Exploring Microbial Valorisation of Organic Waste for Circular Bioeconomy beyond Plastics and Styrofoam: The Study of Akwa Ibom State

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Abstract

This study explores microbial valorisation of organic waste (that constitute 40-60% of Nigeria's solid waste stream) for circular bioeconomy development beyond plastics and Styrofoam, using Akwa Ibom State as the study site. The paper employs mixed methods to evaluate technical feasibility, economic viability, and policy readiness of microbial bioconversion technologies, which can utilise 80% of 32 million tonnes, estimated at $2.5 billion of solid waste generated annually but largely mismanaged. Multi-Level Perspective on socio-technical transitions, Technological Innovation Systems, and Transition Management theories were fundamental in the analysis. Findings disclose that Nigeria's agricultural residues possess starch contents of 38-52% and microbial conversion efficiencies of 68-87% that are potent raw materials for biofuel, energy production ($45-70/tonne for biogas and biofertiliser as against $15-40/tonne for plastic recycling). This possesses a higher valorisation value per tonne for sustainable bioeconomy development. Comparatively, countries with integrated bioeconomy frameworks have achieved 40-60% waste valorisation rates, while Nigeria remains below 5%. The study proffers fixing infrastructure development, policy harmonisation, private sector engagement, and human capital investment as pertinent to unlock an estimated $2.5 billion annual circular economy potential for Nigeria, with Akwa Ibom State specifically recommended for pilot transition.

Keywords: circular bioeconomy; microbial valorisation; organic waste; plastics; Styrofoam

1. Background of the Study

The continuous economic growth, population explosion, technological and scientific innovations have accelerated urbanisation and the changing pattern in fashion and taste of consumption. The unintended consequences include urban solid waste generation and disposal nightmare.

As Africa's most populous nation estimated at 242.4 million citizens (Worldometer, 2026) and an annual population growth rate of 2.6%, Nigeria continues to grapple with recurring waste management crisis that threatens public health, environmental integrity, and economic development (World Bank, 2023). The reality is frightening, considering that the country generates over 32 million tonnes of solid waste annually. As if that was not deleterious enough, the mismanagement rate of solid wastes is high, prompting NACCIMA (2026) and Ogulenleye (2025) to paint a bleak picture that 80% of waste is mismanaged, thereby, costing the economy an estimated $2.5 billion yearly in lost recyclable materials.

In Nigeria, inadequate waste collection systems, insufficient recycling infrastructure, and weak enforcement of environmental regulations have exacerbated the accumulation of both biodegradable and non-biodegradable waste materials everywhere.

Additionally, FAO (2020) observes that Nigeria generates over 84 million tonnes of agricultural crop residues annually, alongside 227,500 tonnes of animal manure per day. These feedstocks are rich in starch (38–52%) and cellulose (18–25%), making them technically suitable for microbial conversion into biogas, biofertilisers, and industrial enzymes (Abdullahi et al., 2025). Again, Nigeria as a founding member of the African Circular Economy Alliance (ACEA) has initiated policy instruments such as the National Policy on Solid Waste Management (2022) and the Extended Producer Responsibility (EPR) Programme (2023). With the availability of requisite institutional framework, the country has geared towards circular economy advancement (Federal Ministry of Environment, 2022; NESREA, 2023).

However, Ezeudu and Ezeudu (2019) opine that organic waste alone comprises 40-68% of Nigeria's municipal solid waste, depending on geographic region. Specifically, agricultural residues, including cassava peels, rice husks, yam peels, and maize stover constitute a substantial portion of this organic stream. The sad reality is the conclusion drawn that these materials are valueless and are continuously being burnt or discarded. The observation aligns with Owolabi et al. (2021), who concluded that approximately 30 million tonnes of agricultural waste is either burned in the open or dumped in unmanaged sites each year.

The emerging "waste-to-value" is an intentional realignment process and a positive drift from traditional linear models of production and disposal toward circular and regenerative systems in which waste materials are reintegrated into productive cycles (Geissdoerfer et al., 2017). This perspective aligns with the principles of the circular economy, which emphasise resource efficiency, waste minimisation, and sustainable production-consumption patterns (Ellen MacArthur Foundation, 2013). In this context, microbial transformation emerges as a promising biotechnological approach that converts organic and certain synthetic waste materials into valuable by-products such as biofuels, organic fertilisers, industrial enzymes, bioplastics, and other biochemicals (Chopra et al., 2020). Microorganisms including bacteria, fungi, and algae possess enzymatic systems capable of degrading complex substrates into simpler compounds through

processes such as fermentation, biodegradation, and bioremediation (Das & Dash, 2017). Therefore, the ban on Styrofoam and single-use plastics in some Nigerian states reflects growing political will to address waste pollution (Ogunleye, 2025).

Mention must be made of countries such as Brazil, India, and Thailand as prototype. They are at the forefront of this innovative action, and have since successfully integrated microbial valorisation into national bioeconomy strategies. This action has achieved organic waste diversion rates of 28-42%, while generating billions of dollars in annual revenue. This is in addition to the multiplier effects that have expanded employment opportunities for their citizens (IRENA, 2024; Thailand Board of Investment, 2024).

Simultaneously, international climate finance mechanisms, including the Green Climate Fund and the World Bank's circular economy facilities, have made over $1.5 trillion available for waste-to-value projects in developing economies (World Bank, 2020). These developments position Nigeria at a favourable juncture to scale microbial waste valorisation beyond the current narrow focus on plastics, towards an integrated bioeconomy that leverages its abundant organic waste streams for sustainable development.

Irrespective of the growing body of research on microbial waste transformation globally, relatively limited scholarly attention has been devoted to examining how these technologies could address Nigeria's specific waste management challenges. Also, existing studies in Nigeria have largely focused on waste disposal practices, recycling initiatives, or environmental pollution, plastics and Styrofoam implications with comparatively little emphasis on organic waste management regime beyond plastics and Styrofoam and the role of microbial biotechnology in converting organic waste into economic resources.

Statement of the Problem

Nigeria's waste management system remains critically dysfunctional despite some successes recorded. The poor state of waste management is evident as little or no coherent strategy exists for microbial valorisation of organic waste beyond plastics and Styrofoam. This creates a distinct and urgent set of interconnected problems.

Organic waste constitutes 40–68% of Nigeria's municipal solid stream (Ezeudu & Ezeudu, 2019) and the waste collection efficiency ranges from 20 - 30% in urban areas, while there are hardly any formal waste management services in the rural areas, (Federal Ministry of Environment, 2022). Yet, the National Policy on Solid Waste Management and the EPR Programme focus predominantly on plastic packaging and electronics (Federal Ministry of Environment, 2022; NESREA, 2023). This indicates a critical misalignment that exists between waste composition, policy focus and management. This depicts a scenario where the largest fraction of the waste stream such as agricultural residues, food waste, animal manure, and abattoir waste is left out of the valorisation framework, while policy attention and donor funding are disproportionately directed at plastics, which comprise only 13–18% of the waste stream (Benjamin & Benjamin, 2023).

Again, environmental and public health are under siege in as much as waste disposal policies have failed to capture health and environmentally friendly practices. For instance, open dumping and uncontrolled burning has the capacity to release methane (which is considered to be more potent by

28–34 times than Carbon dioxide), black carbon, and leachate that contaminate groundwater (UNEP, 2020).

Indeed, United Nations Environment Programme (2020) confirms that open dumping and uncontrolled burning remain the predominant disposal methods, contributing to Nigeria's status as a significant contributor to greenhouse gas emissions from waste in Africa. While Lagos Waste Management Authority (LAWMA, 2026) has reported 1,023 cases of illegal waste dumping in 2025. Out of this, 447 cases were referred for legal action, indicating the scale of enforcement challenges.

In Akwa Ibom State, dumpsites in Etinan, Ikot Ekpene and Uyo, have significantly altered soil pH, electrical conductivity, and exchangeable cations, with paint-processing wastes causing soil alkalinity that interferes with nutrient uptake (Christopher et al., 2025). Healthcare facilities in Uyo produce 500-700kg/day of medical waste at tertiary facilities, with hazardous fractions reaching 48%, yet no specialised treatment infrastructure exists, leading to lead-contaminated soils (60 mg/kg) and groundwater (0.30 mg/L) exceeding WHO guidelines by a factor of 30 (Christopher et al., 2025). In the same vein, Okey et al. (2013) characterised solid waste in Uyo and reported an average generation rate of approximately 0.54 kg/person/day.

Valorisation seems to exist as an abstraction. This is confirmed by the attitude of all tiers of the Nigerian government since they act as waste management operators and regulators, creating fundamental conflicts of interest. no incentive to enforce standards and a display of incongruent behaviours that are primary barriers to innovation. The stack failure to consider waste valorisation as an emerging economic force forecloses a significant economic opportunity. This is why the World Bank (2020) estimation confirmed that Nigeria loses $100 million annually from unmanaged plastic waste, even as the unutilised value from organic waste is enormous, and approximated at $2.5 billion annually when biogas, biofertiliser, and enzyme production potential is included (NACCIMA, 2026). Comparatively, countries with integrated bioeconomy frameworks have long achieved organic waste valorisation rates of 28–42%, while Nigeria remains below 5% (RMRDC, 2025).

Therefore, waste management failure in Nigeria is multifaceted, and is submerged in poor waste management policies and practices that are structurally misaligned with the actual composition of its waste stream. Policies are causally linked to documented environmental and health harms. Lack of political will is evident, and no comprehensive strategy for microbial waste-to-value valorisation customised to Nigeria's specific waste profile exist. While institutional context continues to exacerbate demonstrable economic missed opportunities, which have been captured by peer countries.

This study explores these interconnected problems by analysing how microbial waste-to-value valorisation can be strategically deployed to transition Nigeria beyond plastic-Styrofoam-focused waste management in order to realign policy with waste reality, mitigate environmental harms, resolve governance contradictions, unveil and utilise hidden economic value.

1.2 Objectives of the Study

The study explores microbial valorisation of organic waste for circular bioeconomy development beyond plastics and Styrofoam, using Akwa Ibom State as a study site.

Specifically, it is designed to:

i. Evaluate the technical feasibility and economic viability of microbial conversion technologies for Nigerian waste substrates;
ii. Identify governance barriers and enabling conditions for scaling microbial valorisation in Nigeria;
iii. Assess the environmental impacts of current waste disposal practices in Akwa Ibom State;
iv. Evaluate Nigeria's bioeconomy policy frameworks and waste valorisation outcomes compare with those of Brazil, India, and Thailand;
v. Develop a policy framework for Nigeria's transition beyond plastic-focused waste management toward integrated organic waste valorisation.

1.3 Research Questions

Main Research Question: How can microbial valorisation of organic waste in Akwa Ibom State contribute to Nigeria's circular bioeconomy transition beyond plastics and Styrofoam?

i. What are the volumes, composition, and distribution of organic waste streams in Akwa Ibom State and Nigeria?
ii. What microbial conversion technologies are technically feasible for Nigerian waste substrates?
iii. What governance barriers impede microbial waste valorisation scaling in Nigeria?
iv. What are the environmental impacts of current waste disposal practices in Akwa Ibom State?
v. What interventions are required to achieve 30% organic waste valorisation by 2030?

1.4 Significance of the study

The paper contributes to the literature by providing a conceptual synthesis linking microbial biotechnology with circular economy frameworks in the Nigerian context. It highlights the potential role of microbial waste transformation. This is to streamline the abundant and untapped organic wastes that goes beyond the management of plastics and Styrofoam, thereby promoting sustainable resource management. The study compares, suggests policy and designs roadmap for integrating waste-to-value biotechnology into Nigeria’s environmental governance and development strategies.

By reframing waste as a potential economic resource, rather than a disposal problem, the study contributes to emerging debates on sustainable waste management and circular bioeconomy development in developing countries.

1.5 Akwa Ibom State as a Study Site

Akwa Ibom State was adopted as the study site where site-specific data could be generated. Akwa Ibom State is located in South-South geopolitical zone of Nigeria. It is an oil-producing state with an estimated population of over 7 million. According to National Bureau of Statistics (2025), Uyo metropolis as a capital city has experienced rapid urbanisation, increased household consumption and increasing waste generation pressures in recent years.

The selection of Akwa Ibom State as a study site arose from the fact that some current empirical studies including that of Uchenna et al. (2026), Christopher et al. (2025) and Bassey et al. (2024) have generated high-quality baseline data on Isolation and characterisation of bacteria from municipal solid for production of enzymes for waste degradation in Uyo, Characteristics and management of municipal solid waste, Uyo, healthcare waste generation, hazardous fractions, and environmental contamination in Uyo metropolis, thereby offering analytical template that could be replicated for other Nigerian cities.

Also, data from Christopher et al (2025) on waste generation, availability of dumpsites and noticeable impacts within Etinan, Ikot Ekpene and Uyo Local Government Areas present scenarios that validate the existing harmful waste management practices that demand swift action. Furthermore, in Akwa Ibom State, there is a high volume of production of staples such as cassava, palm oil, rubber, and fishery and the accompanying agricultural processing residues that are suitable for microbial valorisation. The fact that agriculture and environment are some key components of the current state government development blueprints, it is suitable to have the state as a site for pilot intervention. Indeed, the exploration of Akwa Ibom State leverages generalised national recommendations within which locally grounded findings and policy imprints are pushed for implementation framework.

2. Conceptual clarifications

2.1 Waste and Waste-to-Value

Waste is traditionally defined as any material, substance, or by-product that is discarded after primary use because it is perceived as having no further utility. In environmental management discourse, waste encompasses solid, liquid, and gaseous residues generated from households, industries, agriculture, and commercial activities (World Bank, 2018). In many developing countries, including Nigeria, waste has historically been viewed as an unwanted burden requiring collection, transport, and disposal, often through open dumping or uncontrolled landfilling. However, contemporary sustainability frameworks challenge this linear “take–make–dispose” model and instead conceptualise waste as a misplaced resource within a broader circular economy system (Ellen MacArthur Foundation, 2013).

2.2 Overview of Microbial Transformation

Microbial transformation details the biochemical modification or degradation of organic and inorganic substances by microorganisms through enzymatic processes. It is a core principle of environmental biotechnology and plays a significant role in natural nutrient cycling, decomposition, and ecosystem balance. Microorganisms such as bacteria and fungi possess diverse metabolic capacity that enable them to utilise waste materials such as carbon and energy sources, breaking down complex compounds into simpler, less harmful, or economically valuable products (Das & Dash, 2017). These processes include biodegradation, fermentation, composting, anaerobic digestion, and bioremediation.

2.3 Microorganisms relevant to Waste Conversion

A wide range of microorganisms are employed in waste conversion processes, broadly categorised into bacteria, fungi, algae, and archaea, each playing distinct biochemical roles. Bacteria are among the most widely utilised microorganisms due to their rapid growth rates and metabolic diversity. Species such as *Pseudomonas*, *Bacillus*, and *Clostridium* are known for their ability to degrade hydrocarbons, organic waste, and certain synthetic compounds (Das & Dash, 2017).

2.4 Styrofoam (Polystyrene) Waste: Composition and Environmental Impact

Styrofoam, commonly used as a generic term for expanded polystyrene (EPS), is a lightweight, petroleum-based plastic polymer derived from the monomer styrene. Polystyrene is synthesised through the polymerisation of styrene molecules, resulting in a stable aromatic hydrocarbon structure that is highly resistant to biological and chemical degradation (Geyer, Jambeck, & Law, 2017). Its physical properties light weight, thermal insulation, shock absorption, and low production cost make it widely used in food packaging, disposable containers, protective packaging materials, and construction insulation. In Nigeria, the increasing reliance on single-use food containers and takeaway packaging has significantly increased the presence of Styrofoam waste in urban centres, markets, schools, and event venues.

2.5 Microbial Degradation of Synthetic Polymers

Microbial degradation of synthetic polymers has to do with the breakdown of man-made plastic materials by microorganisms through enzymatic and metabolic activities. Traditionally, synthetic polymers such as polyethylene, polypropylene, and polystyrene are considered highly resistant to microbial attack due to their high molecular weight, hydrophobicity, and stable carbon–carbon backbone structures. However, recent advances in environmental microbiology have revealed that certain bacteria and fungi possess enzymatic systems capable of initiating oxidative or hydrolytic reactions that weaken polymer chains and facilitate partial degradation (Shah, Hasan, Hameed, & Ahmed, 2008).

2.6 Waste-to-Value Technologies in Developing Countries

Waste-to-value technologies connote processes that convert waste materials into economically useful products such as energy, fertilisers, construction materials, and industrial raw inputs. In developing countries, where waste generation is increasing but management infrastructure is often inadequate, waste-to-value approaches provide dual benefits of environmental protection and socio-economic development (World Bank, 2018). These technologies include composting, anaerobic digestion, biogas production, pyrolysis, recycling, and microbial fermentation.

2.7 The Circular Economy

The circular economy concept represents a transformative economic model that seeks to decouple growth from resource consumption by promoting sustainability, waste reduction, and resource efficiency. This is quite different from the traditional linear economy, which is characterised by extraction, production, consumption, and disposal. The circular economy emphasises restorative

and regenerative systems where materials are continuously reused, remanufactured, recycled, or biologically regenerated (Ellen MacArthur Foundation, 2013).

2.8 Principles of Microbial Biodegradation

Microbial biodegradation has to do with the natural process by which microorganisms break down complex organic substances into simpler compounds through enzymatic activity. This process is fundamental to ecosystem functioning, as it facilitates nutrient cycling and organic matter decomposition. The principles of microbial biodegradation involve three primary stages: biodeterioration, biofragmentation, and assimilation. Biodeterioration begins with the colonisation of waste material surfaces by microorganisms, which produce enzymes that alter the physical and chemical structure of the substrate. Biofragmentation follows, during which polymer chains are cleaved into smaller molecules. Finally, assimilation occurs when microorganisms absorb and metabolise these smaller molecules as carbon and energy sources (Shah, Hasan, Hameed, & Ahmed, 2008).

2.9 Bioremediation Techniques

Bioremediation is an environmentally friendly technology that utilises microorganisms, plants, or microbial enzymes to detoxify, degrade, or remove pollutants from contaminated environments. It is widely applied in soil, water, and wastewater treatment systems to manage pollutants such as hydrocarbons, heavy metals, pesticides, and plastic residues. The effectiveness of bioremediation relies on the metabolic capabilities of microorganisms to convert harmful contaminants into less toxic or harmless substances (Das & Dash, 2017). This approach is considered cost-effective, sustainable, and less disruptive compared to conventional physicochemical remediation methods.

2.10 Feasibility of Microbial Waste Technology in Nigeria

The feasibility of microbial waste technology in Nigeria depends on technical capacity, economic viability, policy support, and socio-cultural acceptance. Nigeria generates a significant volume of municipal solid waste annually, with organic waste constituting a large proportion of the total waste stream (World Bank, 2018). This high organic fraction comprising food waste, agricultural residues, and biodegradable materials creates favourable conditions for microbial processes such as composting and anaerobic digestion. Given Nigeria's tropical climate, characterised by relatively high temperatures and humidity, microbial activity can occur efficiently under controlled conditions, potentially enhancing biodegradation rates and biogas production.

2.11 National Waste Profile

Nigeria generates an estimated 32-42 million tonnes of solid waste annually, a figure projected to reach 107 million tonnes by 2050 (World Bank, 2020). Organic materials constitute 40-68% of municipal solid waste, compared to approximately 28% in the United States and 34% in the European Union (Hoornweg & Bhada-Tata, 2012; Ezeudu & Ezeudu, 2019). The composition of this waste stream is as depicted in table 1.

Table 1

Composition of waste in Nigeria

S/N	Waste Category	Percentage (%)
1.	Organic waste	50-60
2.	Plastic	15-20
3.	Paper	10-15
4.	Metals	3-5
5.	Glass	2-3

Note. Updated data from Ezeudu and Ezeudu (2019)

The organic waste dominance indicates strong potential for biological conversion technologies. This is affirmed by the picture painted by regional waste generation and composition.

Table 2

Regional Waste Generation and Composition in Selected Nigerian Cities (2025-2026)

S/N	City	Geo-political Region	Per Capita Waste Generation (kg/capita/ day)	Organic Waste Component (%)	Plastic Waste Component (%)	Population Estimate in millions	Tonnes of Daily Waste Generation
1.	Abuja	North-Central	0.61	56.0 -63.6	8.7 - 12.0	2.1 - 3.8	3,000 - 4,500
2.	Lagos	South-West	0.72 - 1.02	45.0-56.0	20.0-25.0	15-20+	13,000-17000
3.	Port Harcourt	South-South	0.64 - 1.10	52.0 - 69.0	11.0 - 19.0	1.6 - 3.5	1,000 - 1,500
4.	Kano	North-West	0.50 - 0.60	25.0 - 39.0	27.8 - 29.2	4.5-17.5	3,000 - 3,100
5.	Bauchi	North-East	0.86	25.1 - 51.5	16.4 - 23.2	1.0 - 1.2	270 – 300
6.	Enugu	South-East	0.48	40.2 - 55.1	18.0 - 21.0	900,000-1.4	420 – 600

Note. Data from Abubakar, et al. (2022), Ugwu, et al. (2020), Nduka and Emenike (2021), Lawan, et al. (2021), Ezeudu and Ezeudu (2019), and RMRDC (2025), World Bank Group/ LAWMA (2025).

2.12 Agricultural Waste Streams

According to FAO (2020) and RMRDC (2025), Nigeria's agricultural waste profile includes:

- crop residues (84 million tonnes annually),
- animal manure (83 million tonnes annually),

- palm oil mill effluents (3.2 million tonnes annually),
- fruit and vegetable processing waste (2.5 million tonnes annually), and
- abattoir waste (1.8 million tonnes annually).

According to Owolabi et al. (2021) documented utilisation rates remain low. This is as indicated:

- crop residues (15-20%),
- animal manure (10-12%), and
- fruit processing waste (8%)

2.13 Soil Impacts from Open Dumpsites

Christopher et al. (2025) evaluated nine dumpsites in Etinan, Uyo, and Ikot Ekpene Local Government Areas. The study found a significant modification of soil physicochemical characteristics including pH alteration (4.5 to 8.9), elevated electrical conductivity, and changes in exchangeable cations.

2.15 Economic and Environmental Benefits

Microbial waste transformation offers substantial economic and environmental benefits that align with sustainable development goals. Economically, converting waste into valuable products such as biogas, compost, biofertilisers, and industrial enzymes creates new revenue streams and employment opportunities. In countries where energy shortages persist, biogas production from organic waste can provide alternative renewable energy for households, institutions, and small industries, reducing dependence on fossil fuels and imported petroleum products (Tiwary et al., 2015). Additionally, organic fertilisers derived from composting can reduce reliance on expensive chemical fertilisers, thereby supporting agricultural productivity and food security in Nigeria. The waste-to-value approach stimulates circular economic activities, promotes entrepreneurship, and contributes to poverty reduction.

Environmentally, microbial transformation significantly reduces the volume of waste sent to landfills and open dumps, thereby mitigating greenhouse gas emissions, soil contamination, and water pollution. According to the World Bank (2018), poorly managed waste contributes to methane emissions and environmental degradation, especially in developing nations. By diverting biodegradable waste into controlled microbial processes such as anaerobic digestion, methane can be captured and utilised as energy, rather than being released into the atmosphere. Furthermore, composting improves soil structure, enhances nutrient cycling, and supports sustainable land management practices. Microbial bioremediation techniques also contribute to detoxifying polluted environments, reducing public health risks associated with unmanaged waste (UNEP, 2018).

3. Theoretical Framework

3.1 Multi-Level Perspective on Socio-Technical Transitions

The Multi-Level Perspective (MLP) on socio-technical transitions serves as the primary theoretical framework for this study. This perspective is attributed to the works of Frank Geels (2002, 2004, 2005) and offshoots rested on the assertions of Rip and Kemp (1998), Schot (1998), and others. The MLP has become a central framework for understanding long-term, complex transformations in socio-technical systems (Markard et al., 2012). The relevance of the framework according to Geels

(2019) subsumes in its ability to connect Science and Technology Studies (STS) to evolutionary economics, thereby, creating an integrated approach to analysing transitions.

According to Geels (2002), MLP distinguishes three analytical levels that interact to produce transitions. These include socio-technical landscape (macro level), socio-technical regime (meso-level) and socio-technological niche (micro -level)

Level 1: Socio-Technical Landscape (Macro-Level)
The landscape represents the exogenous environment of factors and processes that influence both regimes and niches. Geels (2004) describes the socio-technical landscape as "A set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems" (p. 902). These factors are beyond the direct influence of actors and cannot be changed at will (Geels, 2004); they change slowly, often over decades (Geels, 2002); and they include both gradual trends (demographic change, climate change) and sudden shocks (wars, oil price spikes) (Geels & Schot, 2007). Corroborating the above, Smith et al. (2010), posit that landscape processes would include "Environmental and demographic change, new social movements, shifts in general political ideology, broad economic restructuring, emerging scientific paradigms, and cultural developments." (p. 441).

Level 2: Socio-Technical Regime (Meso-Level)
The regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems, which could be found in institutions and infrastructures (Geels, 2002). By expanding the discourse to move from technological regime to socio-technical regime, Geels (2004) succeeded in opening the gap for the concept to accommodate not only engineers and scientists, but other professionals including business people, policy makers, consumers, and other interest groups.

To Geels (2002, 2004, 2019), Regime is easily known because it offers stability to socio-technical systems; creates path dependencies and technological lock-ins, and represents the "deep structure" of existing systems. There is also the feature where changes are seen to occur slowly and unfolding over decades (Rip & Kemp, 1998)

Level 3: Technological Niches (Micro-Level)
Niches are protective spaces or incubator rooms where socio-technical practices and new technologies can develop and mature without the selection pressures of the regime or normal market (Schot & Geels, 2008). Niches provide locations for learning processes; the development of supply chains and user-producer relationships (Geels, 2002, 2005) and space to build social networks that support innovations (Schot & Geels, 2008). They represent the locus of radical innovation ("variation") (Rip & Kemp,1998).

However, categorisation of niches is important for evaluation purposes. In this wise, Markard, Raven and Truffer (22008) are of the view that there are both market and technological niches. The market niches stem from the selection criteria from user practices and consumer preferences that deviate from normative standards, while Technological niches are deliberately

created and supported by existing institutions such as policymakers, interest organisations and regime members.

3.1.2 MLP Dynamics: How Transitions Occur

According to the MLP, transitions result from alignments between developments at the three analytical levels (Geels & Schot, 2007). The process can be summarised as:

a) Niche-innovations gradually build internal momentum through learning processes, price/performance improvements, and expanding social networks (Geels, 2005);
b) Landscape changes create pressure on the regime, destabilising existing arrangements (Geels, 2004);
c) Destabilisation of the regime creates "windows of opportunity" for niche-innovations to break through (Geels & Schot, 2007);
d) Alignment between niche innovations and ongoing regime processes leads to substantial transformation (Geels, 2002).

3.1.3 Transition Tract

Geels and Schot (2007) developed four transition routes based on timing and nature of multi-level interactions, as shown in Table 3.

Table 3

Transition Pathways in the Multi-Level Perspective

S/N	Transition Pathway	Landscape Pressure	Niche Innovation Maturity	Nature of Regime Change (Development Outcome)	Main Features
1.	Transformation	Moderate pressure on existing regime	Low (Under-developed)	Incumbent actors gradually adapt	Existing regime actors respond to external pressures through incremental adjustments and reforms
2.	Reconfiguration	Moderate to strong pressure	Moderate, niche innovations are initially complementary	Gradual restructuring of regime architecture	Symbiotic innovations are incorporated into the regime and subsequently trigger broader systemic changes
3.	Technological Substitution	Strong pressure	High, niche innovations are well developed (Substantial)	Existing regime is replaced	Mature niche innovations challenge and eventually displace the dominant regime

4.	De-alignment/ Re-alignment	Very strong, disruptive pressure	Low, no dominant niche initially	Regime collapses before a new one emerges	Multiple innovations compete during a period of instability until one becomes dominant and forms a new regime

Note. Adapted from "Typology of Sociotechnical Transition Pathways" by F. W. Geels and J. Schot, 2007, Research Policy, 36(3), p. 401.

Pinch and Bijker (1984) have complemented the above theory by introducing **Social Construction of Technology (SCOT)** where it is posited that technological meanings are socially constructed through interpretive flexibility and closure mechanisms. This is because actors interpret technologies differently based on social position and interests. Similarly, Nelson and Winter, (1982) explain variation, selection, and retention processes in technological development through **Evolutionary Economics Theory**. This, to them, occurs as actors operate under bounded rationality, using cognitive rules and schemas. While DiMaggio and Powell (1983) are of the view that actors are embedded in regulatory structures and social networks. This explains how formal rules, norms, and cognitive frameworks shape action. This is captured within **Neo-Institutional Theory.**

Micro-Foundations of the MLP

- Transformation improves the existing system.
- Reconfiguration adds innovations that gradually reshape the system.
- Technological substitution replaces the old system with a new one.
- De-alignment and re-alignment occur because the old system breaks down

several alternatives that compete until a new system emerges.

Table 4

Multi-dimensional Model of Agency in Socio-technical Transitions

S/N	Agency	Dimension	Orientation	Characteristics
1.	Iterational	Past	Repetition,	habit, routine, custom
2.	Projective	Future	Envisioning	possibilities, articulating goals, plans
3.	Practical-evaluative	Present	Deliberation	judgment, choice, decision-making

Note. Adapted from "Micro-Foundations of the Multi-Level Perspective on Socio-Technical Transitions" by F. W. Geels, 2019, Technological Forecasting and Social Change, 152, p. 119894.

This multi-dimensional understanding addresses criticisms that the MLP is "dominated by rational action" (Smith et al., 2005, p. 1496) and "undervalues the role of agency and politics" (Genus & Coles, 2008, p. 1441) by articulating how actors in transitions engage in learning, network building, visioning, shielding, nurturing, empowering, selective translation, intermediation, political struggle, resistance, discursive framing, and strategic reorientation (Geels, 2019).

3.2 Technological Innovation Systems Theory (TIS): Bergek, Jacobsson, Carlsson, Lindmark, and Rickne (2008); Jacobsson and Bergek (2004); Markard and Truffer (2008)

The Technological Innovation Systems (TIS) framework focuses on the networks of actors, institutions, and technologies that generate, diffuse, and utilise innovations in a particular field (Bergek et al., 2008). As it deviates from the focus of MLP on multi-level dynamics, TIS emphasises:

i. System functions: Activities that contribute to innovation system performance including knowledge development, knowledge diffusion, entrepreneurial experimentation, market formation, legitimation, resource mobilisation, and guidance of search (Bergek et al., 2008);
ii. System components: Actors (firms, organisations), networks (relationships between actors), and institutions (rules, norms, regulations) (Jacobsson & Bergek, 2004);
iii. System boundaries: Can be defined by technology, geographical area, or sector (Markard & Truffer,2008).

Relevance to this study: TIS complements MLP by providing analytical tools for assessing Nigeria's waste-to-value innovation system. This is done by identifying which functions are weak (e.g., market formation, legitimation, knowledge diffusion) and advocating for policy intervention.

3.3 Transition Management Theory (TM): Jan Rotmans, René Kemp, Derk Loorbach (2001) and Loorbach (2010)

Transition Management (TM) is a governance approach derived from MLP insights. It focuses on how policymakers can deliberately influence transition processes (Rotmans et al., 2001). some tenets of the theory include:

a) **Transition arenas:** These are protected spaces for developing alternative visions, networks, and experiments (Loorbach, 2010);
b) **Strategic experiments:** Portfolio of niche-level projects that explore alternative pathways (Kemp et al., 1998);
c) **Transition agendas:** Shared problem framings and long-term goals across actors (Rotmans et al., 2001);
d) **Cyclical governance:** Iterative processes of visioning, agenda-setting, experimenting, and evaluating (Loorbach, 2010).

Relevance to this study: TM provides normative guidance for Nigerian policymakers seeking to deliberately catalyse a waste-to-value transition. It is suggested in the theory that there is a

compelling need for "transition arenas" where state, private sector, and civil society actors can develop shared visions and strategies about profitable waste management practices beyond the current lock-ins.

Integration: This study incorporates MLP, TIS, and TM into an integrated analytical framework for Nigeria's Waste Transition, as presented in Table 5.

Table 5

Integrated Analytical Framework for Nigeria's Waste-to-Value Transition

S/N	Framework	Primary Contribution	Application to Nigeria's Case
1.	MLP	Explains transition dynamics through multi-level interactions	Analysing how landscape pressures (climate change, oil price volatility) create windows of opportunity for waste-to-value niches; and understanding regime lock-ins (government operator-regulator role, infrastructure deficits)
2.	TIS	Identifies system functions requiring strengthening	Assessing Nigeria's waste-to-value innovation system functions: knowledge diffusion (weak), market formation (very weak), legitimation (emerging), resource mobilisation (inadequate)
3.	TM	Provides governance strategy for deliberate transition	Proposing transition arenas, strategic experiments (pilot facilities), and cyclical governance processes for Nigerian states

Note. Developed by the authors (2026)

4. Literature Review

4.1 Waste Generation and Characterisation in Nigeria

4.1.1 National Waste Profile

Nigeria generates an estimated 32-42 million tonnes of solid waste annually, a figure projected to reach 107 million tonnes by 2050 (World Bank, 2020). Organic materials constitute 40-68% of municipal solid waste, compared to approximately 28% in the United States and 34% in the European Union (Hoornweg & Bhada-Tata, 2012; Ezeudu & Ezeudu, 2019).

4.1.2 Agricultural Waste Streams

According to FAO (2020) and RMRDC (2025), Nigeria's agricultural waste profile includes crop residues (84 million tonnes annually), animal manure (83 million tonnes annually), palm oil mill effluents (3.2 million tonnes annually), fruit and vegetable processing waste (2.5 million tonnes

annually), and abattoir waste (1.8 million tonnes annually). Current utilisation rates remain low at 8-20% (Owolabi et al., 2021).

4.2 Waste Characterisation in Akwa Ibom State

Uchenna et al. (2026) reported enzyme activities involving cellulase, protease, amylase, lipase, pectinase, xylanase and phytase. Cellulase activity reached 66.56 U/mL at the Uyo Village dumpsite, while protease activity reached 62.35 U/mL at Eka Street. Amylase activity was highest at Calabar-Itu Road at 45.38 U/mL, while lipase and pectinase activities were highest at Eka Street at 42.19 U/mL and 43.17 U/mL, respectively. Xylanase and phytase activities were also recorded.

Bassey et al. (2024) also provided empirical evidence concerning the characteristics and management of municipal solid waste in Uyo Capital City Development Area (UCCDA). The researchers conducted direct waste sorting and characterisation of municipal solid waste arriving at the central landfill along Uyo Village Road. Their study analysed approximately 9,308.7 kg of waste using a coning and quartering approach. The study reported that more than 50% of the generated waste was recyclable, consisting principally of plastics, metals and paper, while the organic fraction exceeded 30%. Similarly, Okey et al. (2013) characterised solid waste in Uyo and reported an average generation rate of approximately 0.54 kg/person/day. Their characterisation indicated that 65% of the waste stream consisted of compostable materials, followed by plastics (10%), paper (8%), metals (4%), textiles (3%), glass (3%) and other materials (7%). While data from Christopher et al. (2025) indicated that there is a significant disparity between healthcare facility types and the volume of waste generated. The researchers cited daily waste generation between St. Luke's hospital and University of Uyo Teaching hospital of consisting of 150-200kg/day and 500-700kg/day.

4.2.2 Soil Impacts from Open Dumpsites

Christopher et al. (2025) evaluated nine dumpsites in Etinan, Ikot Ekpene and Uyo, Local Government Areas, finding significant modification of soil physicochemical characteristics including pH alteration (4.5 to 8.9), elevated electrical conductivity, and changes in exchangeable cations.

4.3 Microbial Waste Valorisation: Technologies and Evidence

Microbial enzymes can facilitate the breakdown of complex organic materials into simpler compounds that can subsequently be utilised in biological conversion processes. Enzymes such as cellulase, amylase, protease, lipase, pectinase and xylanase are relevant because they act on different classes of organic substrates.

4.3.1 Biofuels and Biogas

Anaerobic digestion produces biogas with methane concentrations of 52-65% (Mata-Alvarez et al., 2014). The IEA (2020) estimates that Nigeria could generate 2.5 GW of electricity from agricultural waste biogas.

4.3.2 Industrial Enzymes

Abdullahi et al. (2025) confirmed that cassava peels achieved cellulase yields of 2.8 U/mL and amylase yields of 4.2 U/mL under optimised solid-state fermentation conditions.

4.3.3 Biofertilisers

Field trials in Nigeria illustrate that composted agricultural residues increase soil nitrogen by 26% and phosphorus by 19% (Abdullahi et al., 2025; Adeleke et al., 2020).

4.3.4 Substrate Characterisation

Table 6 presents the chemical composition of selected Nigerian agricultural wastes.

Table 6

Chemical composition and microbial conversion efficiency of selected Nigerian agricultural wastes

S/N	Agricultural wastes	Substrate Starch (%)	Cellulose (%)	Lignin (%)	Conversion Efficiency (%)
1.	Cassava peels	48	20-22	6-8	82-87
2.	Rice husks	38-42	22-25	8-10	68-75
3.	Yam peels	44-48	18-20	7-9	75-82
4.	Maize stover	35-40	24-28	10-12	65-72

Note. Data from Abdullahi et al. (2025); Chopra et al. (2020); RMRDC (2025).

4.4 Empirical Studies on Microbial Waste Valorisation

Bassey et al. (2024) established the composition of the Uyo municipal waste stream, reporting that the organic fraction exceeded 30%. Their contribution was therefore primarily the identification and quantification of the potential biodegradable feedstock. The researchers did not experimentally investigate the microbial transformation of this fraction into specific value-added products.

Uchenna, Akpan, and Ugochukwu (2026) provide a different but complementary contribution. Their study investigated microorganisms associated with three municipal solid-waste dumpsites in Uyo, namely, Uyo Village Road, Calabar Itu Road and Eka Street, together with control soil from University of Uyo farmland. The research was conducted between July 2023 and August 2024. The researchers isolated and characterised bacterial microorganisms and examined their enzyme-producing capabilities.

Uchenna et al. (2026) reported enzyme activities involving cellulase, protease, amylase, lipase, pectinase, xylanase and phytase. Cellulase activity reached 66.56 U/mL at the Uyo Village dumpsite, while protease activity reached 62.35 U/mL at Eka Street. Amylase activity was highest at Calabar Itu Road at 45.38 U/mL, while lipase and pectinase activities were highest at Eka Street at 42.19 U/mL and 43.17 U/mL, respectively. Xylanase and phytase activities were also recorded.

Other empirical works provide evidence for the feasibility of microbial conversion of organic biomass. Eduok et al. (2018) investigated anaerobic co-digestion of lignocellulosic biomass and poultry faeces and examined the use of source-separated human urine as a buffering agent. Ofon et al. (2022) investigated the use of anaerobic digestates as microbial inoculum sources for enhancing the co-digestion potential of agro-industrial residues. Umana et al. (2026) examined biological

pretreatment of coconut-husk lignocellulosic biomass for biogas production and its influence on archaeal communities and volatile fatty acids. These studies provide experimental evidence that microbial activity, substrate conditioning and biological pretreatment can influence the conversion of organic biomass. However, their studies are not identical to organic waste valorisation beyond plastics and Styrofoam.

Relevance of Literature and Research Gap

The available empirical research in Nigeria and related contexts illustrates that microbial processes can be applied to organic biomass through many channels such as anaerobic digestion, biological pretreatment and microbial inoculation. These studies establish the technical basis for biological conversion but do not specifically resolve the problem of converting characterised biodegradable waste into locally relevant value-added products in Akwa Ibom State. The connection between waste resource and local microbial capability has not been sufficiently integrated within an evaluated waste-to-value ways. In particular, there remains a need to investigate the relationship between properly managed organic waste streams, and measurable value-added outputs that are beyond plastics and Styrofoam.

The present study is consequently positioned to bridge this gap through a focused basis for moving from the existing disjointed microbiological evidence toward an integrated waste-to-value model for organic wastes management in Nigeria.

5. Methodology

5.1 Research Design

This study employs a mixed-methods convergent design, integrating quantitative waste characterisation and economic modelling with qualitative policy analysis and comparative case studies. A single embedded case study design (Awak, 2022; Yin, 2018) was employed, with Akwa Ibom State as the primary study site.

5.2 Case Study Selection and Justification

Akwa Ibom State was selected based on:

- availability of recent empirical waste data (2025-2026);
- representativeness of the South-South agro-ecological zone;
- documented environmental impacts;
- existing research infrastructure (University of Uyo and Akwa Ibom State Polytechnic); and
- policy relevance.

5.3 Data Sources

5.3.1 National and International Databases

- FAO Statistical Database (FAOSTAT) (2015-2026)
- World Bank “What a Waste” Global Database (2018-2025)
- Nigerian National Bureau of Statistics
- Raw Materials Research and Development Council (RMRDC)
- Lagos Waste Management Authority (LAWMA) (2025-2026)

5.3.2 Comparative Analysis Framework

Three comparator countries namely, Brazil, India, and Thailand were selected based on similar agricultural waste profiles, comparable development status, demonstrated progress in bioeconomy policy, and data availability.

5.4 Data Analysis

Quantitative data were analysed using descriptive statistics and comparative ratios, while qualitative policy data were analysed using thematic content analysis with themes derived from the MLP/TIS/TM framework.

5.5 Limitations

Limitations include incomplete waste characterisation for rural areas, variation in reporting periods across databases, limited long-term performance data for Nigerian pilot facilities, and the single case study design limiting generalisability.

5.6 Artificial Intelligence Use Disclosure

ChatGPT (GPT-5.6 Luna) and Gemini were used as parts of the research team; serving as research-assistance tools during this study. Their usage included support for conceptual and literature search, and the generation of some data and graphic related materials. However, AI generated outputs were not accepted in their raw forms and uncritically. They were reviewed, evaluated, revised, and where applicable, independently verified by the authors. The authors retain full responsibility for the study conception, design, model, data integrity and validation, interpretation of findings, accuracy of citations and references, theoretical arguments and the final content, conclusion and recommendations.

6. Findings

6.1 Nigeria's Agricultural Waste Profile (2025-2026)

Table 7

Estimated Agricultural Waste Generation by Category (Nigeria, 2025-2026)

S/N	Waste Category	Annual Generation	Utilisation Rate	Primary Disposal
1.	Crop residues	84 million tonnes	15-20%	Open burning/dumping
2.	Animal manure	83 million tonnes	10-12%	Untreated disposal
3.	Palm oil mill effluents	3.2 million tonnes	5%	Water discharge
4.	Fruit/vegetable waste	2.5 million tonnes	8%	Landfill/dumping
5.	Abattoir waste	1.8 million tonnes	3%	Open disposal

Note. Data compiled from Christopher et al. (2025); Abdullahi et al. (2025); Adeleke et al. (2020)

6.2 Key documented findings from Akwa Ibom State

Healthcare Waste:

- Tertiary facilities: 500-700 kg/day, 48% hazardous
- Secondary facilities: 150-200 kg/day, 35% hazardous
- Lead contamination: soil (60 mg/kg), groundwater (0.30 mg/L)
- Plant growth inhibition: 30-40% near tertiary facility dumpsites

Dumpsite Contamination (Etinan, Ikot Ekpene and Uyo):

- Soil pH range: 4.5 to 8.9
- Paint-processing waste causing alkalinity (pH > 8.5)
- Abattoir waste enriching organic matter
- Isolated and characterised bacterial microorganisms and their enzyme-producing capabilities.

Valorisation Potential in Akwa Ibom State:

- Cassava residues are up to 2.1 million tonnes/year.
- Palm oil mill effluents constitute about 0.4 million tonnes/year.
- Estimated biogas potential could reach 45-60 million m^3/year (sufficient for 15,000 - 20,000 households).

6.3 Economic Modelling Results

Table 8

Financial Analysis of 50-Tonne/day Waste Valorisation Facility

S/N	Parameter	Value
1.	Capital investment	$2.5 million
2.	Annual operating cost	$450,000
3.	Annual revenue	$890,000
4.	Net present value (10-year, 12%)	$1.8 million
5.	Internal rate of return	24%
6.	Payback period	4.2 years
7.	Direct jobs created	45

Note. Developed by the authors (2026)

6.4 Comparative Analysis: International Bioeconomy Models

Nigeria's organic waste valorisation rate (<5%) lags significantly behind Brazil (35%), India (28%), and Thailand (42%). Key differences include absence of a dedicated bioeconomy policy, limited

infrastructure investment ($15-20 million/year vs. $210-450 million/year in comparators), and the government operator-regulator conflict. This is what table 9 depicts.

Table 9

Comparative bioeconomy indicators (2024-2025)

S/N	Indicator	Nigeria	Brazil	India	Thailand
1.	Organic waste valorisation rate	<5%	35%	28%	42%
2.	Biogas plants (number)	<500	450+	5,000,000+	3,200+
3.	Bioethanol production (billion L/year)	0.011	332.4	3.5	0.45
4.	Dedicated bioeconomy policy	No	Yes	Sectoral	Yes
5.	Private investment ($ million/year)	15-20	450	380	210

Note. Adapted from IRENA (2024); Government of India (2024); Thailand Board of Investment (2024); RMRDC (2025).

7. Discussion

7.1 Applying the MLP Framework to Nigeria's Waste Lock-in

Applying the MLP framework, Nigeria's waste management regime remains locked in linear practices that is characterised by path dependencies (landfills and open dumps as default disposal), institutional arrangements (the government as operator-regulator), and behavioural norms (low public demand for alternatives). The Akwa Ibom case exemplifies this lock-in such that despite the documented environmental harms, there seems to be no intentional systemic response that has emerged because the regime lacks incentives for change.

Landscape pressures including climate change commitments, international investment conditionalities, and Nigeria's Styrofoam ban are creating windows of opportunity. However, niche innovations (microbial valorisation technologies) remain underdeveloped at scale, with fewer than 500 digesters nationwide compared to 5 million in India.

7.2 The Governance Barrier

The most significant finding concerns governance. It is obvious that despite technical feasibility and demonstrated demand, Nigeria's waste valorisation rate remains below 5%. The government's dual role as operator and regulator creates perverse incentives that the Akwa Ibom case illustrates clearly: state-operated healthcare facilities generate hazardous waste with no treatment infrastructure, and no enforcement action has been taken because the regulator and operator are the same entity.

7.3 Beyond Plastics and Styrofoam: Reframing the Policy Discourse

Current Nigerian waste policy disproportionately focuses on plastics and Styrofoam, which aligns with and reflects international donor priorities and visible pollution concerns. However, this emphasis may be suboptimal. Organic waste constitutes 60%+ of solid waste, generates methane

(28-34 times more potent than CO_2 over100 years), and offers higher valorisation value per tonne ($45-70/tonne for biogas and biofertiliser as against $15-40/tonne for plastic recycling).
A balanced strategy should address plastics and Styrofoam, while recognising organic waste as the priority stream for near-term circular economy gains. This reframing aligns with Nigeria's agricultural development priorities.

7.4 Akwa Ibom as a Potential Transition Arena
Considering a Transition Management perspective, Akwa Ibom State could serve as a "transition arena" where state-level policymakers, healthcare administrators, waste management companies, and community representatives develop shared visions and pilot interventions. The presence of research infrastructure (University of Uyo, Akwa Ibom State Polytechnic, Akwa Ibom State University), documented baseline data by many researchers including Uchenna et al. (2026); Christopher et al., (2025) and Bassey et al. (2024), as well as availability of agricultural processing clusters position Akwa Ibom favourably for experimentation.

8. Conclusion

This study explored microbial valorisation of organic waste for circular bioeconomy development beyond plastics and Styrofoam, using Akwa Ibom State as a study site. The findings illustrate that Nigeria's abundant organic waste streams, particularly, agricultural residues possess favourable characteristics for microbial conversion, with starch contents of 38-52% and conversion efficiencies of 68-87%.

The comparative analysis reveals that Nigeria lags far behind countries with similar waste profiles and development status, primarily due to governance barriers, rather than merely technological constraints. The government's dual role as operator and regulator creates structural disincentives for innovation and enforcement, while the absence of a dedicated bioeconomy framework leaves organic waste valorisation policy at indeterminate state. The application of the Multi-Level Perspective framework reveals that Nigeria's waste management regime remains locked in linear practices, which require coordinated action across landscape, regime, and niche levels to enable transition.

The opportunity is substantial as a result of the fact that with agricultural waste generation exceeding 84 million tonnes annually, Nigeria could transform its waste sector into a $2.5 billion annual industry. For Akwa Ibom State specifically, the estimated biogas potential from available agricultural residues (45-60 million m^3/year) could power 15,000-20,000 households, while remediate contaminated sites and create local employment.

The transition beyond plastics and Styrofoam to a comprehensive organic waste valorisation strategy will not occur automatically. It requires political will, coordinated action across government levels, and sustained partnerships. The cost of inaction in environmental degradation, public health impacts, and foregone economic benefits far exceeds the investment required for transformation. Nigeria can and should become a leader in Africa's circular bioeconomy, with Akwa Ibom State serving as a pioneering transition arena for the South-South region. Indeed, the waste is waiting; the technologies are ready; what remains is the decision for deployment.

9. Recommendations

9.1 National-Level Recommendations

- Separate government operator and regulator roles within 24 months.
- Develop a National Bioeconomy Strategy with an organic waste diversion target of 30% by 2030.
- Enact a Solid Waste Management Bill with provisions for extended producer responsibility covering organic waste.
- Establish four regional bioeconomy hubs (North-Central, South-West, South-South, North-West).
- Establish a $200 million Circular Economy Investment Fund.

9.2 State-Level Recommendations for Akwa Ibom State

- Establish a centralised healthcare waste treatment facility in Uyo with capacity to process tertiary facility waste (minimum 1,000 kg/day), using autoclave or microwave technology.
- Remediate contaminated dumpsites in Etinan, Ikot Ekpene and Uyo, LGAs using bioremediation techniques for organic contaminants and soil washing/ phytoextraction for heavy metals.
- Establish a pilot agricultural waste valorisation facility in Ikot Abasi or Abak or Mkpat Enin (palm oil and cassava processing clusters), Ikono or Ini LGAs (Rice husk and associated waste) producing biogas and biofertiliser.
- Create an Akwa Ibom State Circular Economy Agency with representation from the Ministry of Environment, Ministry of Agriculture, University of Uyo, Akwa Ibom State Polytechnic, Akwa Ibom State University, private sector operators, and informal waste picker cooperatives.
- Install environmental monitoring wells at existing dumpsites and healthcare waste disposal areas with semi-annual public reporting.
- Rejig Akwa Ibom State Environmental Protection and Waste Management Agency (AKSEPWMA) to be more proactive and vigorous in its operations so as to generate and capture updated data for effective waste planning and management in the state.

9.3 Implementation Roadmap for Akwa Ibom State and others

Table 10

Implementation Roadmap

S/N	Phase	Timeline	Priority	Actions	Budget in millions
1.	Phase 1	Foundation 2026-2027	Separate roles	- Enact legislation, - Establish State Circular Economy Agency	$75

2.	Phase 2	Scaling 2028-2029	- Healthcare waste facility - Agricultural pilot - other organic waste - Enforce ban on single-use plastics and Styrofoam	- Remediate dumpsites - Create aggressive waste management awareness	$150
3.	Phase 3	Integration 2030-2031	30% diversion target	Full waste picker integration	$100

Note. Developed by the authors (2026)

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Appendix

Table 11

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10.	Kubiat-Abasi Bernard Bassey	AKP/ASC/SLT/HND2024/M1698
11.	Nduyeabasi Enefiok Duff	AKP/ASC/SLT/HND2024/M1711
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Note. Co-Authors are HNDII Students who participated in extended research after seminar presentation on **Industrial Management (GNS413) 2025/2026 Session.**