RMI | WASTEMAP

Mitigating Methane Emissions from Municipal Solid Waste

A Playbook for Lagos, Nigeria

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Authors and Acknowledgements

Authors

Ebun Ayandele
Jyoti Bodas
Anisha Krishnakumar
Linus Orakwe, ENOP Concept International Limited

Authors listed alphabetically. All authors from RMI unless otherwise noted.

Contributors

Tom Frankiewicz, RMI
Yuchen Wu, RMI
Preston Enubuje, ENOP Concept International Limited
Regina Patinvoh, ENOP Concept International Limited
Lilian Okafor, ENOP Concept International Limited

Contacts

Ebun Ayandele, eayandele@rmi.org
Linus Orakwe, o.orakwe@enopconcept.com

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About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and nongovernmental organisations to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

About WasteMAP

The Waste Methane Assessment Platform (WasteMAP), a joint initiative by RMI and Clean Air Task Force, is an open online platform that brings together waste methane emissions data with decision support tools for stakeholders in the waste sector. The platform is supported by country engagement that involves collaboration with national and subnational governments, waste management officials, and other key decision makers to provide capacity building and technical assistance — providing a pathway to reduce solid waste methane emissions. Please visit our website www.wastemap.earth to learn more.

About GMH

The Global Methane Hub organises the field of philanthropists, experts, nonprofits, and government organisations to ensure we unite around a strategy to maximise methane reductions. We have raised over $200 million in pooled funds from more than 20 of the largest climate philanthropies to accelerate methane mitigation across the globe. Visit www.globalmethanehub.org to learn more about organisations that support the commitment.

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Executive Summary

In 2016, about 2 billion tonnes of municipal solid waste (MSW) were generated globally, and this estimate is projected to increase by 70% to almost 4 billion tonnes by 2050. Much of the increase will be driven by the fastest growing regions, including sub-Saharan and North Africa, South Asia, and the Middle East, where waste is expected to grow by as much as double to triple current levels.

As the seventh most populous country in the world, Nigeria currently generates 32 million tonnes of solid waste annually, a majority of which is sent to dumpsites. This waste generation level is projected to more than triple by 2050, to reach 107 million tonnes annually. The Nigerian city of Lagos, the most populous city in Africa, accounts for about 15% of the annual solid waste generated nationwide.

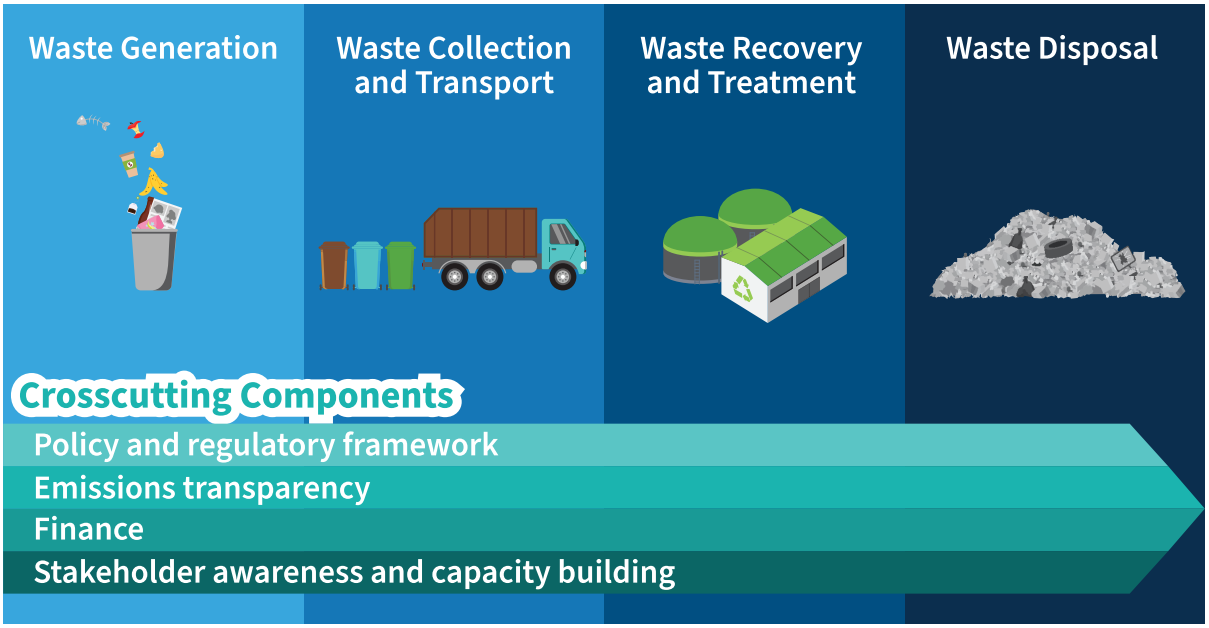
These trends demand that more sustainable waste management systems be deployed in Nigeria and across the globe to promote public health and safety, and to ensure that the waste management system can adequately handle increasing waste generation. However, an equally important but less discussed issue is the climate impact of unsustainable waste management systems. The biodegradable component of MSW (e.g., food scraps and yard waste) decomposes in landfills and dumpsites and generates methane, which is often released into the atmosphere.

Methane is a short-lived climate pollutant with a global warming potential about 80 times higher than carbon dioxide. Thus, curbing methane emissions is a critical opportunity to limit near-term global warming. Achieving the Global Methane Pledge, which aims to reduce global methane emissions across high-emitting sectors (like the waste sector) by at least 30% of 2020 levels by 2030, would eliminate over 0.2°C of warming by mid-century. As a signatory of this pledge, Nigeria can help accelerate progress by implementing methane abatement solutions. However, many countries and cities often lack actionable resources or a "playbook" that defines a pathway for deploying methane abatement strategies tailored to their unique waste management situation.

This playbook provides concrete, actionable strategies to reduce methane emissions from MSW in Lagos, considering the city's existing waste management system. First, it provides a brief overview of current MSW management practices. Next, it explores opportunities across the value chain to deliver deep cuts in MSW methane emissions by leveraging the strategies outlined in RMI's ***A Playbook for Municipal Solid Waste Methane Mitigation: Recommendations Based on Global Waste Management Archetypes*** for the so-called Build the Basics (BtB) waste management archetype, which characterises the solid waste management landscape in Nigeria.

These strategies are organised based on the waste management value chain: waste generation, collection and transport, recovery and treatment, and disposal, as well as a crosscutting component that explores policy and regulatory framework, emissions transparency, finance, and stakeholder awareness and capacity-building opportunities. Together, the strategies provide a holistic approach to curbing methane emissions from MSW (see Exhibit ES1).

Exhibit ES1 Scope of methane mitigation strategies



RMI Graphic. Source: RMI analysis

With a focus on methane mitigation strategies post-waste generation, the playbook explores opportunities to improve, expand, and optimize separation of organic waste at the source, waste collection efficiency, organics processing, design and operation at disposal sites, enabling policy environment, emissions transparency, access to affordable finance, and stakeholder awareness and capacity building. Many of the challenges facing MSW management in Lagos reflect those in other cities across the nation. Accordingly, these solutions, although tailored to Lagos, can be used by other Nigerian cities to unlock significant methane reductions.

To conclude, the authors recommend three key levers to accelerate methane reductions, improve waste management systems, and better align current practices with the waste management hierarchy. These levers — build basic waste infrastructure, develop technical capacity, and provide affordable project finance — will facilitate near-term and long-term emissions reduction. Realizing methane emissions reduction in the near term will require operational improvements to reduce emissions from waste-in-place at dumpsites such as minimising the active working face, installing daily covers, and installing basic gas capture systems.

However, for more sustainable long-term emissions reduction, biodegradable waste should be diverted from disposal sites and the recovered organic material converted for beneficial end use. Key actors can begin to curb MSW methane emissions by deploying basic operational improvements that are relatively inexpensive at the dumpsites and small-scale composting and anaerobic digestion facilities, prior to developing more robust and advanced solutions that are capital intensive and can often pose a major constraint on implementation.

These actions can unlock huge reductions in waste sector methane emissions, help Nigeria deliver on its ambitious climate commitments, and slow down global warming in this decade, while delivering powerful co-benefits such as improved public health and safety and air and land quality, as well as greater economic development.

1. Introduction

In 2020, an estimated 2.24 billion tonnes of municipal solid waste (MSW) were generated globally. By 2050, this value is expected to increase by 70% to 3.88 billion tonnes.[1] In regions with the fastest growing populations, including sub-Saharan and North Africa, South Asia, and the Middle East, waste generation is expected to double or even triple current levels by 2050.[2] This rapid growth in waste generation is driven by growing populations, economic development, and increasing earning power.

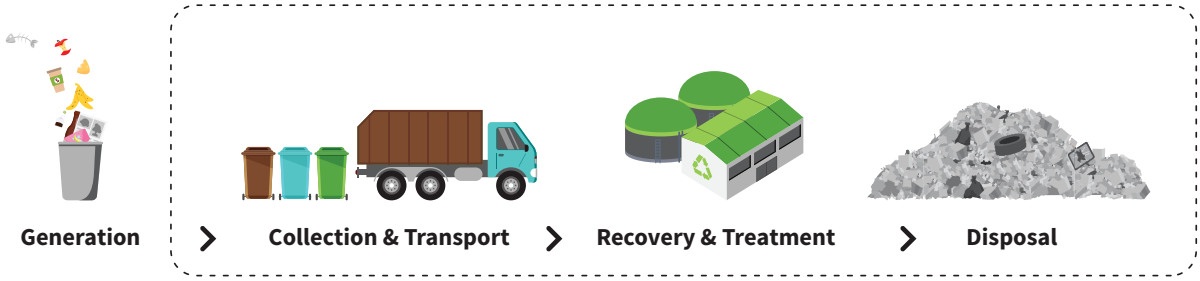
As the seventh most populous country in the world, Nigeria generates about 32 million tonnes of waste annually, and is projected to generate 107 million tonnes annually by 2050.[3] This waste is sent to open dumpsites where the biodegradable components of the waste stream decompose under anaerobic conditions to generate landfill gas (LFG), which is composed of methane and carbon dioxide, the two greenhouse gases (GHGs) that most significantly contribute to global warming.

Methane is a superpotent GHG with a relatively shorter atmospheric lifetime than carbon dioxide. However, methane has over 80 times the global warming impact of carbon dioxide on a 20-year time horizon and has accounted for roughly 30% of global warming since preindustrial times. The waste sector, which accounts for about 20% of human-caused methane emissions, combined with the growing waste trend, underscores the need for more sustainable waste management solutions and an opportunity to slash methane emissions.

The Global Methane Pledge, launched in November 2021, aims to catalyse action to reduce global methane emissions by at least 30% of 2020 levels by 2030. Achieving the Global Methane Pledge would eliminate over 0.2°C of global warming by mid-century.[4] By joining this initiative, Nigeria has pledged absolute methane reduction targets of at least 45% by 2025 and 60%–75% by 2030 from waste and other sectors.[5]

This report aims to help Nigeria meet its ambitious climate targets by outlining a pathway to reduce methane emissions from MSW management in Nigeria's economic hub of Lagos, after waste is generated (see Exhibit 1).

Exhibit 1 The municipal solid waste value chain



The scope of this report includes methane mitigation strategies after waste has been generated. It does not explore strategies prior to waste being generated (i.e., source reduction).

RMI Graphic. Source: RMI analysis

It serves as a playbook for Lagos and recommends concrete, actionable strategies that are tailored to Nigeria's waste management archetype.[6] The strategies in this playbook are intended to support decision makers in improving waste management and protecting public health in Lagos, a city that can represent Nigeria's commitment to its ambitious climate goals.

2. Overview of Municipal Solid Waste Management Landscape

According to Nigeria's National Policy on Solid Waste Management, MSW includes solid waste generated by households; commercial and industrial establishments; institutions such as schools, hospitals, care homes, and prisons; and public spaces, including streets, markets, slaughterhouses, public toilets, bus stops, parks, and gardens. This includes commercial and business waste streams, but excludes hazardous waste, such as from industrial processes.[7]

Nigeria is sub-Saharan Africa's largest economy, and Lagos is the commercial capital and economic nerve center of Nigeria.[8] Lagos produces about one-third of Nigeria's total GHG emissions from waste.[9]

Municipal Solid Waste Management in Lagos

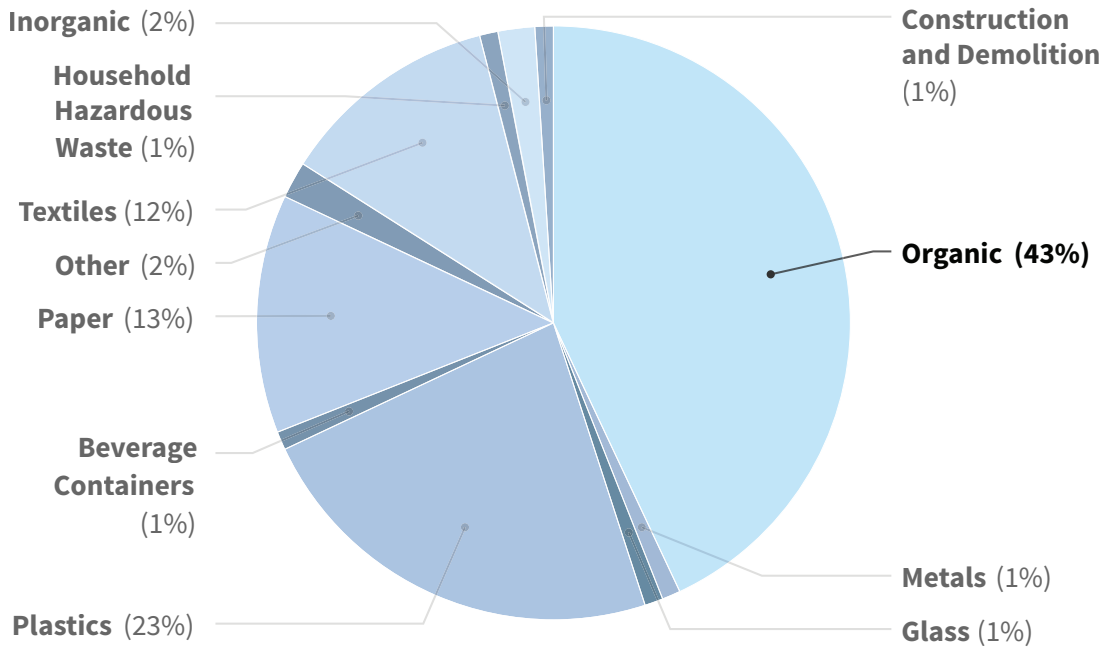
Located in the South West region of Nigeria, Lagos is the most populous city in Africa, with an estimated population of 21 million people.[10] This coastal city, which represents about 10% of Nigeria's population and occupies a total landmass of 3,577 square kilometres, is ranked among the top 10 fastest growing cities in the world.[11] With this comes a huge amount of waste generated in this bustling metropolis. The Lagos Waste Management Authority (LAWMA) is statutorily responsible for regulating all MSW management activities across the value chain. LAWMA is also empowered by the Environmental Management and Protection law of 2017 to handle waste management operations, and thus, the agency plays the dual role of a regulator and an operator.[12]

Waste generation

More than 13,000 tonnes of solid waste are generated daily in Lagos, accounting for about 15% of the total solid waste generation in Nigeria.[13] This waste emanates from households, commercial centres, industrial and market complexes, recreational centres, and highways. Other sources include hospitals, schools, waterfronts, motor parks, and event centres.

Organic waste is the single largest component of the waste stream, accounting for 43% of the total waste generated (see Exhibit 2). Because there is typically no source separation of organic waste in Lagos, most waste generators dispose of all their waste in the same bag or bin for collection.[14] A very small number of organised estates in the city practice a two-bin system where recyclables like glass, plastic, and metal are separated from the residual mixed waste. However, collection is a challenge because waste haulers do not have the capacity for separate collection and may commingle segregated waste with residual mixed waste in the collection vehicle for transportation to the dumpsite.

Exhibit 2 Municipal solid waste management composition in Lagos



RMI Graphic. Source: *Guide for Recycling Activities in Lagos*, Nigeria, Lagos Waste Management Authority, December 2020.

Waste collection and transport

By law, waste generators are required to hand over their solid waste to LAWMA or LAWMA-authorized vendors, typically referred to as private-sector participants (PSPs). LAWMA operates about 100 collection vehicles and contracts an additional 350 vehicles from PSPs to meet the city's waste collection needs.[15] However, Lagos achieves a 48% collection efficiency, underscoring opportunities to expand collection coverage.[16] The city operates a single-bin system and collection is done weekly. Once collected, the commingled waste is transported to one of the five dumpsites that serve the city (see Exhibit 3). In addition to a lack of source-separated organics (SSO) in Lagos, the existing collection infrastructure is insufficient to ensure separate handling of this waste because there are no drop-off centres and the collection vehicles are not suitable to transport the wet organic fraction.

In parts of the city that are far from the dumpsites, MSW is hauled to one of three transfer loading stations, where the waste is emptied into bulk loaders (trailers) for long-distance haulage to a dumpsite. Construction of three additional transfer loading stations is underway to boost collection efficiency.

Waste recovery and treatment

Although there are several smaller informal (i.e., unregistered) resource recovery operations in Lagos, only one centralised material recovery facility is formally recognized by LAWMA. This facility is operated by WestAfricaENRG and equipped with three distinct sorting lines that function in a semiautomated system, which allows for complementary manual sorting and creates employment opportunities.[17] The facility processes recyclables including plastics,[i] nylons, glass, cardboard, aluminium, and metals. About

i Polyethylene and polyethylene terephthalate (more commonly known as PET) are very common recyclable plastics.

2,000 waste pickers scavenge through trash at the city's active dumpsites to recover valuable recyclable materials like plastics, metals, paper, and rubber, which are sold for a profit.[18]

Further, there are over 500 registered operators who handle recyclable materials from waste.[19] These include operators who are licensed to collect recyclable materials from bulk generators, collectors who engage in door-to-door collection services, those who engage in preprocessing of recyclables, and others who convert recovered materials into new products. Some initiatives and technologies being deployed to increase material recovery include buyback centres where reusable and recyclable materials are exchanged for cash or other incentives, recycling banks,[ii] preprocessing plants for recyclable materials, and the PAKAM application, an online platform that links generators and collectors.[20]

Waste disposal

There are currently no sanitary landfills in Nigeria. To manage its MSW, Lagos relies on five active dumpsites. Exposure to these dumpsites often has dangerous impacts, including air, water, and soil pollution that affect the ecosystem and health of people living near them. Examples of medical conditions suffered by people living closer to disposal sites include asthma, skin irritation, cuts, malaria, cough, cholera, and diarrhoea.[21]

In addition to these health impacts, improper waste management also has adverse climate impacts. The untreated organic fraction of this waste, including food waste, yard waste, paper, and cardboard, decomposes as anaerobic conditions are established at the dumpsite, generating LFG, which is primarily methane and carbon dioxide. Without gas collection wells to capture this gas, fugitive methane emissions are released from both active and closed dumpsites, accelerating the earth's warming.

Exhibit 3 Dumpsites in Lagos State

Name	Year opened for operation	Area covered (hectares)	Status
Olusosun	1992	42	Active
Soluos III	2008	5	Active
Ewu Elepe	2008	17	Active
Epe	2008	80	Active
Badagry	2012	20	Active
Soluos I	1994	7.8	Closed
Soluos II	2006	3.2	Closed
Abule-Egba	1992	10.2	Closed

RMI Graphic. Source: **https://hollandcircularhotspot.nl/wp-content/uploads/2020/05/Nigeria-Scoping-Mission-Waste-and-CE-Report-RVO.pdf**; **https://www.researchgate.net/publication/331676603_A_Comprehensive_Study_of_Leachate_Characteristics_from_Three_Soluos_Dumpsites_in_Igando_Area_of_Lagos_State_Nigeria**; **https://core.ac.uk/reader/234678600**; *The City of Lagos: Solid Waste Management*, Lagos Waste Management Authority, 2012; and LAWMA stakeholder conversations.

ii Recycling banks are deployed by LAWMA or donated by friends of the environment. These are typically large bins or receptacles located in public places like bus stops or markets to collect recyclable materials, which are retrieved by waste pickers or recyclers.

Organic Waste Management

As waste generation continues to increase with a rapidly growing population, there is an increasing need to adopt more sustainable alternatives to manage the growing waste. Prioritising source reduction and material reuse and recovery over final disposal will ease the burden on many disposal sites, which are fast approaching their maximum capacity.

Beyond the point of generation, diverting the biodegradable fraction of this waste from disposal sites, and processing it in treatment facilities where it can be converted into useful end products, is the best approach to mitigating methane emissions from waste.

Around the world, several technology options have been deployed to treat solid waste and/or stabilise the biodegradable organic content to minimise further decomposition and reduce methane emissions at landfills and dumpsites. Examples include composting, anaerobic digestion, mechanical biological treatment, waste-to-energy, and advanced thermal treatment. Of these, the two most commonly deployed solutions that are most suitable for the waste management landscape in Nigeria are composting and anaerobic digestion, which are described below. Waste-to-energy and advanced thermal treatment should not be considered as treatment options for organic waste due to concerns of toxic air pollutants that can lead to severe health conditions like cancer and birth defects, especially in nearby marginalized communities.[22] Further, burning organic waste lowers the calorific value of the fuel due to the high moisture content of the wet waste and represents a loss of carbon and plant nutrients that could be applied to the soil.

- **Composting** is a controlled aerobic process (i.e., oxygen is present) that involves the microbial decomposition of organic material like leaves, grass clippings, and food scraps to convert the organic substrate into compost. The compost provides nutrients to the soil in a manner that is readily useful to plants.

- **Anaerobic digestion** is the microbial decomposition of organic waste in the absence of oxygen. This process, which occurs naturally in landfills and dumpsites, takes place in enclosed biodigester tanks where the biodegradable waste is converted into biogas. The biogas can be combusted to generate electricity and heat or can be processed into renewable natural gas and transportation fuels.[23] The digestate co-product can be used as a soil enhancer for agricultural purposes.

Organic Waste Treatment Operations in Lagos

Organic waste constitutes the largest component of MSW in Lagos (see Exhibit 2, page 10). The main sources of organic waste in the city include households, food markets, public and private institutions, and industrial and commercial complexes. Further, the city of Lagos accounts for about 65% of the commercial activity and 70% of the industrial investment in Nigeria and is home to major food and beverage manufacturing and processing industries.[24]

Apart from a small fraction of organic waste that is treated at the only commercial-scale compost plant in Nigeria (which is owned by EarthCare Nigeria Limited), a few household composting activities, organic waste from restaurants and food manufacturing facilities used for animal feed, and a few small-scale biogas plants, the majority of the organic waste generated in the city is disposed of at dumpsites. Effective management of organic waste will reduce odour, disease-carrying vectors, and groundwater contamination from toxic leachate and enable beneficial end products from the recovery of organic matter.

The case studies below describe operations at two organic waste treatment facilities in Lagos: a commercial-scale compost facility and a biogas plant located at Oko-Oba abattoir. However, a few other demonstration projects exist including a black soldier fly treatment facility and a biogas plant at a food and vegetable market.

Case Study: EarthCare Compost Facility in Ikorodu, Lagos

EarthCare Nigeria Limited is a commercial producer of compost located in Ikorodu, Lagos. The facility operates a windrow system that forms organic matter into rows of long piles called "windrows," which are mixed periodically to allow air flow.[25]

The EarthCare plant is designed to produce 200,000 tonnes of compost per year but currently operates at only 10% of its design capacity.[26] To minimise contamination and increase the quality of the product, EarthCare collects food waste feedstock directly from a local market, Mile 12 International Food Markets. Once received at the plant, the feedstock undergoes a screening process to remove impurities before the windrows are formed, followed by enzyme and microbial infusion to accelerate the composting process.

To drive higher uptake of the compost (see Exhibit 4) by farmers across the nation, EarthCare has established a distributor model with at least one distributor in each of Nigeria's six geopolitical zones. These distributors supply the end users, who are predominantly micro-, small-, and medium-scale crop farmers. Despite its marketing strategy, the company has experienced low interest and poor product uptake by farmers who prefer synthetic fertilisers, which they are more familiar with, and which are subsidised by the federal government.[27] This presents an operational challenge and affects the sustainable production of compost.

Lessons learned:

- Direct collection of feedstock from the food market can minimise contamination and improve compost quality.
- Subsidies for compost similar to those for synthetic fertilisers are necessary to level the playing field, improve cost competitiveness, and support robust end markets for compost.
- Educational awareness programmes are necessary to improve farmers' knowledge of compost to improve product uptake.

Exhibit 4 **Bags of Compost at EarthCare Nigeria Limited**

RMI photo

Case Study: Biogas Facility at Oko-Oba Abattoir in Lagos

The Oko-Oba biogas facility is privately owned and operated. Once generated, the biogas is used to process and clean animal skin for a profit, an activity previously powered by burning charcoal and tyres. Biogas is produced through the anaerobic digestion of organic waste feedstock, which is mainly comprised of animal dung from the abattoir, although food waste from the nearby market is occasionally co-digested with the animal waste.

After production, the biogas is pretreated to remove moisture, and then passed through a pressure tank to a storage balloon. Some biogas equipment, like the storage balloon, was purchased from China, which contributed to high up-front cost due to the associated import fees.

Nonetheless, the project demonstrates an economically viable solution to treating organic waste, thanks to its low operational costs combined with the revenue from business operations. Securing organic waste feedstock at no cost, combined with the nonuse of diesel for electricity generation, has enabled the facility owner to keep the operating expenditures (which primarily comprise staff salaries) low. The owner receives an estimated NGN 120,000 in revenue daily from cleaning up animal skin, which can rise up to NGN 150,000 during the weekend and NGN 210,000 during festive seasons.

Biogas replaced charcoal and tyres as a fuel source due to concerns about the impact of long-term exposure of workers to harmful pollutants. Additionally, beyond cleaning animal skin, the biogas is also used to power a 50 kVA (kilovolt-ampere) generator, which powers light bulbs, water pumps, and grinding and mixing equipment for the feedstock. The residual digestate by-product is sold to farmers as organic fertiliser.

At the time of RMI's visit in May 2023, the biogas facility was not operational due to storm damage to the storage balloon. The owner cited funding challenges as the main roadblock to resuming operations. Since halting operations, the facility must pay NGN 100,000 every two weeks to evacuate the animal dung, which is no longer being processed. Further, the workers have since reverted to using charcoal to process the animal skin from the slaughterhouse, an added social cost that cannot be quantified.

Lessons learned:

- Biogas provided clean fuel to this private business owner, thereby lowering workers' exposure to harmful pollutants from burning tyres and charcoal fuel.
- Sourcing locally fabricated biogas equipment can eliminate import fees, lower up-front costs, and improve project viability.
- Co-digesting food waste with animal waste can provide a sustainable solution for recovering resources from animal waste being indiscriminately disposed of due to a lack of proper disposal systems.
- Producing biogas allows the owner to generate profit from a resource that would otherwise incur a significant cost to discard.

3. Mitigating Methane Emissions from Municipal Solid Waste: A Playbook for Lagos

With growing populations driving increasing waste generation, there is the need to implement more sustainable approaches to waste management across the globe. This issue is more dire in densely populated cities like Lagos.

Waste management in Lagos, and Nigeria at large, currently falls under the Build the Basics (BtB) archetype (see Exhibit 5).[28] This archetype is characterized by low to medium collection rates, poor waste management systems, low recycling rates, and limited or no waste treatment prior to final disposal. Waste is disposed of at dumpsites without methane monitoring and capture systems or other environmental control systems. Illegal dumping and open burning of waste are also common. Although waste management regulations exist, enforcement is weak and existing standards do not address organic waste or the emissions from this waste. There is limited technical capacity because waste management infrastructure is lacking.

Consequently, there is a need to deploy more robust waste treatment technologies, upgrade dumpsites, and develop local technical capacity to manage these systems. Accessing funding to build these critical infrastructure projects is a major roadblock for many BtB countries to advance to other waste management archetypes. For more information on other archetypes, namely, Build the Basics Plus (BtB+), Move up the Hierarchy (MuH), and Close the Circle (CtC), see ***A Playbook for Municipal Solid Waste Methane Mitigation: Recommendations Based on Global Waste Management Archetypes***. Despite this significant obstacle, countries in this archetype can begin to take steps towards mitigating methane emissions from MSW by building basic infrastructure and implementing relatively low-cost operational improvements. These can include developing decentralised small-scale organic waste processing facilities for composting and anaerobic digestion, improving compaction of waste mass, installing landfill covers, deploying locally fabricated gas collection and control systems (GCCS) at dumpsites, and limiting waste pickers' access to dumpsites after GCCS have been installed.

Exhibit 5 Global municipal solid waste management archetypes

Build the Basics (BtB)

- Low to medium waste collection rates
- Limited or no source-separated organics or recycling
- Limited or no waste treatment
- Waste is disposed of at dumpsites
- Illegal dumping and open burning of waste are common

Build the Basics Plus (BtB+)

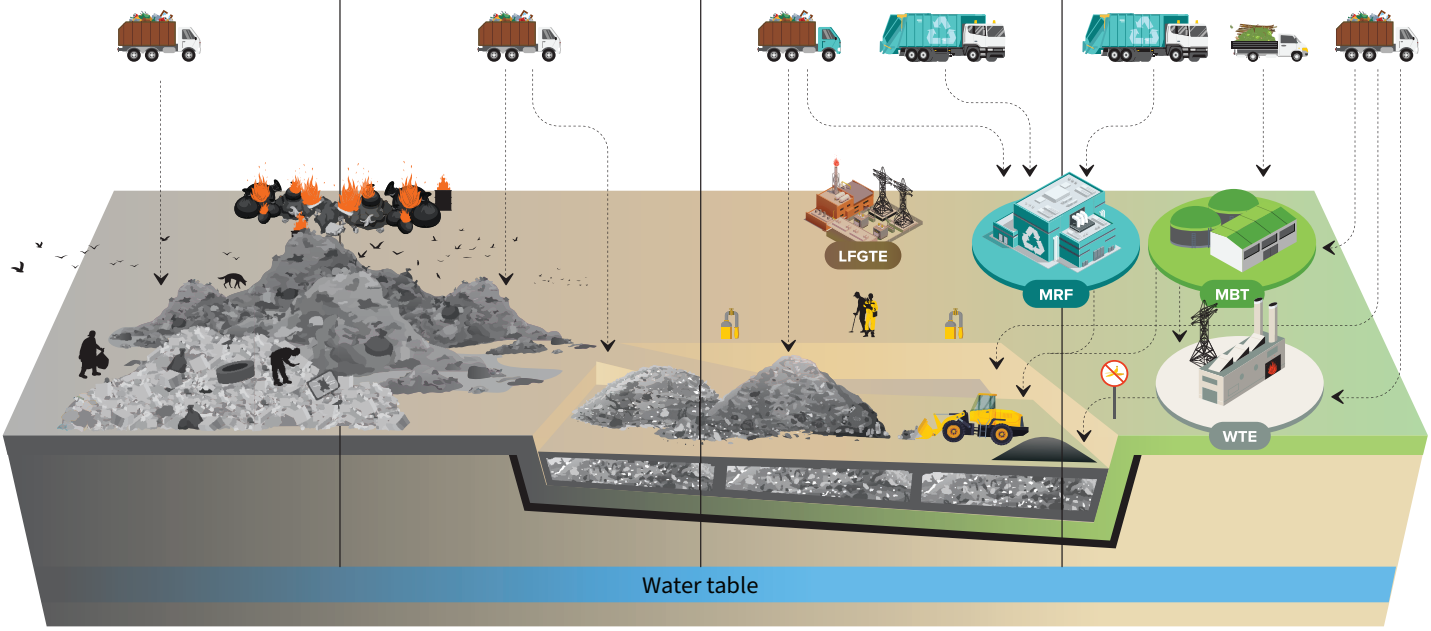
- Higher waste collection rate than BtB
- Limited or no source-separated organics or recycling
- Limited waste treatment
- Transitioning from dumpsites to sanitary landfills
- Illegal dumping and open burning of waste may occur

Move up the Hierarchy (MuH)

- Universal or near-universal waste collection
- Higher source-separated organics and recycling rates than BtB and BtB+; source-separated organics is still relatively limited compared to CtC
- Waste treatment and material recovery facilities are common
- Waste is disposed of in sanitary landfills
- Methane emissions monitoring and capture may occur

Close the Circle (CtC)

- Universal or near-universal waste collection
- In most CtC countries, source-separated organics and recycling rates are higher than in BtB and BtB+ countries and source-separated organics is mandated by law
- Most CtC countries have banned biodegradable waste from landfills
- Mechanical biological treatment and incineration of waste are common
- Least reliant on landfills



Waste collection, treatment, and disposal activities occur at different sites. Note that the primary outputs from the materials recovery facility and the mechanical biological treatment plant (e.g., plastics and biogas) are not depicted. The graphic has been simplified for illustrative purposes.

RMI Graphic. Source: RMI analysis

Per the waste management hierarchy (see Exhibit 6), which ranks waste management practices from the most preferred to the least preferred environmental option, it is worth emphasizing that although these improvements are necessary, source reduction, which describes measures to minimize waste generation, is the preferred waste management practice. Following source reduction, reuse and recycling are the next best options. In the context of MSW methane mitigation, the waste management hierarchy prioritises measures at the top of the hierarchy; these measures aim to reduce the generation of biodegradable waste or divert the biodegradable waste from disposal sites.

Studies show that Nigeria loses and wastes 40% of its total food production, a situation that may worsen given that Nigeria's population is expected to double by 2050.[29] **Thus, food waste prevention is the best and most preferred option to reduce methane emissions from MSW.** Understanding the causes of food loss and food waste, including poor harvest and post-harvest techniques, insufficient distribution and storage infrastructure, lack of cooling and refrigeration, poor food management, and consumer behaviours, is necessary to develop robust solutions that not only deliver deep methane cuts but, equally importantly, address food insecurity and malnutrition in local communities and improve the economic welfare of farmers, producers, and consumers.

Discussing opportunities to reduce methane emissions before the waste is generated is beyond the scope of this report. However, several studies explore robust solutions across the food loss and waste value chain. For example, the World Bank's *Food Smart Country Diagnostic* for Nigeria discusses food loss and waste hotspots and presents solutions including optimizing harvest, enhancing product distribution, and improving food rescue.[30]

The following section explores operational improvements as well as other robust strategies to mitigate methane emissions from MSW in Lagos after the point of generation. These strategies are broadly presented in two categories: (1) the waste value chain, which includes generation, collection and transport, recovery and treatment, and disposal; and (2) crosscutting solutions, which explore methane abatement opportunities across policy and regulatory frameworks, emissions transparency, finance, and stakeholder awareness and capacity building.

These insights were gathered from a combination of literature review and interviews with several key industry stakeholders in Nigeria and globally, including waste management officials, facility managers, technology providers, regulators, enforcement agencies, and academic institutions. Further, we describe the roles and responsibilities of key stakeholders (see Exhibits 7 to 13, and 15).[iii]

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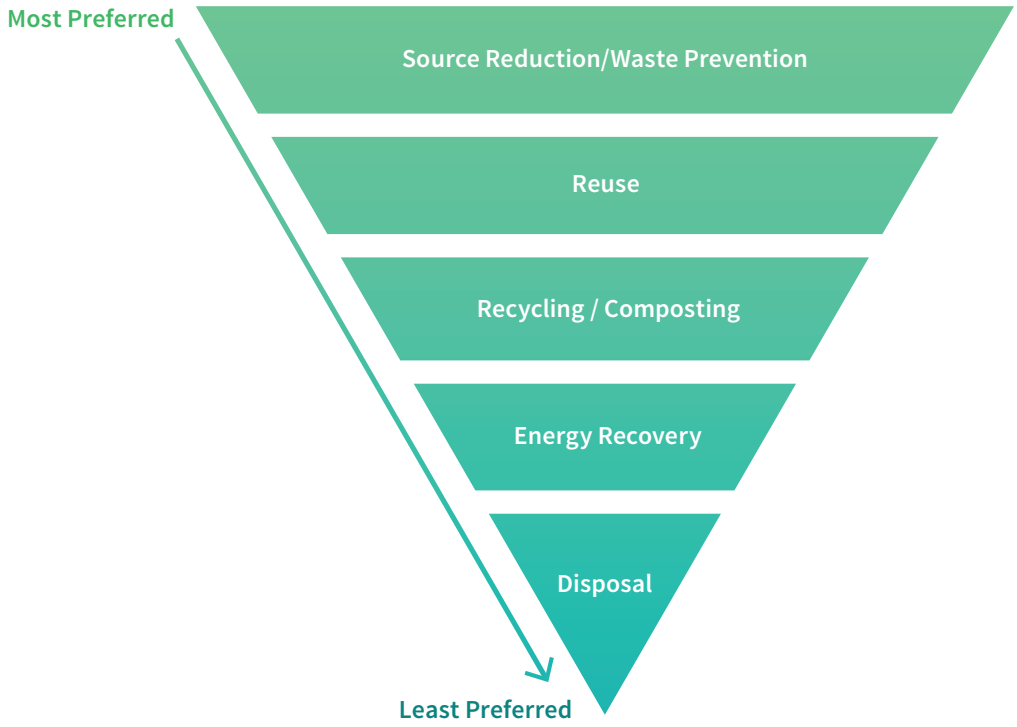
iii The roles and responsibilities presented in the section are for select stakeholder groups considered the most influential actors in implementing and promoting the recommended strategies.

Exhibit 6 Waste management hierarchy



RMI Graphic. Source: RMI analysis

Waste Generation

Reducing organic waste at the source is the cheapest and most effective way to avoid methane emissions from MSW. However, any methane emissions that are generated at the disposal site should be properly managed, starting with diverting organic waste from landfills and dumpsites.

1. Implement source-separated organics programmes

Currently, Lagos does not segregate its organic waste at the source, and biodegradable waste is commingled in a single bin. Source-separated organics (SSO) programmes require households and businesses to segregate organic waste at the point where it is generated, reducing the need for expensive technology to recover organics from mixed waste. Most SSO programmes rely on a combination of colour-coded bins for biodegradable waste and separate collection and transportation to treatment facilities, along with educational and awareness campaigns to improve programme reception and success.

Additionally, successful implementation of SSO programmes may require financial or other incentives because residents and communities often incur a greater cost due to separate collection, which can deter participation. These costs can be particularly burdensome in lower-income communities.

One approach to implementing SSO is to mandate source separation for large waste generators like schools and restaurants. For example, restaurants that meet a minimum threshold set by regulations (e.g., a certain seating capacity or amount of waste generated) could be required to participate in SSO programmes, and restaurants below that threshold could participate voluntarily.[31]

Case Study: "Green Containers" Organic Waste Source Separation Programme in Cajicá, Colombia

Around the early 2000s, the small municipality of Cajicá, Colombia, with a population under 45,000, found its only landfill to have almost reached capacity. Options for increasing the landfill's life span or dumping waste in other cities were unfeasible for Cajicá, in terms of both cost and resources.

At the time, waste management practices, like SSO or organics processing, were not common across the region. However, with 56% of its waste stream made up of organic waste, Cajicá put forth El Plan de Gestión de Residuos Sólidos, a solid waste management plan that aimed at a circular economy model using techniques like gaining public buy-in, increasing solid waste services, and applying the 3R principle (reduce, reuse, and recycle).[32]

In 2005, Cajicá launched a public awareness programme around recycling and sorting waste, alongside the development of a pilot programme requiring the separation of organic waste at the source. The positive results observed during the pilot programme resulted in the 2008 launch of an official compost programme, named the Green Containers Program. Through the programme, the city provides residents with free green containers, which are collected once a week, for their separated biodegradable waste. Additionally, every two months, the municipality distributes "bokashi" to each household, a substance that initiates and speeds up the composting process by pretreating the organic matter in the green containers.

In 2009, within one year of the Green Containers Program's implementation, a 14% decrease in organic waste at landfills was observed. The programme has increased organic waste recovery more than 200%, from 768 tonnes in 2009 to 2,364 tonnes in 2014.[33]

Lessons learned:

- The city's solid waste management plan prioritised circular economy principles, such as organics recycling, to improve project success.
- Cajicá observed positive results from the initial SSO pilot, including a significant reduction in landfilled organic waste, when the new programme was paired with an awareness campaign.
- Initiating the composting process with "bokashi" helps control odour and pests, which are sometimes barriers to the adoption of composting.

Exhibit 7 Stakeholder roles and responsibilities, waste generation

Stakeholder Group	Roles and Responsibilities
State government (LAWMA)	• Implement SSO programmes, provide designated bins to dispose organic waste, and implement enforcement mechanisms. • Promote source segregation through educational awareness campaigns and incentive programs.
Waste generators (e.g., households, markets, commercial centres)	• Segregate organic waste into designated bins. • Improve understanding about how to effectively segregate waste by participating in educational awareness campaigns and incentive programs.

RMI Graphic. Source: RMI analysis

Waste Collection and Transport

Although source separation begins with waste generators, collection is an equally critical component of diverting organic waste from dumpsites. The separated organics must be transported to treatment facilities, which often require additional collection trucks, reassessments of collection routes and collection frequency, and additional training for personnel.[34]

1. Expand waste collection infrastructure

Collecting organic waste typically requires specialised vehicles that are leak-proof and cater to the corrosive nature of food waste.[35] Because Lagos does not have vehicles suitable for collecting organic waste or compartmentalising different waste types, existing vehicles need to be modified or new fleets need to be purchased.

Further, some waste haulers in Lagos have been reported to commingle previously segregated waste, which discourages waste generators from segregating the wet organic fraction, further underscoring the need to build local awareness and technical capacity for key waste personnel.

2. Optimise collection frequency and vehicle routes

After securing vehicles to collect food and yard waste, the waste authority or PSPs should assess options to improve the efficiency of the collection process, including how frequently waste is picked up and the most optimal routes. This assessment is valuable in deciding which residential or commercial entities should pilot SSO programmes. Travelling double distances to separately collect organic waste can be a deterrent to waste haulers due to the increased cost, driven by fuel as well as labour. Minimising this distance by

optimising collection frequency and vehicle routes can help reduce the number of trips and personnel, as well as the time spent and distance travelled during the collection process.

Because food waste decomposes, a best practice is to use a separate bin for organic waste and to collect it more frequently (e.g., weekly) than residual mixed waste and other recyclables (e.g., every other week). Reducing the frequency of mixed waste collection service, and simultaneously repurposing the freed-up personnel to collect organic waste can create efficiencies. This also serves as an effective way to encourage waste generators to place biodegradable waste in its designated bins for quicker collection to avoid the smell of rotten waste.[36]

Exhibit 8 Stakeholder roles and responsibilities, waste collection and transport

Stakeholder Group	Roles and Responsibilities
State government (LAWMA)	• Evaluate existing collection infrastructure to assess capacity, technology, and investment needs, and evaluate collection routes and frequency to optimise for time, worker, and cost efficiency. • Facilitate the expansion of collection infrastructure by seeking funding for capital projects or operational upgrades. • Redesign fee structures to incentivise participation in source separation, such as applying a volume-based fee for waste collection. • Minimise contamination during collection and transportation by providing training for waste haulers.
PSPs	• Attend trainings for waste haulers, effectively handle segregated organics to minimise contamination. • Optimize collection (e.g., collection route and schedule) with guidance from LAWMA.

RMI Graphic. Source: RMI analysis

Waste Recovery and Treatment

In addition to segregating organics via source separation, successful methane mitigation through organic waste diversion also depends on being able to treat the diverted waste. Insufficient processing capacity hinders efforts to divert organics from dumpsites. The most common treatment options for organic waste are composting and anaerobic digestion.[37] Both centralised and decentralised composting and anaerobic digestion facilities as well as robust end markets for end products are essential to scaling organics recycling.

1. Develop centralised organics processing facilities

Diverting organic waste requires processing technology like anaerobic digestion and composting facilities to convert biodegradable waste into useful end products. Other than the EarthCare Nigeria Limited composting facility, there are no commercial-scale organic waste treatment facilities in Lagos. Where access to capital for larger infrastructure projects is available, large, centralised facilities can accelerate methane reductions in the sector by increasing the volume of organics that can be processed while also benefitting from economies of scale. Additional studies are needed to evaluate the processing capacity, investment, and incentive programs required to develop, optimize, and scale these facilities.

The compost made from the aerobic decomposition of organic waste can be applied as soil amendment and sold to farmers for private use in gardens. At the same time, biogas from the anaerobic digestion of organic material can be used to generate electricity. This is an attractive end use that can help address unreliable power supply and replace expensive diesel and petrol generators. The digestate co-product can also be sold as organic fertiliser.

2. Develop decentralised organics processing facilities

The initial investment for large-scale organics processing facilities is often a significant barrier for many cities and municipalities, including Lagos. A low-cost alternative is to build small-scale decentralised composting and anaerobic digestion facilities to serve large waste generators, such as an on-site digester at a food and vegetable market, restaurant, or university campus. This ensures sufficient feedstock with low levels of contamination, thereby improving the project's economic viability. The biogas generated can meet on-site energy needs, such as providing biogas for cooking at restaurants or electricity for cold storage at food markets.[38] Additionally, such decentralised facilities alleviate challenges with space constraints, which can be a significant cost driver for large-scale waste treatment facilities due to hefty premiums for securing land in a densely populated city like Lagos.

Case Study: Deployment of Modular Anaerobic Digestion Systems to Treat Kitchen Waste in Dar es Salaam, Tanzania

Dar es Salaam is the administrative, commercial, and industrial hub of Tanzania. Kitchen waste makes up more than 40% of household waste, which is typically disposed of near the generation site or dumped illegally on roadsides. In November 2006, a Tanzanian branch (ARTI-TZ) of the Indian organisation Appropriate Rural Technology Institute (ARTI) began installing household-scale biogas systems, which the organisation had developed in 2003 in East Africa. Within two years, about 31 ARTI compact biogas systems were installed throughout Tanzania and Uganda.

Initially, an ARTI biogas research plant was tested at the Ardhi University campus in Dar es Salaam and monitored by Eawag/Sandec and Ardhi University. The study revealed that although the ARTI biogas plant could process organics and produce biogas effectively, design improvements were needed to lower its operation and maintenance costs. Additionally, the study noted that widespread implementation of the ARTI system in Tanzania would be hindered by the significant investment cost of $420.

The study assumed that a Tanzanian household produced 2 kg of fruit and vegetable peelings and food leftovers per day; therefore, the biogas plant was fed about 2 kg of feedstock daily. This amount of feedstock generated approximately 170 litres of biogas, enough to fuel about one-third of the cooking time of an average five-person Tanzanian household. If the daily feedstock were increased to 5 kg, which could be achieved by solving some operational and logistical challenges, the resulting biogas would entirely meet the cooking needs of an average five-person Tanzanian household.

Increasing the daily feedstock from 2 to 5 kg also helped reduce barriers to scaling. The biogas system costs $420 per household. At 2 kg of daily feedstock, the ARTI system saved each household approximately $136 per year in charcoal costs, resulting in a payback period of three years. However, at 5 kg of daily feedstock, biogas could be used in place of other cooking fuels, bringing the payback period down to one year.

In 2012, ARTI-TZ phased out its Tanzanian operations due to a lack of profit and high maintenance costs. However, the company SimGas used the ARTI principles and introduced an improved biogas system that could meet the needs of different households by offering three system sizes and using alternative low-cost construction materials. Within two years, SimGas sold 1,000 biogas systems, underscoring the importance of pilot projects in deploying new technology and refining business models to achieve scale.[39]

Lessons learned:

- The Ardhi University study on the ARTI biogas system demonstrated how biogas can be effectively produced by processing organic waste.
- Design improvements in the ARTI system could promote widespread implementation by reducing the up-front investment and maintenance cost.
- Increasing the volume of feedstock from 2 kg to 5 kg adequately meets the cooking needs of a five-person household in Tanzania and could further improve annual household charcoal savings of $136 and significantly reduce the payback period.
- By offering various system sizes and leveraging lower cost material, SimGas reduced overall system cost and mitigated the financial barrier to scaling these systems.

3. Support end markets

The long-term sustainability of organics recycling strongly depends on available end markets for product uptake. In Nigeria, using biogas to generate electricity is a very attractive end use because current generation capacity is insufficient to meet demand. However, waste-derived products and co-products like biogas, compost, and organic fertiliser may be threatened by existing products with established markets. For example, many farmers in Nigeria prefer synthetic fertilisers because they are subsidised.[40] Farmers are also already familiar with synthetic fertilisers and have limited knowledge of compost application. These end markets must provide a reasonable return on investment to encourage private-sector investment. However, these markets are nascent and often require economic tools and incentives until projects can be financially sustainable.

Several economic tools can be deployed to support end markets. Subsidies can lower up-front or operating costs as well as barriers to entry for new market players. End markets can also be created or fostered through procurement standards to ensure high-quality products, procurement contracts to guarantee an off-taker, policies and regulations that facilitate market development, and private-sector partnerships. These tools can improve the cost-competitiveness of waste-derived end products with alternatives in the marketplace.

Exhibit 9

Stakeholder roles and responsibilities, waste recovery and treatment

Stakeholder Group	Roles and Responsibilities
State government (LAWMA) **Private sector** (waste treatment operator, project developers)	• Evaluate organics processing capacity requirements. • Conduct feasibility assessments to evaluate technical and investment needs and project viability. • Seek funding to support project development. • Develop and operate waste treatment facilities to meet processing needs. • Meet product quality standards to support end markets.
Technology providers, engineering/consulting firms, nongovernmental organisations (NGOs), academic institutions	• Organise and provide capacity-building trainings to develop technical expertise for key personnel to improve project operations.

RMI Graphic. Source: RMI analysis

Waste Disposal

Although source reduction and organic waste diversion are the most preferred mitigation actions to avoid methane emissions from MSW, critical actions can be taken at the dumpsite to effectively capture and control the gas. These include minimising the surface area of the working face, installing landfill covers, installing gas collection systems, and leveraging biocovers to oxidise methane. Implementing these strategies, in addition to those that take place before final disposal, will also enable the city of Lagos to begin reducing methane emissions from waste-in-place at the dumpsites.

1. Minimise the surface area of the working face

In conjunction with use of landfill covers, minimising the total area of the dumpsite that is exposed can reduce the migration of methane emissions to the surface. Additionally, a smaller active working face means there is less area for disease-carrying vectors such as birds and rodents to feed from and spread diseases.[41]

2. Install landfill covers

In Lagos, waste is routinely disposed of at open dumpsites that are uncovered and may be uncompacted. These conditions pose health and safety risks to workers, neighbouring communities, and waste pickers who scavenge these dumps for valuable materials. Installing landfill covers — including daily, intermediate, and final covers — not only minimises odour and disease-carrying vectors, it also deters unwanted scavenging and provides an opportunity for targeted gas collection and reduction of gas migration. Daily cover materials such as soil, green waste, compost, or shredded tyres can be used overnight in active areas of the disposal site.[42] For extended periods (e.g., several months), intermediate covers should be used, while final covers should be installed in areas of the dumpsite no longer actively accepting waste.[43]

3. Utilise biocovers to oxidise methane emissions

Biocovers consist of a layer of porous material and another layer of mature compost, which oxidises methane. Leveraging the naturally oxidising power of biocovers can reduce the release of methane by converting this short-lived climate pollutant into carbon dioxide, a less-potent GHG. Some examples of biocovers include compost, dewatered sewage sludge, and yard waste.[44] Biocovers should not be considered an alternative to gas capture systems; however, they are an inexpensive option to reduce methane emissions for sites without GCCS. Also, for sites with gas capture systems, biocovers can further oxidise fugitive methane that is not captured by the GCCS.[45]

4. Install gas collection and control systems

Installing gas collection systems at active and inactive dumpsites in Lagos enables the capture of LFG for beneficial use such as electricity, heating, steam, or destruction by flare. However, to derive the benefits of installing capture systems at these dumpsites, additional operational improvements should be made prior to or concurrent with implementation. These include installing landfill covers and limiting waste pickers' access to dumpsites to avoid damaging the gas capture systems and to minimise fire hazards from oxygen intrusion.

GCCS are still nascent in Nigeria but have high potential to meet part of its growing energy demand, given the unreliable electric grid. In 2010, a study conducted by the Centre for People and Environment on four

dumpsites in Nigeria estimated that at a minimum cost of $0.20 per kilowatt-hour (kWh), equivalent to NGN 30.30 per kWh,[iv] generating electricity from captured LFG was economically viable across all four sites.[46] Utilising the captured gas for beneficial end uses should be prioritised over flaring the gas.

Exhibit 10

Stakeholder roles and responsibilities, waste disposal

Stakeholder Group	Roles and Responsibilities
State government (LAWMA)	• Evaluate the financial and technical requirements for facility upgrades and secure financing for project development. • Implement best management practices at dumpsites (e.g., install landfill covers and GCCS) to improve operation of sites and minimise fugitive emissions and restrict waste pickers' access to dumpsites to prevent damage to the GCCS and minimise fire hazards.
Technology providers, engineering firms, NGOs, academic institutions	• Collaborate with LAWMA to develop and implement upgrades at dumpsites and provide operations and maintenance support. • Provide technical capacity-building trainings for key operations personnel to ensure long-term operation and sustainability of GCCS.

RMI Graphic. Source: RMI analysis

Crosscutting Strategies

The mitigation strategies explored above do not highlight opportunities that intersect multiple aspects of the waste management value chain. These opportunities, including policy and regulatory framework, emissions transparency, finance, and stakeholder awareness and capacity building, can accelerate implementation across the value chain.

Policy and regulatory framework

Although industry efforts can and should play an important role in organic waste management in Lagos, government policy and regulation are critical to scaling up solutions and accelerating the pace of methane action to be consistent with international climate objectives. Without policy instruments to promote source reduction, SSO, organic waste disposal bans, and GCCS, achieving methane emissions reductions in the waste sector often relies on voluntary interventions, which are insufficient. An enabling policy environment also increases investor confidence and attracts the financial investments needed to achieve scale.[47]

iv Using a currency conversion rate in the study year, US$1 is equivalent to NGN 151.52.

1. Set minimum thresholds for mandatory SSO for large waste generators

Nigeria's National Policy on Solid Waste Management establishes the role of key stakeholders in promoting SSO. According to the policy, the Lagos State Ministry of the Environment and local governments are responsible for developing SSO programmes in their jurisdictions.[48] In developing and establishing these schemes, the State Ministry of the Environment can set minimum thresholds for participation that would require large waste generators to separate their biodegradable waste at the source. This type of policy can target generators with high organic waste volumes, such as restaurants, schools and universities, and food markets. Such laws should be complemented by educational awareness programmes and compliance mechanisms to promote participation.

2. Phase out organic waste disposal from dumpsites

As discussed above in Section 2, diverting decomposable waste before it reaches landfills and dumpsites is the most effective pathway to reducing MSW methane emissions post-waste generation and advancing a more circular use of resources. Sending organic waste to dumpsites discards resources that could be converted to revenue-generating end products, while also releasing harmful climate pollutants. An organic waste phaseout plan should include key targets and interim milestones. Rolling out an organic waste disposal ban in phases allows key implementers time to secure the technical and financial resources necessary for successful implementation.

This roll-out plan should include several strategies described in this section, such as the distribution of separate waste bins, adequate collection and processing infrastructure, long-term guarantees by government to facilitate private-sector investment, a competitive market for end products, and stakeholder awareness and capacity building programs, among others. In the absence of such strategies, an organic waste ban will result in unintended consequences such as the dumping of biodegradable waste into drains and storm water channels, which can be detrimental to the environment and to public health and safety.

3. Integrate the informal recycling sector

In Nigeria, as in many BtB countries, the informal recycling sector or waste pickers are a critical component of waste management. Waste pickers recover recyclables from dumpsites and sell them to aggregators or directly to recycling companies, which reuse these materials. However, these waste pickers often face social discrimination, risk of injury from unsafe environments, risk of illness from exposure to toxins, and economic vulnerability from low wages.

Providing formal employment for this community is beneficial to both municipal authorities and waste pickers. The city benefits from high collection or recovery rates, improved data tracking and more accurate waste inventories, and the networks, ideas, and experiences the informal recycling sector can provide. In turn, the informal recycling sector benefits from safer working conditions, better wages, and education that formal employment could provide.[49]

4. Implement landfill taxes and pay-as-you-throw programmes

Disincentivizing waste disposal at dumpsites is one way to improve organics diversion. Landfill taxes and pay-as-you-throw (PAYT) programmes are two policy instruments that can encourage diversion practices. Landfill taxes, which have been successfully implemented in Europe, are usually levied based on the volume of waste

disposed of at the landfill, and are paid in addition to normal landfill charges. Although the landfill tax is charged to the operator — in this case, LAWMA — these costs are eventually passed to the waste generator.

PAYT programmes follow a similar principle, where waste generators pay a user charge based on the volume of waste disposed instead of paying a flat fee. Unit-based PAYT programmes are generally correlated with reduced organic waste generation in cities that implement them. Because cities that use PAYT programs have a greater chance of also having a waste diversion and curbside food scrap collection programme, as reported in a 2017 study by the Massachusetts Institute of Technology, PAYT programmes could provide a foundation for other organic waste management initiatives.[50]

5. Develop procurement standards and set purchase targets for organics-derived products

For the long-term sustainability of mitigation solutions, there must be a market to support technology deployment and uptake of end products. The lack of end markets generally deters private-sector investment. Several actions can facilitate robust market development, including developing procurement standards and setting purchase targets for state and local government agencies. Well-established procurement standards can improve consumer demand and promote product transparency. At the same time, establishing purchase targets for government agencies ensures that state and local governments purchase a minimum volume of products (e.g., compost) from local manufacturers, which in turn drives demand and supports end market creation.

6. Develop landfill design and operational standards to capture and control methane

Establishing landfill design and operational standards to capture and control methane emissions from decomposed biodegradable waste is a major action that Lagos can implement to move from the current BtB archetype, to BtB+,[v] a more advanced MSW management archetype.[51] Although the city does not currently have any sanitary landfills, the Department of Pollution Control and Environmental Health, under the Federal Ministry of Environment, can establish design and operational standards to improve dumpsite operations and facilitate upgrades to sanitary landfills. These landfill standards should include provisions that promote human and environmental health and reduce methane emissions through the use of landfill covers, installation of GCCS, and the use of liners for leachate control. The standards should also include mechanisms to ensure compliance. The National Environmental Standards and Regulations Enforcement Agency can implement these standards via compliance monitoring and enforcement. LAWMA can further enable implementation by aligning with established federal policies and regulations, adapting these standards to be more stringent, and ensuring compliance at the state level.

7. Mandate GHG reporting

Emissions mitigation is more effective when there is a solid and comprehensive baseline for current conditions and when most emissions sources are known and measured. For example, the most recent emissions inventory for Lagos is from 2015. Such outdated data often does not provide an accurate reflection of sectoral emissions. Mandating annual GHG emissions reporting enables an emissions inventory that is updated frequently. The reported data can then be used to guide policymaking and implementation as well as to prioritise resource allocation and deployment in the locations that need

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v The BtB+ archetype shares certain characteristics with BtB in their waste management approach; however, BtB+ countries demonstrate relatively more advanced waste management practices. The main differences include higher collection rates and a noticeable progression from dumpsites to sanitary landfills. For more information, see ***A Playbook for Municipal Solid Waste Methane Mitigation: Recommendations Based on Global Waste Management Archetypes***.

it most. Mandatory GHG reporting creates a strong incentive for regular updates to the emissions inventory, which can serve as a mechanism to track progress towards the emissions reduction actions and goals in Lagos' Climate Action Plan.[52]

8. Implement compliance mechanisms

Without mechanisms to ensure compliance, policies and regulations that promote methane abatement may not be properly implemented. Weak enforcement may result from insufficient staffing to enforce rules, budget constraints, absence of compliance mechanisms, poor awareness of rules, or inadequate waste management infrastructure. For example, a law that bans indiscriminate dumping or burning of waste should also ensure that waste collection services are provided. Otherwise, waste generators resort to illegal dumping and burning, as is often seen in many remote communities. Similarly, adequate systems and mechanisms should be in place to ensure compliance with rules. These could include measures to penalise noncompliance, such as fines and penalties, as well as incentives to induce compliance. At the same time, understanding the factors that drive noncompliance is necessary to improve policy outcomes.

9. Streamline permitting process and enhance coordination

Securing permits for infrastructure projects can face significant delays that can discourage project developers. In some cases, delays are due to important environmental and safety considerations that can take time to address. In other cases, delays are due to poor organisation and coordination among relevant government agencies. Enhanced coordination among government agencies can streamline permitting processes and accelerate the implementation of projects that advance methane mitigation.

Beyond the permitting process, improved coordination also enhances other approval processes and ensures project continuity. Securing project buy-in from government officials can be challenging, especially when there is a change in government administration. Although inevitable, such administrative changes can result in a lack of project continuity, which can be disruptive to implementing critical infrastructure projects. For example, a biogas plant at the Ketu Fruit Market in Lagos experienced major setbacks due to administrative changes. This pilot plant was established to learn the operational procedures and considerations of biogas technology prior to expansion and replication in other food and vegetable markets. However, this project was abandoned because of the varied interests demonstrated by different government regimes. This type of disruption owing to changes in political leadership and a lack of coordination can be mitigated by creating an infrastructure implementation unit that is independent of government administration.

Case Study: Using Financial and Social Levers to Scale Organic Waste Management Best Practices in Chile

Because Chile faces space constraints for landfill sites, diverting and treating organic waste, which can extend a landfill's life span, offers economic, GHG mitigation, and city planning benefits. Launched in 2021, Chile's National Organic Waste Strategy aims to recover 30% of municipal organic waste by 2030 and 66% by 2040 by reducing food waste and increasing composting.[53]

The plan includes the implementation of gradual taxes on industrial waste (to be implemented in 5 years) and on municipal waste (to be implemented in 10 years) designed to reduce waste generation and increase source separation of organic waste by 2040. Additionally, Chile will increase infrastructure to turn waste into fertiliser and energy.

To implement this strategy, Chile will need to mobilise wide-scale public participation in waste diversion and reduction measures. To aid this effort, Reciclo Organicos helped develop resources to educate the public, including:

- Composting manuals for homes, municipalities, and mayors
- Presentations at schools
- Webinars to inform citizens and NGOs on the connection between waste management practices and climate change

The programme also utilises social media platforms like Facebook and Instagram, the account on the latter of which has gained 60,000 followers, to reach citizens and boost engagement on home composting and food waste prevention. Additionally, Reciclo Organicos is engaging with private-sector actors and development banks to further the strategy's implementation.

Chile is also investing in monitoring, reporting, and verification systems to further enable implementation of its nationally determined contributions. With technical and financial aid from the Canada-Chile Reciclo Organicos Programme, verification methods have been developed to track Chile's emissions. The country is currently attempting to use blockchain to enable digital verification of emissions data.[54]

Lessons learned:

- The National Organic Waste Strategy is a significant component in promoting sustainable organic waste management in Chile.
- Chile's national plan includes a tax to discourage landfilling of organics, which will be introduced gradually in future years, allowing sufficient time for proper planning to secure and allocate resources to support implementation.
- Using various communication platforms and channels (e.g., social media, webinars, and presentations) is essential to maximise outreach, boost stakeholder engagement, and produce broad participation.

Exhibit 11 Stakeholder roles and responsibilities, policy and regulatory framework

Stakeholder Group	Roles and Responsibilities
Federal government (National Council on Climate Change, Department of Pollution Control and Environmental Health, National Environmental Standards and Regulations Enforcement Agency)	• Create federal legislation to promote the deployment of methane mitigation technologies for subnational decision makers (e.g., phase out organic waste disposal, set minimum thresholds for mandatory SSO for large waste generators, develop landfill design and operational standards, integrate the informal recycling sector into formal waste management frameworks, mandate emissions reporting). • Ensure compliance and enforce federal rules and standards • Develop procurement standards for waste-derived end products and set purchase targets for government agencies to promote market development. • Implement mechanisms to ensure compliance with federal rules and standards and increase awareness of new policies and regulations. • Ensure best available technology with local adaption is deployed for environmental management and pollution control.
State government (LAWMA)	• Adapt federal standards that advance methane mitigation at the state level and ensure compliance. • Streamline the permitting process.

RMI Graphic. Source: RMI analysis

Emissions transparency

Data availability and emissions transparency underpin each methane abatement strategy. Improving the availability of data such as waste characterisation, waste flow, and emissions quantification can highlight priority intervention areas and help track the progress of deployed solutions.

1. Update waste characterisation studies

Waste characterisation studies evaluate the amount and component of waste generated by demographics. This data helps target waste management and resource recovery efforts to the specific profile and needs of the city. Keeping these records updated, especially when evaluating waste management systems, technologies, and infrastructure needs, is critical for efficient planning.[55] As such, waste characterisation studies should be conducted regularly to provide insights on waste trends and how the waste stream changes over time. This data also enables the quantification of methane emissions, which in turn informs mitigation action. Unavailable or outdated data often means relying on modelling defaults or inaccurate inputs, which can result in inaccurate emissions estimates.

2. Collect robust waste sector data

Understanding a city's waste management needs requires a data collection system that is consistent, accurate, and robust enough to meet its evaluation and analysis needs. Data collection should be done to aid the planning, operation, and maintenance of waste management systems throughout the value chain. Understanding how much waste is generated and collected, as well as the waste flow, is especially critical in conducting feasibility assessments to evaluate infrastructure capacity and investment needs. Existing data collection and reporting frameworks, such as the UN Habitat Waste Wise Cities Tool, the Climate and Clean Air Coalition Data Collection Tool for Urban Solid Waste Management, and the City MSW Rapid Assessment Data Collection Tool, can guide LAWMA in developing a robust waste inventory.

3. Make waste and emissions data publicly available

When data is made publicly available, it can be used by various parties to conduct studies, inform policy, evaluate infrastructure and technology needs, and undertake other efforts to promote thought leadership, emissions transparency, innovation, and the advancement of waste management systems. Publicly available waste and emissions data enables transparency and dialogue around waste management, especially related to diversion and resource recovery measures, which broadly improves the system's progress.[56]

Exhibit 12 Stakeholder roles and responsibilities, emissions transparency

Stakeholder Group	Roles and Responsibilities
State government (LAWMA)	• Conduct regular waste characterisation studies. • Develop robust inventories for waste and emissions data. • Update data regularly and make data publicly available.
Academic institutions, consultants, NGOs	• Collaborate with LAWMA to conduct waste characterisation studies. • Provide input on improving data access and data accuracy.

RMI Graphic. Source: RMI analysis

Finance

A study by the Climate Policy Initiative revealed that climate finance significantly falls short of the required investment to slow global temperature rise to 1.5°.[57] The inability to access affordable finance is often cited as one of the most significant barriers to developing critical low-carbon projects for many BtB countries like Nigeria. Therefore, access to affordable finance will enable infrastructure upgrades and accelerate the deployment of methane abatement technologies.

1. Provide affordable finance through subsidies, grants, and concessional financing

Developing and scaling technology for organic waste management often requires high capital investments that pose a barrier to entry for many municipalities and cities like Lagos. Equipment and machinery are already expensive. When they are imported, their high costs are exacerbated by import duties, taxes and tariffs, and volatile foreign exchange rates. These costs can hinder implementation, especially when municipal authorities are already cost burdened.

Development finance institutions can play a role in providing low-interest financing. Grants and philanthropic funding can help lower the entry barrier for new investors and enable technology deployment. Subsidies can also help alleviate funding challenges for technology providers, dumpsite operators, and end users, particularly in nascent markets. Further, educational awareness programmes can help spread awareness of available funding opportunities.

2. Reduce the cost of finance through risk-sharing mechanisms

High-risk projects have higher financing costs due to higher risk exposure for investors. In emerging economies, waste management projects often do not have the same access to risk-mitigation tools that are standard in more well-understood markets. Risk-sharing mechanisms like blended financing can lower

the cost of finance associated with such markets by spreading the risk across a diverse funding source, including public, private, philanthropic, and other sources of capital like development finance institutions and multilateral banks.[58] This approach leverages the different risk tolerance levels of investors to catalyse private-sector investment.

3. Access project preparation facilities

Accessing affordable finance is difficult because many projects are non-bankable. This may be driven by a lack of technical capacity, poor business models, or foreign exchange volatility, among other factors. To reflect the market risk, investors charge high interest rates that often make finance unaffordable. Project preparation facilities can help prepare projects for investment by conducting market research and feasibility assessments. These facilities can also help develop viable business models for waste projects and serve as a de-risking mechanism to improve investor confidence, mobilise investment in the sector, and further unlock finance.[59]

4. Guarantee revenue through procurement contracts and offtake agreements

Because cost is a major hindrance for the planning and implementation of organic waste management solutions, reducing the cost burden can help ease implementation and improve waste management planning. Procurement contracts and offtake agreements can guarantee revenue to help recoup costs and earn a return on investments, while also assuring product delivery for the buyer.

5. Expand revenue models and tariff structures to improve cost recovery

Cost recovery is a challenge for many municipalities and waste management authorities, including LAWMA, because user charges are often insufficient to cover operating costs. The waste management authority must balance affordability for customers with ability to recover costs, which often leads to tariffs that are insufficient to recoup investments. LAWMA can improve cost recovery by expanding revenue models to include higher tariffs, a tipping fee, or through income from the sale of recyclables and waste-derived end products like compost, biogas, or fuel.

Similarly, exploring different pricing structures can help improve payment collection and willingness to pay. Aside from inability to pay, which is often the case in low-income communities, residents who can afford to pay may be reluctant because they do not consider waste services as critical as other utilities like electricity or water. Service providers can improve cost recovery by incorporating tariffs and user charges into other utility bills that have a higher payment collection success rate, such as electricity or water bills. Several countries in Latin America and the Caribbean, including Colombia, Ecuador, and Venezuela, recover solid waste management cost using this method.[60] Further, PAYT models can reduce overall volumes of waste to be handled and subsequently reduce operating costs, thereby improving project viability.

Exhibit 13 Stakeholder roles and responsibilities, finance

Stakeholder Group	Roles and Responsibilities
Investment community (donors, foundations, development finance institutions, multilateral development banks, green banks)	• Provide grants, concessional loans, and loan guarantees to reduce cost burden for project developers and support project implementation.
Federal government (Ministry of Finance) **and state government**	• Provide subsidies to defray the up-front and operating costs and catalyse private sector investment. • Reduce or eliminate import duties and fees on relevant technologies and equipment. • Provide tax credits (e.g., an investment tax credit) and facilitate access to affordable finance (e.g., commercial loans, loan guarantees, green credit lines, concessional finance). • Facilitate partnership between financial institutions and waste service providers. • Facilitate investment training programmes for waste service providers and technology providers to improve awareness on funding opportunities.
Waste service providers (LAWMA, PSPs)	• Access project preparation facilities to improve project readiness for investment. • Improve cost recovery by expanding service offering and implementing innovative pricing structures (e.g., tipping fees, PAYT, sale of recyclables and waste-derived products). • Where applicable, establish procurement contracts and offtake agreements with key customers to improve cost recovery.
Multilateral organizations, development agencies, and NGOs	• Develop project preparation facilities for waste projects. • Work with LAWMA and the private sector to conduct feasibility assessment and evaluate projects for investment readiness.

RMI Graphic. Source: RMI analysis

Stakeholder awareness and capacity building

Until recently, waste sector methane has received little to no attention. Oftentimes, this lack of awareness manifests in several aspects of the value chain that slow down methane reduction efforts. Capacity building through training programmes and awareness creation is a key pillar to enable successful adoption of new technologies and waste management practices. From generation to collection and transport, recovery and treatment, and disposal, there is a need to improve public awareness and develop capacity among key stakeholders to further sustainable organic waste management in Lagos. Educational outreach programmes can promote a deeper understanding of solid waste management and its link to environmental concerns, public health and safety, and the benefits of deploying waste management technologies, which will encourage reception and better decisions.

Exhibit 14

Waste management officials and key stakeholders at a capacity-building workshop in Lagos

During a workshop organised by RMI, in partnership with the National Council on Climate Change and the International Solid Waste Association, waste management officials and key stakeholders are provided training on best practices in solid waste management, organic waste diversion, biogas development, and landfill gas management. Photo credit: RMI

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1. Develop technical capacity among key waste management officials, regulators, and policymakers

Limited technical capacity among key waste service personnel can reduce long-term sustainability of projects. This limited (or lack of) technical capacity may result in frequent equipment failure and significant delays in repairs, further exacerbating the inability to recover costs and access financing for waste projects. Capacity-building training may include conferences and workshops (see Exhibit 14), facility tours, peer-to-peer exchange programmes, or educational curriculums at tertiary institutions. Similarly, developing technical capacity among policy and regulatory officials can help prioritise

enacting rules and regulations that advance methane abatement. Targeted trainings may include sustainable waste management practices like organics recycling, leachate and LFG management, landfill design and operations, landfill mining, waste economics, and investment training programs. Tours of small-scale demonstration projects or case studies that are conveyed through site visits, hands-on training, interactive media, visual communications, and storytelling can facilitate knowledge exchange and help decision makers better understand the systematic changes needed to progress long-term sustainability of MSW projects.

2. Implement educational awareness and outreach programmes

Educational awareness is necessary to promote best practices and improve participation in relevant initiatives. Education and outreach campaigns empower waste workers and citizens to make better decisions by helping them understand the underlying motivation for why the initiatives are important and beneficial, and how their actions can benefit the community.

To be successful, education and outreach programmes should first understand the critical knowledge gaps and then be tailored to address them. For example, waste generators may throw food waste in a mixed waste bin instead of designated food waste bins; waste haulers may commingle source-segregated organics during collection; farmers may be reluctant to purchase organic fertilisers because they prefer chemical fertilisers. Awareness campaigns should target various stakeholder groups to address such knowledge gaps by teaching people to effectively segregate organic waste to reduce contamination, educating waste haulers on best practices to minimize contamination of SSO, and educating farmers on the benefits of compost and organic fertilisers. These programmes should consider the local context by communicating in the local languages and leveraging multiple communication channels such as leaflets, radio jingles, TV ads, social media, conferences, workshops, and school curriculums to maximise outreach and participation. Additionally, leveraging authority figures or people with significant reach such as community leaders and influencers can promote the success of such initiatives.

These programmes can also introduce incentives that further drive change at the grassroots level. For example, citizens may be more encouraged to routinely take their SSO to drop-off centres in exchange for food vouchers or other incentives. Incentive programmes could also be designed to optimise for a specific outcome. For example, an incentive programme can minimise contamination at the source by providing the highest rewards for non-contaminated waste.[61]

Exhibit 15 Stakeholder roles and responsibilities, stakeholder awareness and capacity building

Stakeholder Group	Roles and Responsibilities
State government (LAWMA), **local government, technology providers, engineering and consulting firms, NGOs**	• Identify knowledge gaps among key waste management personnel and other stakeholder groups, and conduct targeted capacity-building training programmes and educational awareness initiatives tailored to specific audiences.
Waste service providers (waste haulers, LAWMA, PSPs)	• Attend and participate in training programmes to build technical capacity. • Implement best management practices in daily waste operations.
Regulators and policymakers	• Attend and participate in training programmes to build technical capacity. • Leverage technical knowledge to enact policies and regulations that advance methane mitigation.
Federal government, state government, and investment community	• Conduct investment trainings to educate stakeholders on how to access finance.
Public sector, private sector, civil society, and impacted communities	• Attend and participate in educational awareness and outreach programmes. • Implement lessons learned to promote best management practices (e.g., effectively segregate organic waste, practise home composting).

RMI Graphic. Source: RMI analysis

4. Conclusion and Recommendations

The current decade is crucial for Nigeria to achieve its dual goals of economic development and emissions reduction. As a signatory to the Global Methane Pledge, slashing methane emissions from top-emitting sectors including waste aligns with Nigeria's national climate targets. It is also a socioeconomic opportunity to create an efficient waste management system that protects environmental safety and human health.

This playbook uses the pathways outlined for the BtB archetype in RMI's recently published report, ***A Playbook for Municipal Solid Waste Methane Mitigation: Recommendations Based on Global Waste Management Archetypes***, to recommend methane abatement strategies that reflect the current waste management situation in Lagos, the most populous metropolis in Nigeria. The methane abatement strategies presented in this playbook span the waste management value chain, including waste generation, collection and transport, recovery and treatment, and final disposal. The playbook also explores strategies to promote an enabling policy environment, improve access to affordable finance, improve data and emissions transparency, and develop local technical capacity and awareness.

The strategies discussed in this report are extensive and may seem overwhelming to implement. However, the authors recommend three key levers, **build basic infrastructure, build technical capacity, and provide affordable finance** (see Exhibit 16, next page), that can propel the city of Lagos from BtB to BtB+ to better align its waste management practices with the waste hierarchy and slash methane emissions. In the near term, key actors can facilitate the deployment of basic infrastructure like small-scale composting and anaerobic digestion facilities and implement basic upgrades at dumpsites such as minimising the surface area of the active working face and installing relatively low-cost GCCS and landfill covers. However, to achieve long-term emissions reduction, these operational improvements should be paired with sustainable solutions that prevent future dumping of organic waste at disposal sites. Local technical capacity and access to low-cost financing are critical to deploying more robust technological solutions and achieving scale.

Exhibit 16 Key levers for progressing across waste management archetypes

RMI Graphic. Source: RMI analysis

Implementing these strategies will improve the diversion of organic waste and enable methane capture from dumpsites, an approach that is guaranteed to significantly curb MSW methane emissions. However, as these strategies are often interdependent, effective planning and coordination is necessary. Collaboration among the key implementers identified in this report can help mobilise public participation, finance, enabling policy, technology, and markets for a systematic shift in solid waste management. The importance of end markets cannot be overlooked as organic waste-derived end products that guarantee a return on investment are crucial to mobilising private-sector investment and scaling methane abatement solutions for solid waste operations in the long term.

Although these strategies are tailored to the current waste management landscape in Lagos, many of the challenges discussed reflect those across the country and are broadly applicable to other cities in Nigeria. Therefore, this playbook is intended to serve as a resource for waste management officials and other key decision makers in Nigeria as they prioritise abating waste sector methane.

Timely and tailored implementation of the strategies recommended in this playbook can bridge systematic gaps and allow Lagos to advance from its current waste management approach, characterised by the Build the Basics archetype, to one that is more aligned with the widely established waste management hierarchy, thereby promoting a transition towards a circular and low-carbon economy.

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RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621

www.rmi.org