"Reducing Emissions in Lagos State: An Integrated Approach to Identifying Emission Points and Implementing Sustainable Solutions"

Submitted to

AIChE

As part of

Sustainable Energy Corps Project

By

Ahmadu Bello University

November 15, 2023

Table of Contents

Reducing Emissions in Lagos State: An Integrated Approach to Identifying Emission Points and Implementing Sustainable Solutions

Timothy Japheth Clement[1], Promise Akhonowe[1], Yusuf Benjamin Philibus[1], Bonet Cephas Ishaya[1], Andoma Ismail[1]

Abstract: Emissions reduction in urban centers is a critical global challenge. Lagos State, Nigeria, as a rapidly growing megacity, faces the imperative to reduce emissions for both environmental sustainability and public health. This project presents a comprehensive study focused on identifying emission sources and developing practical strategies for emissions reduction in Lagos State. The research begins by conducting a meticulous assessment of emission points within the state, encompassing various sectors, including transportation, industrial processes, energy consumption, and waste management. Data collection is accomplished through field surveys, emissions inventories, and satellite imagery analysis obtained from previous related works. The identification of major emission sources provides a baseline for subsequent analysis. .Building on the emission source identification, the project outlines a series of practical and actionable steps for emissions reduction. These steps involve the deployment of existing technologies and policy measures to mitigate emissions in a cost-effective and sustainable manner. Strategies encompass transitioning to clean energy sources, improving energy efficiency, enhancing public transportation, and fostering sustainable waste management practices. The project emphasizes the importance of integrating policies and tax incentives to bolster the feasibility and cost-effectiveness of proposed solutions. It highlights the need to prioritize high-value projects with significant emissions reduction potential while exploring innovative approaches for marginally beneficial initiatives. The proposed steps are presented within the framework of existing environmental regulations and international climate agreements, aligning Lagos State with global efforts to combat climate change. This project serves as a comprehensive guide for policymakers, local authorities, and stakeholders in Lagos State, offering a clear path to reduce emissions and transform the state into a sustainable and environmentally responsible urban center. The strategies outlined can be adapted and scaled to address emissions reduction challenges in other metropolitan areas, contributing to a greener and more sustainable future.

CHAPTER 1

1.0 Introduction

Global warming is the long-term rise in Earth's average surface temperature, it is one of the most pressing environmental challenges facing our planet today. The scientific consensus is clear that human activities, primarily the burning of fossil fuels, are the primary cause of this warming trend.

Since the pre-industrial period, the average global temperature has risen by about 1 degree Celsius (1.8 degrees Fahrenheit). This may seem like a small change, but it has a profound impact on Earth's climate system. The consequences of global warming are already being felt around the world, in the form of more extreme weather events, rising sea levels, and disruptions to ecosystems.

If we continue on our current trajectory, the planet could warm by as much as 3 degrees Celsius (5.4 degrees Fahrenheit) by the end of the century. This would have catastrophic consequences, including widespread sea level rise, mass displacement of people, and the collapse of many ecosystems.

However, it will require a concerted global effort to reduce greenhouse gas emissions. This will involve transitioning to renewable energy sources, improving energy efficiency, and protecting forests.[1]

1.1 Significance of Greenhouse gas Emissions

Nigeria's greenhouse gas emissions have increased significantly since 1970, with the highest level of emissions recorded in 1996 at 399.71MtCO2. This represents a 142.37% increase from the 1970 level of 164.91 MtCO2. . This is due to a number of factors, including population growth, economic development, and increased reliance on fossil fuels for power generation. The main sources of these emissions are the power, cooking, oil and gas, transport, and industry sectors.

Figure1 shows the trend of the greenhouse gas emissions in Nigeria from 1970 to 2018. There was also a notable uptick in emissions from 2015 to 2018.[2]

The Lagos State Government undertook a climate risk assessment (CRA) which revealed that Lagos's population and economy are most at risk of flooding. Flooding can occur as a result of subsidence in coastal areas, extreme precipitation events and/or sea level rise. Other significant climate risks include heatwaves, the urban heat island effect, erosion and thunderstorms.

A vulnerability assessment showed that an estimated 65% of the residents of Lagos are extremely poor and therefore highly vulnerable to climate impacts. It further identified close to 7,000 infrastructure assets, buildings and other features that are vulnerable to climate risk. The majority of these, over 6,500, with a value of more than N73 billion, were classified as 'Highly vulnerable'.

In addition, the vulnerability assessment determined that, besides infrastructure, the economic sectors most at risk of climate change impacts are tourism, due to its reliance on coastal features; and agriculture, due to its sensitivity to changing weather patterns.

The Lagos State Government developed a greenhouse gas (GHG) emissions inventory for the year 2015, based on the GPC Protocol for Cities. It showed that in 2015, Lagos State generated emissions of 26,443,656 tCO2e, or 1.3 tCO2e per capita, which is similar to other large African cities. As the figure shows, the highest- emitting sectors were stationary Within those sectors, energy use in manufacturing & industry, energy use in residential buildings,[3]

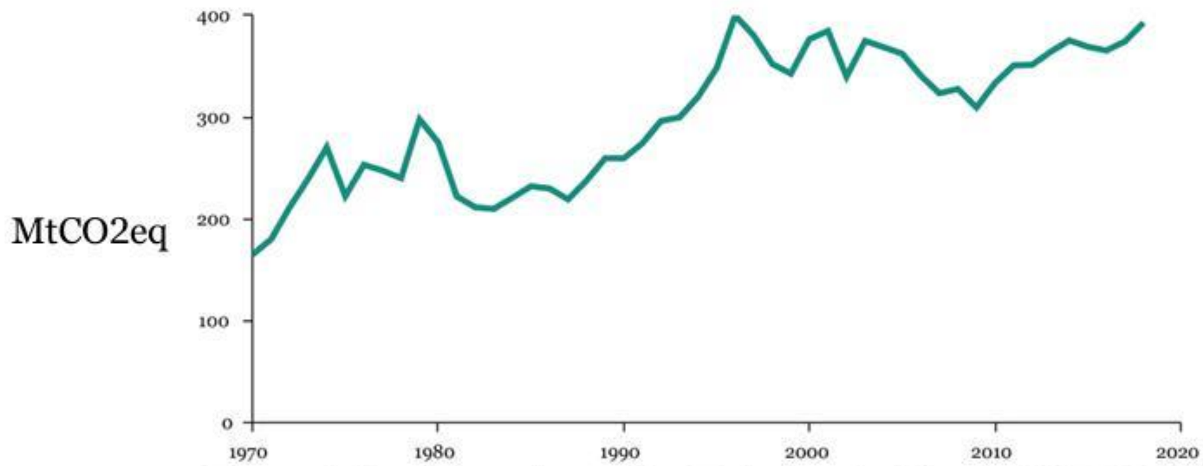

Figure 1. Total Greenhouse Gas Emissions in Nigeria (1970-2018)

Data Source: IEA-EDGARCO2,
https://edgar.jrc.ec.europa.eu/report_2022

1.2 Study Area

Figure 2. A View of Lagos State, Nigeria. Image source: https://guardian.ng/

Lagos is a state in Nigeria, The State is located on the South–Western part of Nigeria, on the narrow plain of the Bight of Benin. Lying approximately on longitude 20 42'E and 32 2'E respectively, and between latitude 60 22'N and 60 2'N, Lagos State is bounded in the North and East by Ogun State of Nigeria, in the West by Republic of Benin, and stretches over 180 kilometers along the Guinea Coast of the Bight of Benin on the Atlantic Ocean. Having a Coastline of 180 km and a land area of 3,577 km² which is about 0.4% of the Country's (Nigeria) landmass. According to the 2006 National Census, Lagos State has a population of 9,013,534 in relation to the National count of 140,003,542. National Bureau of Statistics and Lagos State Ministry of Economic Planning and Budget estimated the state's population at 26.44 million in 2019.

From The Sun newspaper of February 13 2023, Lagos State Governor Babajide Sanwo-Olu has said the state has about 30 per cent of the country's Gross Domestic Product (GDP), with her current GDP at over N120 Billion.

Lagos state controls over 70 percent of the economic activities of the country despite being the smallest State in Nigeria by landmass. From Lagos state Gross Domestic Product (GDP) Survey, 2010, Seven (7) out of the 28 Sectors emerged as major drivers of Lagos economy:

Manufacturing – 29.60%, Road Transport – 26.47%, Building and Construction – 19.70%, Wholesale and Retail – 8.39%, Telecommunications – 3.71%, Financial Institutions – 3.51% and Real Estate – 2.01%.[4]

Chapter 2

2.1 Definition and Characteristics

Greenhouse gases are gases that trap heat in the atmosphere, causing the planet to warm. They come from both natural and human sources (anthropogenic sources). Some of the most common greenhouse gases include Carbon dioxide CO_2, methane CH_4, Nitrous oxide, and Fluorinated gases (HFCs, PFCs, SF_6 and NF_3). Total fossil greenhouse gas emissions are the summation of the individual emissions of this gas.

• Carbon Dioxide (CO_2) that enters the atmosphere through the burning of fossil fuels, solid wastes, trees and wood products, and as a result of other chemical reactions. It is removed from the atmosphere when it is absorbed by plants as part of the biological carbon cycle;

• Methane (CH_4) which is emitted during the production and transportation of coal, natural gas, and oil. Its emission also results from livestock, poultry and other agricultural practices and by the decay of organic waste in municipal solid waste landfills;

• Nitrous Oxide (N_2O) is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste;

• Fluorinated Gases which includes Hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. These are sometimes used as substitutes for ozone-depleting substances. They are typically emitted in smaller quantities, but referred to as High Global Warming Potential gases ("High GWP gases") because they are potent greenhouse gases

2.2 Characteristics and examples of Greenhouse Gases:

Infrared Absorption.

Variability

Persistence.

Concentration Levels

Global Warming Potential (GWP).

Common greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), fluorinated gases (e.g., hydrofluorocarbons - HFCs), and water vapor (although its concentration is primarily influenced by natural processes). Understanding the characteristics of these gases is crucial for comprehending their role in climate change and formulating effective mitigation strategies.

2.3 Sources of Greenhouse Gas Emissions:

Burning of Fossil Fuels: Coal, Oil, and Natural Gas:

• Combustion of fossil fuels for energy production in power plants, industries, and transportation releases significant amounts of carbon dioxide (CO_2) into the atmosphere.

Transportation:

•Automobiles, Trucks, and Aircraft: Internal combustion engines in vehicles burn gasoline and diesel, emitting CO_2 and other pollutants.

•Shipping and Rail Transport: Transportation of goods and passengers via ships and trains also contributes to greenhouse gas emissions.

Deforestation and Land Use Changes:

•Clearing of Forests: Deforestation releases stored carbon as both CO_2 and methane. Changes in land use, such as converting forests into agricultural areas, contribute to emissions.

Agriculture:

•Enteric Fermentation: Livestock, particularly cattle, produce methane during digestion.

•Rice Paddies: Microbial activity in flooded rice fields generates methane.

•Fertilizer Use: Nitrous oxide emissions result from the application of nitrogen-based fertilizers.

Industrial Processes:

•Manufacturing and Chemical Production: Certain industrial activities release CO_2 and other greenhouse gases. Additionally, some processes emit fluorinated gases, which have high global warming potential.

Waste Management:

•Landfills: Decomposition of organic waste in landfills produces methane.

•Wastewater Treatment: Microbial processes in sewage treatment release methane and nitrous oxide.

Energy Production:

•Power Plants: Beyond fossil fuels, other energy sources like biomass and peat can release CO2 and other emissions.

•Oil and Gas Extraction: Extraction processes release methane, a potent greenhouse gas.

Residential and Commercial Energy Use:

•Heating and Cooking: Combustion of fossil fuels for heating and cooking purposes in homes and businesses contributes to CO2 emissions.

Aviation and Shipping:

•Jet Fuel Combustion: Aircraft emit CO2, and their operations also contribute to non-CO2 emissions.

•Maritime Transportation: Shipping activities release CO2 and other pollutants.

Methane Leaks:

•Oil and Gas Production: Extraction and distribution of oil and natural gas can result in methane leaks.[5]

Chapter 3

3.1 Climate risk assessment

Due to its situation on the coast, low-lying topography and high water table, Lagos is particularly vulnerable to climate hazards. The climate risk assessment (CRA) conducted for Lagos State describes the physical and climatic features of the region; elevation ranges from 38 meters below to 78 meters above sea level, while its topography favors water retention inland. Water bodies cover a large part of the State; however, recent land-use changes have led to a slight decrease in water bodies as they have made way for settlements. As a result of these characteristics, Lagos's population is highly vulnerable to extreme weather events and other climate hazards.[6]

3.2 Rising Global temperature

The global commitment to limiting the average temperature increase to 1.5 °C will not stop climate change altogether; the climate will continue to change even if ambitious mitigation actions are undertaken. Like other cities around the world, Lagos must prepare to address current and future impacts of climate change. To allow Lagos to live up to its reputation as a Centre of Excellence and a state of aquatic splendor, appropriate measures will need to be taken to protect its citizens, its economy, its infrastructure and its ecosystems.

The comparison of Lagos's emissions profile to national emissions reveals several trends and specific opportunities. In 2015, Lagos was responsible for approximately 29% of national waste emissions, 8% of residential energy-related emissions and 13% of national transport emissions. This suggests that the transition to a low-emissions economy in Lagos will be critical for the national government to achieve its climate mitigation goals. In comparison to those of major cities in OECD countries, such as Copenhagen (2.5 tCO_2e), London (3.9 tCO_2e) and Washington DC (11 tCO_2e); Lagos's per capita emissions(1.3tCO_2e) are relatively low, however they are comparable to those of other major cities in Africa, such as Accra (1.2 tCO_2e), Dar EsSalaam (1.4tCO_2e) and Addis Ababa (1.6tCO_2e).[6]

3.3 Climate Hazards

The highest-priority risk to Lagos State is that of flooding, which is closely related to coastal subsidence. An increase in subsidence will lead to an increase in the area at risk of inundation and related impacts. The second priority risk identified is heat stress; the total area at risk of experiencing extreme heat is growing. This manifests in the urban heat island effect, which affects different parts of the state to a varying extent. Local Government Areas at significant risk of heat stress are Lagos Island, Lagos Mainland, Agege, Kosofe and Oshodi-isolo. A total of nine hazards have been identified as relevant to Lagos State, all of which will be exacerbated by further climate change:

1. Heat waves, as a result of increases in maximum, average and minimum surface temperatures
2. Inland flooding, as a consequence of changes in precipitation intensity, duration and frequency
3. River flooding
4. Flash flooding
5. Erosion
6. Thunderstorms
7. Coastal and lagoon flooding (due to sea-level rise)
8. Tropical storms
9. The urban heat island effect.[7]

Chapter 4

Figure 3. Map obtained from Onilude, O and Vaz, E. Data Analysis of Land Use Change and Urban and Rural Impacts in Lagos State, Nigeria. MDPI Spatial Data Science and Digital Earth.

4.1 Overview of the Report

This GHG Report covers the whole territory of the Lagos and estimates are computed at the regional scale. This GHG Report includes estimates for the four IPCC sectors ,Energy; Industrial Processes and Product Use (IPPU); Agriculture, Forestry and Other Land Use (AFOLU) and Waste.

The GHG Report includes emissions of the direct GHGs carbon dioxide(CO2), methane(CH4) and nitrous oxide (N2O). Additionally, estimates of the GHG precursors oxides of nitrogen (NOX), carbon monoxide (CO),non methane volatile organic compounds (NMVOCs), and Sulphur dioxide (SO2) were possible when AD were available.

Global Warming Potentials (GWPs) adopted for providing a consistent basis for comparing the relative effect of the emissions of all GHGs uniformed over a period of 100years by converting the emissions of the other GHGs to that of CO2 were from the IPCC Fifth Assessment Report (AR5).

The period 2015-2022

Lagos remained a net emitter over the period 2015 to 2022 as the Land category emissions exceeded removals from all categories combined. The total emissions increased by 4,013,216 Gg from 26,443,656 Gg in 2015 to 30,456,872 in 2022, representing an increase of 20.9% over these 7 years. During the same period, the state recorded a regression of 23% in removals, from 5,908 Gg CO_2-eq to 4,543 Gg CO_2-eq.[6]

4.2 Method

Estimates of GHG emissions provided in this report have been compiled using the 2006 IPCC Guidelines for National GHG Inventories (IPCC 2007) and the IPCC Good Practice Guidance (GPG) and Uncertainty Management in National GHG Inventories(IPCC2000).The purpose of adopting these guidelines and GPG is to ensure that the GHG emission estimates are Transparent, Accurate, Complete, Consistent and Comparable (TACCC) as far as possible.

4.2.1 Key Category Analysis

A key category analysis (KCA) was conducted to identify activities in the four IPCC sectors responsible for 95% of the emissions and sinks within the economy, the objective being to identify which sources should be given priority for refining emission estimates. Results of the KCA from the GHG inventory of the NC3, availability of resources, existing capacity and availability of AD dictated the choice of source categories to be included for compilation. A prioritization exercise was conducted, and the highest emitting source categories were privileged, the intent being to improve estimates by moving to Tier 2. .

Key Category Analysis gives the characteristics of the emission sources and sinks. According to the 2006 IPCC Guidelines (V1_4_Ch4_Method_Choice), key categories are those which contribute 95% of the total annual emissions, when ranked from the largest to the smallest emitter. A key category is one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct GHGs in terms of the absolute level of emissions, the trend in emissions, or both(IPCC,2000). Thus, it is a good practice to identify key categories, as it helps prioritize efforts and improve the overall quality of the national inventory, while also guiding mitigation policies, strategies, and actions.[8]

4.3 Data Collection and Analysis

These section highlights the collection of data, showcasing new technologies and discussing the integration of smart transportation infrastructure into the Nigerian transportation space. Solutions are being sought to address issues such as traffic congestion, road accidents, parking problems, and environmental pollution, which are some of the emission points in the sector.

Furthermore, the World Bank has provided a detailed analysis of air pollution in Lagos, highlighting that road transport, industrial emissions, and generators are the major sources of pollution. The city's heavy traffic, with older vehicles using high-sulfur fuel, contributes significantly to high ambient PM2.5 levels, which are known to cause respiratory and cardiovascular diseases, as well as premature deaths. Industrial zones in Lagos, such as Apapa, Idumota, Ikeja, and Odogunyan, are noted for high levels of pollution due to activities in cement, chemicals, furniture, refinery, and steel industries. Generators, which supply half of Lagos' energy demand, are also a major pollution source due to the poor combustion of gasoline and oil.

Overall, the analysis of the current emission data for Lagos State indicates that significant sources of greenhouse gases are intertwined with the energy and transportation infrastructure, as well as industrial activities. The high levels of PM2.5 and the associated health and economic costs underline the urgency of implementing cleaner technologies, shifting to sustainable transport options, and improving fuel quality. Collaborative efforts are required from local and international bodies to mitigate these emissions and improve air quality, with innovative financing methods like the World Bank's Pollution Management and Environment Health Program and the IFC's Breath Better Bond being potential avenues for investment in climate-friendly infrastructure projects.

PM2.5 refers to particulate matter that is less than 2.5 micrometers in diameter. These fine particles are so small that they can be inhaled deep into the lungs and even enter the bloodstream, posing significant health risks. PM2.5 can come from various sources, including combustion engines, industrial processes, wood burning, and certain chemical reactions that occur in the atmosphere. Because of their small size, PM2.5 particles can remain in the air for longer periods and can be transported over long distances by wind currents, contributing to air pollution far from their source. Exposure to PM2.5 has been linked to various health problems, including heart disease, lung cancer, respiratory infections, and can exacerbate asthma.[9]

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4.3.1 Analysis of Emission Reduction Options

This section outlines the different mitigation strategies we proposed for the reduction of the increasing challenge of GHG emissions in the Lagos metropolitan area. We evaluated a range of options to reduce emissions at each identified point. We considered both technological and non-technological solutions. We estimated the costs and emission benefits associated with each option, based on the available data and assumptions. For each option, we first defined the baseline scenario and the option scenario, based on the data we collected and the assumptions we made. The baseline scenario is the current situation, where no emission reduction measures are implemented. The option scenario is the future situation, where a specific emission reduction measure is implemented.

For the analysis of emission reduction options, we used the following equations to estimate the emission benefits and costs of each option.

Emission benefits

This is the amount of emissions avoided or reduced by implementing an option, compared to the baseline scenario. Simply it is the difference between the emissions in the baseline scenario and the emissions in the option scenario. We calculated it as follows:

$$EB = E_B - E_{O.} \qquad \text{Eq 4.1}$$

Where:

- EB is the emission benefits of an option (MtCO2e)
- E_B is the emissions in the baseline scenario (MtCO2e)
- E_O is the emissions in the option scenario (MtCO2e)

To calculate the emissions in each scenario, we multiplied the amount of activity (such as fuel consumption, vehicle kilometers, waste generation, etc.) by the emission factor (such as kgCO2/liter, kgCO2/passenger-km, kgCO2/kg of waste, etc.). We then converted the units from kgCO2 to MtCO2 by dividing by 10^6. We also assumed a linear trend for the emission benefits over 10 years (2020-2030).

Cost

This is the total system costs of implementing an option, including the capital costs, the operating costs, and the cost of scrapping old equipment or vehicles. It is the sum of the capital costs, the operating costs, and the cost of scrapping old equipment or vehicles. We calculated it as follows:

$$C = C_C + C_O + C_S. \quad \text{Eq 4.2}$$

Where:

- C is the total system costs of an option (US$ billion)
- C_C is the capital costs of an option (US$ billion)
- C_O is the operating costs of an option (US$ billion)
- C_S is the cost of scrapping old equipment or vehicles (US$ billion)

To calculate the costs (capital costs, Operating cost and cost of scrapping an old equipment or vehicles). We multiplied the amount of activity (such as new vehicles, new infrastructure, new equipment, etc.) by the unit cost (such as US$/vehicle, US$/passenger-km, US$/liter, etc.). We then converted the units from US$ to US$ billion by dividing by 10^9. We also assumed a 10-year time horizon for the costs.

4.3.2 Evaluation of Emission Reduction Options

Road transport

- Using cleaner passenger vehicles

This option involves replacing old and inefficient vehicles with newer and cleaner ones, such as hybrid, electric, or compressed natural gas (CNG) vehicles. This option could reduce PM2.5 emissions by 34% and greenhouse gas emissions by 26% by 2030[1]. The estimated cost of this option is $3.4 billion, which includes the capital cost of new vehicles, the operating cost of fuel and maintenance, and the cost of scrapping old vehicles.

- Shifting to public transport

This option involves expanding and improving the public transport system, such as buses, rail, and water transport. This option could reduce PM2.5 emissions by 28% and greenhouse gas emissions by 22% by 2030[1]. The estimated cost of this option is $2.9 billion, which includes the capital cost of new infrastructure, vehicles, and stations, and the operating cost of fuel and maintenance.

Industrial emissions

- Adopting cleaner fuel

This option involves switching from diesel to natural gas or renewable energy sources for power generation and industrial processes. This option could reduce PM2.5 emissions by 16% and greenhouse gas emissions by 13% by 2030[1]. The estimated cost of this option is $1.2 billion, which includes the capital cost of new equipment, pipelines, and connections, and the operating cost of fuel and maintenance.

- Implementing emission standards and monitoring

This option involves enforcing emission standards and monitoring for industrial facilities, such as oil and gas, manufacturing, and construction. This option could reduce PM2.5 emissions by 8% and greenhouse gas emissions by 6% by 2030[1]. The estimated cost of this option is $0.4 billion, which includes the cost of compliance, inspection, and enforcement.

Waste management

- Adopting composting, recycling, and waste-to-energy

This option involves diverting organic waste from landfills to composting facilities, increasing the recycling rate of other waste materials, and converting waste to energy through incineration or anaerobic digestion. This option could reduce methane emissions by 77% and other air pollutants by 12% by 2030[1]. The estimated cost of this option is $1.1 billion, which includes the capital cost of new facilities, equipment, and vehicles, and the operating cost of collection, processing, and disposal.

- Improving waste collection and disposal

This option involves improving the efficiency and coverage of waste collection and disposal services, reducing the amount of waste that is burned or dumped illegally. This option could reduce methane emissions by 23% and other air pollutants by 4% by 2030[1]. The estimated cost of this option is $0.4 billion, which includes the cost of collection, transportation, and disposal.

4.4 Tools and Technologies for Monitoring Greenhouse Gas Emissions:

Satellite-Based Remote Sensing:

•Satellite Observations: Remote sensing satellites equipped with various sensors can monitor greenhouse gas concentrations and sources from space, providing a broad-scale view of emissions.

Ground-Based Monitoring Stations:

•Flux Towers: These tall towers equipped with gas analyzers measure gas concentrations at different heights, helping to understand how emissions vary vertically.

Air Quality Monitoring Stations: Fixed stations across regions measure atmospheric concentrations of greenhouse gases and pollutants.

Mobile and Airborne Measurements:

•Mobile Laboratories: Vehicles equipped with gas analyzers and other instruments travel to different locations, providing flexible and localized measurements.

•Aircraft Surveys: Aircraft-mounted sensors collect data on greenhouse gas concentrations, particularly useful for studying specific regions or large emission sources.

Emission Inventories:

•National and Regional Inventories: Governments and organizations compile data on greenhouse gas emissions from various sources to create inventories, aiding in policy development and monitoring progress.

Isotope Analysis:

•Isotope Ratio Mass Spectrometry (IRMS): Analyzing isotopic compositions of greenhouse gases helps distinguish between natural and anthropogenic sources.

Emission Modeling:

•Computer Models: Computational models simulate and predict greenhouse gas emissions based on various factors, aiding in understanding trends and assessing the effectiveness of mitigation strategies.

Gas Analyzers and Sensors:

•Infrared Gas Analyzers (IRGA): These devices measure concentrations of greenhouse gases like carbon dioxide, methane, and nitrous oxide based on their absorption of infrared light.

•Chemical Ionization Mass Spectrometry (CIMS): Sensitive mass spectrometry techniques can detect trace gases, including certain greenhouse gases.

Unmanned Aerial Vehicles (UAVs):

•Drones: UAVs equipped with gas sensors can be deployed in specific areas to collect data on greenhouse gas concentrations, especially in hard-to-reach or hazardous locations.

Fluorescence-Based Techniques:

•Laser-Induced Fluorescence (LIF): This technique uses lasers to induce fluorescence in certain gases, allowing for their detection and quantification.

Data Integration and Analysis Platforms:

•Geographic Information System (GIS): GIS platforms integrate spatial data to analyze and visualize greenhouse gas emissions in relation to geographical features.

Crowdsourced Data and Citizen Science:

•Mobile Apps: Citizen science initiatives and mobile apps engage the public in collecting data on local emissions, contributing to broader monitoring efforts.

4.5 International Agreements and Protocols

The Paris Agreement was adopted after the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015. The 191 signatory countries to this historic agreement have committed to taking action to limit the global average temperature rise due to climate change to well below 2 °C, and preferably below 1.5 °C. In the lead-up to COP21, more than 160 countries submitted Intended Nationally Determined Contributions (INDCs), setting out each country's approach to reducing emissions and adapting to a changing climate. Since COP 21, countries have been invited to confirm these intentions by ratifying the Paris Agreement and submitting Nationally Determined Contributions (NDCs) to the UNFCCC. Nigeria's INDC falls under the remit of the Nigeria Climate Change Policy and Response Strategy (NCCPRS) and focuses on the delivery of direct development benefits and sustainable economic growth whilst reducing GHG emissions and building resilience to climate change.[10]

CHAPTER 5

5.1 LAGOS' GREENHOUSE GAS EMISSIONS PROFILE

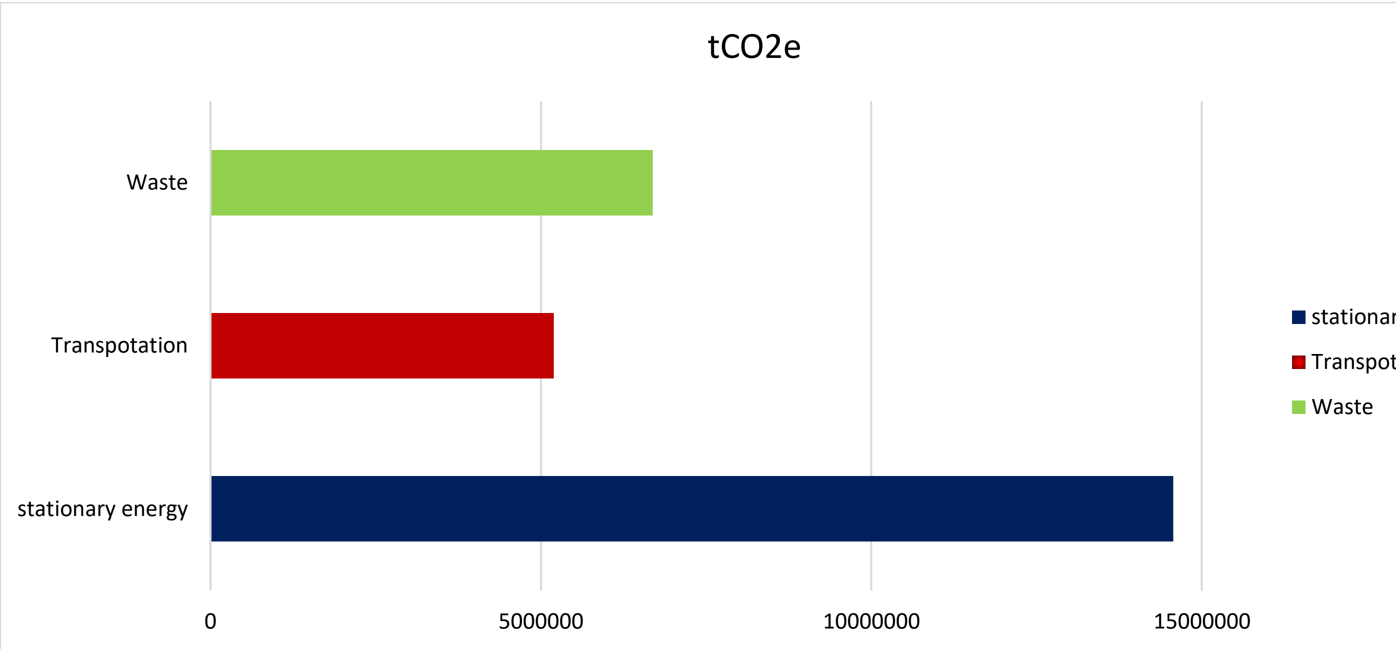

Figure 4. A bar chart depicting Lagos emissions by sector

As Lagos is the economic center of Nigeria, Lagos State's GHG emissions account for a large share of national emissions. Lagos's large and growing population, rapid urbanization and industrialization result in high GHG emissions primarily from energy consumption, transport and waste.

According to the Lagos state climate Action Plan (CAP): Second Five year plan 2020-2025, the Lagos State Government developed a greenhouse gas (GHG) emissions Inventory for the year 2015, based on the GPC Protocol for Cities. It showed that in 2015, Lagos State generated total emissions of 26,443,656 tCO_2e, or 1.3 tCO_2e per capita, accounting for approximately 29% of national waste emissions, 8% of residential energy-related emissions and 13% of national transport emissions. The highest emitting sectors were stationary energy-55% (this is energy generated for use in buildings and industry), transport-20% and waste-25%. The emissions in the stationary energy sector are particularly high due to the widespread use of diesel or petrol-powered generators. Grid electricity is also a significant source of emissions due to the high share of gas-fired and oil-based energy generation in the national energy mix. Transport emissions are the result of combustion of petrol and diesel use in on-road vehicles. Emissions from waste arise from methane production in landfills and wastewater, and from waste burning.

When data was unavailable, the inventory team benchmarked against other cities, downscaled national data and/or used international estimates in accordance with best practice. Assumptions are transparently documented with proposed improvements in the Greenhouse Gas Emissions report and the City Inventory Reporting and Information System(CIRIS).

The generation of stationary energy for consumption in manufacturing and construction and for use in residential buildings are the two largest sources of emissions. This is primarily due to the use of generators for electricity generation. On-road transport is the third-largest source of emissions, due mainly to petrol and diesel consumption in passenger vehicles and buses. Emissions from solid waste and waste- water are the fourth and fifth largest emissions sources, respectively, caused by gas emissions from landfill sites, open burning of waste and wastewater emissions.

But this has changed as transport sector has emerged the largest emitter overtime followed closely by stationary energy and then waste sector. This is due to increase in buses and other forms of road transport.

5.2 GREENHOUSE GAS EMISSIONS FROM TRANSPORTATION IN LAGOS

Figure 5. A picture of Lagos road traffic congestion. Image source: Getty Image

The majority of transport emissions, which accounted for 45% of total emissions, are generated through petrol and diesel use in on-road transportation(see figure 6).[11] The consumption of jet kerosene in aviation contributes the remaining 18% of transport emissions. A very small proportion of transportation emissions (0.15%) was generated by waterborne transport as depicted by figure 7 below.

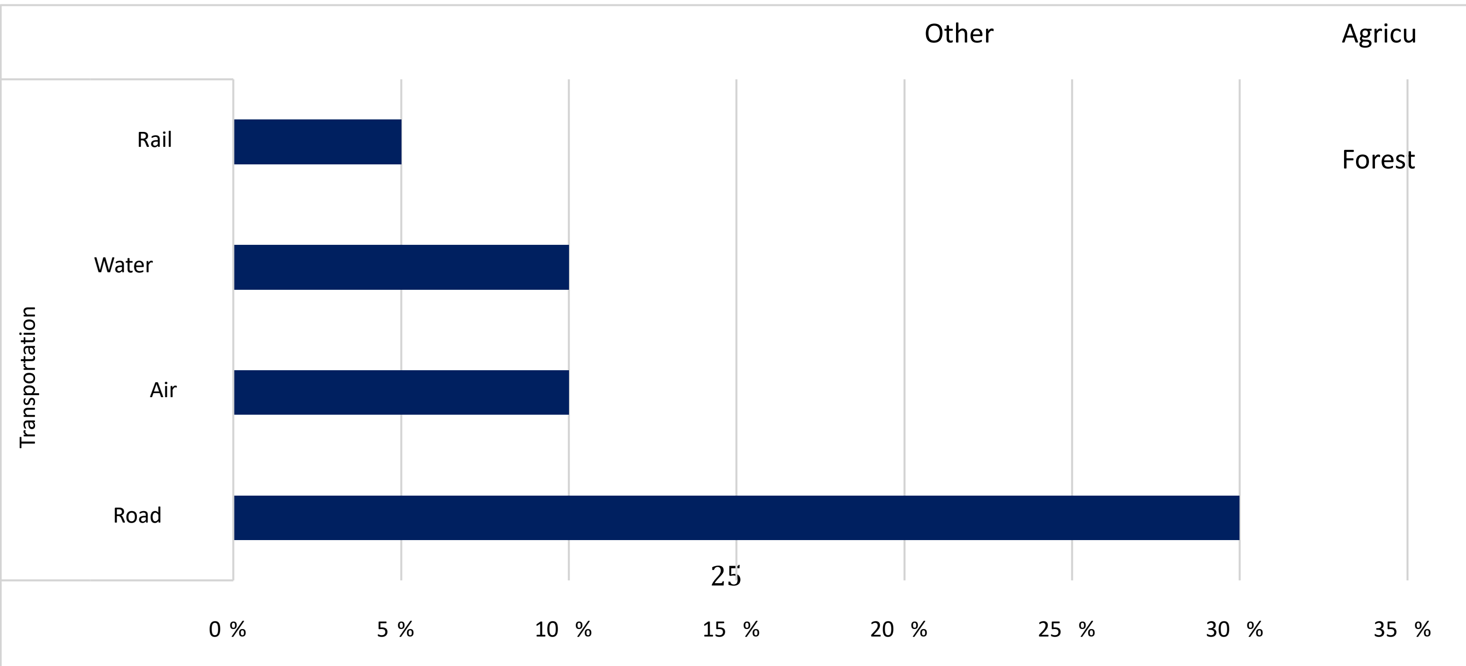

FIGURE 6. A CHART SHOWING BREAKDOWN OF EMISSION FROM TRANSPORT SECTOR IN LAGOS STATE

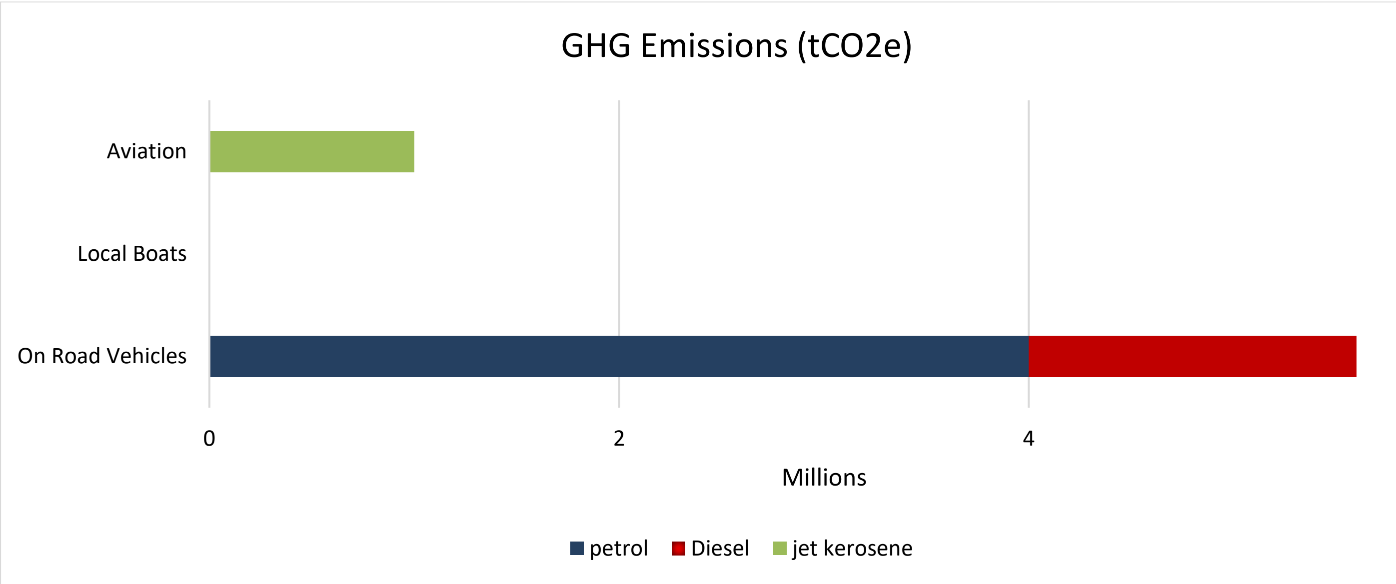

Figure 7. A chart showing the breakdown of emission fuel for the transport sector

5.3 GREENHOUSE GAS EMISSIONS FROM STATIONARY ENERGY IN LAGOS

Figure 8. Egbin power plant. Image source: https://www.sahara-group.com/

Stationary energy emission refers to the energy-related emissions from sources that are fixed in one location, such as power plants, manufacturing facilities, and residential buildings. In Lagos, Nigeria's most populous city and a major economic hub, these emissions are a significant concern due to the city's dense population and industrial activities.

The majority of stationary energy emissions in Lagos come from three key sectors:

•Stationary energy Power Generation: Due to frequent inefficient power supply from the power grid supply, many businesses and households rely on diesel generator for power generations, which emit significant amounts of greenhouse gases and pollutants. The largest thermal power plant in West Africa (Egbin thermal power plant) located in Lagos contributes significantly to emissions generated in the state.

The Egbin Thermal Power Plant, located in Ikorodu, Lagos State, is the largest power plant in West Africa. It was built by the Nigerian government and commissioned in 1985. Egbin generates 1,320MW of electricity using six gas-fired steam turbines. This accounts for about 20% of the electricity supplied to Nigeria’s National Grid. Egbin is the largest provider of electricity in Nigeria, supplying power to residential, commercial, and industrial consumers.

Research has shown that global warming is primarily caused by the excessive release of greenhouse gases, particularly carbon dioxide, into the atmosphere. Human activities are the main source of these emissions, primarily from the burning of fossil fuels, which release combustion byproducts into the air. The process of electricity generation in a steam thermal plant involves the combustion of fossil fuels in a boiler to generate heat. In Egbin's power generation process, natural gas is the fossil fuel used.

Power plants and industrial facilities account for a significant portion of Lagos's emissions and according to the Egbin sustainability report of 2019, CO2 emissions from the combustion of natural gas for power generation in Egbin power plant was 2.16 million metric tons. The Greenhouse gas (CO2) emission fell to 2.16 million metric tons in 2019 from 2.56 million metric tons in 2018. Also 85.9ppm average composition of NOx was recorded in stack emissions. This figures presents highly significant amount of emissions.

•Stationary Energy Industrial: Lagos is home to a variety of industries, including manufacturing and refining. These industries are major contributors to the city's stationary energy emissions, particularly in terms of carbon dioxide and other greenhouse gases.

•Stationary Energy Residential : Energy used for lighting, cooking, heating, and cooling in buildings contributes to Lagos' stationary energy emissions. The use of traditional biomass for cooking in some areas also adds to the emission levels.

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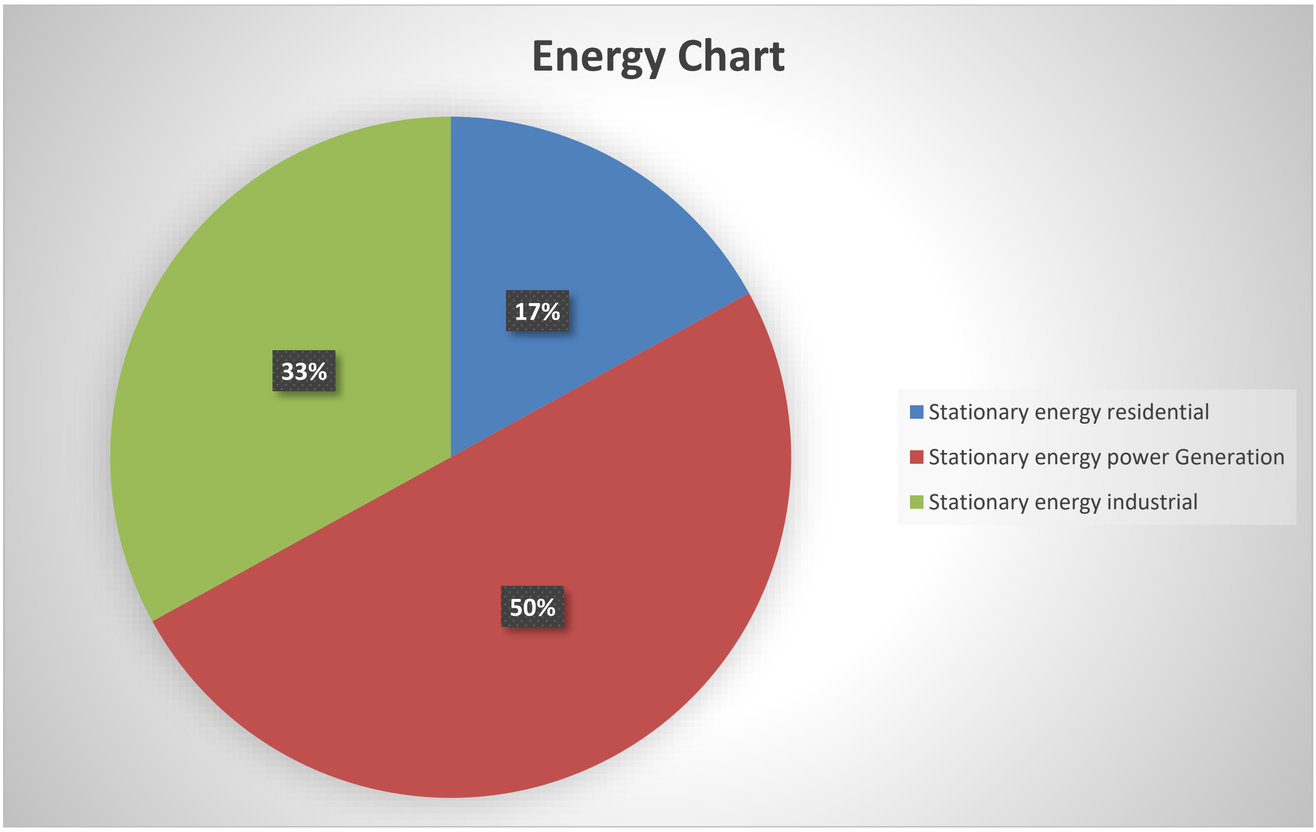


Figure 8. A chart showing stationary energy contributor

5.4 GREENHOUSE GAS EMISSIONS FROM WASTE IN LAGOS

Figure 9. Waste disposal and emission. Image source: https://www.premiumtimesng.com/

Emissions from waste arise from the decomposition of organic matter under anaerobic conditions, resulting in the generation and release of methane into the atmosphere. Methane has a higher global warming potential (GWP) than CO_2, but remains in the atmosphere for a shorter period. [CO_2 (carbon dioxide) stays in the atmosphere for up to 200 years. CH_4 (methane) stays in the atmosphere for approximately 12 years, but 1 tonne of CH_4 has a global warming impact equivalent to 28 tonnes of CO_2. Source: IPCC.] The burning of waste by households and on open dump- sites also generates GHG emissions and air pollution. Waste currently accounts for 25% of Lagos's emissions, roughly half of which results from industrial waste and the other half from solid waste (illegal dumping and doped landfill) and waste water. Figure 10 shows waste emission broken down.[12]

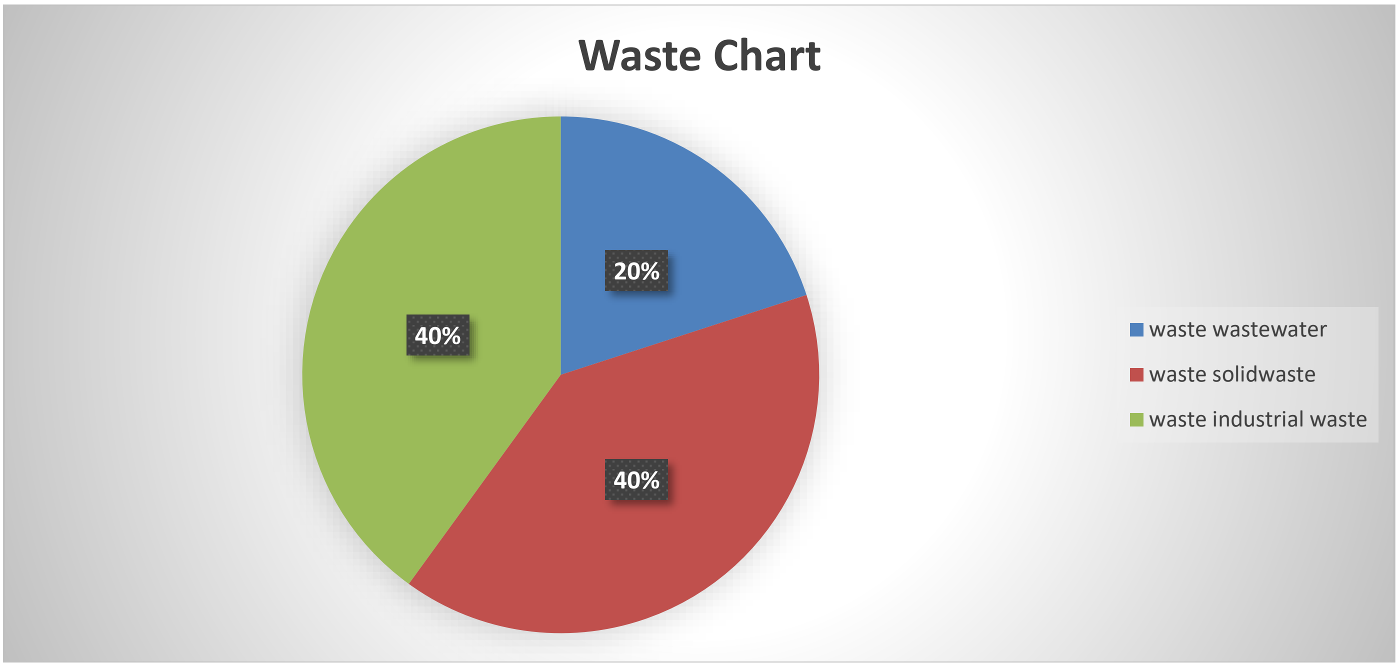


Figure 10

These three sectors are typically the largest emitters in urban areas. Reporting on emissions from other sectors, such as agriculture, forestry, industrial processes and product use, is recommended but not required under the GPC standard.

Emissions were calculated using collected and existing data, which was entered into an excel- based tool, The City Inventory Reporting and Information System(CIRIS),to pro- duce a BASIC reporting format.

Chapter 6

6.0 Impacts on Ecosystems and Biodiversity

Lagos State has developed a vulnerability analysis and risk profile to identify the most high-risk, high- vulnerability zones. Assets located in or along flood plains, riverbanks and the Atlantic coastal region are among the most vulnerable to the growing risk of flooding and sea-level rise. The analysis identified 6,983 assets within the state, including infrastructure, buildings and other features, as vulnerable to, and to varying extents exposed to, climate risk.

The demographic composition of Lagos State's population also has significant implications for its vulnerability. Of the projected 2023 population, approximately 13 million of 22 million inhabitants, or just under 65%, are expected to be vulnerable to climate impacts. A large percentage of Lagos's residents is considered extremely poor, which drastically reduces the population's adaptive capacity. In addition, rapid population growth forms a significant stressor across all sectors, both public and private. The analysis also identified three economic sectors that are particularly vulnerable to climate impacts: tourism, agriculture and infrastructure.

Lagos's tourism industry is highly reliant on coastal features, which are under significant threat from inundation and sea level rise. These hazards have already led to the loss of Alfa beach, a once vibrant tourist attraction.

Furthermore, a number of residents of coastal communities have lost their homes to storm surges. Climate change will exacerbate the vulnerability of coastal communities, threatening tourism and the local economy. Promotion of the tourism industry to create economic and social prosperity is one of the strategic goals of the Lagos Resilience Strategy. It must be acknowledged that an increase in coastal tourism, and subsequently in economic activity in coastal areas, will result in increased vulnerability to climate impacts as it will increase the number of people and the value of assets exposed to those impacts. Agricultural activities are intrinsically vulnerable to climate change and its impacts. Rising temperatures and extreme heat events form significant risks for farmers, while storm surges, coastal inundation and subsidence will also threaten the fishing industry.

Climate change impacts on agriculture will not only negatively impact the local economy and food security, but may also lead to loss of life in communities that rely on subsistence farming. Although impact projections contain large uncertainties, significant land-use change is expected in the next century and subsidence and inundation are highly likely to occur. This will exacerbate agricultural vulnerability and exposure. Examples of such impacts includes

6.1 Ocean Acidification

The increased concentration of greenhouse gases, particularly CO2, leads to ocean acidification by altering the chemistry of seawater. This process has far-reaching consequences for marine life, particularly organisms that rely on carbonate ions for building their skeletons and shells. Addressing the root cause of increased CO2 emissions is crucial to mitigating the impacts of ocean acidification. Greenhouse gases, particularly carbon dioxide (CO2), play a significant role in ocean acidification through a process known as carbon dioxide dissolution and subsequent chemical reactions. Here's how it happens:

•Carbon Dioxide Dissolution: The increased concentration of carbon dioxide in the atmosphere, largely due to human activities such as burning fossil fuels and deforestation, leads to higher CO2 levels in the surface layer of the ocean.CO2 dissolves in seawater, forming carbonic acid (H2CO3).

•Chemical Reactions: Carbonic acid undergoes dissociation in seawater, releasing hydrogen ions (H+) and bicarbonate ions (HCO3-).The released hydrogen ions make the seawater more acidic by lowering its pH.

•Impact on Carbonate Ion Concentration: The excess hydrogen ions resulting from the dissociation of carbonic acid can also react with carbonate ions (CO3^2-) in the seawater.

This reaction reduces the concentration of carbonate ions, which are essential building blocks for marine organisms like corals, mollusks, and some planktonic species.

•Effects on Marine Life: Many marine organisms, especially those with calcium carbonate skeletons or shells (e.g., corals, mollusks, and some plankton), rely on carbonate ions to build and maintain their structures.

The decrease in carbonate ions hinders the ability of these organisms to form and maintain their calcium carbonate structures.

•Ecological Consequences:

Weakening the structures of coral reefs and shells can have cascading effects on marine ecosystems. Coral reefs provide habitat for numerous species, and shell-forming organisms are critical components of the marine food web.

Additionally, some species may be more vulnerable to ocean acidification than others, potentially leading to shifts in the composition of marine communities.

•Global Implications: Ocean acidification poses a global threat to marine biodiversity and ecosystems, impacting fisheries, coastal economies, and the livelihoods of communities dependent on marine resources.

6.2 Sea Level Rise:

The warming of the planet contributes to the melting of glaciers and polar ice caps, resulting in rising sea levels.

Sea level rise can lead to the loss of coastal habitats, threatening the existence of species that depend on these ecosystems, such as mangroves, estuaries, and salt marshes.

6.3 Loss of Biodiversity:

The combined effects of temperature changes, altered precipitation, sea-level rise, and extreme weather events can contribute to habitat loss and fragmentation.

Habitat loss is a significant driver of biodiversity loss as it diminishes the available living space for various species.[13]

Chapter 7

7.1 MITIGATION

Mitigation is action to limit Climate change This action either reduces emission of greenhouse gases or remove those gases from the atmosphere The recent rise in global temperature is mostly due to emissions from burning fossil fuels such as coal, oil, and natural gas. There are various ways that mitigation can reduce emissions. These are transitioning to sustainable energy sources, conserving energy, and increasing efficiency. It is possible to remove carbon dioxide (CO_2) from the atmosphere. This can be done by enlarging forests, restoring wetlands and using other natural and technical processes. The name for these processes is Carbon Sequestration. Governments and companies have pledged to reduce emissions to prevent dangerous climate change. These pledges are in line with international negotiations to limit warming.

7.2 Energy sector

Energy sector emissions account for 30%% of Lagos State's total GHG emissions. The national grid does not produce enough electricity to meet the growing demand, which means that users have to rely on diesel generators as backup, also during power outages. A 2013 survey found over 17,000 such generators in 13,000 residential, industrial and commercial locations.

Deploying decentralized renewable energy installations can enhance the reliability and climate resilience of the energy supply while reducing emissions.

Renewable Energy Integration:
Technology: Solar and wind power

Many countries have adopted solar and wind energy as practical solutions for reducing emissions in their energy sectors. These technologies are well-established and continue to grow in use.

Energy-Efficient Lighting Upgrades:
Technology: LED lighting technology

Many businesses and municipalities are replacing traditional incandescent and fluorescent lighting with energy-efficient LED lights. This technology is readily available, cost-effective, and provides significant energy and cost savings.

Industrial Cogeneration:

Technology: Combined Heat and Power (CHP) systems

Industries often use CHP systems to simultaneously generate electricity and useful heat from a single energy source, such as natural gas. These systems have been in use for years, offering energy efficiency and emissions reductions.

Building Energy Retrofits:

Technology: Energy-efficient HVAC systems and insulation

Building owners and governments are retrofitting existing structures with energy-efficient heating, ventilation, and air conditioning (HVAC) systems and improving insulation. These technologies are mature and yield substantial energy savings.

Carbon Capture and Storage (CCS):

Technology: Carbon capture technology

Some industrial facilities use CCS to capture and store carbon emissions. CCS is a proven technology used in various applications to mitigate emissions from industrial processes.[14]

7.3 Transport Sector

Transport sector emissions account for 45% of Lagos State's total GHG emissions. The development of Lagos State's public transport infrastructure has not kept pace with its population growth. As a result, 1 million vehicles travel in the State every day, causing significant congestion and pollution. The State has already undertaken several interventions to improve Lagos's public transport infrastructure, for the benefit of the population and to reduce emissions. Projects include the expansion of the bus rapid transit (BRT) system and the planning of a light rail transit (LRT) system. The State also aims to launch new ferry routes for commuters. In addition, the State has adopted laws and policies to ban certain vehicles from major highways and to promote and develop infrastructure for non- motorized transport, among others. The following actions are planned:

Public Transportation Electrification:

Technology: Electric buses and trams

Cities like Los Angeles and New York have introduced electric buses and trams into their public transportation systems. Electric public transit vehicles are a proven technology that reduces emissions and improves air quality.

Adoption of Electric Vehicles:

Technology: Electric Vehicles (EVs)

Tesla and Other EV Manufacturers: Companies like Tesla, Nissan, and Chevrolet have produced and sold electric vehicles for years. The Tesla Model 3, for instance, is one of the most popular EVs worldwide, with a proven track record for reliability and range.

Existing technology, such as lithium-ion batteries, enables these vehicles to travel hundreds of miles on a single charge, making them practical for daily use.[15]

Introduction of Biofuel

The introduction of bioethanol and biodiesel would gradually phase out the tradition gasoline, it could be mixed with gasoline, and also bio diesel to replace diesel, which would lead to a cleaner emission and less carbon emission.

Bioethanol, a form of renewable energy, plays a significant role in reducing greenhouse gas emissions, aligning with the global efforts to mitigate climate change. Let's explore how bioethanol achieves this:

1. Bioethanol

- Derived from Biomass: Bioethanol is produced from biomass, primarily using crops like corn, sugarcane, and wheat. These plants absorb carbon dioxide (CO2) from the atmosphere during their growth, contributing to a carbon cycle.
- Renewable Source: Unlike fossil fuels, bioethanol comes from renewable resources. Its feedstock can be replanted and harvested continuously, ensuring a sustainable energy source.

2. Reduction of Greenhouse Gas Emissions

- Lower Carbon Footprint: When burned, bioethanol releases CO2, but the amount is significantly lower than that released by fossil fuels. Moreover, the CO2 emitted is partially offset by the CO2 absorbed during the feedstock's growth.
- Lifecycle Emissions: Studies show that bioethanol's lifecycle emissions (from

production to consumption) are lower compared to gasoline. For example, sugarcane-based ethanol can reduce greenhouse gases by about 90% compared to gasoline.

3. Blending with Gasoline

- E10, E15, and E85: Bioethanol is often blended with gasoline in various proportions, such as E10 (10% ethanol), reducing overall emissions from vehicles.
- Improved Engine Efficiency: Some high-ethanol blends like E85 (85% ethanol) can be used in flexible fuel vehicles, further enhancing emission reduction.

4. Economic and Environmental Benefits

- Reduced Dependency on Fossil Fuels: It decreases reliance on oil imports, promoting energy independence.
- Agricultural Boost: Bioethanol production supports the agricultural sector by creating a market for certain crops.

Bioethanol, as a cleaner-burning fuel, contributes significantly to reducing greenhouse gas emissions. Its role in a sustainable energy future is promising, but it's also crucial to balance its production with environmental and economic considerations. As we continue to explore renewable energy sources, bioethanol remains a key player in the journey towards a more sustainable and eco-friendly world.[16]

•Expansion of the BRT network in Lagos, including construction of four bus terminal gateway hubs: Expand and improve the BRT network, including by deploying low-emission buses, and construct bus gateway terminals to transfer passengers from interstate buses and private vehicles to the BRT at the edge of the city.
•Implementation of physical and spatial development plans that encourage low-emission development: Introduce new requirements for spatial planning to promote transit-oriented development.
•Adopt and implement the NMTP, including improvements to ferry safety and services: Develop infrastructure and introduce incentives for non-motorized transport, and expand and improve regulatory oversight of the ferry services.
•Encourage the uptake of low-emission vehicles: Provide incentives and invest in infrastructure to promote the uptake of ultra-low emission vehicles and impose restrictions on the use of high-polluting vehicles.
•Encourage the shift of freight from road to rail: Establish rail links between major ports,

industrial centers and airports to allow for freight transportation by rail.

These options involves expanding and improving the public transport system, such as buses, rail, and water transport. This option could reduce PM2.5 emissions by 28% and greenhouse gas emissions by 22% by 2030[1]. The estimated cost of this option is $2.9 billion, which includes the capital cost of new infrastructure, vehicles, and stations, and the operating cost of fuel and maintenance.[17]

7.4 Waste Sector

Waste sector emissions account for 25.3% of the total GHG emissions of Lagos State and are expected to grow significantly due to population growth and changing consumption patterns as residents' disposable income increases. Waste water emissions are also projected to increase as the population grows. Several interventions are already underway to improve waste management and curb emissions, including the construction of new waste processing facilities, initiatives to promote recycling and the upgrading and expansion of sewers and waste water treatment.

Waste-to-Energy Conversion:

Technology: Waste-to-energy plants

Waste-to-energy facilities, which incinerate waste to produce electricity and heat, are deployed in various regions. This technology addresses waste management while contributing to emission reductions.

Water and Waste water Treatment Upgrades:

Technology: Advanced treatment processes

Municipalities upgrade water and wastewater treatment plants with advanced processes that reduce energy consumption and emissions while improving water quality.

•Waste infrastructure development strategy: Develop and implement a comprehensive strategy to expand and enhance solid waste management infrastructure.

•Implement waste separation at source and promote alternative uses for organics: Divert organic waste from landfill by encouraging separation at source and introducing composting technologies.

•Waste management strategies for underserved communities: Implement composting, waste-to-energy and other waste recovery initiatives in underserved communities.

•Monitor, evaluate and update private sector participants' (PSP) waste collection contracts:

Evaluate and where necessary update waste collection contracts to double the collection rate of residential waste (to at least 90%).
•Construct sanitary landfills with land-fill gas capture at existing and new sites: Convert existing open dumps into sanitary landfills and capture methane to produce electricity.
•Scale up biodigester use in households and communities: Equip low-income communities with biodigesters to treat solid and liquid waste.
•Install effluent treatment plants for 50% of industrial businesses: Institute incentives to ensure 50% of industrial businesses effectively treat their waste water.[18]

Others sectors

Improved Agricultural Practices:

Technology: Precision agriculture techniques

Example: Precision agriculture, which utilizes technology like GPS-guided tractors and sensors to optimize farming practices, reduces emissions by improving efficiency and minimizing resource use.

Afforestation and reforestation:

Planting of trees and green plants helps with carbon sequestration in a process where the plants takes in CO2 from the atmosphere thereby helping to take off the CO2 in the atmosphere.

7.5 Reducing Green House Emissions

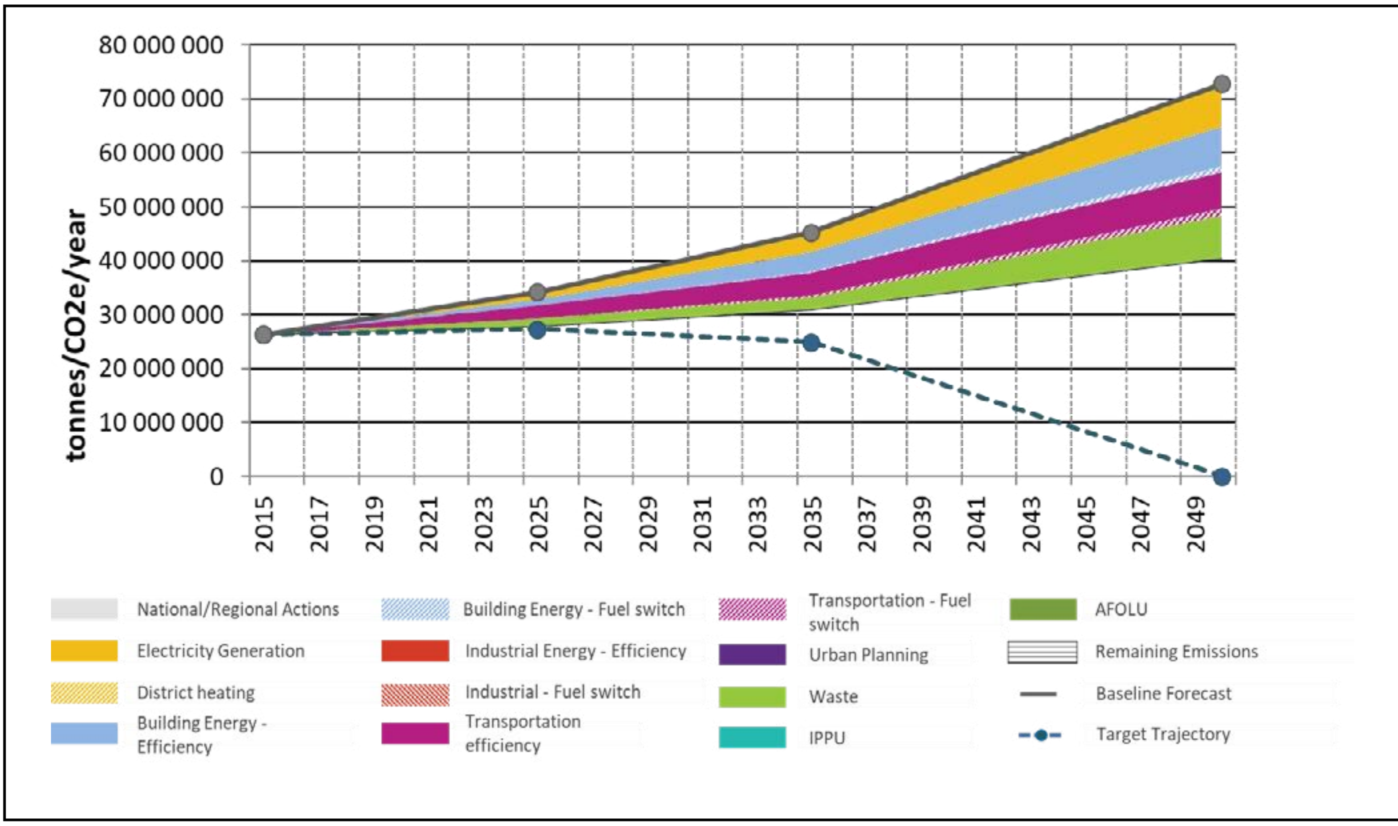
Greenhouse gas emissions inventory

Strategies to achieve carbon neutrality by 2050, as is required to meet the targets of the Paris Agreement, must be built on reliable climate evidence. Lagos has developed an emissions inventory to allow it to identify the areas and sectors with the highest potential for GHG emissions reduction, select transformative climate actions and accelerate the transition to a zero-carbon economy.

The actions discussed in this section aim to transform Lagos’s waste and waste water management systems to reduce GHG emissions and improve sanitation in the city. LAWMA’s goals are to go beyond just creating an efficient waste collection system, to developing a system that can effectively recycle and manage waste to reduce GHG emissions and environmental impact. Key waste and wastewater targets that will contribute to emissions reductions under the CAP include:

• Divert 50% of organic waste to composting sites by 2050;

• Reduce open dumping and burning of organic waste by 50% by 2050



CAP Scenario emissions reductions by 2050

Figure 12. CAP Scenario emissions reductions

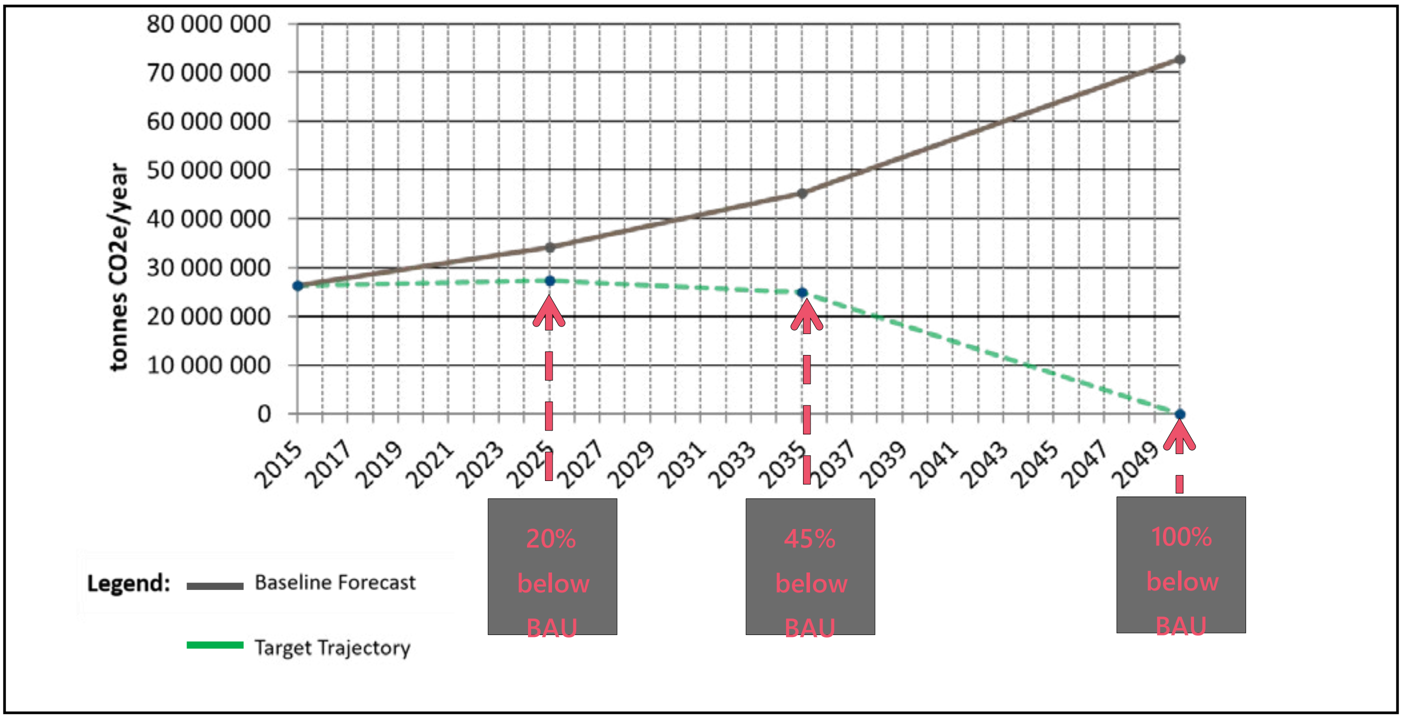


Figure 13 The first city-level GHG inventory for Lagos was published in 2018, using data for the year 2015. In 2019, the GHG inventory was updated with improved 2015 data. The inventory was developed based on the GPC Protocol for Cities,[GPC Protocol: https://ghgprotocol.org/ greenhouse-gas- protocol-accounting-reporting-standard-cities] which meets IPCC standards but provides a methodology tailored to urban contexts. The GPC standard requires that cities, at a minimum, report on their emissions in the following sectors:

Stationary energy

Emissions resulting from fuel combustion to generate energy for use in buildings (residential, commercial and industrial), including solid and liquid fuels (scope 1) as well as electricity supplied to buildings by the grid (scope 2).

Transport

Emissions resulting from fuel combustion to generate energy for transport, including liquid fuels (scope 1) as well as grid-supplied energy for electric vehicles (scope 2).

Waste

Emissions resulting from the treatment of solid waste (e.g. waste disposed of in open landfills, dumping, burning) and waste water (e.g. wastewater pre-treated in septicsystems, sewage treatment plants and septage handling facilities)within the city boundaries(scope1)as well as waste generated in the city but treated outside the city boundaries (scope 3).

These three sectors are typically the largest emitters in urban areas.

Reporting on emissions from other sectors, such as agriculture, forestry, industrial processes and product use, is recommended but not required under the GPC standard. Emissions were calculated using existing data, which was entered into an excel based tool, the City Inventory Reporting and Information System (CIRIS), to produce a BASIC reporting format.[19]

Chapter 8

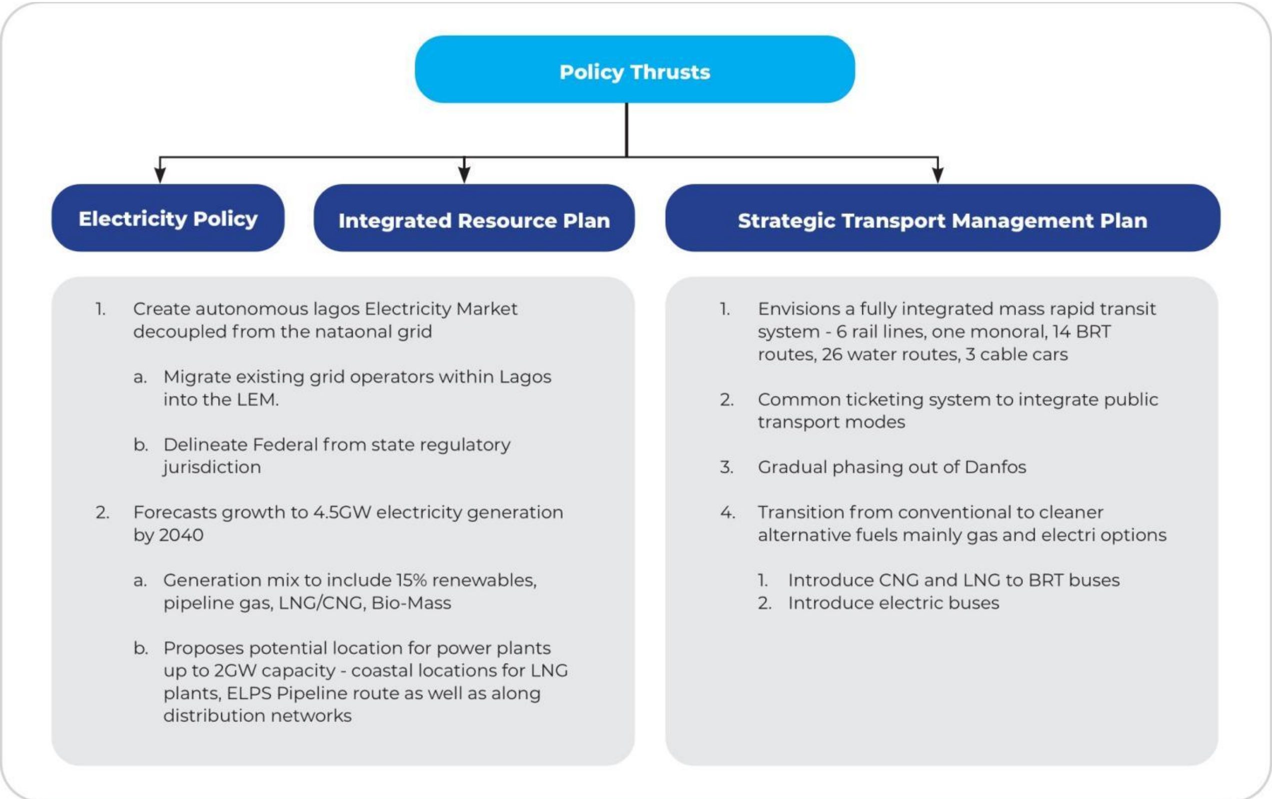


Figure 14. Policy Thrust. Image Source: Lagos CAP final report.

8.1 National and International Policies

National Policies: At a national level, Nigeria's Climate Change Act of 2021 provides a framework for achieving low greenhouse gas emissions through green growth and sustainable development. This Act also aligns with Nigeria's commitment to net-zero emissions declared at COP26.

Energy Transition Plan: Nigeria's Energy Transition Plan (ETP), released in August 2022, outlines the country's strategy to achieve its 2060 net-zero target. This plan is critical for states like Lagos, which is a significant contributor to Nigeria's GDP and faces major threats from air pollution due to traffic congestion and industrial activities.

These initiatives show a comprehensive approach to mitigating climate change effects, with an emphasis on collaboration, innovation, and sustainable development. The Lagos Government's strategic actions are not only aimed at reducing greenhouse gas emissions but also ensuring the city's adaptation to the changing climate and enhancing the quality of life for its residents.[20]

8.2 Role of Governments and Regulatory Bodies

The Lagos State Government has actively engaged in combating climate change and promoting low greenhouse gas emissions through various policies and strategic actions:

Climate Action Plan 2020-2025: This plan was unveiled with the goal of transforming Lagos into a zero-carbon city by 2050. It focuses on reducing emissions in key sectors such as energy, transport, and waste management. The state government has committed to engaging with experts, organizations, and the global community to remain at the forefront of climate action. The policy as shown in figure 14 are some policy thrust hat the government has introduced and these includes:

1. Electricity policy:

•Create autonomous Lagos Electricity Market decoupled from the national grid.

•Delineate federal from state regulatory jurisdiction.

•Forecast growth to 4.5GW electricity generation by 2040

•Generation mix to include 15% renewables, pipeline gas, LNG/CNG, Bio Mass.

•Proposes potential locations for Power plants up to 2GW capacity- coastal for LNG plants, ELPS pipeline route as well as distribution networks.

2. Strategic Transport Management System:

• Envision a fully integrated mass raid transit system - 6 rail lines, one monorail, 14 BRT routes, 26 water routes, 3 cable cars.

• Common ticketing system to integrate public transport modes.

• Gradual phasing out of the traditional yellow buses locally known as danfo.

•Transition from conventional to cleaner alternative fuels mainly gas and electric options by introducing CNG and LNG to BRT buses and also introducing electric buses.

Sustainable Urban Planning:

Lagos has integrated climate resilience into urban development, with investments in flood control, sustainable transportation systems, and green spaces. This is part of the broader goal to build a climate-resilient state that prioritizes the well-being of residents.

Infrastructure Projects:

As part of the climate change plan, the state is constructing an 18 km embankment and sea walls to protect over 2.7 million people, including vulnerable populations, from climate threats. This project aims to attract public funding and commercial investment to support resilience.

Government Incentives and Infrastructure:

Many governments have introduced incentives, tax credits, and rebates to encourage the adoption of electric vehicles. These policies, combined with existing charging infrastructure, support the practicality of EVs.

For instance, Norway has seen a significant increase in EV adoption due to strong government incentives.

Corporate Fleets and Public Transit:

Businesses and public transportation agencies have integrated electric vehicles into their fleets. These entities use readily available electric bus and electric van technology to reduce emissions and operational costs.

Major cities, like London, have electric bus fleets that contribute to lower emissions and improved air quality.

Used EV Market:

The availability of used electric vehicles demonstrates the maturity and feasibility of the technology. As new EV models are introduced, used EVs become affordable options for consumers.

The used EV market is expanding as more early adopters upgrade to newer models, making electric vehicles accessible to a wider range of buyers.

Charging Networks:

The establishment of charging networks, including public and private charging stations, further supports the feasibility of electric vehicles. Drivers can easily find places to charge their EVs, reducing range anxiety.

Companies like Charge Point and EVgo offer nationwide charging infrastructure in the United States.

The adoption of electric vehicles demonstrates the practicality of existing technology for emissions reduction in the transportation sector. These vehicles have become a viable and widely accepted solution, benefiting from advancements in battery technology and supportive policies. As technology continues to improve, electric vehicles will play an increasingly significant role in reducing greenhouse gas emissions from the transportation sector.[21]

Chapter 9

9.1 COST AND CARBON BENEFITS EVALUATION

For the cost and carbon benefit evaluation, we used the following equation to calculate the cost-effectiveness ratio of each option:

Cost-effectiveness

This is the ratio of the total system costs to the emission benefits of an option. It indicates how much it costs to achieve a unit of emission reduction. We calculated it as follows

$$CE = C/EB. \qquad \text{Eq 9.1}$$

Where:

- CE is the cost-effectiveness ratio of an option (US$/tCO2e)
- C is the total system costs of an option (US$ billion)

- EB is the emission benefits of an option (MtCO2e)

We assessed the carbon benefits and total system costs for each proposed emissions reduction plan. We also compared the carbon benefits achieved with the overall costs incurred. To calculate the cost-effectiveness ratio, we divided the total system costs of an option by the emission benefits. We then converted the units from US$/MtCO2 to US$/tCO2 by multiplying by 10^3. Table below summarizes the results of our evaluation.

Table 9.1 comparison of cost effectiveness for emission reduction options

Option	Carbon Benefits (MtCO2e)	Total System Costs (US$ billion)	Cost-Effectiveness (US$/tCO2e)
Using cleaner passenger vehicles	9.8	3.4	347
Shifting to public transport	8.3	2.9	349
Adopting cleaner fuel	4.9	1.2	245
Implementing emission standards and monitoring	2.3	0.4	174
Adopting composting, recycling, and waste-to-energy	5.6	1.1	196
Improving waste collection and disposal	1.7	0.4	235

Options:

Plan A: Transition to Renewable Energy

Expected Carbon Benefits: Transitioning to renewable energy sources, such as wind and solar power, is estimated to reduce the city's annual CO2 emissions by 10,000 metric tons.

Total System Costs: The cost of installing solar panels, wind turbines, and grid infrastructure is estimated to be $5 million.

Plan B: Promote Public Transportation

Expected Carbon Benefits: Encouraging the use of public transportation could reduce the city's annual CO_2 emissions by 5,000 metric tons.

Total System Costs: Implementing this plan would involve investing in a new fleet of electric buses and improving public transit infrastructure at a cost of $2 million.

Now, let's compare the two plans using the Cost and Carbon Benefit Evaluation:

Plan A: Carbon Benefits: 10,000 metric tons of CO_2 reduction

Total Costs: $5 million

Carbon Benefit-to-Cost Ratio: 10,000/5,000,000 = 0.002 (or 0.2%)

Plan B: Carbon Benefits: 5,000 metric tons of CO_2 reduction

Total Costs: $2 million

Carbon Benefit-to-Cost Ratio: 5,000/2,000,000 = 0.0025 (or 0.25%)

Plan B(Promote Public Transportation) has a higher carbon benefit-to-cost ratio, indicating that it is more cost-effective in terms of emissions reduction compared to Plan C (Transition to Renewable Energy).

However, other factors, such as feasibility, public support, and potential co-benefits (e.g., reduced traffic congestion and improved air quality with Plan B), were also considered when making the final decision. The city's decision-makers would need to weigh these factors and the results of this evaluation to make an informed choice regarding which plan to implement.

Plan C: Energy Efficiency Upgrades

Expected Carbon Benefits: Upgrading equipment and processes is estimated to reduce the company's annual CO_2 emissions by 3,000 metric tons.

Total System Costs: The cost of implementing energy-efficient technologies and equipment is $2 million.

Plan D: Carbon Offsetting

Expected Carbon Benefits: The company can purchase carbon offsets to compensate for its emissions, effectively reducing its annual CO_2 emissions by 2,000 metric tons.

Total System Costs: The cost of purchasing carbon offsets is $500,000.

Plan C: Carbon Benefits: 3,000 metric tons of CO_2 reduction

Total Costs: $2 million

Carbon Benefit-to-Cost Ratio: 3,000/2,000,000 = 0.0015 (or 0.15%)

Plan D: Carbon Benefits: 2,000 metric tons of CO_2 reduction

Total Costs: $500,000

Carbon Benefit-to-Cost Ratio: 2,000/500,000 = 0.004 (or 0.4%)

Plan D(Carbon Offsetting) has a significantly higher carbon benefit-to-cost ratio, indicating that it is more cost-effective in terms of emissions reduction compared to Plan C (Energy Efficiency Upgrades). However, the company should consider the long-term sustainability and reputation benefits of each plan in addition to these ratios.

Plan E: Renewable Energy Procurement

Expected Carbon Benefits: Procuring renewable energy for public buildings is estimated to reduce the city's annual CO_2 emissions by 6,000 metric tons.

Total System Costs: The cost of renewable energy contracts and infrastructure upgrades is $3 million per year.

Plan F: Urban Reforestation

Expected Carbon Benefits: Planting trees in the city to absorb CO_2 is estimated to reduce the city's annual CO_2 emissions by 4,000 metric tons.

Total System Costs: The cost of tree planting and maintenance is $1.5 million per year.

Plan E: Carbon Benefits: 6,000 metric tons of CO_2 reduction

Total Costs: $3 million per year

Carbon Benefit-to-Cost Ratio: 6,000/3,000,000 = 0.002 (or 0.2%)

Plan F: Carbon Benefits: 4,000 metric tons of CO_2 reduction

Total Costs: $1.5 million per year

Carbon Benefit-to-Cost Ratio: 4,000/1,500,000 = 0.00267 (or 0.267%)

Plan F (Urban Reforestation) has a higher carbon benefit-to-cost ratio, suggesting it is more cost-effective in terms of emissions reduction. However, other factors like public engagement and the potential for community beautification should be considered when making a decision.

9.2 Categorization of Projects

We categorized the proposed emission reduction options based on their carbon benefits versus total system cost. We classified them as follows:

High Value – Accelerate Implementation

We identified the following projects that offer significant carbon benefits at reasonable costs. We prioritized these projects for expedited implementation.

- Implementing emission standards and monitoring

This project has the lowest cost-effectiveness ratio among all the options, meaning that it can achieve the highest carbon benefits per unit of cost. It can also improve the environmental performance and compliance of the industrial sector, which is a major source of emissions in Lagos.

- Adopting composting, recycling, and waste-to-energy

This project has the second lowest cost-effectiveness ratio among all the options, and it can also reduce methane emissions, which have a higher global warming potential than CO2. It can also improve the waste management system in Lagos, which is currently inadequate and poses health and environmental risks.

Margin Benefit vs. Costs – Seek New Innovation

We identified the following projects that offer moderate carbon benefits compared to costs. We explored opportunities for innovation or alternative approaches to enhance their feasibility.

- Adopting cleaner fuel

This project can reduce emissions from both the industrial and transport sectors, but it requires a large upfront investment in new equipment and infrastructure. It also depends on the availability and affordability of natural gas or renewable energy sources. We suggest seeking new innovation opportunities to lower the costs and increase the supply of cleaner fuel options.

- Improving waste collection and disposal

This project can reduce emissions from the waste sector, but it has a relatively high cost-effectiveness ratio compared to other options. It also does not address the root cause of the waste problem, which is the excessive generation of waste. We suggest seeking new innovation opportunities to reduce the amount of waste produced and increase the efficiency of waste collection and disposal services.

Low Benefits at High Cost – Redirect or Seek New Innovation Opportunity

We identified the following projects with limited carbon benefits but high costs. We considered redirecting resources to other projects or seeking new innovation opportunities with greater potential.

- Using cleaner passenger vehicles

This project has the highest cost-effectiveness ratio among all the options, meaning that it can achieve the lowest carbon benefits per unit of cost. It also requires a large-scale replacement of existing vehicles, which may face social and economic barriers. We suggest redirecting resources to other projects that can achieve higher carbon benefits at lower costs, such as shifting to public transport or adopting cleaner fuel.

- Shifting to public transport

This project has a similar cost-effectiveness ratio as using cleaner passenger vehicles, and it can also reduce emissions from the transport sector. However, it also requires a large-scale expansion and improvement of the public transport system, which may face technical and institutional challenges. We suggest seeking new innovation opportunities to enhance the accessibility, affordability, and reliability of public transport services.[21

Chapter 10

10.1 Future Trends

Lagos State is an economic hub in Nigeria and West Africa, and its population is expected to continue to grow. The population of Lagos is projected to double by 2050. This growth will likely result in an increase in gross domestic product (GDP), but also in increased demand for housing, energy and waste management. Meeting the basic needs of Lagos's rapidly growing population will put enormous pressure on its municipal systems, which already struggle to serve the city's current population. The Paris Agreement was adopted after the 21st Conference of the Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015. The 191 signatory countries to this historic agreement have committed to taking action to limit the global average temperature rise due to climate change to well below 2 °C, and preferably below 1.5 °C. In the lead-up to COP21, more than 160 countries submitted Intended Nationally Determined Contributions (INDCs), setting out each country's approach to reducing emissions and adapting to a changing climate. Since COP 21, countries have been invited to confirm these intentions by ratifying the Paris Agreement and submitting Nationally Determined Contributions (NDCs) to the UNFCCC. Nigeria's INDC falls under the remit of the Nigeria Climate Change Policy and Response Strategy (NCCPRS) and focuses on the delivery of direct development benefits and sustainable economic growth whilst reducing GHG emissions and building resilience to climate change.[22]

Nigeria's latest GHG emissions estimates indicate around 2 tonnes of CO2 equivalent (tCO2e) per capita, per year and the INDC projects that by 2030, under a business-as-usual (BAU) scenario, total emissions will grow by 114% to 900 million tCO2e (approximately 3.4 tCO2e per capita). The high-growth scenario projects 2030 emissions of over 1 billion tCO2e/year. The conditional INDC target for 2030 aims to stabilize emissions at around 2 tCO2e per capita. The INDC sets out a series of mitigation goals to be achieved by 2030, including:

- Ending gas flaring by 2030;
- Deploying 13 GW of off-grid solar PV generation capacity;
- Installing efficient gas generators;
- Improving energy efficiency by 2% per year (30% by 2030);
- Achieving a shift in transport use from private cars to buses;
- Improving the electricity grid;
- Promoting climate-smart agriculture and reforestation. The mitigation actions included in the INDC to a large extent reflect existing policies and strategies. However, additional legislation and regulatory changes will be required to reach Nigeria's emissions reduction targets.

Climate change has been recognized as a critical development issue since the early 1990's, due to its predicted impacts on biodiversity, livelihoods and national and global economies. Studies have shown that poor countries and people will disproportionately suffer from the effects of climate change due to their lack of institutional, financial and technological capacity for adaptation and mitigation. The unique features of Lagos State, including its large and rapidly growing population and its topography, marked by extensive low-lying and coastal areas and a high water table, further increase its vulnerability to climate change impacts. In 2008, the State established a unit (now a fully-fledged department)within the Ministry of the Environment and Water Resources to coordinate its climate change response strategies. The State has taken proactive steps to address climate change impacts because it recognized that temperature increases, sea level rise and increased flooding are likely to severely affect all parts of its economy and society, and jeopardizes its development.[23]

10.2 Innovations in sustainability

Innovations in sustainability encompass a wide range of developments aimed at reducing environmental impact. Examples include advancements in renewable energy technologies, such as more efficient solar panels and energy storage solutions. Circular economy practices, emphasizing recycling and reusing materials, contribute to sustainability. Smart grid technologies enhance energy efficiency, while green building materials and designs promote eco-friendly construction. Sustainable agriculture practices, like precision farming, help minimize environmental impact. Overall, ongoing innovations across various sectors play a crucial role in fostering a more sustainable future. Some of which includes:

Renewable Energy Technologies:

Advancements in solar panel efficiency, like perovskite solar cells.

Improved wind turbine designs for increased energy output.

Energy Storage Solutions:

Development of high-capacity and long-lasting batteries for storing renewable energy.

Circular Economy Practices:

Innovative recycling technologies, such as chemical recycling for plastics.

Upcycling initiatives that transform waste materials into valuable products.

Smart Grid Technologies:

Integration of smart meters and sensors to optimize energy distribution and consumption.

Green Building Materials and Designs:

Use of sustainable materials like bamboo and recycled steel.

Implementation of energy-efficient designs and smart building systems.

Sustainable Agriculture:

Precision farming techniques using IoT devices and data analytics for optimal resource use.

Agro ecology practices that promote biodiversity and reduce the need for synthetic inputs.

Transportation Innovations:

Electric vehicles (EVs) and advancements in battery technology for longer ranges.

Development of sustainable fuels such as biofuels and hydrogen.

Water Conservation Technologies:

Smart irrigation systems that optimize water usage in agriculture.

Water purification technologies for efficient water treatment.

Waste Reduction Initiatives:

Zero-waste packaging solutions.

Innovative methods for repurposing and reusing waste materials.

Carbon Capture and Storage (CCS):

Technologies to capture and store carbon emissions from industrial processes.[24]

10.3 Public Awareness and Advocacy

Educational Campaigns: Awareness programs, workshops, and educational campaigns inform the public about the importance of sustainable practices, fostering a deeper understanding.

Social Media Activism: Online platforms provide a space for individuals and organizations to share information, raise awareness, and mobilize support for sustainable causes.

Non-Governmental Organizations (NGOs): NGOs often lead advocacy efforts, campaigning for policy changes, sustainable practices, and environmental protection.

Celebrities and Influencers: High-profile individuals can leverage their platforms to champion sustainable living, influencing a broad audience to adopt eco-friendly habits.

Community Engagement: Local initiatives and community-based projects create a sense of shared responsibility, encouraging sustainable practices at the grassroots level.

Consumer Awareness: Informed consumers make choices that prioritize sustainable products and services, driving businesses to adopt more environmentally friendly practices.

Policy Advocacy: Advocacy groups work towards influencing policymakers to enact and enforce regulations that promote sustainability and environmental protection.

Global Events: Events like Earth Day or climate strikes draw attention to environmental issues and encourage collective action on a global scale.

Media Coverage: News outlets and documentaries contribute to public awareness by highlighting environmental challenges, solutions, and success stories.

Corporate Responsibility: Companies engaging in transparent and sustainable practices contribute to public awareness by setting examples for responsible business behavior.[25]

Chapter 11

11.1 Conclusion

Lagos State is responsible for a significant portion of Nigeria's waste, residential energy-related, and transport emissions. Therefore, transitioning to a low-emissions economy in Lagos is critical for Nigeria to achieve its climate mitigation goals. The Lagos

State Emissions Reduction Project was designed to take inventory of the resources/infrastructures that are emission sources or points of carbon emission which cause climate change in the state.

The project engaged various stakeholders across the state to obtain their views on climate change risks/vulnerabilities and strategies of adaptation. It also outlines several strategies for reducing emissions in Lagos State, including improving waste management, promoting energy efficiency, and increasing the use of renewable energy sources. And also it emphasizes the importance of integrating policies and tax incentives to bolster the feasibility and cost-effectiveness of proposed solutions.

Key Category Analysis is a good practice to identify key categories of emissions, as it helps prioritize efforts and improve the overall quality of the national inventory, while also guiding mitigation policies, strategies, and actions.

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List of Abbreviation

AD	Activity Data
CO2	Carbon Dioxide
EF	Emission Factor
GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Emission Inventories
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
NCC	Nigerian Communications Commission
NERC	Nigerian Electricity Regulatory Commission
NORSDA	National Oil Spill Detection and Response Agency
PM2.5	Particulate Matter 2.5
REDD+	Reducing Emissions from Deforestation and Forest Degradation
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute
CDM	Clean Development Mechanism
BAU	Business As Usual

APPENDIX:

A). Road transport:

- Using cleaner passenger vehicles:

- Emission benefits: We assumed that the baseline scenario is the current situation, where there are 2.5 million passenger vehicles in Lagos, with an average fuel efficiency of 8 km/liter and an average emission factor of 2.4 $kgCO_2$/liter. We also assumed that the option scenario is the future situation, where 50% of the passenger vehicles are replaced with cleaner ones, such as hybrid, electric, or CNG vehicles, with an average fuel efficiency of 16 km/liter and an average emission factor of 1.2 $kgCO_2$/liter. We calculated the emission benefits as follows:

$$EB = 2.5\times10^6\times8\times2.4\times365 = 17.5\times10^9 \ kgCO_2/year$$

$$EO = (2.5\times10^6\times0.5\times8\times2.4) + (2.5\times10^6\times0.5\times16\times1.2)\times365 = 12.9\times10^9 \ kgCO_2/year$$

$$EB = EB - EO = 17.5\times10^9 - 12.9\times10^9 = 4.6\times10^9 kgCO_2/year$$

$$EB = 4.6\times10^9\div10^6 = 4.6 \ MtCO_2/year$$

Assuming a linear trend, the emission benefits for 10 years (2020-2030) are:

$$EB = 4.6\times10 = 46 \ MtCO_2$$

Costs: We assumed that the capital cost of a new cleaner vehicle is $20,000, the operating cost of fuel and maintenance is $0.1/km, and the cost of scrapping an old vehicle is $500. We calculated the costs as follows:

$$CC = 2.5\times10^6\times0.5\times20{,}000 = US\$25\times10^9$$

$$CO = (2.5\times10^6\times0.5\times8\times0.1) + (2.5\times10^6\times0.5\times16\times0.1)\times365\times10 = US\$8.2\times10^9$$

$$CS = 2.5\times10^6\times0.5\times500 = US\$0.6\times10^9$$

$$C = CC + CO + CS = 25\times10^9 + 8.2\times10^9 + 0.6\times10^9 = US\$33.8\times10^9$$

$$C = 33.810^9\div10^9 = US\$33.8 \ billion$$

Cost-effectiveness: we calculated the cost-effectiveness ratio as follows:

$$CE = C/CB = 33.8/46 = US\$0.735/kgCO_2\}$$

$$CE = 0.735\times10^3 = US\$735/tCO_2$$

- Shifting to public transport:

- Emission benefits: we assumed that the baseline scenario is the current situation, where there are 2.5 million passenger vehicles in Lagos, with an average fuel efficiency of 8 km/liter and an average emission factor of 2.4 kgCO2/liter. We also assumed that the option scenario is the future situation, where 40% of the passenger vehicles are shifted to public transport, such as buses, rail, and water transport, with an average emission factor of 0.8 kgCO2/passenger-km. We calculated the emission benefits as follows:

EB = 2.5×10^6×8×2.4×365 = 17.5×10^9kgCO2/year

EO = (2.5×10^6×0.6×8×2.4) + (2.5×10^6× 0.4×8×0.8)×365 = 13.8×10^9kgCO2/year

EB = EB – EO = 17.5×10^9 – 13.8×10^9 = 3.7×10^9×kgCO2/year

EB = 3.7×10^9÷10^6 = 3.7MtCO2/year

Assuming a linear trend, the emission benefits for 10 years (2020-2030) are:

EB = 3.7×10 = 37MtCO2

Costs: We assumed that the capital cost of new infrastructure, vehicles, and stations for public transport is $10,000/passenger-km, and the operating cost of fuel and maintenance is $0.05/passenger-km. We calculated the costs as follows:

CC = 2.5×10^6×0.4×8×10,000 =US$ 80×10^9

CO = 2.5×10^6×0.4×8×0.05×365×10 = US$2.9×10^9

C = CC + CO = 80×10^9 + 2.9×10^9 = US$82.9×10^9

C = 82.9×10^9÷10^9 = US$82.9 billion

Cost-effectiveness: We calculated the cost-effectiveness ratio as follows:

CE = C/EB = 82.9/37 = US$2.24/kgCO2

CE = 2.24×10^3 = US$2,240/tCO2

B). Industrial emissions:

- Adopting cleaner fuel:

- Emission benefits: We assumed that the baseline scenario is the current situation, where the industrial sector consumes 2.5 billion liters of diesel per year, with an average emission factor of 2.7 kgCO2/liter. We also assumed that the option scenario is the future situation, where 50% of the diesel consumption is replaced with natural gas or renewable energy sources, with an average emission factor of 1.35 kgCO2/liter. We calculated the emission benefits as follows:

$$EB = 2.5\times10^9\times2.7 = 6.75\times10^9 kgCO_2/year$$

$$EO = (2.5\times10^9\times0.5\times2.7) + (2.5\times10^9\times0.5\times1.35) = 5.06\times10^9 kgCO_2/year$$

$$EB = EB – EO = 6.75\times10^9 – 5.06\times10^9 = 1.69\times10^{\wedge} kgCO_2/year$$

$$EB = 1.69\times10^9\div10^6 = 1.69MtCO_2/year$$

Assuming a linear trend, the emission benefits for 10 years (2020-2030) are:

$$EB = 1.69\times10 = 16.9MtCO_2$$

Costs: We assumed that the capital cost of new equipment, pipelines, and connections for natural gas or renewable energy sources is \$0.5/liter, and the operating cost of fuel and maintenance is \$0.4/liter. We calculated the costs as follows:

$$CC = 2.5\times10^9\times0.5\times0.5 = US\$0.625\times10^9$$

$$CO = 2.5\times10^9\times0.5\times0.4\times10 = US\$5\times10^9$$

$$C = CC + CO = 0.625\times10^9 + 5\times10^9 = US\$5.625\times10^9$$

$$C = 5.625\times10^9\div10^9 = US\$5.625 \text{ billion}$$

Cost-effectiveness: We calculated the cost-effectiveness ratio as follows:

$$CE = C/EB = 5.625/16.9 = US\$0.333/kgCO_2$$

$$CE = 0.333\times10^3 = US\$333/tCO_2$$

- Implementing emission standards and monitoring:

  - Emission benefits: We assumed that the baseline scenario is the current situation, where the industrial sector emits 2.5 $MtCO_2$/year, without any emission standards or monitoring. We also assumed that the option scenario is the future situation, where the industrial sector reduces its emissions by 10% by complying with emission standards and monitoring. We calculated the emission benefits as follows:

$$EB = 2.5MtCO_2/year$$

$$EO = 2.5\times0.9 = 2.25MtCO_2/year$$

$$EB = EB – EO = 2.5 – 2.25 = 0.25MtCO_2/year$$

Assuming a linear trend, the emission benefits for 10 years (2020-2030) are:

$EB = 0.25 \times 10 = 2.5MtCO_2$

Costs: We assumed that the cost of compliance, inspection, and enforcement for emission standards and monitoring is \$0.1/kgCO2. We calculated the costs as follows:

$C = 2.5 \times 10^6 \times 0.1 \times 10 = US\$0.25 \times 10^9$

$C = 0.25 \times 10^9 \div 10^9 = US\$0.25$ billion

Cost-effectiveness: We calculated the cost-effectiveness ratio as follows:

$CE = C/EB = 0.25 \div 2.5 = US\$0.1/kgCO_2$

$CE = 0.1 \times 10^3 = US\$100/tCO_2$

C). Waste management:

- Adopting composting, recycling, and waste-to-energy:

- Emission benefits: We assumed that the baseline scenario is the current situation, where the waste sector generates 4 Mt of waste per year, with an average emission factor of 0.8 kgCO2/kg of waste. We also assumed that the option scenario is the future situation, where 50% of the organic waste is diverted to composting, 30% of the other waste materials are recycled, and 20% of the waste is converted to energy. We calculated the emission benefits as follows:

$EB = 4 \times 10^6 \times 0.8 = 3.2 \times 10^6 kgCO_2/year$

$EO = (4 \times 10^6 \times 0.5 \times 0) + (4 \times 10^6 \times 0.3 \times 0.2) + (4 \times 10^6 \times 0.2 \times 0.8) = 0.64 \times 10^6 kgCO_2/year$

$EB = EB – EO = 3.2 \times 10^6 – 0.64 \times 10^6 = 2.56 \times 10^6 kgCO_2/year$

$EB = 2.56 \times 10^6 \div 10^6 = 2.56MtCO_2/year$

Assuming a linear trend, the emission benefits for 10 years (2020-2030) are

$EB = 2.56 \times 10 = 25.6MtCO_2$

Costs: We assumed that the capital cost of new facilities, equipment, and vehicles for composting, recycling, and waste-to-energy is \$50/ton of waste, and the operating cost of collection, processing, and disposal is \$10/ton of waste. We calculated the costs as follows:

$CC = 4 \times 10^6 \times 50 = US\$200 \times 10^6$

$CO = 4 \times 10^6 \times 10 \times 10 = US\$400 \times 10^6$

$C = CC + CO = 200 \times 10^6 + 400 \times 10^6 = US\$600 \times 10^6$

$C = 600 \times 10^6 \div 10^9 = 0.6US\$$ billion

Cost-effectiveness: We calculated the cost-effectiveness ratio as follows:

$CE = C/EB = 0.6 \div 25.6 = US\$0.023/kgCO_2$

$CE = 0.023 \times 10^3 = US\$23/tCO_2$

- Improving waste collection and disposal:

  - Emission benefits: We assumed that the baseline scenario is the current situation, where the waste sector generates 4 Mt of waste per year, with an average emission factor of 0.8 $kgCO_2/kg$ of waste. We also assumed that the option scenario is the future situation, where the efficiency and coverage of waste collection and disposal services are improved by 20%, reducing the amount of waste that is burned or dumped illegally. We calculated the emission benefits as follows:

$EB = 4 \times 10^6 \times 0.8 = 3.2 \times 10^6 kgCO_2/year$

$EO = 4 \times 10^6 \times 0.8 \times 0.8 = 2.56 \times 10^6 kgCO_2/year$

$EB = EB – EO = 3.2 \times 10^6 – 2.56 \times 10^6 = 0.64 \times 10^6 kgCO_2/year$

$EB = 0.64 \times 10^6 \div 10^6 = 0.64 MtCO_2/year$

Assuming a linear trend, the emission benefits for 10 years (2020-2030) are:

$EB = 0.64 \times 10 = 6.4 MtCO_2$

Costs: We assumed that the cost of collection, transportation, and disposal of waste is \$15/ton of waste. We calculated the costs as follows:

$C = 4 \times 10^6 \times 15 \times 10 = US\$600 \times 10^6$

$C = 600 \times 10^6 \div 10^9 = US\$0.6$ billion

Cost-effectiveness: We calculated the cost-effectiveness ratio as follows:

$CE = C/EB = 0.6 \div 6.4 = US\$0.094/kgCO_2$

$CE = 0.094 \times 10^3$ = US\$94/tCO_2