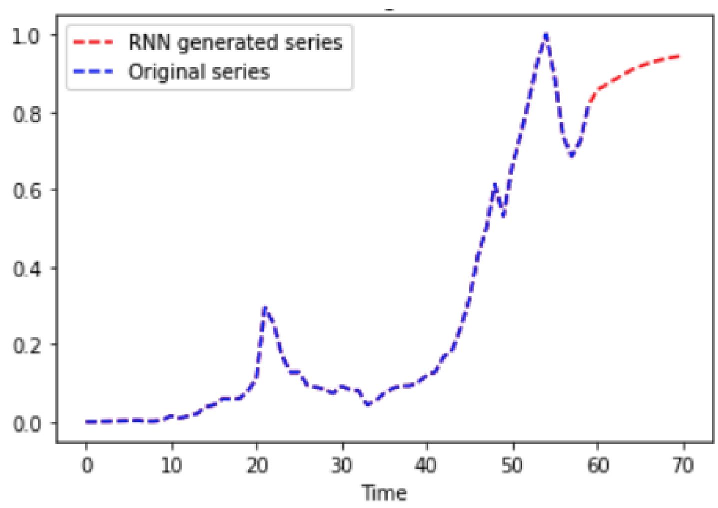


Figure 2.2: Original GDP sequence (in blue) and the predicted LSTM GDP (in red).

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 number of waste materials that are sent to MSWDS and other landfills, thereby leading to a reduction of emissions from those sites.

Thus the amount of waste that is processed for further use instead of 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 from 1960-2030. However, 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. This is based on certain circular economy-related programs implemented in Nigeria between 2017 - 2022, which is assumed to have contributed approximately 2% of an increase in national recycling activities. These initiatives include the EPR, which is being implemented with three PROs increasing its members in key sectors, Community based Waste Management Projects installed by the Federal Government nationwide, and various LAWMA affiliated projects which, in addition to the informal sector, have increased the amount of waste recycled in Lagos.

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 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 specifically 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 between 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.

As Nigeria intends to increase its emission ambition to be highlighted in the revised NDC 2021-20205, an ambitious national recycling target is required to be set and committed to. This target can be an average value with some exceptions in certain sectors due to some peculiarities but can be reflective of the circularity efforts being carried out nationwide. A national recycling target of approximately 13.82% was calculated and chosen using the current status of Lagos State (2021) as a reference point. This is based on research that shows Lagos State has a very high number of circular economy projects, which can have some of its measures similarly replicated nationwide using existing waste infrastructure, active projects in various states, dormant government facilities, and certain installations under development soon to be commissioned. These, in addition to the efforts of the NCEWG and the PRO programme, as well as new collaborations with State Governments on Waste-to-Wealth schemes, can ensure that this target of 13.82% national recycling target within the period of 2021-2025 is achievable.

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 [16].

Assumption 5. In the period 2023-2030, Lagos maintains its recycled waste rate at 13%, and the rest of the country achieves a 7.1% recycled rate.

This implies that 13% of 6.3% of the waste generated (W) represents recycled waste in Lagos. And 7.1% of 93.7% of the waste generated (W) represents recycled waste for the rest of the country. Adding these two together will give: (0.13 x 0.063)W + (0.071 x 0.937)W = 0.00819W + 0.066527W = 0.074717W = 7.47% of total waste will be the amount of recycled waste for Nigeria.

Assumption 6. In the period 2023-2030, not less than 7.47% 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

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 [17] + 10% total plastic packaging waste generated/annum [18]
    - 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 [19].
3. E-waste:
    - 2006-2030 Waste Generated and Emissions: The simulated model already has the estimated quantity of e-waste generated each year for this period.
    - 2014-2030 Waste Recycled and Emissions: The e-waste recycled per annum is approximately 500,000 tonnes [20]. 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 each year for this period.
    - 2016-2022 Waste Incinerated and Emissions: Medical waste incinerated per annum was taken to be approximately 5,500 tonnes [17] for all 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 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 reviews 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 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. 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. The environmental policies and regulations that impact the waste management sector and its corresponding GHG emissions have been briefly described in Sections 3.2.1 and 3.2.2.

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 sanitation, 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 that 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 by 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 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 as 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 sus-

tainably 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 (2020):** 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 of 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 that supports the fight against transboundary 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 that involve the sustainable creation and utilization of plastics according to national sustainable development objectives with specified targets and timelines.

The key waste policies which are influential to the emissions of greenhouse gases are: the National Policy on Environmental Sanitation which facilitates the sustainable disposal of all kinds of waste material leading to a reduction in waste emissions but is required to be implemented in urban and rural areas by Waste Management Authorities in various states nationwide; the National Policy on Chemical Management which aims to ensure the proper use of chemicals minimizing the release of harmful by-products into the atmosphere when implemented by all stakeholders in the chemicals value chain; the National Policy on Environment which involves the sustainable use of resources in various economic sectors thereby reducing waste generated and its accompanying emissions during production and consumption which take place throughout products lifecycle; and National Policy on Solid Waste Management which highlights eco-friendly guidelines and processes for disposing solid waste ensuring waste quantities and GHGs are reduced when implemented by waste generators and enforced by the relevant government agencies.

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 that 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 of 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 place 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 Act 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 incorpora-

tion 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 that 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 to reduce 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 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 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.

The waste regulations relevant to the release of GHGs in the waste management sector are:

- NESREA 2007 Act which has authorized the creation of a government regulation agency to enforce all Nigerian environmental legislation which, if adequately done, will reduce waste quantities and emissions as waste sector stakeholders comply with regulations;
- The National Environmental (Control of Bush/Forest Fire and Open Burning) Regulations, S. I. No. 15 that gives regulations on the burning of vegetation and wastes to minimize the release of GHGs with enforcement in rural areas yet to be fully carried out;
- The National Environmental (Ozone Layer Protection) Regulations which prohibits the trade and use of ozone-depleting substances emitted into the atmosphere and this regulation is implemented by continuous liaisons with government agencies and

producers, researching alternative raw materials, and undertaking strict compliance by enforcement agencies;

- The National Environmental Protection (Pollution Abatement in Industries and Facilities Generating Wastes) Regulations S.I.9 which sets limits for industrial waste released into the environment and consequently the quantity of associated emissions released though it requires the collaboration of producers in industries in the country;
- The National Environmental Protection Management of Solid and Hazardous Waste Regulations S.I.15 which sustainably manages hazardous waste disposal and reduces waste quantities and emissions executed by relevant government establishments and industries;
- National Environmental (Food, Beverages and Tobacco Sector) Regulations, S. I. No. 33, which curtails the amount of organic waste and its accompanying emissions by applying sustainable processes through production, consumption and waste generation but is the regulation is challenging to implement due to lack of MRV tools and proper coverage across the country;
- National Environmental (Electrical/Electronic Sector) Regulations, S. I. No 23, which outlines guidelines for the Electrical/Electronic sector to minimize the release of harmful and toxic substances such as POPs into the environment through the enforcement of this regulation, is quite challenging due to the large size of the informal recycling sector;
- National Environmental (Hazardous Chemicals and Pesticides) Regulations, S. I. No 65 facilitates the use of sustainable agricultural practices and eco-friendly products to minimize the emission of hazardous agricultural substances and related chemicals. However, the implementation of this regulation needs to be enhanced by the exemplary penalizing of defaulters who obtain hazardous products across the chemical value chain and monitoring the regulation's compliance with emphasis on the small scale farms and agricultural industries.
- National Environmental (Chemicals, Pharmaceuticals, Soap and Detergent Manufacturing Industries) Regulations, S. I. No. 36, which minimizes the release of harmful emissions during production and consumption of products through the regulation, is yet to adequately cover the informal sector of production nationwide;
- National Environmental (Textile, Wearing Apparel, Leather and Footwear Industry) Regulations, S. I. No. 34 provides guidelines on the release and reduction of waste effluents and subsequently emissions from industries in the Nigerian fashion sector. However, this legislation requires strict compliance and enforcement, especially regarding wastewater effluents from the textile industry.

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 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 supports 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 the government on capacity building, strategies, initiatives; setting targets to ensure the proper implementation of the National Policy on Plastic Waste Management; and collecting 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.

The Federal Government institutions whose roles are vital in reducing emissions from the waste sector are the Federal Ministry of Environment and its agency National Environmental Standards, Regulation and Enforcement Agency (NESREA) which develops and enforces environmental legislation. It also influences the other arms and agencies of the Federal Government to act in their roles in contributing to waste emission reduction. However, the nationwide coverage by NESREA across all Local Government Areas in the country is still ongoing and is required for effective enforcement to be carried out.

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 to 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 creating 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 the increased usage of landfill sites and lead towards waste-to-wealth initiatives 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 franchisees, 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.

Though State Ministries of Environment have a role to play in waste management, the most critical State Government organizations in waste emission reduction are the State

Waste Management Authorities which are responsible for waste management activities in the various States. These agencies determine the daily waste quantities processed and disposed of and consequently the amount of emissions released from the disposed waste materials. However, they are sometimes hindered by inadequate financing, infrastructure, and poor disposal and collection methods.

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 an 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 the provision of quality service, and create empowerment schemes in waste management.

The Local Government Councils are responsible for waste management in various Local Government Areas. However, in many cases nationwide, the State Waste Management Authorities usually undertake this role complementing the councils' efforts, which provide other amenities such as land for waste facilities and landfill sites.

3.3.4 Civil Societies Organizations, NGOs, CBOs

The organizations are interested in contributing toward achieving sustainable waste management objectives. They create programs to inform and educate the populace on waste management processes and practices mediating between the government and private sectors. 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 a profit. They are to be licensed where applicable by the relevant authorities and 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.

The emergence of PPPs in the waste management sector have also made the private sector vital in waste emission reduction as their collaboration with regards to finance, and technical expertise can enhance the sustainable waste management and reduction techniques.

3.3.6 International Organizations/ Donor Agencies

These are foreign-affiliated organizations that have interests in collaborating with other stakeholders in the waste management process. They can work with the government to provide instruments that stimulate entrepreneurial growth in the waste management sector and 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.

Organizations can greatly contribute to waste emission reduction when they provide funding and technical expertise in areas such as Nigeria's NDC revision, circular economy initiatives, POPs, PCBs, sustainable agricultural practices and other waste reduction projects.

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 concerning the waste sector. 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, several initiatives 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 are 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 to recognise 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, consisting 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 [21]and [22] 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: [23]

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 using and managing 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 of 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

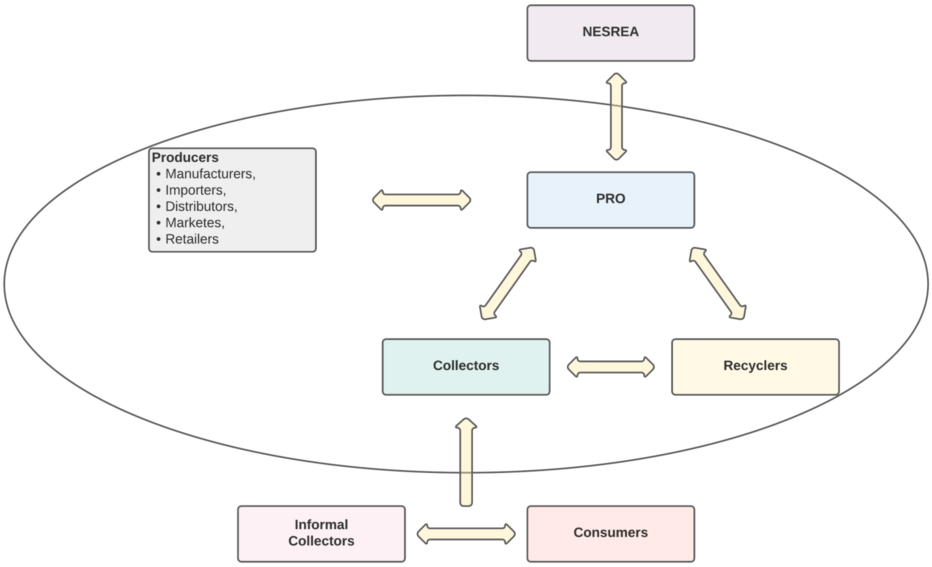


Figure 4.1: EPR implementation framework in Nigeria [24]; [25]
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consumers.

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 that 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 raw material for the original product or other alternative uses. The recycler may work with the producer to reuse the waste material or re-purpose/re-manufacture the original product.

4. The Collector is a party that 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 illustrated 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)

Plastic packaging is important to the environment due to the sheer volume of waste it generates and its GHG emissions from polymer products. [26] demonstrated that common plastic products such as PET, PS, HDPE, LDPE, PC, AC, and PP emitted some amounts of methane and ethylene when exposed to sunlight. This implies that large quantities of plastic waste can contribute significant amounts of GHGS if allowed to degrade under solar radiation.

The FBRA 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, engages with stakeholders, promotes safe and sustainable waste management practices, collects post-consumer packaging waste, and recycles this waste. The Alliance also collects packaging wastes with Recycle Points, WestAfricaENRG, 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 wastes 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)

Further analysis of these quantities illustrated in Figure 4.2 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%.

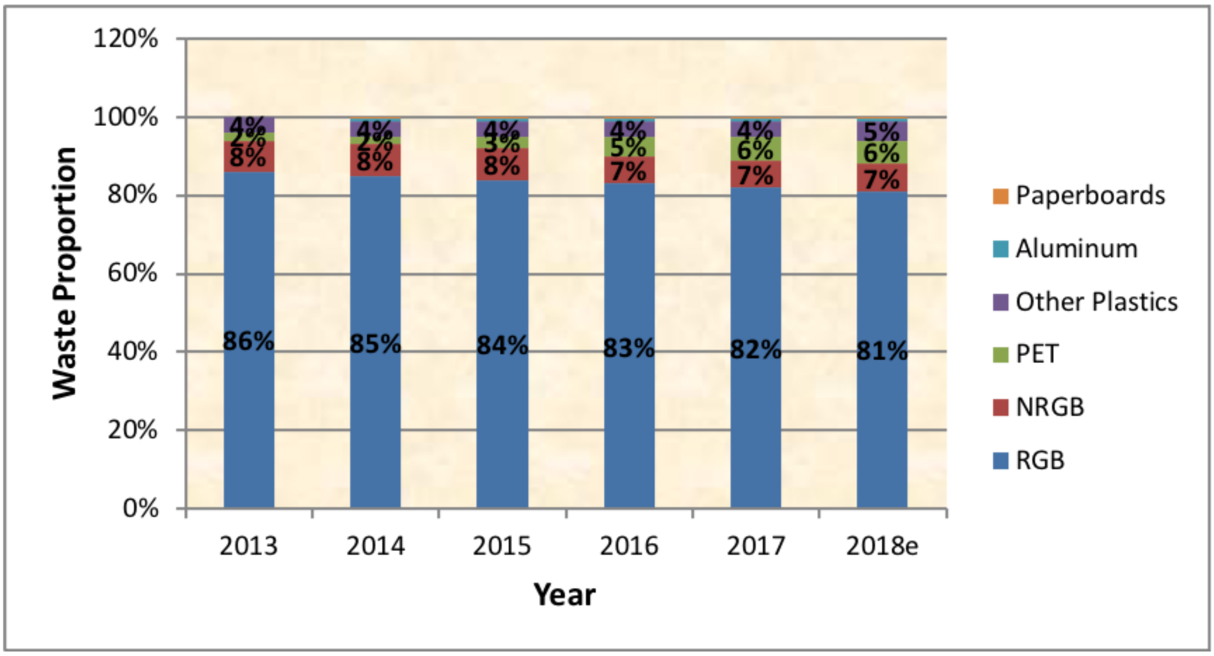

Figure 4.2: Total beverage packaging waste [27]

Polyethene terephthalate (PET) bottles have become popularly used, and their 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.

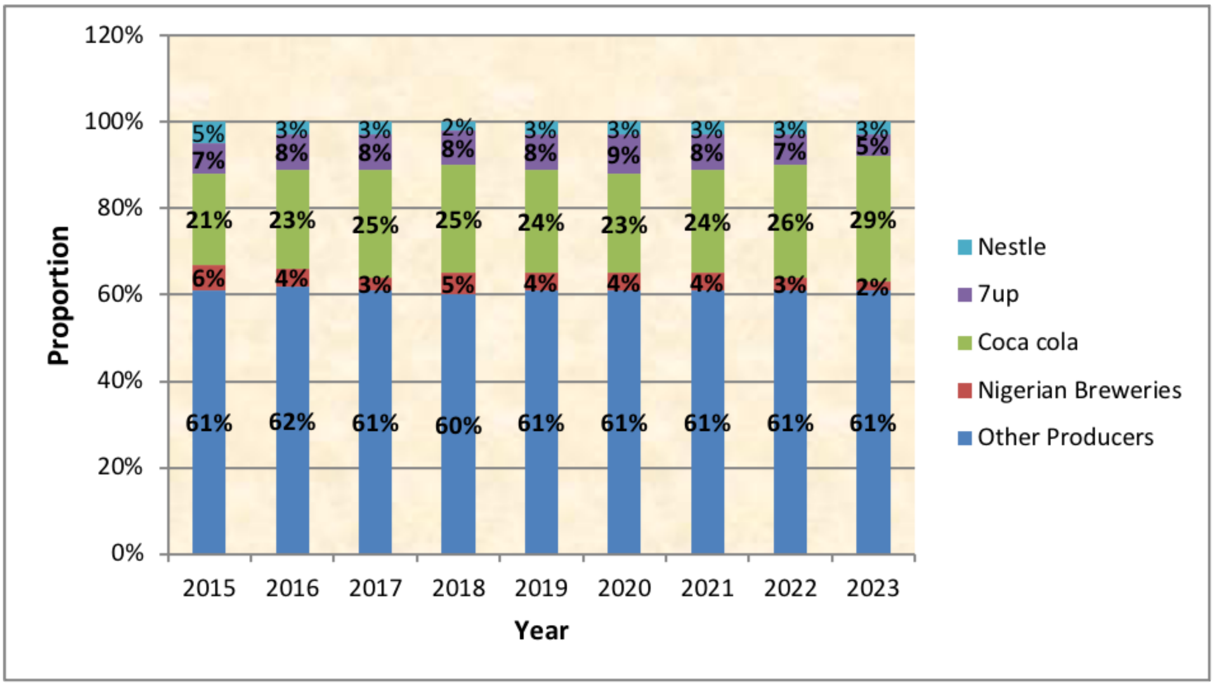

Figure 4.3: Beverage plastic packaging waste trend of Key Organizations from 2015 to 2023 [27]

After use, plastic products are usually indiscriminately disposed of in the environment. However, 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 number of plastics collected and recycled, with a 97.8% increase in plastic waste in 2019 and an 88.4% increase in 2020.

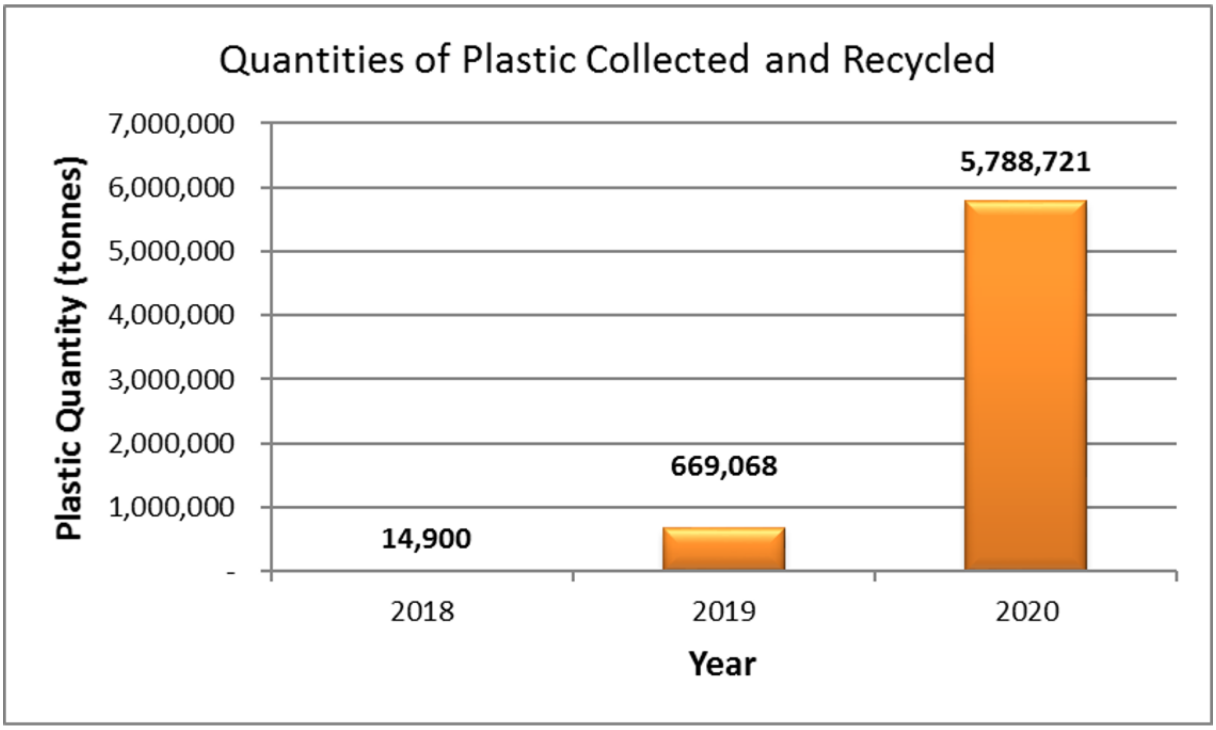

Figure 4.4: Recycled Plastic Quantities in 2018-2020 [18]

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 [18].

In 2020, FBRA was 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 [18]. 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)

The generation of electrical and electronic waste contributes to the release of harmful chemicals and GHGs into the atmosphere when burned. Therefore it is essential to effectively manage this waste stream to reduce the adverse impacts on health and the environment. Section 4.4 (POPs and Mercury Emissions) of this report highlights some of these materials, their products and the corresponding impacts of their waste materials on human health.

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 in Figure 4.5 showing the gradual increase in e-waste and depicting a steady consumption in electrical and electronic products.

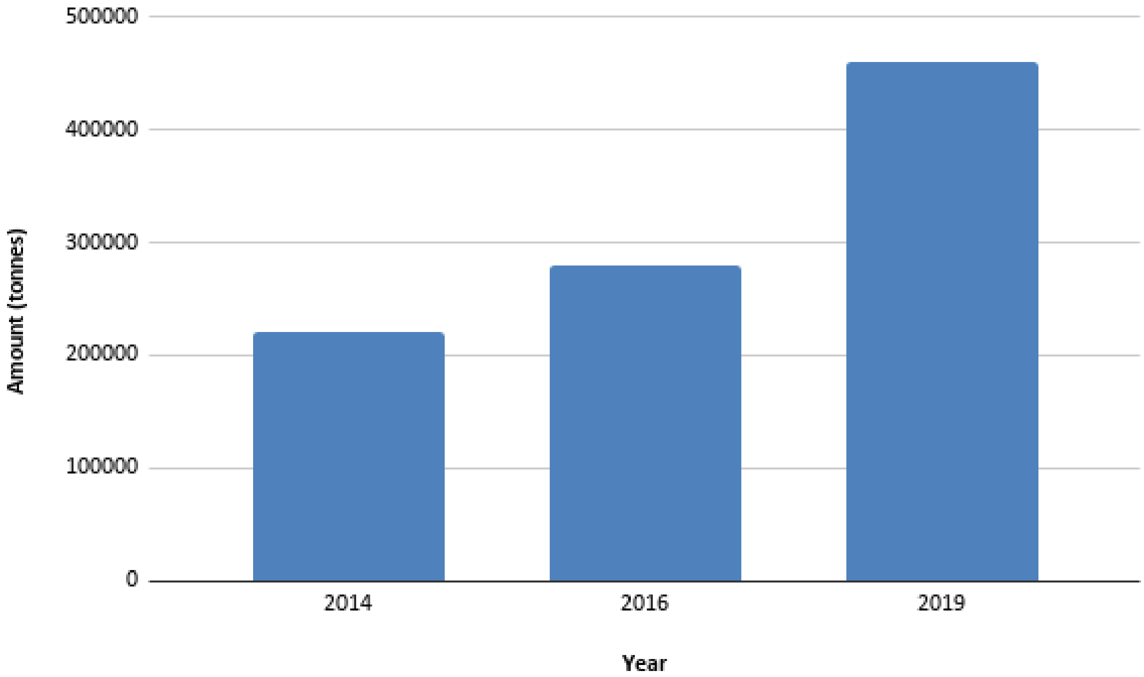

Figure 4.5: National E-waste Generation Rate [28]

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.

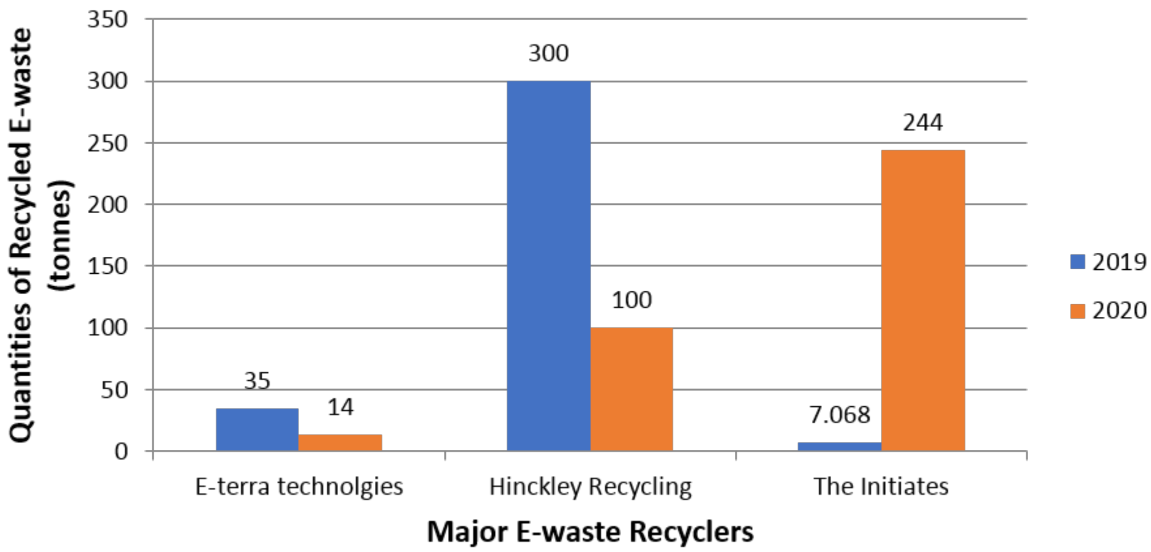

Figure 4.6: Quantities of E-waste processed by Nigeria's Major Recyclers in 2019-2020 [29]

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)

Lead-acid batteries are a reliable source of power supply in many industries, but they can be hazardous to the environment if not properly disposed of. The lead and sulphuric acid components can pollute groundwater, the former causing an array of health issues-particularly in children, and the latter is corrosive, making it dangerous to handle.

The ARBR focuses on recycling used lead-acid batteries and engages in collecting, storage and transportation of these batteries to prevent the release of dangerous substances into the environment. It also undertakes a buy-back process, creates awareness of its activities, and establishes 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 is 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.

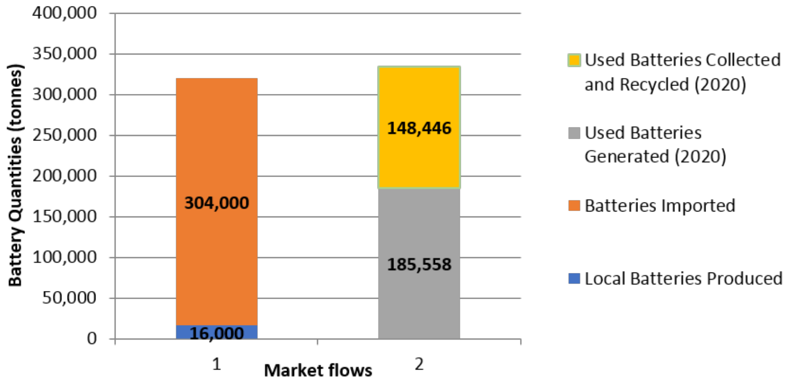

Figure 4.7: Battery Quantities showing Market Inflows (1) and Outflows (2) [30]

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]

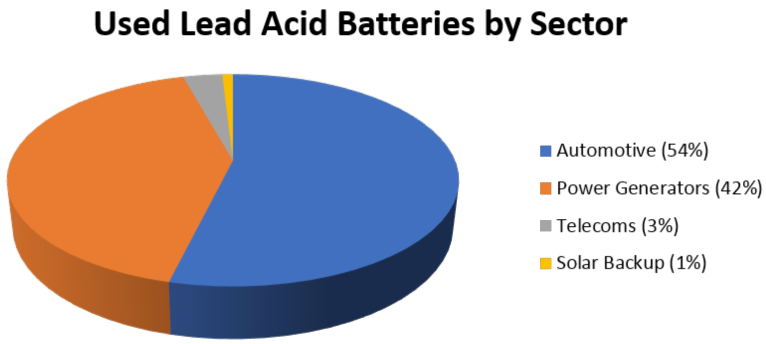

Figure 4.8: Sectoral Use for Lead Acid Batteries (Source: [31]

Recycling lead-acid batteries are cost-intensive and require 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.

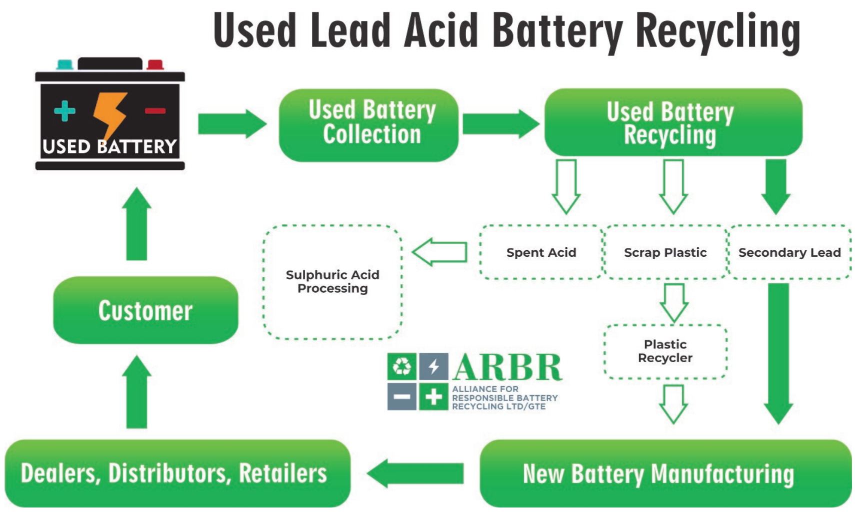

Figure 4.9: The Battery Recycling Process [**aarbr**]

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.

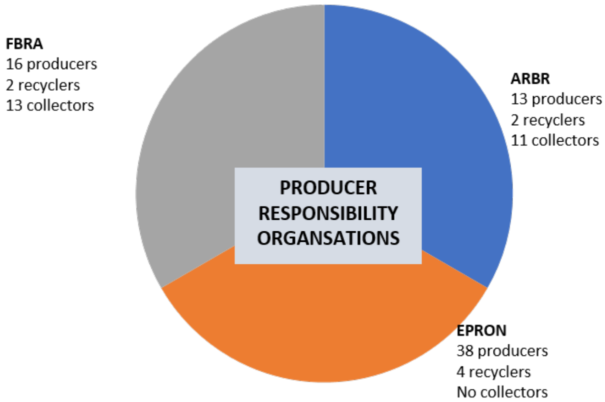

Figure 4.10: Stakeholders of Producer Responsibility Organization (PROs) of the Nigeria EPR Program.

Eighty per cent (80%) of lead-acid batteries are recycled through the informal sector carries out about 70%. 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 for recycling 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 that have an impact on the waste management sector and its corresponding GHG emissions, which were identified in Chapter 3 - Sections 3.2.1 and 3.2.2 of this report were assessed and tabulated in Appendix A.1 & A.2 highlighting their circular economy features. Figure 4.11 outlines Regulations influencing waste and of those regulations, key waste regulations influencing GHG Emission Reduction.

Figure 4.12 clearly outlines Environmental Policies in Nigeria influencing GHG Emission Reduction.

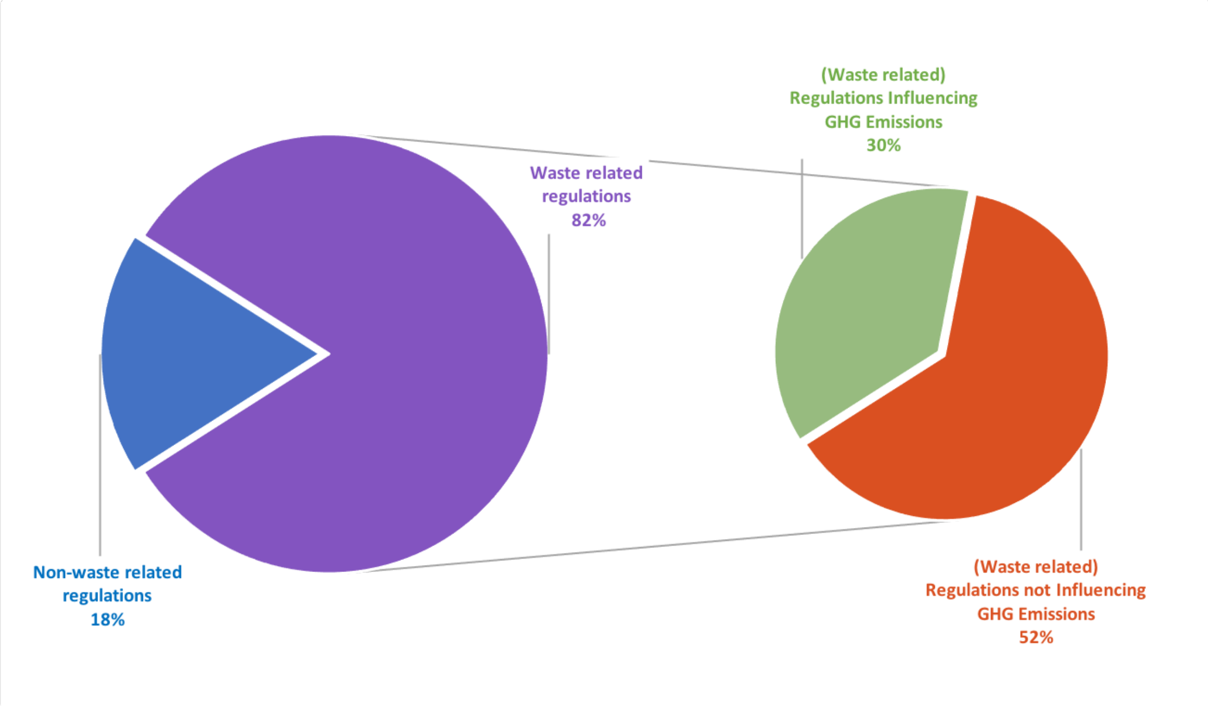

Figure 4.11: Nigerian Environmental Regulations.

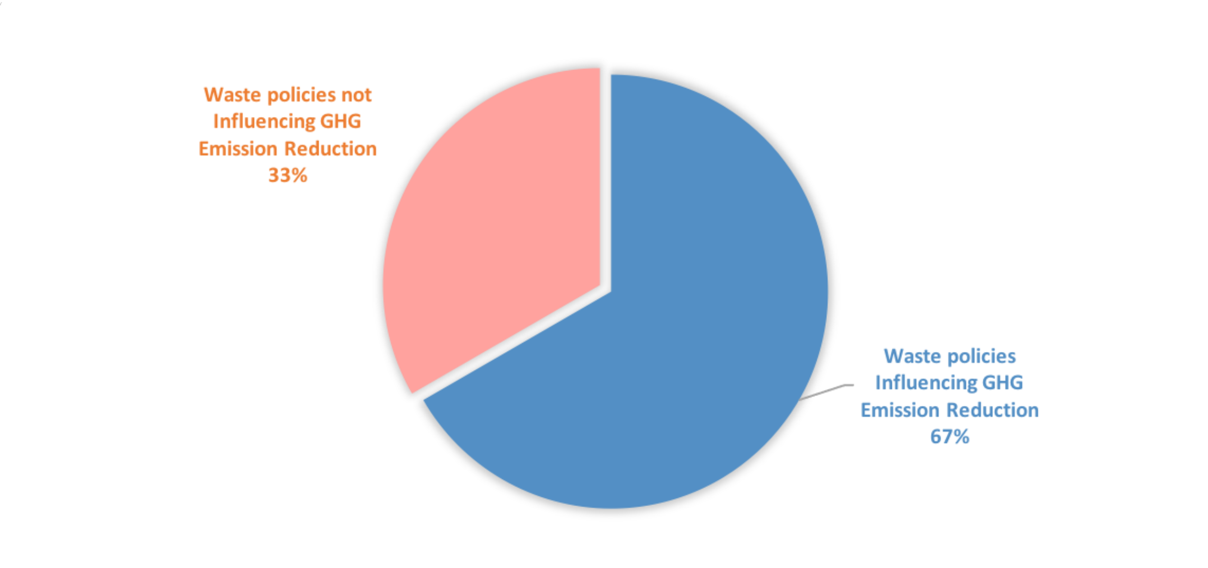

Figure 4.12: Nigerian Environmental Policies.

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, the absence of basic amenities, and a lack of proper communication have 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 has 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 a 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 the 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 that 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 in 2014. Stakeholders of these projects are governments, donor agencies, and the private sector. It can be noted that fewer stakeholders were involved in initiatives that 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 that 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 that has already been indiscriminately disposed of.

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 sachets. 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 centres 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 a 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 a 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 the 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 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 sachets 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 the 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 that 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 parameters 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 the 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 CH_4 generated from decomposable material.
- $DDOC_m\ decomp_T$ = DDOCm decomposed in year T, Gg.
- F = fraction of CH_4, by volume, in generated landfill gas (fraction).
- 16/12 = molecular weight ratio CH_4/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; Unmanaged - shallow (<5m waste) was used in estimating our FOD model as 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].

Parameter for the amount of waste deposited to SWDS The amount of waste deposited to SWDS will take into consideration the per cent of waste deposited by urban and rural populations. Our model now takes into consideration the differences in the amount of waste deposited to solid waste disposal sites (SWDS) from urban and rural populations in Nigeria. From the TNC [45] we have that on average, the percentage of deposited waste to SWDS is 30% for the rural fraction of the population and 55% for urban. For our model, we used the mid-point of 42.5% as an anchor to model a randomized value that is monotonically increasing between decades. The idea of using the mid-point was also adopted by the TNC.

Waste per capita To obtain the urban and rural waste per capita for Nigeria, we used the following estimations:

- The World Bank (2018) [46] approximates that waste generation rate of Sub-Saharan Africa to be 0.46 kg/person/day. This can be assumed to be the average of the urban and rural waste generation rates.
- The World Bank (2018) also approximates that Nigeria has an urban waste generation rate of 0.74kg/person/day. Therefore, the rural waste generation rate can be obtained as follows:

$$\begin{aligned}
\text{Average waste gen. rate} &= \frac{\text{Urban waste gen. rate} + \text{Rural waste gen. rate}}{2} \\
0.46 &= \frac{0.74 + \text{Rural waste gen. rate}}{2} \\
\text{Rural waste generation rate} &= (2 * 0.46) - 0.74 \\
&= 0.92 - 0.74 \\
&= 0.18 kg/person/day
\end{aligned}$$

  This implies that the ratio of urban waste per capita to rural waste per capita:

$$\begin{aligned}
&= 0.74/0.18 \\
&= 4.11/1 \text{ or } 4:1
\end{aligned}$$

  This analysis is consistent with Nnaji (2015) [47] who exhibited that MSW per capita in Nigeria ranged from 0.13 to 0.71kg/person/day.

- Using the derived ratio of 4:1 for we were able to use a similar methodology as described above to derive the rural waste generation rate for Nigeria as 0.145kg/person-/day given that the urban waste generation rate is 0.58kg/person/day as provided by the Federal Ministry of Environment.

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/materials. 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 provide the breakdown 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 1960, 875 Gg of MSW was estimated to be deposited in SWDS. Whereas in 2020, 10,979 Gg of MSW was estimated to be deposited. We observed that there was a 1154.74% 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 a 40.69% 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, 12,735 Gg and 16,984 Gg of MSW will be deposited at SWDS, respectively. The time period between 2021 to 2030 shows a projected percentage increase of 33.36% of waste deposited in SWDS in Nigeria.

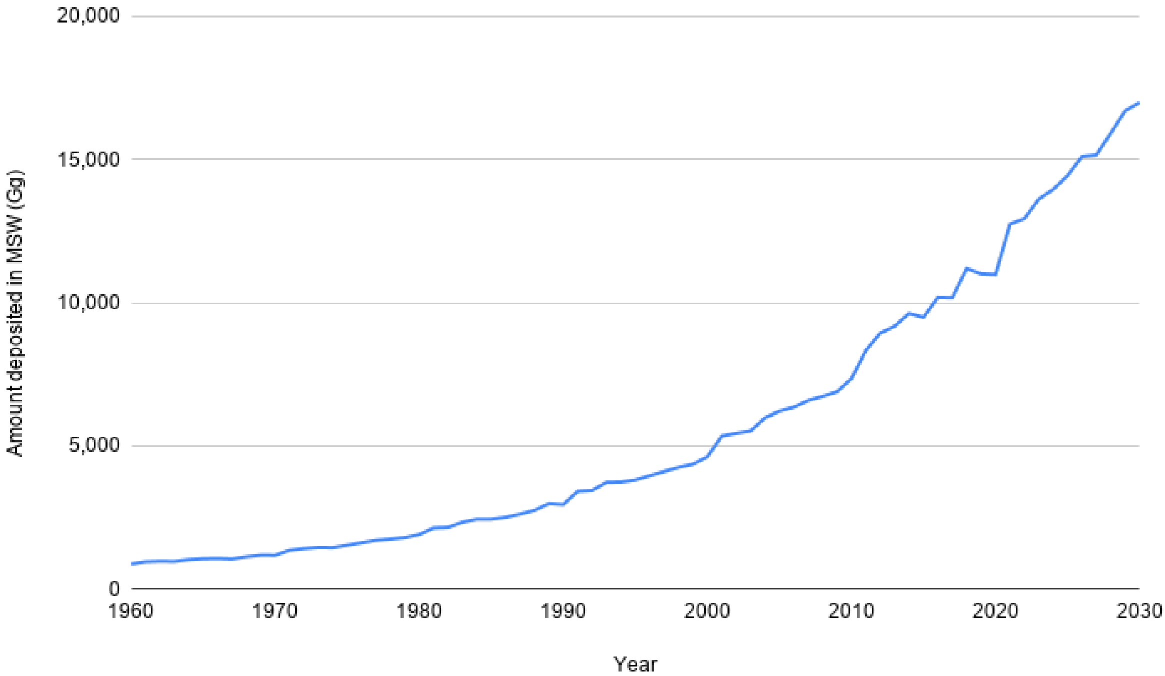

Figure 5.1: Amount of MSW deposited in SWDS.

Time Intervals (years)	**Percentage change** (%)
1960 - 1970	34.6%
1971 - 1980	40.69%
1981 - 1990	38.27%
1991 - 2000	35.18%
2001 - 2010	37.52%
2011 - 2020	31.88%

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.

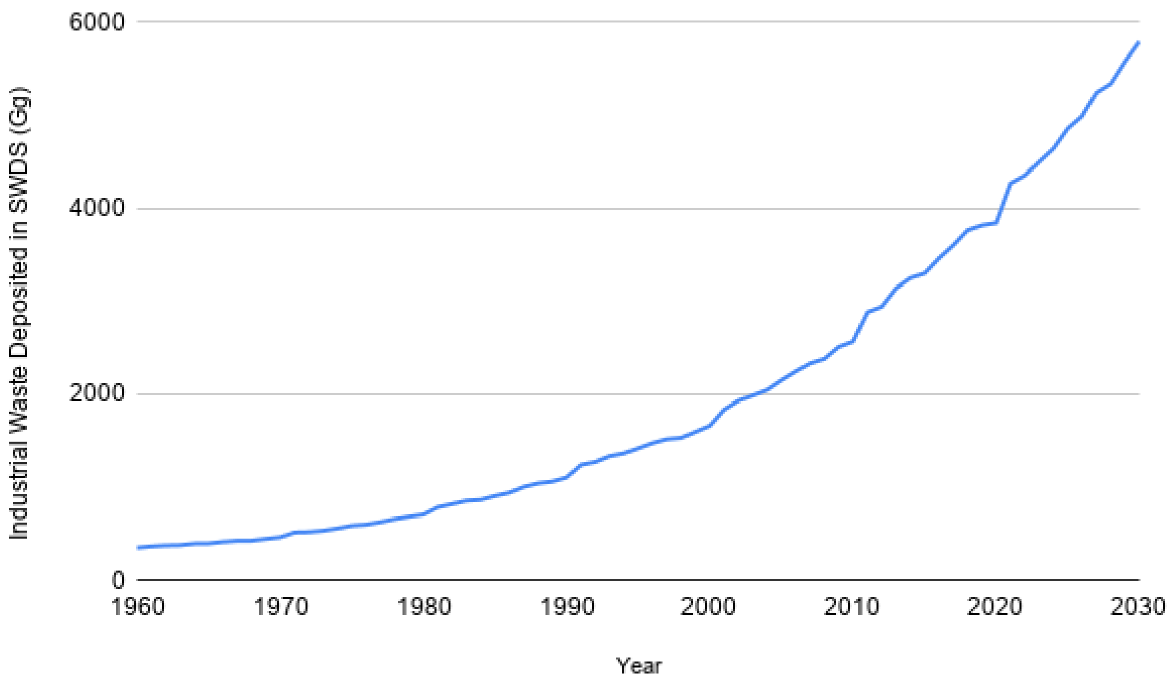

Figure 5.2: Amount of Industrial waste deposited in SWDS.

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 981.69% 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 36.92% increase in the amount of waste deposited at SWDS. Table 5.4 shows that the interval between 1981 and 1990 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 the year 2021 to 2030. We estimate that in the years 2021 and 2030, 4,264 Gg and 5,787 Gg of industrial waste will be deposited at SWDS, respectively. The time period between 2021 to 2030 shows a projected percentage increase of 35.72% of waste deposited in SWDS in Nigeria.

Time Intervals (years)	**Percentage change (%)**
1960 - 1970	31.5%
1971 - 1980	36.92%
1981 - 1990	40.25%
1991 - 2000	33.65%
2001 - 2010	39.74%
2011 - 2020	33.15%

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 168 Gg CO_2-eq. From Figure 5.3, our results show that in 2020, 11,046 Gg CO_2-eq 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 6475.00% 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 525.00% per 10-year window from 1961 to 2020. This is because organic solid waste decays over time. In the year the waste is first deposited, it will not emit methane till decades after. We see a huge percentage from 1962-1970 because factored into it are the methane emissions from previous decades before the 60-year time interval chosen. 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.

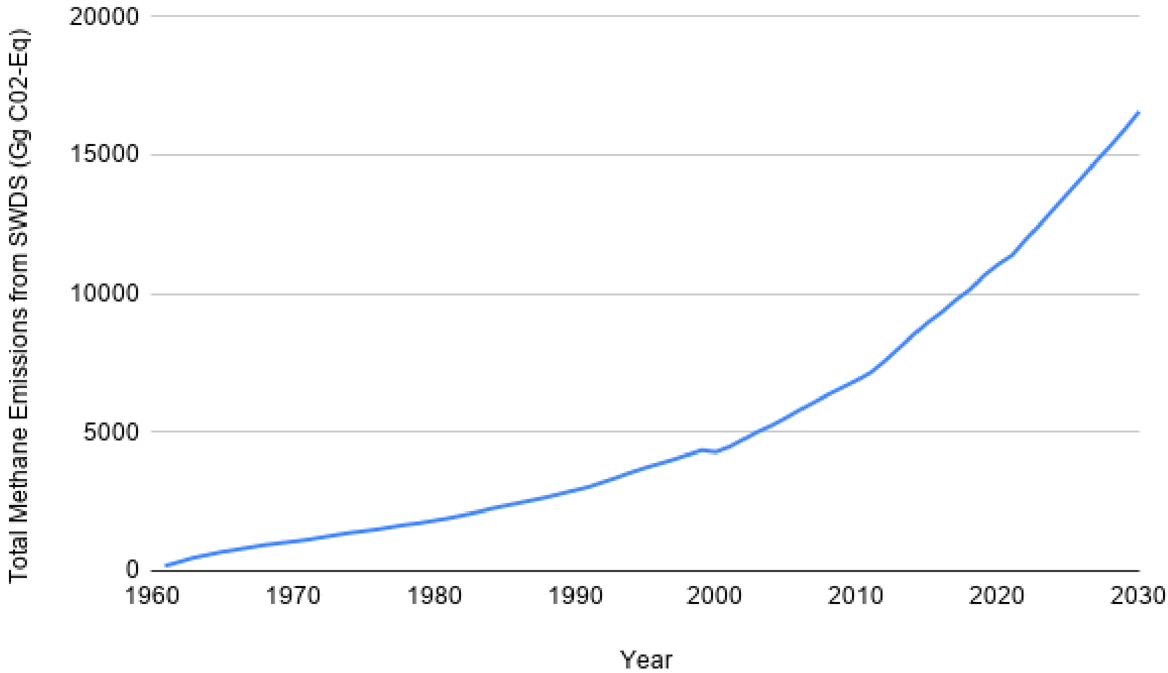

Figure 5.3: Annual methane emissions from SWDS from 1961 to 2030.

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 11,382 Gg CO_2-eq of methane will be emitted and in 2030, 16,569 Gg CO_2-eq of methane is estimated to be emitted SWDS. The time period between 2021 to 2030 shows a projected percentage increase of 45.57% of methane emitted in SWDS in Nigeria.

Time Intervals (years)	Percentage change (%)
1961 - 1970	525.00%
1971 - 1980	62.26%
1981 - 1990	53.33%
1991 - 2000	41.67%
2001 - 2010	53.52%
2011 - 2020	54.25%

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 1962-2020. 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 7260% within the 60-year interval. Results show that there is a percentage increase of 63.89% in methane emissions from Garden from 1971 to 1980 (see Table 5.6).

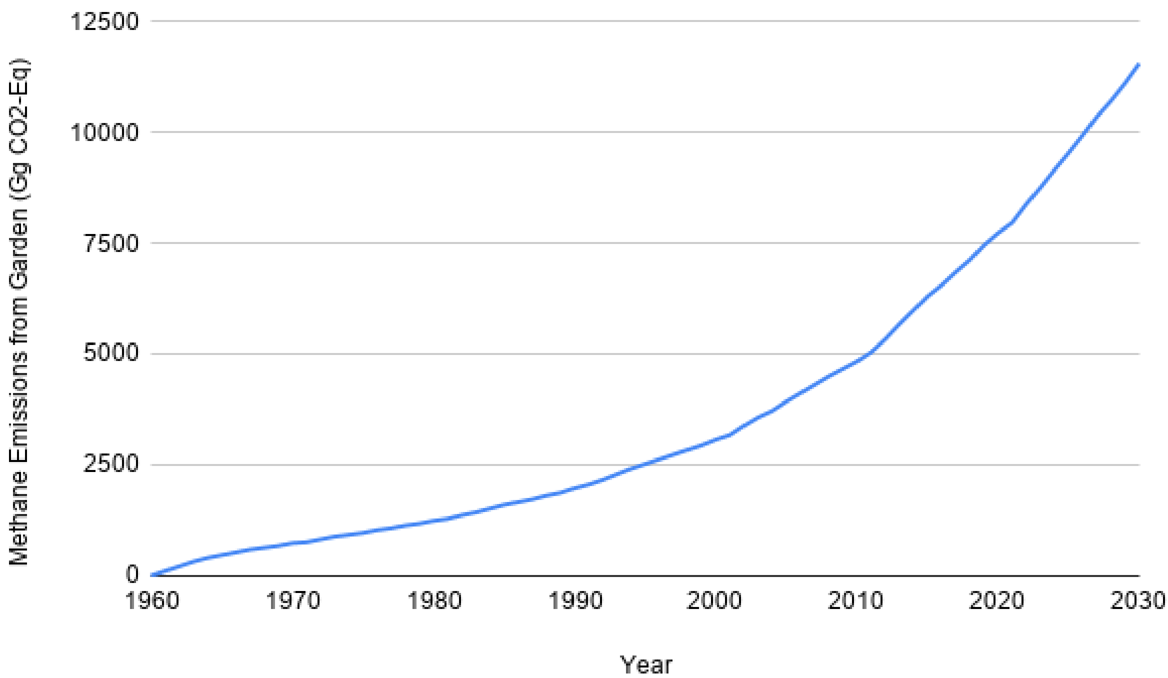

Figure 5.4: Methane Emissions from Garden (Gg CO_2-eq) from 1961 to 2030.

Results also show that Paper had an increase of 2400% in the methane emissions from 1961- 2020, a 60-year interval. We see from Table 5.6, from 1971 to 1980, there was a percentage increase of methane emissions by 100.00%. The results in Table 5.6 shows the percentage increase for Paper for the 60-year interval.

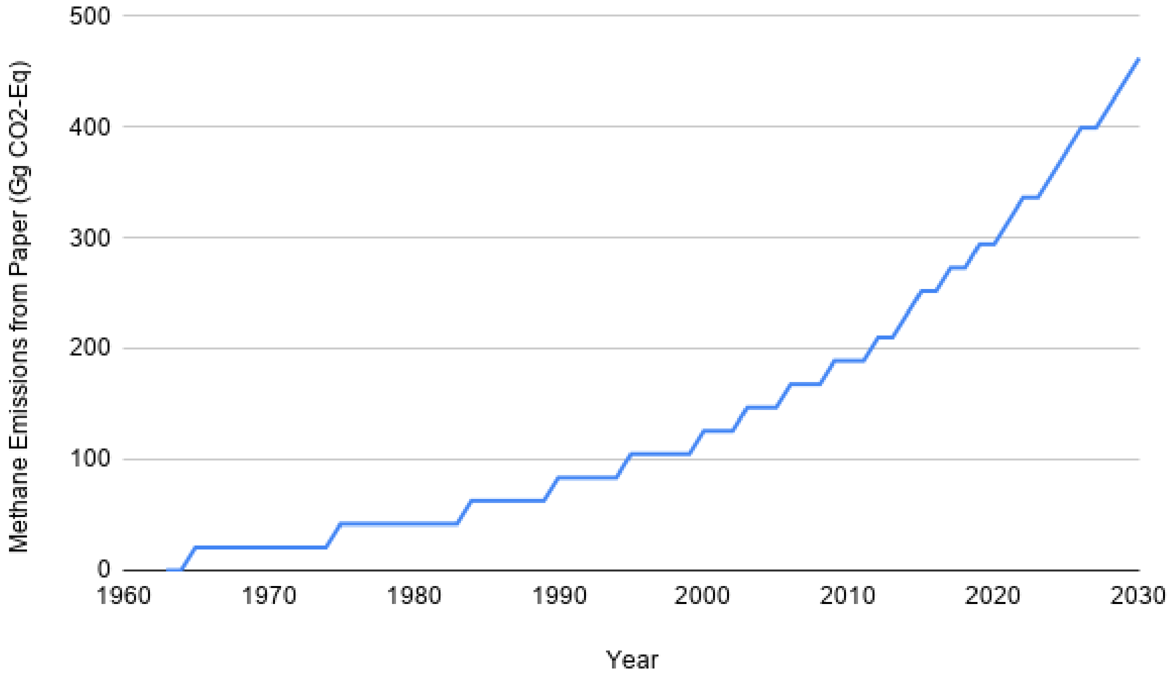

Figure 5.5: Methane Emissions from Paper (Gg CO_2-eq) from 1961 to 2030.

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.

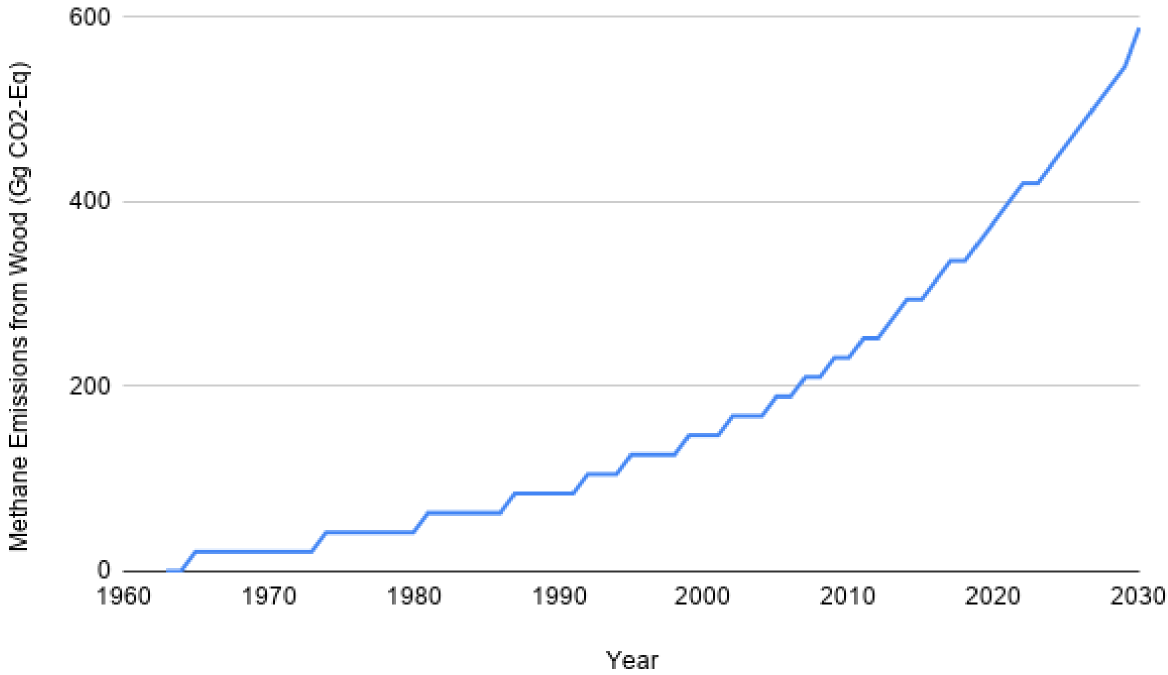

Figure 5.6: Methane Emissions from Wood (Gg CO_2-eq) from 1961 to 2030.

Further, we observed from Table 5.6 that from 1971 to 1980, in Garden, paper and wood, there was a percentage increase of 63.89%, 100% and 100% respectively.

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 45.12% for Garden, 46.67% for Paper and 47.37% for Wood.

Time Intervals (years)	**Percentage change (%)**		
	Garden	**Paper**	**Wood**
1961 - 1970	250.0%	-	-
1971 - 1980	63.89%	100.00%	100%
1981 - 1990	54.10%	100.00%	33.33%
1991 - 2000	48.98%	50.00%	75.00%
2001 - 2010	52.32%	50.00%	57.14%
2011 - 2020	53.33%	55.56%	50.00%

Table 5.6: Percentage change per 10 years for Methane Emissions from Harvested Wood Products (HWP) from 1962 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 of 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 (CH_4) and nitrous oxide (N_2O) 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 CH_4 and N_2O from the 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 the 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 [48]).

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 [49].

5.3 Open Burning of Waste

The challenge of efficient waste management in 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 [50].

The most common form of getting rid of waste in Nigeria is open burning of refuse in residential areas and at illegal dumpsites [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 practised in Nigeria [51].

Like other types of combustion, open burning is a major source of greenhouse gas emissions. The CO_2 emissions from the 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 [52] for calculating the 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. The amount of waste burned can be determined by obtaining 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 basis. 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 [52].

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 the 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 [52]. 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.

Estimating openly burned waste includes the fraction of the population burning waste, and this value is distinct and different from the percentage of waste that is deposited in disposal sites. Hence, there is no issue of double-counting from both estimates (i.e. from SWDS and open-burning). In addition, our model integrates the differences in the percentage of waste open-burned from urban and rural populations in Nigeria.

5.3.3 Results

In this section, we will discuss the results of estimating N_2O and CO_2 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

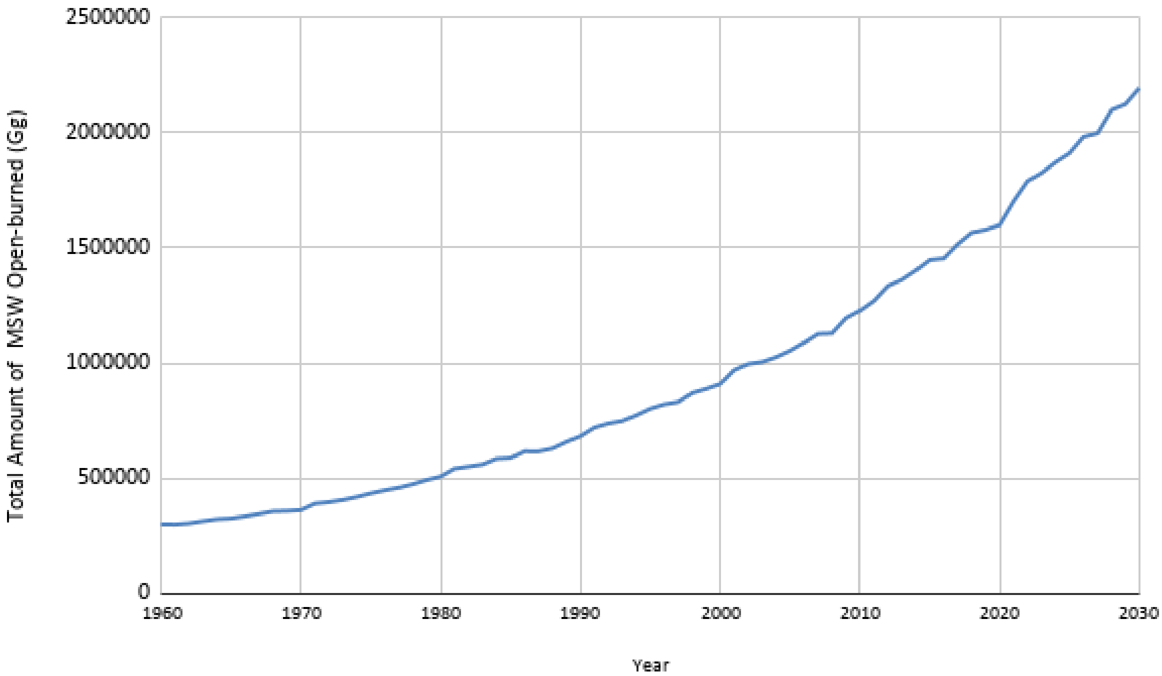

Figure 5.7: Total Amount of MSW Open Burned 1960 to 2030.

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 28.87%.

Nitrous Oxide (N_2O Emissions from MSW Open burned

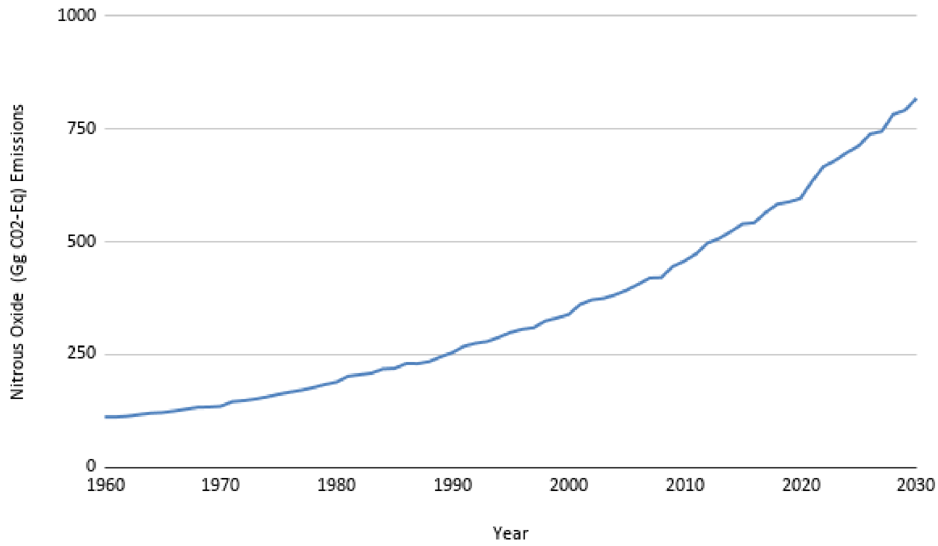

Figure 5.8: Total Nitrous Oxide (N_2O) for Open Burning from 1960 to 2030.

In Figure 5.8 above, our results show the net N_2O emissions for open-burned waste was 112.34 Gg CO_2-eq in 1960. Whereas in 2020 the net N_2O emission was 595.64 Gg CO_2-eq. 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 633.85 Gg CO_2-eq and in 2030, it is projected that the net N_2O emissions for open-burned waste will be 816.79 Gg CO_2-eq.

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 28.87%.

Carbon Dioxide (CO_2) Emissions from MSW Open burned

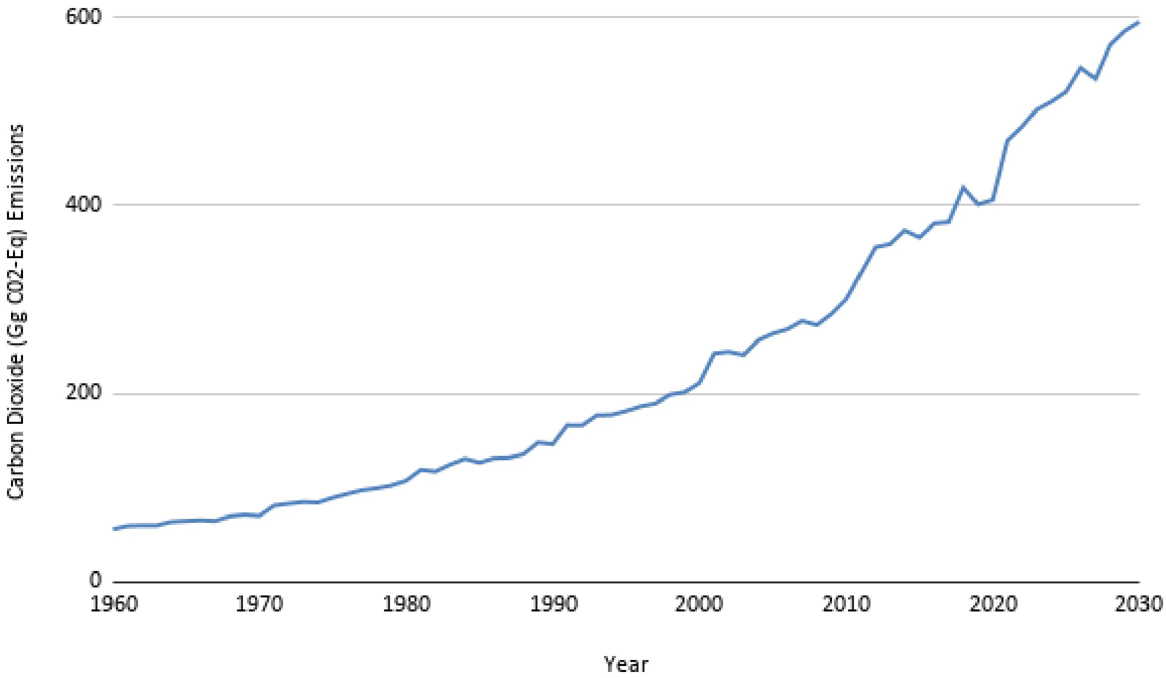

Figure 5.9: Carbon Dioxide (CO_2) Emissions for Open Burning from 1960 to 2030.

In Figure 5.9 above, our results show the net CO_2 emissions for open-burned waste in 1960 was 56.37 Gg. Whereas in 2020, the net CO_2 emission was 406.11 Gg. This shows that within the 60-year interval (1960 to 2020), there was a 620.48% 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 468.82 Gg, and in 2030, it is projected that the net CO_2 emissions for open-burned waste will be 594.97 Gg.

Time Intervals (years)	**Percentage change** (%)
1960 - 1970	25.1%
1971 - 1980	32.62%
1981 - 1990	22.59%
1991 - 2000	26.81%
2001 - 2010	23.75%
2011 - 2020	23.89%

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. 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 26.91%.

Total Emissions (Gg CO_2-eq) from MSW Open burned

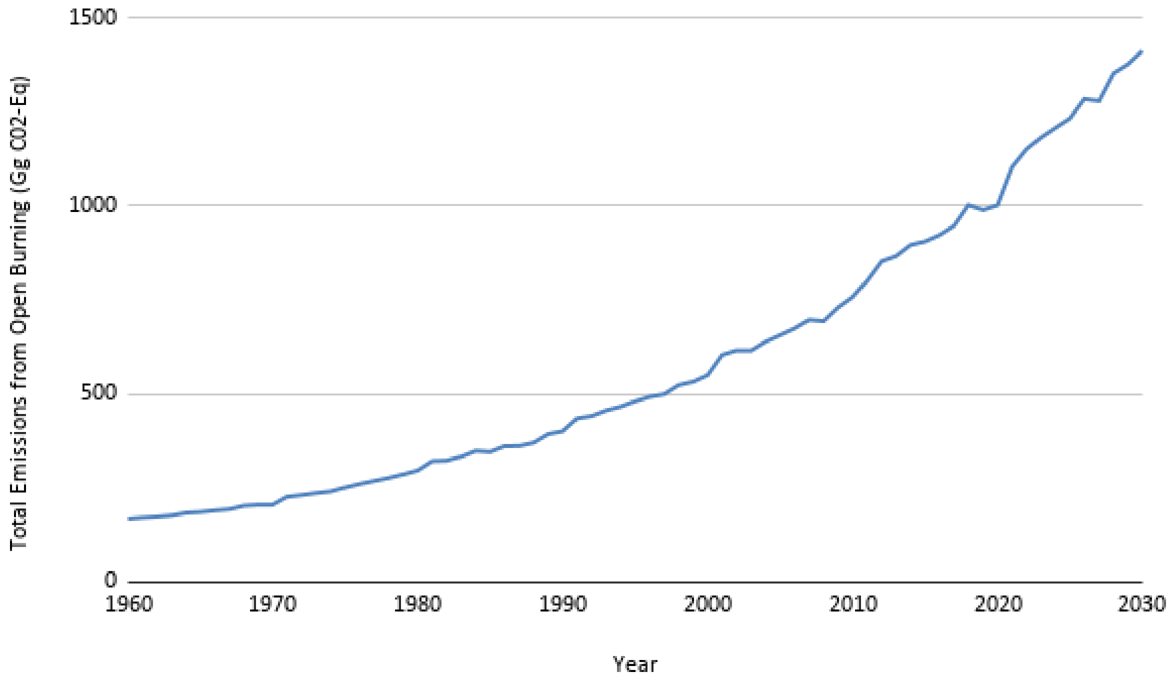

Figure 5.10: Total (Gg CO_2-eq) Emissions for Open Burning from 1960 to 2030.

In this section, our results reflect the total emissions from N_2O and CO_2 for open burning from 1960 - 2020.

In Figure 5.10 above, our results show the total emissions (Gg CO_2-eq) for open-burned waste in 1960 was 168.71 Gg CO_2-eq. Whereas in 2020 the net CO_2 emission was 1001.74 Gg CO_2-eq. In 2021, it is projected that total emissions (Gg CO_2-eq) from opening burning will be 1102.68 Gg CO_2-eq and in 2030, it is projected that the net CO_2 emissions for open-burned waste will be 1411.76 Gg CO_2-eq.

Time Intervals (years)	**Percentage change** (%)
1960 - 1970	22.1%
1971 - 1980	30.83%
1981 - 1990	24.68%
1991 - 2000	26.38%
2001 - 2010	25.45%
2011 - 2020	25.07%

Table 5.10: Percentage change per 10 years for Total Emissions (Gg CO_2-eq) from Open burning from 1960 to 2020.

In Table 5.10, 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 493.78% increase for the 60-year time interval. Results also show that the projected amount of the total emissions (Gg CO_2-eq) for open-burned waste in Nigeria for 2021 - 2030 will see a percentage increase of 28.03%.

For the full results of GHG emissions from open burning, the reader is directed to Appendix C.1.

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 [53]. 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 [53] 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 [53]. Also, wastewater could be collected and treated, and it could also be uncollected - in open pits/latrines [53]. 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. [53].

Domestic wastewater is usually derived from residential sources - for example, waster from food preparation, cleaning, laundry, and waster from personal hygiene [54]. Also, based on the source, domestic wastewater can be considered as black water or greywater. Blackwater consists mainly of human excreta, including urine and faecal sludge, while greywater includes wastewater from the kitchen and bathing [54].

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 [53]. This is done by using the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) parameters to measure the organic content of the wastewater [53].

5.4.1 Domestic Wastewater

According to the IPCC guidelines [53], BOD is more regularly reported for domestic wastewater, and COD is primarily used for industrial wastewater. Therefore, the BOD parameters and values were 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, [53] 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 [53]. The default value (37) was multiplied by $0.001 * 365$ to get the (kg BOD/cap/yr) - 13.505 (see Table 5.11).

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 the majority of wastewater in Nigeria end up in Septic tanks, Latrines, and River discharge [55].

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 5.11: 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 [53] 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 [53] 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 CH_4/ kg BOD] (A)**	**Methane correction factor for each treatment system – MCFj (B)**	**Emission Factor [kg CH_4/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 CH_4/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 [53].

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 [55]). In Nigeria, wastewater treatment before discharge or re-use by these facilities is completely non-existent or inadequately done [55]. 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 [55].

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 to 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 5.11, our results show that in 1960, the net methane (CH_4) emission was 2659.65 Gg CO_2-eq. Whereas, in 2020, it is estimated that 13455.33 Gg CO_2-eq 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 5.12). The interval between 1971 and 1980 is the highest percentage of Methane emissions increase per 10-year window from 1960 to 2020. Table 5.12 shows the percentage change per 10 years from 1960 to 2020.

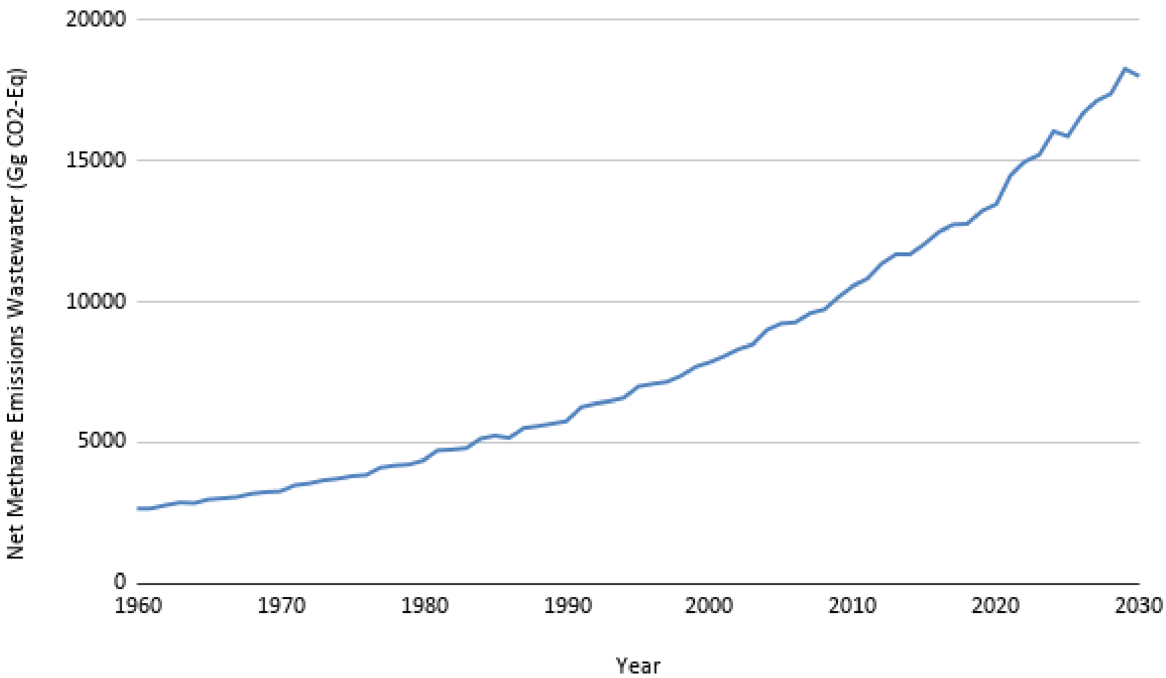

Figure 5.11: Annual methane emissions for wastewater from 1960 to 2030.

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 5.12: 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 14487.9 Gg CO_2-eq of methane will be emitted, and in 2030, an estimate of 17996.58 Gg CO_2-eq 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.

For the full results of GHG emissions from wastewater, the reader is directed to Appendix D.1.

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 the most commonly used electronic products. Many of these products are discarded, reused, refurbished, or recycled [56].

According to the UN [57], 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 rising, henceforth leading to rapidly growing e-waste volumes [58] in the country. This has resulted in the dumping of e-waste in open dumpsites across the country [59]. 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 with the open burning of e-waste [59].

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 [60], 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.

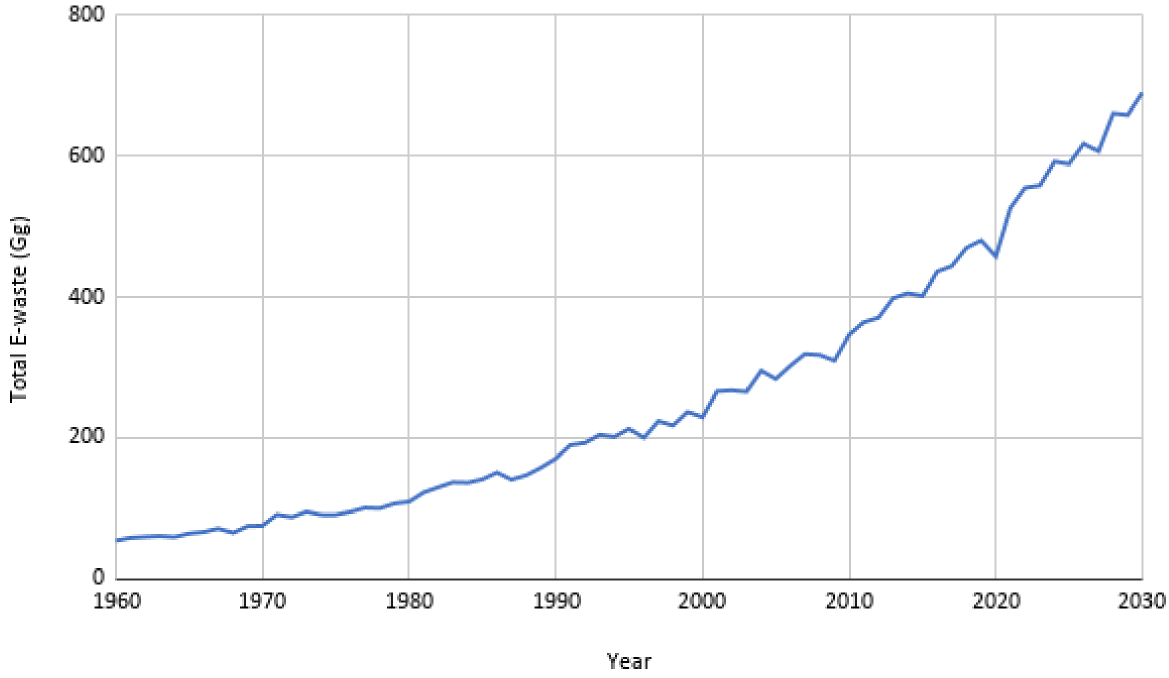

Figure 6.1: Total E-waste Deposited from 1961 to 2030.

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 of 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 [61]. Medical wastes are generated from hospitals and clinics, medical laboratories and doctor offices [61]. Medical waste management in Nigeria is a serious issue, and it poses potential risks and hazards to the environment [62].

The burning and burial of medical waste is a very common practice in hospitals in Nigeria [61]. Medical waste should be separate from municipal waste, but in Nigeria, medical wastes are still handled and deposited together with municipal waste [62].

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.

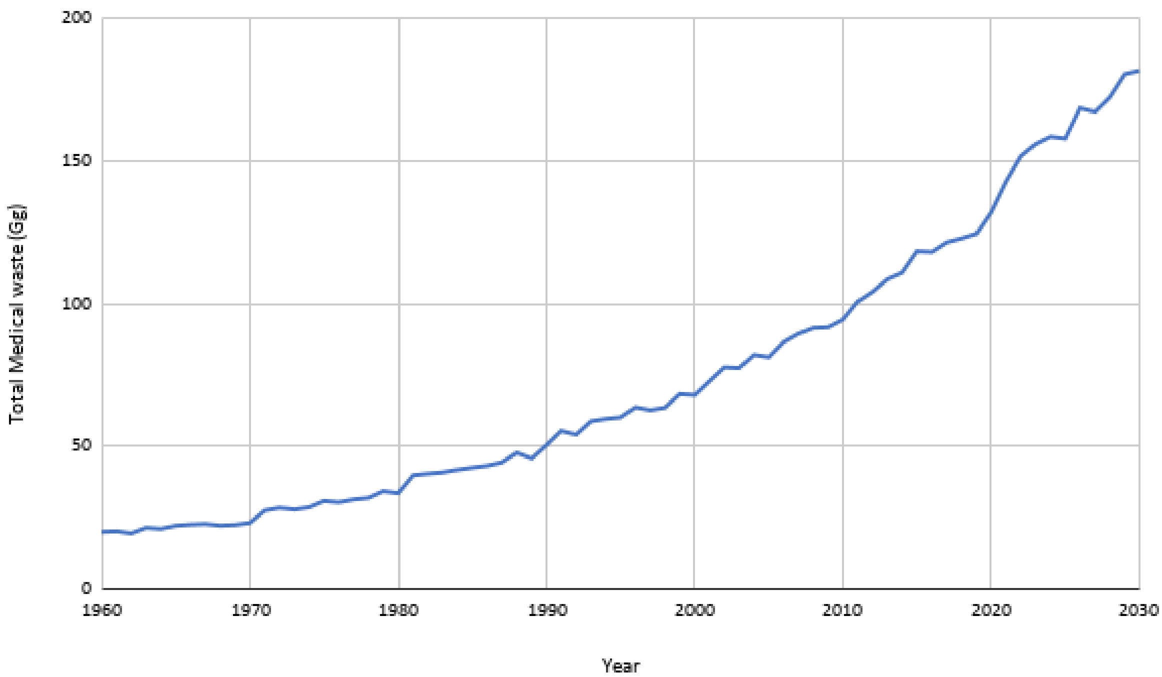

Figure 6.2: Total Medical Waste generated from 1961 to 2030.

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 [63]

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, motorbikes, and lorries [10].

In Nigeria, heavy metal contamination around the informal ULAB recycling centres is a serious public health problem [64]. When lead batteries reach their end of life, they pose a risk to the environment and the people if not disposed of properly or well-managed [9].

Incompetent production and recycling procedures of used lead-acid batteries (ULAB) can release tons of lead, and fumes are released into the environment [64]. 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 [63].

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 the 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 to 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.

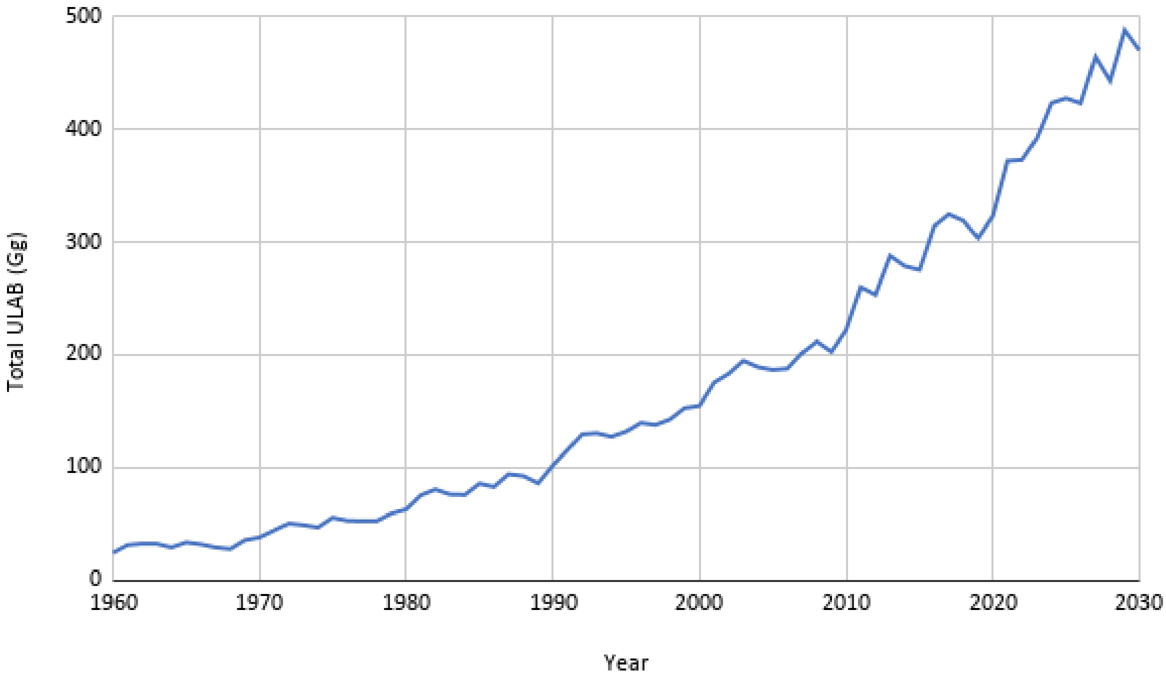

Figure 6.3: Total ULAB (Gg) generated from 1960-2030

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 environmental challenge [65]. Plastic waste management has become one of Nigeria's greatest challenges [65].

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 [65]. It is estimated that fifty per cent of the plastic products are single-use plastic products and therefore will be thrown away after use [65].

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 of in unsuitable and inaccessible areas [65]. The common practices in Nigeria comprise of plastic bottles and containers being thrown on the ground, thrown out of cars, thrown into gutters littering the environment and consequently causing polluting [65]. 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.

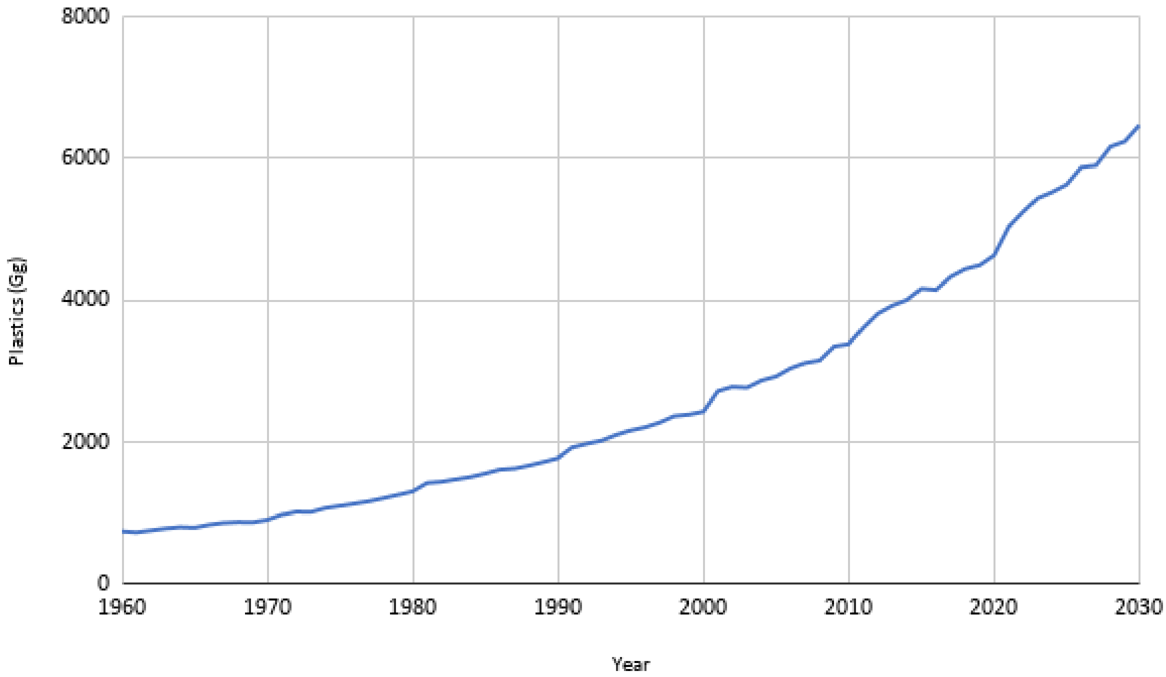

Figure 6.4: Total Amounts of Plastic waste (Gg) deposited from 1960-2030

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 the 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.

6.5 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 [66] 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, leukaemia 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 [67]. 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 4.11 and Table 4.12. The PCBs highlighted in Table 4.11 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 the potential to generate employment due to the reuse and recovery of valuable materials from electronics as the United Nations Environment Programme [68] 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 sometimes 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 [69]. 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 [70]. 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 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 [71] 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 are 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 sawmill 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 sawmill factories are situated by riverine areas and wood wastes are gathered close to the rivers [72]. 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.

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 decrease 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)**
2011	666	0.0181	0.1204009062
2012	714	0.0184	0.1311708917
2013	734	0.0183	0.1346441461
2014	770	0.0209	0.1607133759
2015	759	0.0195	0.1477182241
2016	815	0.0201	0.1641224069
2017	814	0.0213	0.1735338603
2018	895	0.0215	0.1928692283
2019	880	0.0228	0.2008846923
2020	878	0.0231	0.2024069466
2021	1,019	0.0239	0.2439818172
2022	1,034	0.0243	0.2508174844

Table 7.1: Organic Waste Reduction from 2011 to 2022.

To estimate organic waste reduction from 2023 to 2030, we projected that 7.47% of organic waste will be recycled. 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).

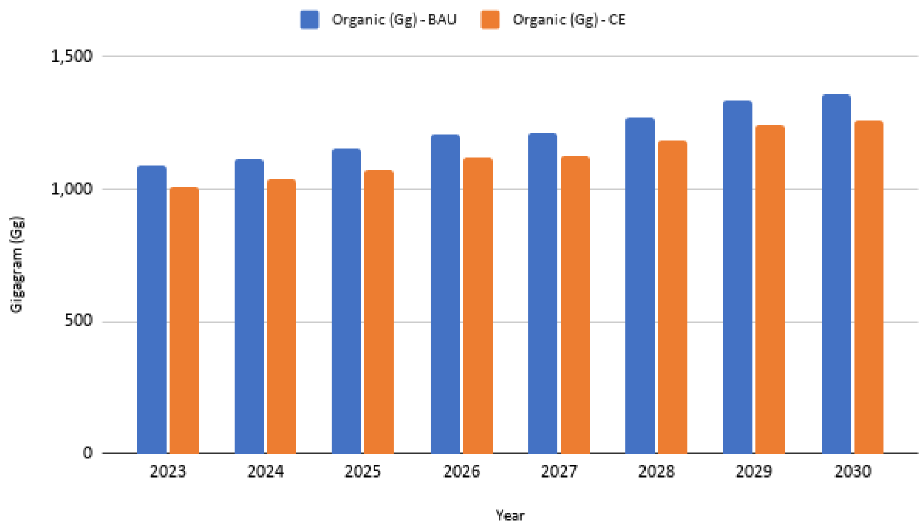

Figure 7.1: Organic waste reduction from 2023 to 2030.

Organic Waste Emission Reduction. Consequently, the amount of Emission from CH_4 (shown in Figure 7.2) shows an approximately 10% reduction across the time frames from 2023 to 2030 (see Table 7.2).

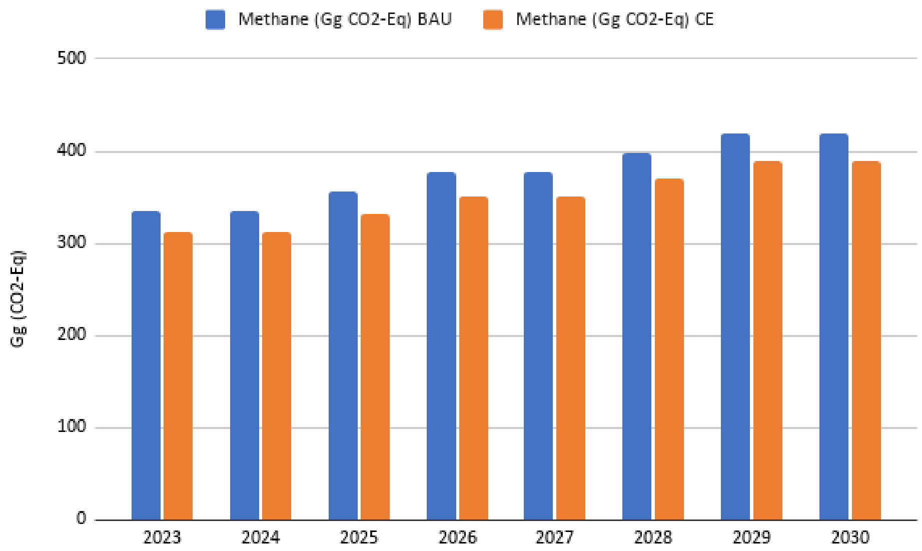

Figure 7.2: Organic waste emission reduction from 2023 to 2030.

Table 7.2 shows the Methane emission reduction from organic waste (Gg CO_2-eq) from 2023 to 2030.

Year	Methane (Gg CO_2-Eq) **BAU**	Methane (Gg CO_2-Eq) **CE**
2023	336	312.15
2024	336	312.15
2025	357	331.66
2026	378	351.17
2027	378	351.17
2028	399	370.68
2029	420	390.19
2030	420	390.19

Table 7.2: Emission reduction from organic waste (Gg CO_2-eq) from 2023 to 2030.

7.2 Plastics Waste and Emission Reduction

Plastics Waste 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. [16] 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 7.3. 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 7.3.

Year	**Plastics (15% of MSW) (Gg)**	**Recycled Plastic (Gg)**	**Reduction in Plastic Waste (Gg)**	**Percent Change (%)**	**Methane (Gg CO_2-eq)**	**New Methane Emission (Gg CO_2-eq)**
2020	1646.85	176.48	1470.37	-0.10716	11,046	9,862
2021	1910.25	202.82	1707.43	-0.10618	11,382	10,174
2022	1939.5	205.75	1733.75	-0.10608	11,970	10,700

Table 7.3: Reduction in plastic waste from 2020 to 2022.

Plastics Waste Emission Reduction. To estimate the reduction in plastics waste and the corresponding reduction in emissions from 2023 - 2030, we projected that up to 7.47% of plastics will be recycled. The results of waste reduction from plastics are shown in Figure 7.3.

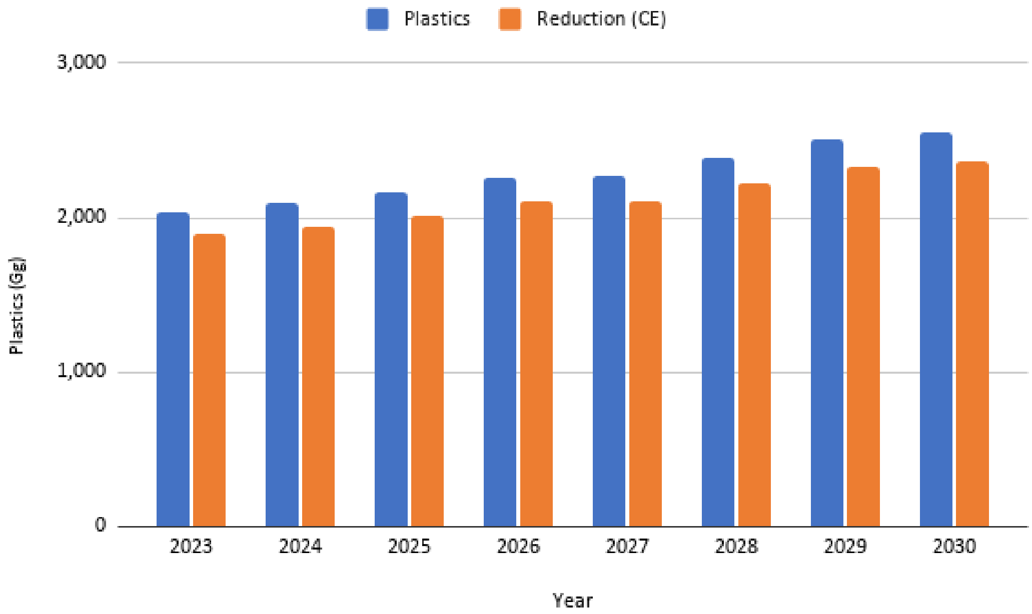

Figure 7.3: Plastic waste reduction from 2023 to 2030.

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

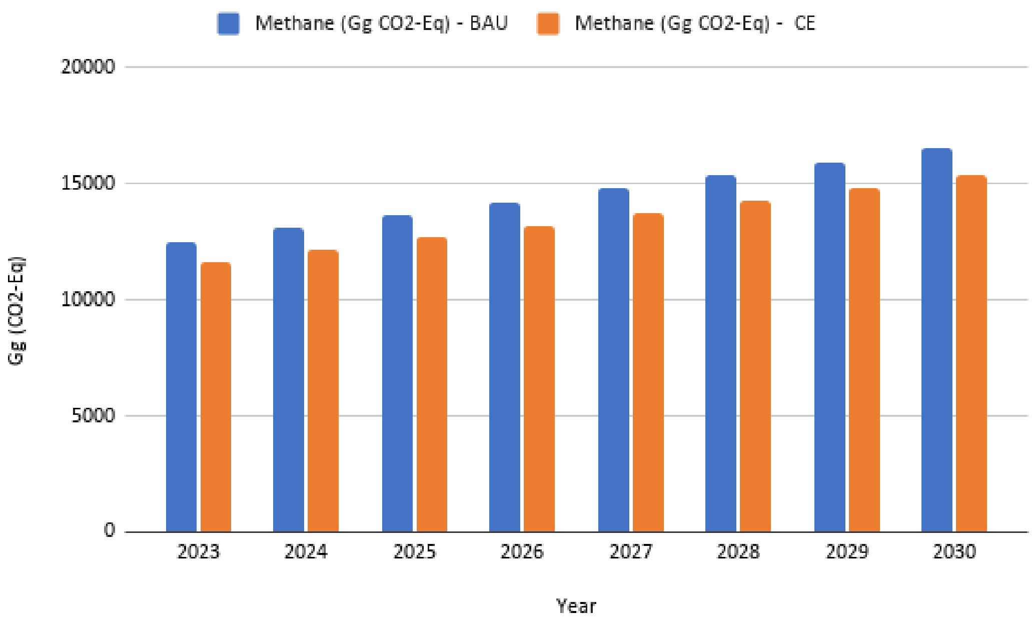

Figure 7.4: Plastic waste emission reduction from 2023 to 2030.

Table 7.4 shows the emission reduction from plastic waste (Gg CO_2-eq) from 2023 to 2030.

Year	Methane (Gg CO_2-Eq) **BAU**	Methane (Gg CO_2-Eq) **CE**
2023	12516	11627.76992
2024	13083	12154.53131
2025	13650	12681.2927
2026	14217	13208.05409
2027	14805	13754.32516
2028	15351	14261.57687
2029	15939	14807.84794
2030	16569	15393.13837

Table 7.4: Emission reduction from plastic waste (Gg CO_2-eq) from 2023 to 2030.

7.3 Medical Waste Reduction

Medical Waste Reduction. In estimating the reduction in medical waste from 2020 to 2022, the Federal Ministry of Environment [16] 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 7.5

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 7.5: Reduction in medical waste from 2016 to 2022.

Medical Waste Emission Reduction. To estimate medical waste reduction from 2023 - 2030, we projected that 7.47% 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.

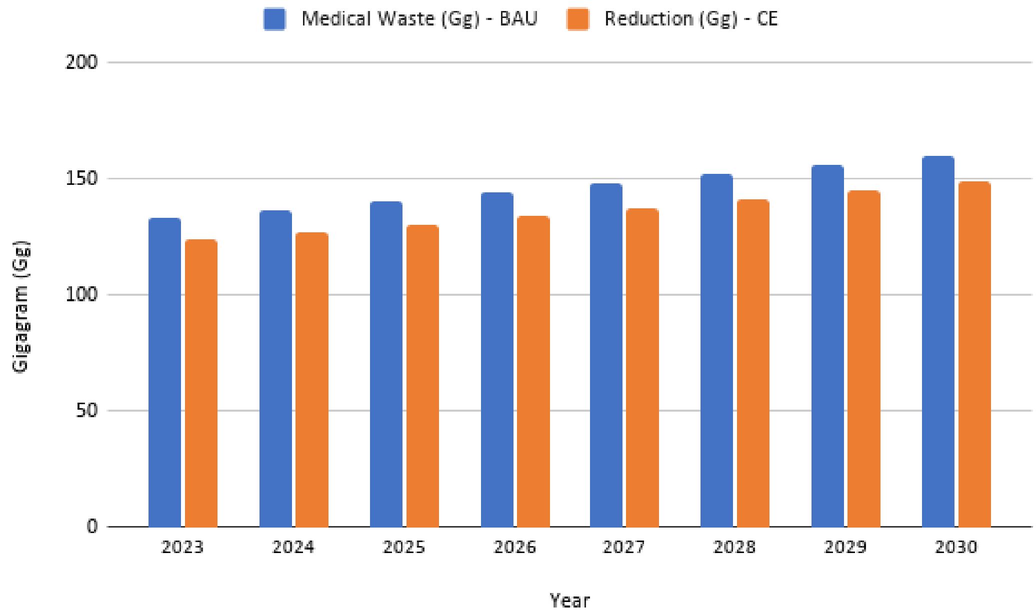

Figure 7.5: Medical waste reduction from 2023 to 2030.

Figure 7.6 compares the emissions from Medical waste under BAU scenario against emission under projected Medical waste recycling regimes.

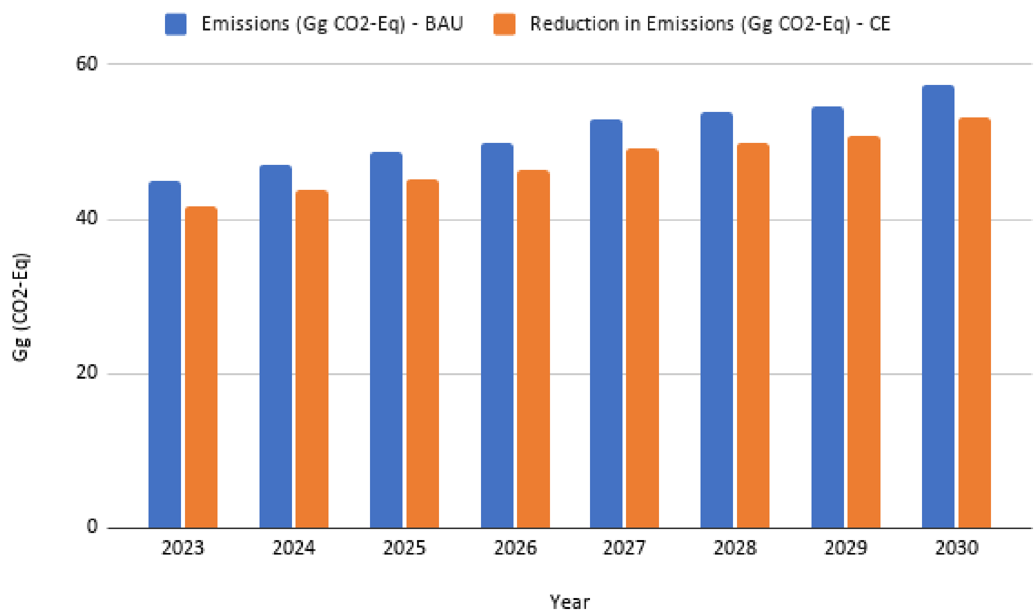

Figure 7.6: Medical waste emission reduction from 2023 to 2030.

Table 7.6 shows the emission reduction from medical waste (Gg CO_2-eq) from 2023 to 2030.

Year	Total Emissions Medical (Gg CO_2-Eq) **BAU**	Reduction in Emissions (Gg CO_2-Eq) **CE**
2023	44.94143694	41.75205248
2024	47.03737336	43.69924538
2025	48.73543927	45.27680369
2026	49.80353933	46.26910329
2027	53.05024533	49.28539846
2028	53.75898054	49.94383646
2029	54.65232595	50.77378332
2030	57.32696161	53.25860659

Table 7.6: Emission reduction from medical waste (Gg CO_2-eq) from 2023 to 2030.

7.4 E-Waste Reduction

E-Waste Reduction. The United Nations Environment Programme [68] 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 7.7.

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 7.7: Reduction in E-waste from 2014 to 2030.

E-Waste Emission Reduction. Figure 7.7 compares the emissions from e-waste under BAU scenario against emission under projected E-waste recycling regimes. E-waste is informally recycled by open burning to retrieve the valuable materials from the electronics. We assume that 20% of e-waste is open burned.

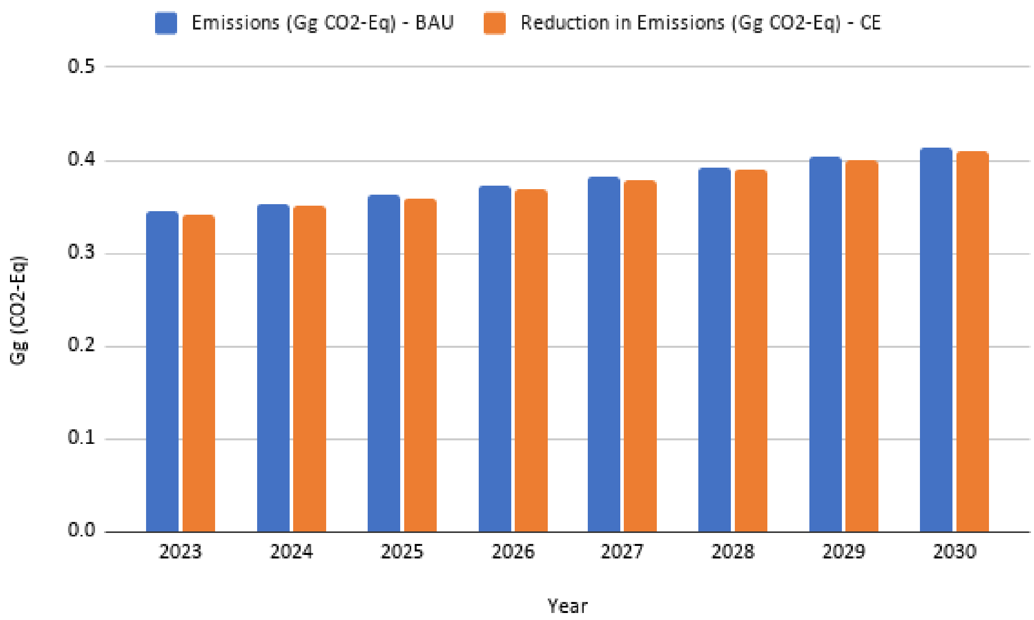

Figure 7.7: E-waste emission reduction from 2023 to 2030.

Table 7.8 shows the emission reduction from e-waste (Gg CO_2-eq) from 2023 to 2030.

Year	E-Waste Emission from Open Burning (Gg CO_2-Eq) **BAU**	Reduction in Emissions (Gg CO_2-Eq) **CE**
2014	0.272303477	0.2696349029
2015	0.2796088099	0.2768686435
2016	0.2870532831	0.284240161
2017	0.294636753	0.2917493129
2018	0.3023564727	0.2993933792
2019	0.310211983	0.3071719055
2020	0.318200653	0.3150822866
2021	0.3267869483	0.3235844362
2022	0.3355847069	0.3322959767
2023	0.3446004774	0.3412233927
2024	0.3538362441	0.3503686489
2025	0.3633004339	0.3597400897
2026	0.3730031809	0.3693477498
2027	0.3829543358	0.3792013833
2028	0.3931693888	0.3893163288
2029	0.4036604227	0.3997045506
2030	0.4144472616	0.4103856784

Table 7.8: Emission reduction from e-waste (Gg CO_2-eq) from 2023 to 2030.

7.5 Battery Waste Reduction

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 7.9.

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 7.9: Reduction in ULAB waste from 2016 to 2030.

Battery Waste Emission Reduction. Figure 7.8 compares the projected emissions from ULAB under BAU scenario against emission under projected ULAB recycling regimes from 2023 - 2030. For batteries, 80% is recycled and will not change too much as the battery association are focused on converting dirty /informal battery recyclers to clean/ formal ones. So while 80% is recycled, the remaining 20% goes to landfill sites or is kept indoors. A small percentage of used batteries goes to landfill sites due to their high resale value. This information has been confirmed by the questionnaires we prepared for the Battery PRO.

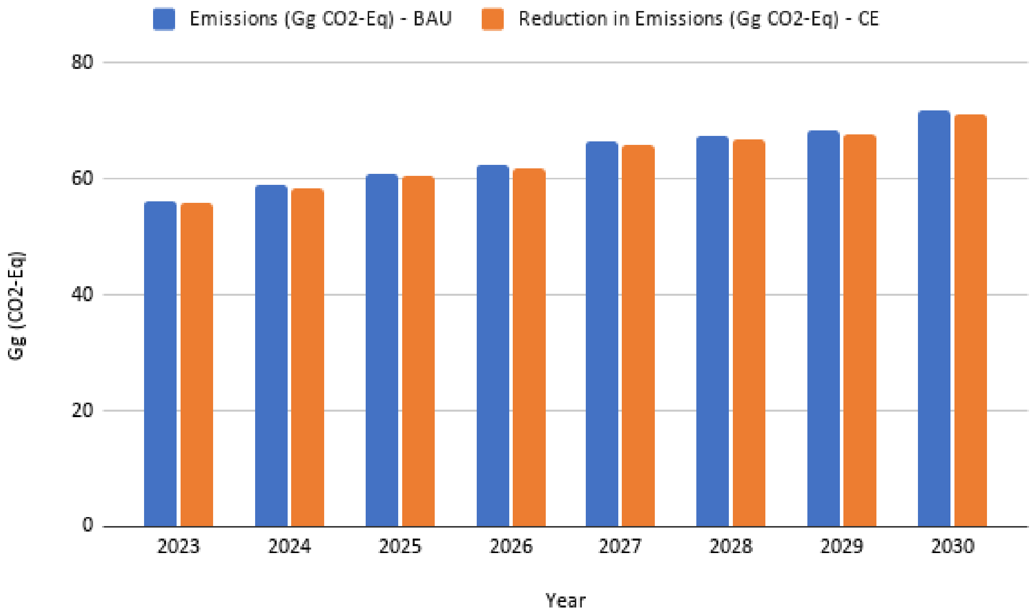

Figure 7.8: ULAB emission reduction from 2023 to 2030.

Table 7.10 shows the emission reduction from battery waste (Gg CO_2-eq) from 2023 to 2030.

Year	ULAB Emission from landfills (Gg CO_2-Eq) **BAU**	Reduction in Emissions (Gg CO_2-Eq) **CE**
2023	56.2658674	55.81574046
2024	58.89400692	58.42285487
2025	61.02171272	60.53353901
2026	62.35817875	61.85931332
2027	66.43217115	65.90071378
2028	67.31649963	66.77796764
2029	68.43285184	67.88538902
2030	71.78706068	71.21276419

Table 7.10: Emission reduction from battery waste (Gg CO_2-eq) from 2023 to 2030.

Chapter 8

Results & Recommendations for NDC Revision

8.1 List of Results

From the model and projections made, the following estimates were made:

1. **Waste Emission Modelling (Business-as-usual scenario)**
   - **Amount of Waste Deposited in SWDS**
     - Solid Waste Disposal Sites (SWDS)
       * 875 Gg of MSW was deposited in 1961, while 10,979 Gg of MSW was to be deposited in 2020. This represented a 1154.74% increase in the amount of MSW deposited in SWDS within a 60-year interval.
       * 12,735 Gg of MSW is projected to be deposited in 2021, while 16,984 Gg of MSW is projected to be deposited in 2030 at SWDS. This represents a percentage increase of 33.36% of waste deposited in SWDS in Nigeria within this time period.
     - Industrial Waste
       * An increase of 981.69% in the amount of industrial waste was deposited in SWDS within a 60-year interval from 1960 to 2020.
       * 4,264 Gg of industrial waste is projected to be deposited at SWDS in 2021, while 5,787 Gg will be deposited in 2030. This represents a 35.72% increase in Nigeria within this time period.
   - **Annual Methane Emission from SWDS**
     - 168 Gg CO2- eq of methane was emitted from SWDS in 1961, while 11,046 Gg CO2-eq of methane was emitted in 2020 representing a 6475% increase within the 60-year interval.
     - A projection of 11,382 Gg CO2-eq of methane will be emitted from SWDS in 2021 while 16,569 Gg CO2-eq of methane is projected to be emitted in 2030 representing a 45.57% increase.

- **Methane emission from harvested wood products (HWP)**
  - The estimated methane emissions for Garden had a percentage increase of 7260% between 1961 and 2020.
  - Projected results show a percentage increase in methane emissions of 45.12% for Garden, 46.67% for Paper and 47.37% for Wood between 2021 and 2030.
- **Open Burning**
  - Total Amount Of Municipal Solid Waste Open-Burned.
    * In 1960, estimated total amount of municipal solid waste open-burned was 301583.59 Gg while in 2020, it was 1599031.15 Gg. This shows there was a 430.21% increase within a 60- year interval.
    * In 2021, it is projected that the total amount of MSW open-burned will be 1701618.73 Gg and in 2030, this amount will be 2192725.69 Gg representing a 28.87% increase.
  - Nitrous Oxide (N2O) Emissions from MSW Open burned.
    * In 1960, estimated net N2O emissions for open-burned waste was 112.34 Gg CO2-eq while it was 595.64 Gg CO2- eq representing a 430.21% increase within the 60-year interval.
    * In 2021, it is projected that the net N2O emissions for open-burned waste will be 633.85 Gg CO2-eq but will increase by 28.87%. to 816.79 Gg CO2-eq in 2030.
  - Carbon Dioxide (CO2) Emissions from MSW Open burned.
    * In 1960, the estimated net CO2emissions from open-burned waste was 56.37 Gg, whereas it was 406.11 Gg in 2020, representing a 620.48% increase.
    * In 2021, it is projected that total CO2emissions for open-burned waste will be 468.82 Gg but will increase by 26.91% to 594.97Gg in 2030.
  - Total Emissions (Gg CO2-eq) from MSW Open burned.
    * In 1960, estimated total emissions (Gg CO2-eq) for open-burned was168.71GgCO2-eq, and the figure was 1001.74 Gg CO2-eq in 2020 showing a 493.78% increase.
    * In 2021, projected total emissions from opening burning will be 1102.68GgCO2-eq and 1411.76 GgCO2-eq in 2030 representing a 28.03% rise.
- **Wastewater Treatment and Discharge**
  - The methane emissions in 1960 and 2020 were 2659.65 Gg CO2-eq and 13455.33 Gg CO2-eq respectively representing a 405.91% increase in net methane emissions.
  - The methane emissions projected in 2021 and 2030 were 14487.9 Gg CO2-eq and 17996.58 Gg CO2-eq respectively representing a 24.22% increase of methane will be emitted from wastewater in Nigeria.

2. **Waste Data Modelling (Business-as-usual scenario)**
   - **E-waste Data Model**
     - In 1960, the estimated amount of E-waste generated was 54.77 Gg and by 2020, this figure had increased by 677.16% over the 60 year time interval.
     - From the projected results, e-waste is projected to rise by 31.06% between 2021 and 2030.
   - **Medical Waste Data Model**
     - In 1960, the estimated amount of medical waste generated was 20.26 Gg while in 2020, the amount was 131.89 Gg.
     - Also, projected amounts of medical waste in 2030 is 181.26Gg representing an increase of 27.09% from 2021.
   - **Batteries Waste Data Model**
     - In 1960, the estimated amount of ULAB waste generated was 24.75 Gg while it was 322.98 Gg in 2020highlighting an increase of 1204.79% over the 60 year time interval.
     - From the projected results, ULAB waste is projected to rise by 26.37%between 2021 and 2030 generating approximately 469.66 Gg of battery waste in 2030.
   - **Plastics Waste Data Model**
     - In 1960, the estimated amount of plastic waste deposited was 746.55 Gg while it was 4637.1 Gg in 2020.
     - Projected amounts of plastic waste to be deposited in the year 2021 is 5035.95 Gg increasing by 28.51% to 6471.75Gg in 2030.
3. **Waste/ Emission Reduction Models**
   - **Organic Waste and Emission Reduction**
     - Organic Waste and Emission Reduction
     - A proposed projection of 7.47% organic waste per annum will be recycled between 2023 to 2030 and this will result in approximately 10% annual reduction in methane emissions within the same period.
   - **Plastic Waste and Emission Reduction**
     - A proposed projection of 7.47% plastic waste per annum will be recycled between 2023 to 2030 and this will result in approximately 20% annual reduction in methane emissions within the same period
   - **Medical Waste and Emission Reduction**
     - A proposed projection of 7.47% medical waste per annum will be recycled between 2023 to 2030, and this will result in approximately 7% annual reduction in methane emissions within the same period
   - **E-waste and Emission Reduction**

  - A proposed projection of approximately 2% e-waste per annum will be recycled between 2023 to 2030, and this will result in approximately 0.1% annual reduction in methane emissions within the same timeframe. However, if the proposed national percentage of 7.47% is targeted, the emission reduction will increase.

- **Battery Waste and Emission Reduction**
  - A proposed projection of 80% ULAB waste per annum will be recycled between 2023 to 2030 and this will result in approximately 5% annual reduction in methane emissions within the same period.

8.2 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, both general and specific recommendations are developed for consideration for the NDC revision and highlighted below:

A. General Policy and Governance Structure

1. **The National Policy on Environment (2016)** should be revised between 2022 and 2023 through a collaboration of the regulatory agencies, key stakeholders and the National Assembly to incorporate circular economy strategies and bioeconomy measures such as the mandatory use of eco-friendly materials, and increased efficiencies in the production processes of key waste emitting sectors. These sectors include but are not limited to harvested wood products, agricultural produce, food and beverage industries, food supply chain, and textile factories, and enforcement can be enhanced with incentives and penalties issued accordingly.
2. **The Industrial and Compliance Unit of NESREA** should be expanded with sub-units created for each EPR and other critical waste streams to ensure the implementation of waste-related legislation, the effective monitoring of EPR activities and to ensure compliance in various sectors. These may include an Agricultural and Organic Waste Control Unit, Battery Standards Enforcement Unit, Waste Electrical and Electronic Equipment Unit, Plastic Packaging Control Unit etc. and can be carried out in 2023 to ensure adequate preparations are made.
3. **Circularization of the Nigerian economy and waste reduction** In order to facilitate the circularization of the Nigerian economy and reduce the amount of waste generated, techniques known as R-strategies or a circular economy R framework 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. Hence, the NDC under review will apply the R-strategies as much as possible in all the priority sectors of the NDC to contribute to the conditional and unconditional mitigation and adaptation targets.

B. Policy & Regulatory Interventions for Specific Waste Streams

1. **Organic Waste**

   i **The Draft National Policy on Municipal and Agricultural Waste (MAW) Management** should be enacted and strictly implemented by the end of 2021/start of 2022 by the regulatory agencies and members of the agricultural and food supply chain to reduce waste emissions from these sectors and optimize waste generated for alternative uses.

   ii **Federal Government Integrated Waste Management Projects** which have been established in Imo, Abuja and Ekiti states to produce compost, biogas, and animal feed, respectively, should be revamped and made operational in collaboration with State Governments and interested PPPs between 2022 and 2023.

   iii **New Waste Management PPPs** should be created at the start of 2022 to convert organic and agricultural waste into livestock and domestic animal feed to be available all year round situated in Northern Nigeria where livestock rearing are common, and also to manufacture compost which can be situated in Southern Nigeria's rain forest regions. This will aid the attainment of the proposed target of recycling 7.47% organic waste. These schemes can be done in collaboration between the Ministries of Environment and Agriculture and key partners.

   iv **Waste-to-energy plants should be established** between 2022 and 2023 in order to achieve the proposed target of recycling 7.47% organic waste to reduce waste emissions by approximately 10%. This should be carried out at landfill sites of densely populated areas in the country with huge waste generation potential, such as Ibadan, Port-Harcourt, Onitsha, and Kano, among several others, for biogas and electricity generation. These projects can be developed by the Federal and State Ministries of Environment and Power for PPPs and private investors to implement.

2. **WasteWater**

   i **A strict enforcement of wastewater legislation should be carried out** between 2021 and 2025 to achieve a target of at least recycling 7.47% wastewater by regulatory agencies with severe penalties on defaulters who release untreated wastewater into the environment. Key sectors such as manufacturing industries, chemical and textile factories, food processing plants, eateries etc. should have wastewater treatment and reuse plants in each factory depending on the type of effluent generated and legislation such as the National Environmental Protection (Pollution Abatement in Industries and Facilities Generating Wastes) Regulations S.I.9 should be properly enforced.

   ii **New centralized and decentralized water treatment facilities** should be installed where no such facilities exist between 2022 and 2024 in order to meet the proposed national recycling target of 7.47%. These should be located at strategic stormwater and wastewater collection points based on drainage networks within urban and rural areas of the country. For a centralized plant that can be mostly installed in rural communities, new and existing drainage networks should be built in accordance with the Development Master Plans in those localities. This should move stormwater and wastewater from various channels to a common drainage outlet so that one water treatment plant can be established along that outlet which would cater for surrounding communities. For decentralized facilities mostly applicable in urban settings, settlements should be partitioned into 'drainage zones' based on their size and direction of wastewater flow, and water treatment plants should be established for each zone at common water collection points of the drainage channels. This would require collaboration by the Ministries of Environment and Water Resources, State Governments, PPPs and interested investors.

iii **Retrofit of existing physical and chemical treatment applications in State-owned Water Treatment Plants** with aerobic water treatment systems should be undertaken to increase water treatment efficiency and minimize emission producing materials in the water. Treatment plants in some industrial and commercial cities can be started off as pilot projects before expansion is carried out to other states. State Governments and State Ministries of Water Resources and Environment can facilitate this modification in the treatment plants. These upgrades can be undertaken between 2022 and 2023.

iv **Access to funding by industrial wastewater generators** should be facilitated by the government, financial institutions and international donor organizations for the procurement of cleaner production technologies and sustainable waste disposal techniques by manufacturing industries, chemical and textile factories, food processing plants and other high GHG waste emission sectors. These should be facilitated between 2022 and 2023.

v **New drainage networks should be constructed and existing ones should be modified** according to plans laid out by the Local Planning Authorities to ensure that wastewater follows the appropriate channels to designated collection points for treatment between 2022 and 2025. The Local Authorities in each council should ensure that adequate drainage systems are in place before building permits are given and land documents are approved.

vi **Frequent clearing of drainage pathways should be carried out by State Waste Management Agencies** to make them free from refuse and illegal structures built along with the drainage systems. These State Waste Management Agencies should also work with local communities to sensitize and enforce penalties on illegal dumping of refuse in drainage pathways and increase its workforce during rainy seasons. State Governments, Ministries of Environment and donor agencies can also provide additional support with funding and technical assistance with the exercise taking place frequently from 2021.

3. **Plastic Waste:** In order to attain the 7.47% plastic recycling target, which would lead to an estimated 20% annual reduction in waste plastic emissions, the 26 plants of the Plastic Recycling Program installed nationwide should be resuscitated by the Federal Government between 2022 and 2023. Regulatory agencies need to ensure that plastic producers in all states are part of the current EPR programme. Feasibility studies need to be carried out in the plastic recycling value chain to attract investors, and this can be facilitated by the Federal Ministry of Environment in

collaboration with State Ministries of Commerce.

4. **E-Waste:** New and innovative legislation which would prevent e-waste from being dumped into the country should be developed at the start of 2022, implemented and enforced to achieve the proposed national recycling target of 7.47%. Enforcement of international agreements ratified by the country can also be carried out by the relevant enforcement agencies. Informal e-waste recyclers can also be encouraged to transition to the formal sector with incentives such as technical assistance and access to funds.

5. **Battery Waste:** Assistance should be provided for members of the informal battery recycling sector to transition to the formal sector with incentives such as technical training of clean technologies and methods, access to funding and incentivizing other factors of productions so they can expand and upscale their operations. This should be done between 2022 and 2023 in order to sustain the proposed target of recycling 80% ULAB.

6. **Medical Waste:** It is recommended that in order achieve a recycling target of reducing 7.47% medical waste in Nigeria, all 23 existing medical incinerators and facilities across Nigeria of the National Hospital Intervention Scheme should be made operational with additional installations carried out across the country including rural areas by 2022.

C. Recommendations on Waste Management Practices

1. Open Burning & Landfills

i **The legislation on open burning of waste** as highlighted in the National Policy on Solid Waste Management and which is being driven by the FMOE, should be facilitated by the end of 2021 to ensure its quick completion and implementation.

ii **An increase informal waste collection activities** should be carried out in urban and rural areas by engaging private waste collectors to complement existing waste collectors by the end of 2021. The geographical areas covered by waste collectors should also be expanded to ensure a wider reach in waste collection.

iii **The incorporation of best practices at landfills and waste dump sites** should be undertaken and enforced by Local Waste Management Authorities and communities where dumpsites are located by 2022. The State Ministries of Environment should also liaise regularly with Local Government Councils providing a supervisory role on the sustainable management of landfill sites.

iv **Awareness campaigns of the general populace** on available alternatives to open burning such as recycling and compost making should be carried out from 2021 onwards, which should be continuous on various media in addition to highlighting the short and long term hazards of open burning to the health and environment.

D. Extended Producer Responsibility (EPR) – Producer Responsibility Organization (PRO)

1. **Regulatory and enforcement agencies** such as NESREA, SON, MAN, Nigerian Customs Service should be strengthened between 2022 and 2024 with increased funding, technical expertise, personnel and up-to-date equipment so as to effectively

enforce the EPR-PRO program, regulate the various sectors, cover more geographical areas and expand the program to other critical waste streams.

2. **Access to low-interest loans, grants and incentives** by the government, financial institutions and donor agencies should be made available between 2022 and 2024 to registered PRO members to enable a transition to cleaner technologies and sustainable methods and assist informal recyclers to migrate to the formal sector. An example is the ARBR, in which members can utilize environmentally cleaner methods to recycle used batteries if funding is made available to them.

3. **An engagement with foreign manufacturers** by the Federal Government should be carried out by mid-2022 to convince them to be part of the EPR programme through their channel partners, who should only be licensed to distribute their products if they are registered with the EPR programme and are conforming to its guidelines. The activities of EPRON, which is the e-waste PRO would be greatly enhanced if Original Equipment Manufacturers (OEMs) are partakers of the Nigerian EPR programme.

4. **Sector-specific Waste Databases** should be developed to aid the effective implementation of the EPR programme and incorporate circular economy measures to achieve its goals. This can be undertaken between 2022 and 2024 as a result of a joint effort based on data from the PROs, Federal Ministry of Environment, National Bureau Statistics, Nigerian Customs Service, Standard Organization of Nigeria, NGOs and other relevant stakeholders with the aim of tracking the flow of goods throughout their lifecycle.

5. **Waste-to-wealth training programmes** should be undertaken nationwide to encourage waste start-ups and value chain businesses. This can be facilitated by PRO members, donor agencies, State Governments, and the Federal Ministry of Environment and should be carried out continuously from 2021 onwards.

6. **EPR Awareness Forums** should take place quarterly in all the states of the country where key stakeholders give updates on their waste management activities, circular economy initiatives, challenges, opportunities, legislation implementation etc. so other potential stakeholders begin to understand and harness the benefits of the EPR programme. This can be initiated in the fourth quarter of 2021.

7. **Circular Economy Research Centers (CERC)** should be established in higher institutions in the six geopolitical zones to produce indigenous solutions, increase circularity adoption, analyze trends, and improve resiliency in key sectors. This should be carried out at the start of 2023.

8. **Higher taxes should be placed on products made using non-biodegradable materials and unsustainable processes** from the start of 2023 onwards, having undertaken due consultations with the relevant stakeholders. This would encourage eco-friendly materials and processes and also develop local value chains to enhance the recycling potential of products in a bid to achieve the proposed 7.47% national recycling target.

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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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

					Composition of waste going to solid waste disposal sites							
Year	Population	Waste per capita	Total MSW	% to SWDS	Food	Garden	Paper	Wood	Textile	Nappies	Plastics, other inert	Total
	millions	kg/cap/yr	Gg	%	%	%	%	%	%	%	%	(=100%)
1960	45138458	66.7	3011.52225	29%	8%	43%	10%	4%	4%	0%	31%	100%
1961	46063563	67	3087.302924	31%	8%	43%	10%	4%	4%	0%	31%	100%
1962	47029822	67.3	3166.547897	31%	8%	43%	10%	4%	4%	0%	31%	100%
1963	48032934	67.6	3249.14369	30%	8%	43%	10%	4%	4%	0%	31%	100%
1964	49066760	68	3334.58989	31%	8%	43%	10%	4%	4%	0%	31%	100%
1965	50127921	68.3	3422.693404	31%	8%	43%	10%	4%	4%	0%	31%	100%
1966	51217973	68.6	3513.736052	30%	8%	43%	10%	4%	4%	0%	31%	100%
1967	52342233	68.9	3607.987087	29%	8%	43%	10%	4%	4%	0%	31%	100%
1968	53506196	69.3	3705.943138	30%	8%	43%	10%	4%	4%	0%	31%	100%
1969	54717039	69.6	3808.0826	31%	8%	43%	10%	4%	4%	0%	31%	100%
1970	55982144	69.9	3915.055258	30%	8%	43%	10%	4%	4%	0%	31%	100%
1971	57296983	73.3	4199.178339	32%	8%	43%	10%	4%	4%	0%	31%	100%
1972	58665808	73.9	4332.734005	33%	8%	43%	10%	4%	4%	0%	31%	100%
1973	60114625	74.4	4474.221649	32%	8%	43%	10%	4%	4%	0%	31%	100%
1974	61677177	75	4626.604295	31%	8%	43%	10%	4%	4%	0%	31%	100%
1975	63374298	75.6	4791.529775	32%	8%	43%	10%	4%	4%	0%	31%	100%
1976	65221378	76.2	4970.639757	33%	8%	43%	10%	4%	4%	0%	31%	100%
1977	67203128	76.8	5162.903561	33%	8%	43%	10%	4%	4%	0%	31%	100%
1978	69271917	77.4	5365.029547	33%	8%	43%	10%	4%	4%	0%	31%	100%
1979	71361131	78.1	5571.939407	32%	8%	43%	10%	4%	4%	0%	31%	100%
1980	73423633	78.7	5780.223744	33%	8%	43%	10%	4%	4%	0%	31%	100%
1981	75440502	82.8	6245.59889	34%	8%	43%	10%	4%	4%	0%	31%	100%
1982	77427546	83.8	6492.283414	33%	8%	43%	10%	4%	4%	0%	31%	100%
1983	79414840	84.9	6744.968123	35%	8%	43%	10%	4%	4%	0%	31%	100%
1984	81448755	86	7008.016547	35%	8%	43%	10%	4%	4%	0%	31%	100%
1985	83562785	87.2	7284.16285	33%	8%	43%	10%	4%	4%	0%	31%	100%
1986	85766399	88.3	7575.016623	33%	8%	43%	10%	4%	4%	0%	31%	100%
1987	88048032	89.5	7880.00868	33%	8%	43%	10%	4%	4%	0%	31%	100%
1988	90395271	90.7	8198.31655	33%	8%	43%	10%	4%	4%	0%	31%	100%
1989	92788027	91.9	8528.211261	35%	8%	43%	10%	4%	4%	0%	31%	100%
1990	95212450	93.1	8868.988303	33%	8%	43%	10%	4%	4%	0%	31%	100%
1991	97667632	97.4	9508.901899	36%	8%	43%	10%	4%	4%	0%	31%	100%
1992	100161710	98.1	9828.652353	35%	8%	43%	10%	4%	4%	0%	31%	100%
1993	102700753	98.9	10157.31049	37%	8%	43%	10%	4%	4%	0%	31%	100%
1994	105293700	99.7	10495.91851	36%	8%	43%	10%	4%	4%	0%	31%	100%

Continued on next page

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	100.5	10845.59782	35%	8%	43%	10%	4%	4%	0%	31%	100%
1996	110668794	101.3	11207.1438	35%	8%	43%	10%	4%	4%	0%	31%	100%
1997	113457663	102.1	11580.35715	35%	8%	43%	10%	4%	4%	0%	31%	100%
1998	116319759	102.9	11966.27993	35%	8%	43%	10%	4%	4%	0%	31%	100%
1999	119260063	103.7	12365.84123	35%	8%	43%	10%	4%	4%	0%	31%	100%
2000	122283850	104.5	12779.85092	36%	8%	43%	10%	4%	4%	0%	31%	100%
2001	125394046	109.6	13737.97792	39%	8%	43%	10%	4%	4%	0%	31%	100%
2002	128596076	110.9	14260.09307	38%	8%	43%	10%	4%	4%	0%	31%	100%
2003	131900631	112.2	14804.12967	37%	8%	43%	10%	4%	4%	0%	31%	100%
2004	135320422	113.6	15371.8726	39%	8%	43%	10%	4%	4%	0%	31%	100%
2005	138865016	115	15964.58095	39%	8%	43%	10%	4%	4%	0%	31%	100%
2006	142538308	116.3	16583.54793	38%	8%	43%	10%	4%	4%	0%	31%	100%
2007	146339977	117.7	17229.39094	38%	8%	43%	10%	4%	4%	0%	31%	100%
2008	150269623	119.1	17902.72474	38%	8%	43%	10%	4%	4%	0%	31%	100%
2009	154324933	120.5	18602.95969	37%	8%	43%	10%	4%	4%	0%	31%	100%
2010	158503197	122	19331.10855	38%	8%	43%	10%	4%	4%	0%	31%	100%
2011	162805071	127.6	20777.3712	40%	8%	43%	10%	4%	4%	0%	31%	100%
2012	167228767	129.1	21583.64085	41%	8%	43%	10%	4%	4%	0%	31%	100%
2013	171765769	130.5	22415.22931	41%	8%	43%	10%	4%	4%	0%	31%	100%
2014	176404902	131.9	23270.9704	41%	8%	43%	10%	4%	4%	0%	31%	100%
2015	181137448	133.3	24149.95372	39%	8%	43%	10%	4%	4%	0%	31%	100%
2016	185960289	134.7	25051.05037	41%	8%	43%	10%	4%	4%	0%	31%	100%
2017	190873311	136.1	25974.98642	39%	8%	43%	10%	4%	4%	0%	31%	100%
2018	195874740	137.4	26921.02818	42%	8%	43%	10%	4%	4%	0%	31%	100%
2019	200963599	138.8	27888.79831	39%	8%	43%	10%	4%	4%	0%	31%	100%
2020	206139589	135.1	27850.36087	39%	8%	43%	10%	4%	4%	0%	31%	100%
2021	211700711.3	140.7	29779.23462	43%	8%	43%	10%	4%	4%	0%	31%	100%
2022	217401423	141.7	30811.32281	42%	8%	43%	10%	4%	4%	0%	31%	100%
2023	223241624.4	142.8	31875.39996	43%	8%	43%	10%	4%	4%	0%	31%	100%
2024	229225172	143.8	32972.46385	42%	8%	43%	10%	4%	4%	0%	31%	100%
2025	235356154.7	144.9	34103.56232	42%	8%	43%	10%	4%	4%	0%	31%	100%
2026	241641336.5	146	35270.151	43%	8%	43%	10%	4%	4%	0%	31%	100%
2027	248088276.9	147	36473.83102	42%	8%	43%	10%	4%	4%	0%	31%	100%
2028	254705440.2	148.1	37716.3696	42%	8%	43%	10%	4%	4%	0%	31%	100%
2029	261502320.2	149.1	38999.72336	43%	8%	43%	10%	4%	4%	0%	31%	100%
2030	268489582.5	150.2	40326.06509	42%	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	0.143542529	602.3044501	59%	355.3856434
1961	4467	0.138227129	617.4605849	60%	370.0150204
1962	4909	0.129009896	633.3095794	60%	378.7332323
1963	5165	0.125813889	649.828738	59%	383.358947
1964	5553	0.120100482	666.9179779	60%	398.9170094
1965	5874	0.116537058	684.5386807	59%	400.6801261
1966	6367	0.110373364	702.7472104	59%	417.917647
1967	5203	0.138688721	721.5974175	60%	429.7002036
1968	5201	0.142508869	741.1886275	58%	431.1764724
1969	6634	0.114805023	761.6165201	59%	449.9916242
1970	12546	0.062411211	783.0110517	60%	466.9236865
1971	9182	0.09146544	839.8356679	62%	520.1325649
1972	12274	0.070600196	866.546801	60%	523.6734139
1973	15163	0.059014992	894.8443298	60%	538.1603805
1974	24847	0.037240748	925.320859	61%	561.8164365
1975	27779	0.034497496	958.3059551	62%	592.1133366
1976	36309	0.027379657	994.1279514	61%	602.7376252
1977	36035	0.028654939	1032.580712	61%	629.5230084
1978	36528	0.029374888	1073.005909	62%	662.2194292
1979	47260	0.023579938	1114.387881	62%	689.0383188
1980	64202	0.018006367	1156.044749	62%	711.861223
1981	164475	0.007594587	1249.119778	63%	789.5075435
1982	142769	0.009094808	1298.456683	63%	824.2872729
1983	97095	0.013893544	1348.993625	64%	859.956596
1984	73484	0.019073585	1401.603309	62%	870.2893599
1985	73746	0.019754733	1456.83257	63%	911.4219219
1986	54806	0.027643019	1515.003325	62%	944.7890676
1987	52676	0.029918782	1576.001736	64%	1007.666676
1988	49648	0.033025768	1639.66331	64%	1045.755873
1989	44003	0.038761954	1705.642252	62%	1064.717727
1990	54036	0.032826221	1773.797661	62%	1107.987435
1991	49118	0.038718604	1901.78038	65%	1245.47409
1992	47795	0.041128371	1965.730471	65%	1275.950842
1993	27752	0.073200566	2031.462098	66%	1336.521354
1994	33833	0.06204545	2099.183701	65%	1366.530654
1995	44062	0.049228804	2169.119565	66%	1422.495363
1996	51076	0.043884187	2241.428759	66%	1478.378983
1997	54458	0.042529499	2316.07143	66%	1520.230915
1998	54604	0.043829316	2393.255987	64%	1534.429042
1999	59373	0.041654763	2473.168246	65%	1598.891827
2000	69449	0.036803556	2555.970185	65%	1663.70473
2001	74030	0.037114624	2747.595584	67%	1837.030373
2002	95386	0.029899761	2852.018614	68%	1933.385433
2003	104912	0.028221995	2960.825934	67%	1989.198236
2004	136386	0.022541716	3074.374519	67%	2047.212201
2005	176134	0.018127767	3192.916189	67%	2150.588213
2006	236104	0.014047664	3316.709587	68%	2244.612768
2007	275626	0.012502007	3445.878189	68%	2331.715996
2008	337036	0.010623628	3580.544949	67%	2381.171907
2009	291880	0.012746992	3720.591939	67%	2510.250176
2010	361457	0.010696215	3866.22171	66%	2567.116746
2011	404994	0.010260582	4155.47424	69%	2884.265124
2012	455502	0.009476859	4316.728171	68%	2941.978629
2013	508693	0.008812871	4483.045862	70%	3138.089336
2014	546676	0.008513624	4654.194079	70%	3247.75831
2015	486803	0.009921859	4829.990744	68%	3299.684234
2016	404650	0.012381589	5010.210075	69%	3461.282391
2017	375746	0.013825822	5194.997283	69%	3599.842205
2018	397190	0.013555743	5384.205637	70%	3761.263323
2019	448120	0.012447022	5577.759662	68%	3815.184093

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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	0.011873044	5570.072174	69%	3840.292854
2021	476219	0.012506529	5955.846925	72%	4263.764899
2022	483074	0.012756357	6162.264562	71%	4349.376632
2023	490357	0.013000895	6375.079993	71%	4496.585369
2024	496789	0.013274233	6594.492771	70%	4639.009545
2025	502046	0.013585832	6820.712465	71%	4854.68854
2026	506304	0.013932401	7054.030199	71%	4988.197419
2027	509779	0.014309664	7294.766205	72%	5236.519902
2028	512618	0.014715195	7543.27392	71%	5333.344908
2029	514929	0.015147612	7799.944671	71%	5571.65262
2030	516802	0.015606002	8065.213018	72%	5787.277588

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	70	376	86	35	35	875	271	355
1961	76	409	93	38	38	951	295	370
1962	78	418	95	39	39	971	301	379
1963	77	414	94	39	39	963	299	383
1964	82	441	101	41	41	1,027	318	399
1965	85	454	104	42	42	1,057	328	401
1966	85	459	105	43	43	1,068	331	418
1967	84	451	103	42	42	1,049	325	430
1968	90	484	110	45	45	1,126	349	431
1969	94	507	116	47	47	1,180	366	450
1970	94	506	115	47	47	1,178	365	467
1971	108	582	133	54	54	1,354	420	520
1972	113	607	138	56	56	1,412	438	524
1973	116	625	142	58	58	1,454	451	538
1974	116	622	142	58	58	1,447	449	562
1975	122	658	150	61	61	1,531	475	592
1976	129	695	158	65	65	1,617	501	603
1977	136	732	167	68	68	1,703	528	630
1978	140	751	171	70	70	1,746	541	662
1979	144	773	176	72	72	1,798	557	689
1980	152	819	187	76	76	1,905	591	712
1981	171	917	209	85	85	2,132	661	790
1982	172	924	211	86	86	2,150	666	824
1983	186	1,002	228	93	93	2,330	722	860
1984	195	1,047	239	97	97	2,434	754	870
1985	195	1,047	239	97	97	2,436	755	911
1986	200	1,075	245	100	100	2,501	775	945
1987	209	1,124	256	105	105	2,614	810	1,008
1988	220	1,181	269	110	110	2,746	851	1,046
1989	239	1,283	292	119	119	2,983	925	1,065
1990	236	1,268	289	118	118	2,948	914	1,108
1991	273	1,468	335	137	137	3,414	1,058	1,245
1992	275	1,480	337	138	138	3,443	1,067	1,276
1993	298	1,603	365	149	149	3,729	1,156	1,337
1994	299	1,607	366	149	149	3,737	1,158	1,367
1995	305	1,639	373	152	152	3,811	1,181	1,422
1996	317	1,702	388	158	158	3,958	1,227	1,478
1997	328	1,765	402	164	164	4,105	1,273	1,520
1998	340	1,825	416	170	170	4,245	1,316	1,534
1999	349	1,873	427	174	174	4,356	1,350	1,599
2000	369	1,985	452	185	185	4,615	1,431	1,664
2001	427	2,297	523	214	214	5,341	1,656	1,837

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	Amounts deposited in SWDS							
Year	Food	Garden	Paper	Wood	Textile	Deposited MSW	Inert	Industrial
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
2002	435	2,338	533	217	217	5,437	1,685	1,933
2003	441	2,373	541	221	221	5,519	1,711	1,989
2004	478	2,570	586	239	239	5,977	1,853	2,047
2005	497	2,670	608	248	248	6,209	1,925	2,151
2006	508	2,729	622	254	254	6,346	1,967	2,245
2007	526	2,829	645	263	263	6,580	2,040	2,332
2008	538	2,891	659	269	269	6,723	2,084	2,381
2009	551	2,961	675	275	275	6,887	2,135	2,510
2010	588	3,159	720	294	294	7,345	2,277	2,567
2011	666	3,580	816	333	333	8,325	2,581	2,884
2012	714	3,840	875	357	357	8,930	2,768	2,942
2013	734	3,945	899	367	367	9,175	2,844	3,138
2014	770	4,139	943	385	385	9,625	2,984	3,248
2015	759	4,079	930	379	379	9,486	2,941	3,300
2016	815	4,379	998	407	407	10,183	3,157	3,461
2017	814	4,373	997	407	407	10,170	3,153	3,600
2018	895	4,810	1,096	447	447	11,187	3,468	3,761
2019	880	4,731	1,078	440	440	11,003	3,411	3,815
2020	878	4,721	1,076	439	439	10,979	3,404	3,840
2021	1,019	5,476	1,248	509	509	12,735	3,948	4,264
2022	1,034	5,560	1,267	517	517	12,930	4,008	4,349
2023	1,089	5,852	1,334	544	544	13,610	4,219	4,497
2024	1,116	6,001	1,368	558	558	13,956	4,326	4,639
2025	1,154	6,204	1,414	577	577	14,429	4,473	4,855
2026	1,208	6,493	1,480	604	604	15,099	4,681	4,988
2027	1,212	6,516	1,485	606	606	15,153	4,698	5,237
2028	1,274	6,845	1,560	637	637	15,919	4,935	5,333
2029	1,335	7,178	1,636	668	668	16,693	5,175	5,572
2030	1,359	7,303	1,664	679	679	16,984	5,265	5,787

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

	Methane generated									
Year	Food	Garden	Paper	Wood	Textile	Industrial	Total	Methane recovery	**Methane emission**	**Methane emission**
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg CO_2 eq
1960	0	0	0	0	0	0	0	0	0	0
1961	0	5	0	0	0	2	8	0	8	168
1962	1	10	0	0	0	3	15	0	15	315
1963	1	15	0	0	1	5	22	0	22	462
1964	1	19	0	0	1	6	27	0	27	567
1965	1	22	1	1	1	7	32	0	32	672
1966	1	25	1	1	1	8	36	0	36	756
1967	1	28	1	1	1	8	40	0	40	840
1968	1	30	1	1	1	9	44	0	44	924
1969	1	32	1	1	2	10	47	0	47	987
1970	1	35	1	1	2	10	50	0	50	1050
1971	1	36	1	1	2	11	53	0	53	1113
1972	2	39	1	1	2	12	57	0	57	1197
1973	2	42	1	1	2	13	61	0	61	1281
1974	2	44	1	2	2	13	65	0	65	1365
1975	2	46	2	2	3	14	68	0	68	1428
1976	2	49	2	2	3	14	71	0	71	1491
1977	2	51	2	2	3	15	75	0	75	1575
1978	2	54	2	2	3	16	79	0	79	1659
1979	2	56	2	2	3	17	82	0	82	1722
1980	2	59	2	2	3	17	86	0	86	1806
1981	2	61	2	3	4	18	90	0	90	1890
1982	2	65	2	3	4	19	95	0	95	1995

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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**	**Methane emission**
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg CO_2 eq
1983	3	68	2	3	4	20	100	0	100	2100
1984	3	72	3	3	4	21	106	0	106	2226
1985	3	76	3	3	5	22	111	0	111	2331
1986	3	79	3	3	5	23	116	0	116	2436
1987	3	82	3	4	5	24	121	0	121	2541
1988	3	86	3	4	5	25	126	0	126	2646
1989	3	89	3	4	6	26	132	0	132	2772
1990	4	94	4	4	6	27	138	0	138	2898
1991	4	98	4	4	6	28	144	0	144	3024
1992	4	103	4	5	6	30	152	0	152	3192
1993	4	109	4	5	7	31	160	0	160	3360
1994	4	115	4	5	7	33	169	0	169	3549
1995	5	120	5	6	7	34	177	0	177	3717
1996	5	125	5	6	8	36	184	0	184	3864
1997	5	130	5	6	8	37	191	0	191	4011
1998	5	135	5	6	9	39	199	0	199	4179
1999	5	140	5	7	9	40	207	0	207	4347
2000	5	146	6	7	9	42	214	10	204	4284
2001	6	151	6	7	10	43	223	10	213	4473
2002	6	161	6	8	10	45	236	10	226	4746
2003	6	170	7	8	11	47	249	10	239	5019
2004	7	177	7	8	11	50	260	10	250	5250
2005	7	187	7	9	12	52	273	10	263	5523
2006	7	196	8	9	12	54	287	10	277	5817
2007	8	205	8	10	13	56	300	10	290	6090
2008	8	214	8	10	14	59	313	10	303	6363
2009	8	222	9	11	14	61	325	10	315	6615
2010	9	230	9	11	15	64	337	10	327	6867
2011	9	240	9	12	15	66	351	10	341	7161
2012	10	254	10	12	16	70	371	10	361	7581
2013	10	270	10	13	17	73	393	10	383	8043
2014	11	285	11	14	18	77	415	10	405	8505
2015	11	300	12	14	19	80	436	10	426	8946
2016	12	312	12	15	20	84	454	10	444	9324
2017	12	326	13	16	21	87	475	10	465	9765
2018	13	339	13	16	21	91	493	10	483	10143
2019	13	355	14	17	23	95	517	10	507	10647
2020	14	368	14	18	23	98	536	10	526	11046
2021	14	379	15	19	24	101	552	10	542	11382
2022	15	399	16	20	25	106	580	10	570	11970
2023	16	417	16	20	27	110	606	10	596	12516
2024	16	436	17	21	28	115	633	10	623	13083
2025	17	454	18	22	29	119	660	10	650	13650
2026	18	473	19	23	30	124	687	10	677	14217
2027	18	493	19	24	32	129	715	10	705	14805
2028	19	510	20	25	33	134	741	10	731	15351
2029	20	529	21	26	34	138	769	10	759	15939
2030	20	550	22	28	36	144	799	10	789	16569

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

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 Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq
1960	336	21	21	336	21	21	0	0	0	0	0	0
1961	357	21	42	693	42	63	105	0	0	105	0	0
1962	357	21	42	1050	63	84	210	0	0	210	0	0
1963	357	21	42	1407	63	126	315	0	0	315	0	0
1964	378	21	42	1785	84	168	399	0	0	399	0	0
1965	399	21	42	2184	105	189	462	21	21	462	21	21
1966	399	21	42	2583	126	231	525	21	21	525	21	21
1967	399	21	42	2982	147	273	588	21	21	588	21	21
1968	420	21	42	3402	168	294	630	21	21	630	21	21
1969	441	21	42	3843	189	336	672	21	21	672	21	21
1970	441	21	42	4284	210	378	735	21	21	735	21	21
1971	504	21	42	4788	252	420	756	21	21	756	21	21
1972	525	21	42	5313	273	462	819	21	21	819	21	21
1973	546	21	42	5859	294	525	882	21	21	882	21	21
1974	546	21	42	6405	315	567	924	21	42	924	21	42
1975	567	21	42	6972	357	630	966	42	42	966	42	42
1976	609	21	63	7581	378	672	1029	42	42	1029	42	42
1977	630	42	63	8211	420	735	1071	42	42	1071	42	42
1978	651	42	63	8862	441	798	1134	42	42	1134	42	42
1979	672	42	63	9534	483	840	1176	42	42	1176	42	42
1980	714	42	63	10248	525	903	1239	42	42	1239	42	42
1981	798	42	63	11046	567	987	1281	42	63	1281	42	63
1982	798	42	63	11844	609	1050	1365	42	63	1365	42	63
1983	861	42	84	12726	651	1134	1428	42	63	1428	42	63
1984	903	42	84	13629	693	1218	1512	63	63	1512	63	63
1985	903	42	84	14532	735	1302	1596	63	63	1596	63	63
1986	945	42	84	15477	777	1386	1659	63	63	1659	63	63
1987	987	42	84	16443	840	1470	1722	63	84	1722	63	84
1988	1029	42	84	17472	882	1554	1806	63	84	1806	63	84
1989	1113	63	105	18585	945	1659	1869	63	84	1869	63	84
1990	1092	63	105	19698	1008	1743	1974	84	84	1974	84	84
1991	1281	63	105	20979	1071	1869	2058	84	84	2058	84	84
1992	1281	63	105	22260	1134	1974	2163	84	105	2163	84	105
1993	1386	63	126	23646	1197	2100	2289	84	105	2289	84	105
1994	1407	63	126	25053	1260	2226	2415	84	105	2415	84	105

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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 Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq	Gg Co2 eq
1995	1428	63	126	26481	1344	2352	2520	105	126	2520	105	126
1996	1470	84	126	27951	1407	2478	2625	105	126	2625	105	126
1997	1533	84	126	29484	1491	2625	2730	105	126	2730	105	126
1998	1596	84	147	31080	1575	2772	2835	105	126	2835	105	126
1999	1638	84	147	32697	1659	2898	2940	105	147	2940	105	147
2000	1722	84	147	34440	1743	3066	3066	126	147	2919	105	147
2001	1995	105	168	36435	1848	3234	3171	126	147	3045	126	147
2002	2037	105	189	38451	1953	3423	3381	126	168	3234	126	147
2003	2058	105	189	40530	2058	3612	3570	147	168	3423	126	168
2004	2226	105	189	42756	2163	3801	3717	147	168	3591	147	168
2005	2331	126	210	45087	2289	4011	3927	147	189	3780	147	189
2006	2373	126	210	47460	2394	4221	4116	168	189	3969	147	189
2007	2457	126	210	49917	2520	4431	4305	168	210	4158	168	189
2008	2520	126	231	52416	2646	4662	4494	168	210	4347	168	210
2009	2583	126	231	54999	2793	4893	4662	189	231	4515	168	210
2010	2751	147	252	57750	2919	5124	4830	189	231	4683	189	231
2011	3108	168	273	60858	3087	5418	5040	189	252	4893	189	231
2012	3339	168	294	64197	3255	5712	5334	210	252	5187	210	252
2013	3423	168	315	67620	3423	6006	5670	210	273	5523	210	273
2014	3591	189	315	71232	3612	6321	5985	231	294	5838	231	273
2015	3549	189	315	74760	3780	6636	6300	252	294	6153	231	294
2016	3801	189	336	78582	3990	6993	6552	252	315	6405	252	315
2017	3801	189	336	82383	4179	7329	6846	273	336	6720	252	315
2018	4179	210	378	86562	4389	7686	7119	273	336	6972	273	336
2019	4116	210	357	90678	4599	8064	7455	294	357	7308	294	357
2020	4095	210	357	94773	4809	8421	7728	294	378	7581	294	378
2021	4767	231	420	99540	5040	8841	7959	315	399	7812	315	378
2022	4830	252	420	104370	5292	9282	8379	336	420	8232	315	399
2023	5082	252	462	109452	5544	9723	8757	336	420	8610	336	420
2024	5208	273	462	114681	5817	10185	9156	357	441	9009	357	441
2025	5397	273	483	120078	6090	10668	9534	378	462	9408	378	462
2026	5649	294	504	125727	6363	11172	9933	399	483	9786	378	483
2027	5670	294	504	131376	6657	11676	10353	399	504	10206	399	504
2028	5943	294	525	137340	6951	12201	10710	420	525	10563	420	525
2029	6237	315	546	143577	7266	12768	11109	441	546	10962	441	546
2030	6342	315	567	149919	7602	13335	11550	462	588	11403	462	567

Appendix C

Results from Open Burning

Table C.1: Open burning emissions (CO_2-eq)

Year	CO_2 Emissions	N_2O Emissions	Total Open Burning (CO_2-eq)
1960	56.36581133	112.3398867	168.71
1961	59.83653133	112.1866839	172.02
1962	60.38563667	113.9169479	174.30
1963	60.29950667	117.4639187	177.76
1964	64.168126	120.5787606	184.75
1965	65.06749333	121.8455808	186.91
1966	65.823098	125.2478116	191.07
1967	65.02921333	129.2263839	194.26
1968	70.07068933	133.3652161	203.44
1969	71.76394133	134.0727696	205.84
1970	70.52409467	135.5146252	206.04
1971	81.38413067	145.8690023	227.25
1972	83.540358	148.1815478	231.72
1973	85.24318	151.7660835	237.01
1974	84.71321467	156.5830585	241.30
1975	89.70684067	162.3223743	252.03
1976	94.002282	167.2161421	261.22
1977	97.78477133	171.4727428	269.26
1978	99.81871533	177.2374766	277.06
1979	102.713534	184.0258853	286.74
1980	107.934926	189.3760907	297.31
1981	119.4835767	202.2918937	321.78
1982	117.6678287	205.599773	323.27
1983	124.9327347	209.0258416	333.96
1984	131.1087873	218.2765564	349.39
1985	127.050682	219.5717007	346.62
1986	131.5526227	230.3011245	361.85
1987	132.082588	230.2476421	362.33
1988	136.0641333	234.8599471	370.92

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Table C.1 – continued from previous page

Year	CO_2 Emissions	N_2O Emissions	Total Open Burning (CO_2-eq)
1989	148.4183653	245.4136986	393.83
1990	146.4782073	254.7250785	401.20
1991	166.85295	268.6578843	435.51
1992	166.663464	275.1589402	441.82
1993	177.276594	279.2215611	456.50
1994	177.712986	288.6041385	466.32
1995	181.7881047	299.1798358	480.97
1996	186.9350633	306.0393291	492.97
1997	189.829882	309.721806	499.55
1998	199.0519593	324.4885008	523.54
1999	201.680732	331.0981054	532.78
2000	211.5935507	338.8003375	550.39
2001	242.8453427	361.1750933	604.02
2002	244.7472207	371.2632398	616.01
2003	241.4085667	374.4909274	615.90
2004	257.0248927	382.2501388	639.28
2005	264.0716027	392.5387555	656.61
2006	268.5639733	405.6696832	674.23
2007	277.3326453	419.8131175	697.15
2008	273.152044	420.681411	693.83
2009	284.974184	445.1145843	730.09
2010	300.5256467	457.2419734	757.77
2011	327.8054633	473.1365442	800.94
2012	355.7356147	497.1658514	852.90
2013	359.2084613	507.3468741	866.56
2014	373.6710707	522.3369283	896.01
2015	366.3678847	539.2699495	905.64
2016	380.811354	541.7170777	922.53
2017	382.2502567	564.6094268	946.86
2018	419.100286	583.0813997	1002.18
2019	401.1573867	587.9535186	989.11
2020	406.1052893	595.6391089	1001.74
2021	468.8249427	633.8529807	1102.68
2022	483.714374	666.4103637	1150.12
2023	501.9499027	679.6824557	1181.63
2024	510.2843093	697.1300234	1207.41
2025	520.6983833	711.6450527	1232.34
2026	546.256238	737.8545346	1284.11
2027	534.6118873	744.000525	1278.61
2028	570.574246	781.5960382	1352.17
2029	585.3199147	790.7030747	1376.02
2030	594.968814	816.7903173	1411.76

Appendix D

Results from Waste Water

Table D.1: Waste water emissions (CO_2-eq)

Year	Emissions, CO_2-eq
1960	2659.65
1961	2667.84
1962	2784.18
1963	2880.99
1964	2858.52
1965	2990.61
1966	3031.14
1967	3078.6
1968	3195.99
1969	3254.16
1970	3275.79
1971	3497.13
1972	3561.39
1973	3670.38
1974	3729.18
1975	3823.68
1976	3862.11
1977	4125.87
1978	4201.05
1979	4240.11
1980	4377.03
1981	4726.26
1982	4755.03
1983	4807.74
1984	5147.94
1985	5251.47
1986	5172.09
1987	5525.1
1988	5590.83

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Table D.1 – continued from previous page

Year	Emissions, CO_2-eq
1989	5679.87
1990	5765.76
1991	6267.45
1992	6386.73
1993	6474.3
1994	6586.44
1995	6996.57
1996	7084.35
1997	7157.85
1998	7371
1999	7697.76
2000	7859.25
2001	8073.24
2002	8319.99
2003	8493.45
2004	9001.02
2005	9228.03
2006	9268.35
2007	9596.37
2008	9727.62
2009	10173.45
2010	10555.65
2011	10817.31
2012	11351.13
2013	11680.83
2014	11682.3
2015	12062.82
2016	12481.98
2017	12728.73
2018	12757.71
2019	13219.29
2020	13455.33
2021	14487.9
2022	14957.25
2023	15211.35
2024	16045.47
2025	15869.07
2026	16635.78
2027	17117.1
2028	17368.26
2029	18259.5
2030	17996.58

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