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IMPLEMENTING ZERO-WASTE SOLUTIONS IN NSUKKA, NIGERIA: CHALLENGES, OPPORTUNITIES, AND PATHWAYS FOR SUSTAINABLE WASTE MANAGEMENT

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Abstract

This paper examines the challenges, opportunities, and pathways for implementing zero-waste solutions in Nsukka, Enugu State, Nigeria, with a focus on sustainable waste management practices. Like many towns in Nigeria, Nsukka relies on open dumpsites and poorly managed landfills, resulting in significant environmental and public health concerns. This study identifies major barriers to effective waste management, including inadequate policy frameworks, negative public attitudes towards waste disposal, and insufficient infrastructure for waste segregation and recycling. It explores potential zero-waste strategies such as community-based waste segregation, composting, upcycling, recycling, and the application of technology-driven waste management systems. The study adopts a qualitative approach, drawing on a review of relevant literature, policy analysis, and comparative case studies to examine existing challenges and identify viable solutions. It also highlights the importance of policy reforms, stronger enforcement of waste management regulations, and public-private partnerships in improving waste management outcomes. Drawing on successful international models, including Rwanda's plastic ban, Sweden's waste-to-energy system, San Francisco's mandatory recycling programmes, and the "From Glass Waste to Wealth" initiative at Zighy Bay in Oman, the paper proposes adaptable circular strategies for Nsukka. The findings suggest that adopting a zero-waste approach can reduce pollution, improve public health, and create socio-economic opportunities within the community.

Keywords: zero-waste, Nsukka, sustainable waste management, challenges and opportunities.

Introduction

The management of solid waste has become a pressing environmental and public health concern in Nsukka, Enugu State, Nigeria, as rapid urbanisation and population growth continue to increase the volume of waste generated. In many parts of the town, waste disposal practices are poorly managed, with residents relying on open dumpsites and landfills that not only degrade the environment but also pose significant risks to public health. Available studies illustrate the scale of the challenge. For instance, Ugwu, Echiegu, and Okonkwo report that residents of Nsukka urban generate an average of 4,970.83 m³ of solid waste weekly. Within this figure, the University of Nigeria (which has its main campus located in Nsukka town) contributes approximately 2,218.66 kg of waste daily, with a per capita generation rate of 0.06 kg. Organic matter and polythene constitute the largest components of

the waste stream, accounting for 32.36% and 34.29%, respectively.¹ These figures underscore the urgent need for sustainable approaches to waste management in Nsukka, including the adoption of zero-waste strategies.

Studies on municipal solid waste generation in Nsukka indicate that household size, consumption patterns, and proximity to dump sites significantly influence the volume of waste generated.² Furthermore, unmanaged waste remains a common feature of the urban landscape. Plastics, nylons, and other forms of refuse are frequently found along roadsides and in public spaces, creating environmental, aesthetic, and public health concerns.³ Like many towns in Nigeria, Nsukka relies on open dumpsites and poorly managed landfills as major components of its waste management system. These facilities are often located on the outskirts of the town or in undeveloped areas and typically lack modern waste-treatment technologies. Consequently, waste management remains a significant challenge. In addition to their environmental impacts, such dumpsites may contribute to conditions that increase public health risks, including the spread of vector-borne and water-borne diseases.

Waste segregation is also largely absent in Nsukka. Organic waste, plastics, and potentially hazardous materials are commonly disposed of together, increasing the risk of soil and water contamination and exposing nearby communities to environmental and health hazards. Waste management services are often irregular and inadequate, further contributing to waste accumulation and environmental degradation across the metropolis. The implications of poor waste management extend beyond local environmental concerns. Waste disposal practices have direct consequences for climate change, making effective waste management an important component of climate protection policies and actions.⁴ Poorly managed waste generates methane, a potent greenhouse gas that contributes significantly to global emissions.⁵ Addressing waste management challenges in Nsukka is therefore essential not only for environmental sustainability and public health but also for broader climate-change mitigation efforts.⁶

Efforts such as the Don't Litter Initiative, spearheaded by Professor Egodi Uchendu of the University of Nigeria, Nsukka, demonstrate the potential for positive change in waste management practices within the metropolis.⁷ The initiative promotes responsible waste disposal and environmental

¹ K. C. Ugwu, E. A. Echiegu, and W. I. Okonkwo, "Solid Waste Generation and Management in Nsukka Urban," *World Journal of Engineering Research and Technology* 4, no. 1 (2018): 21–34.

² Ibid.

³ Ibid; A. Obianuju, O. V. Amarachi, and E. A. E. Sylvia, "Burden of Plastic Waste in Nsukka Metropolis," *Journal of Environment and Earth Science* 14, no. 5 (2024).

⁴ United Nations Environment Programme, *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions*, 2021, <https://www.unep.org/resources/report/global-methane-assessment>.

⁵ Ibid; Intergovernmental Panel on Climate Change, *Climate Change 2021: The Physical Science Basis*, 2021, <https://www.ipcc.ch/report/ar6/wg1/>.

⁶ World Bank, *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*, 2018, <https://openknowledge.worldbank.org/handle/10986/30317>.

⁷ Egodi Uchendu, "How to Make a University a Clean Place: The 'Don't Litter Initiative' at the University of Nigeria, Nsukka," January 31, 2023, <https://www.alumniportal-deutschland.org/en/magazine/alumni-stories/how-to-make-a->

awareness, particularly within the university community. However, it remains at an early stage and requires greater public engagement and institutional support to achieve wider impact. Building on such efforts, this paper explores how zero-waste practices can be adopted in Nsukka to address existing waste-management challenges and promote environmental sustainability.

Conceptualising Zero-Waste

Zero-waste represents a fundamental shift in approaches to sustainable consumption and production. Rather than viewing waste as an inevitable by-product of human activity, the concept regards discarded materials as valuable resources that can be recovered, reused, recycled, or repurposed within a circular economy. According to the Zero Waste International Alliance, zero-waste is “an ethical, economical, efficient and visionary goal”⁸ that encourages individuals and communities to redesign their lifestyles and practices to emulate natural cycles, where discarded materials become resources for further use. This approach moves beyond conventional waste disposal towards resource management, with an emphasis on waste prevention, sustainable design, responsible consumption, and maximum resource recovery. Consequently, zero-waste prioritises reducing waste generation at source rather than relying primarily on landfilling or incineration.⁹

Traditional waste management systems, which largely depend on landfills and open dumpsites, often contribute significantly to environmental pollution. The zero-waste approach seeks to minimise such impacts by promoting the efficient use of resources within a circular economic framework based on nature’s “no-waste” principle. Under this model, materials are kept in productive use for as long as possible, thereby reducing pressure on natural resources and limiting environmental degradation. Zero-waste initiatives can contribute significantly to sustainable waste management by promoting waste prevention, resource efficiency, and improved recycling practices. Such initiatives also have the potential to address broader environmental and developmental concerns, including environmental protection, food security, and public health. While zero-waste does not reject the need for waste management, it advocates the optimisation of existing recycling and recovery systems alongside the development of innovative approaches aimed at minimising waste generation and maximising resource utilisation.

Challenges to the Implementation of Zero-Waste Practices in Nsukka

The implementation of zero-waste practices in Nsukka faces numerous challenges, including weak policy implementation, negative public attitudes towards waste management, and infrastructural deficiencies in waste collection, segregation, and recycling systems.¹⁰ As Adekunle et al. observed,

[university-a-clean-place/](https://www.unn.edu.ng/wp-content/uploads/2024/02/UNN-RG-Compilation-2023-2025.pdf); University of Nigeria, Nsukka, *Research Groups Compilation 2023–2025*, 2024, <https://www.unn.edu.ng/wp-content/uploads/2024/02/UNN-RG-Compilation-2023-2025.pdf>.

⁸ Zero Waste International Alliance, “Zero Waste Definition,” 2004, <https://zwia.org/zero-waste-definition/>.

⁹ A. U. Zaman, “A Comprehensive Review of the Development of Zero Waste Management: Lessons Learned and Guidelines,” *Journal of Cleaner Production* 91 (2015): 12–25.

¹⁰ Ugwu, et al, “Solid Waste Generation and Management in Nsukka Urban,” A. H. Ononuju, C. W. Romanus, S. I C. Dibia, T. E. Iwuagwu, and K. G. Usman, “Household Solid Waste Management Attitude and Practices,” *Journal of Home Economics Research* 30, no. 2 (2024): 107–119.

waste management remains a major challenge globally, particularly in developing countries, owing to its significant environmental, economic, and public health implications.¹¹ Effective waste management is therefore essential, as improperly stored and disposed waste can create serious health, safety, and environmental problems.

All living organisms generate waste; however, human activities produce waste on a scale far greater than that of other species. To protect ecosystems and sustain human well-being, waste must be managed, stored, and disposed of efficiently and responsibly. Although zero-waste practices offer a promising pathway towards sustainable waste management in Nsukka, their successful implementation depends on addressing a number of existing structural and behavioural barriers. One of the major challenges relates to policy implementation and institutional effectiveness. In 2004, the Enugu State Waste Management Authority (ESWAMA) was established through Enugu State Law Nos. 8 and 12 of 2004, replacing the Enugu State Environmental Protection Agency (ESEPA). ESWAMA was mandated to oversee environmental sanitation and waste management in designated urban centres across the state, including Nsukka. To enhance service delivery, the agency operates in partnership with Private Sector Participants (PSPs), whose responsibilities include waste collection, transportation, processing, recycling, and disposal.

Despite this institutional framework, waste-management challenges persist across the state. Research by Uwadiogwu and Iyi found that ESWAMA performed inadequately in several key areas of its mandate, including waste processing, treatment, recycling, sewage-disposal planning, staff training, and policy advisory functions.¹² The continued presence of unmanaged waste in public spaces suggests a gap between the agency's statutory responsibilities and its operational effectiveness. This situation highlights the broader challenge of translating waste-management policies into practical and sustainable outcomes.

Public attitudes towards waste disposal also constitute a significant obstacle to the implementation of zero-waste practices. Sustainable waste management depends not only on government policies and institutional capacity but also on the active participation of residents and businesses. However, indiscriminate waste disposal, poor waste segregation, and inadequate waste packaging remain common practices in many parts of Nsukka.¹³ Such practices contribute to blocked drainage systems, environmental pollution, increased flooding risks, and adverse public health outcomes.¹⁴ Infrastructural limitations further complicate waste-management efforts. Although successive administrations have invested in waste-management facilities, including the provision and rehabilitation of dumpsters and waste-compactor trucks,¹⁵ available infrastructure remains inadequate

¹¹ I. M. Adekunle et al., "Recycling of Organic Wastes Through Composting for Land Applications: A Nigerian Experience," *Waste Management & Research* 29, no. 6 (2011): 582–593, <https://doi.org/10.1177/0734242X1038731>.

¹² Benjamin O. Uwadiogwu and Edmund A. Iyi, "An Evaluation of the Operational Efficiency of a Public Agency: ESWAMA in Enugu City, Nigeria," unpublished manuscript.

¹³ M. Lynas, B. Z. Houlton, and S. Perry, "Greater than 99% Consensus on Human-Caused Climate Change," *Environmental Research Letters* 16 (2021): 114005. <https://doi.org/10.1088/1748-9326/ac2966>.

¹⁴ C. C. Nnaji et al., "Evaluation of Solid Waste Storage and Disposal Practices in Nsukka, Enugu State," *IOP Conference Series: Materials Science and Engineering* 1036 (2021).

¹⁵ B. O. Uwadiogwu and K. E. Chukwu, "Strategies for Effective Urban Solid Waste Management in Nigeria," *European Scientific Journal* 9, no. 88 (2013): 296–308, <http://ejournal.org/index.php/esj/issue/view/67>.

relative to the volume of waste generated. Overflowing dumpsters and visible waste accumulation in public spaces indicate deficiencies in waste-storage, collection, and transportation systems.

Furthermore, ESWAMA's responsibilities extend beyond waste collection to include street cleaning, drainage maintenance, disposal of abandoned vehicles and animal carcasses, preparation of waste-management master plans, and the design, operation, and supervision of waste-disposal facilities across the state.¹⁶ The breadth of these responsibilities, combined with documented operational shortcomings, underscores the need for complementary approaches involving communities, households, businesses, and civil society organisations. Addressing these challenges is essential if zero-waste principles are to be successfully integrated into waste-management practices in Nsukka and contribute meaningfully to environmental sustainability.

Opportunities for Zero-waste in Nsukka

Given the challenges discussed above, it is imperative that residents of Nsukka urban identify and actively engage in zero-waste practices in order to promote a healthier and more sustainable environment. Several opportunities exist that can support the implementation of zero-waste systems. These opportunities are discussed below.

Community-Based Waste Management Programmes (Community-Based Waste Segregation)

Community-based waste management programmes are local initiatives, often implemented in collaboration with non-governmental organisations and government agencies, aimed at improving waste handling practices at the community level. These programmes empower residents to take responsibility for environmental cleanliness while also creating opportunities for income generation through the sale of recyclables, composting, and small-scale recycling activities. Through education and sensitisation, households are encouraged to separate organic waste, plastics, and other recyclable materials at source, thereby reducing the volume of waste sent to landfills. When effectively supported by local leadership, such initiatives can contribute to behavioural change and strengthen sustainable waste practices.¹⁷

Community-based waste segregation refers to a system in which households and communities, rather than relying solely on municipal authorities, take responsibility for sorting waste at source. This typically occurs at household or neighbourhood level, where waste is separated into categories such as organic waste, recyclables (paper, plastics, and metals), and non-recyclables. This approach enhances the efficiency of downstream waste processing and reduces environmental burden. In Nsukka, strengthening community participation in waste segregation could significantly improve waste management outcomes.

Composting

Composting is the natural process of converting organic waste materials such as food scraps and leaves into nutrient-rich fertiliser that can improve soil quality. It is a biological decomposition process that

¹⁶ Enugu State Government, *Enugu State Waste Management Authority Law*, No. 8 (2004).

¹⁷ R. E. Marshall and K. Farahbakhsh, "Systems Approaches to Integrated Solid Waste Management in Developing Countries," *Waste Management* 33, no. 4 (2013): 988–1003. <https://doi.org/10.1016/j.wasman.2012.12.023>.

transforms organic waste into a valuable soil amendment. Organic waste constitutes a significant proportion of household waste and can be effectively managed through local composting systems. The establishment of community composting sites, particularly in market areas where food waste is abundant, would reduce the volume of waste sent to landfills while producing fertiliser for agricultural use. Residents in Nsukka can therefore contribute to sustainable waste management by adopting household and community-level composting practices instead of indiscriminate disposal of organic waste.

Upcycling and Recycling

Upcycling, also known as creative reuse, refers to the process of transforming waste materials or unwanted products into new items of equal or greater value in terms of functionality or aesthetics. It involves giving discarded materials a new life without breaking them down into raw components.¹⁸ Examples include converting used tyres into furniture or repurposing glass bottles into decorative lighting.

Recycling, according to the United States Environmental Protection Agency (EPA), involves the collection and processing of materials that would otherwise be discarded and converting them into new products.¹⁹ Recycling reduces the volume of waste sent to landfills and contributes to environmental protection by lowering air, water, and land pollution. For example, used newspapers and magazines can be repulped and transformed into new paper products such as cardboard and tissue paper.

It is important to distinguish between recycling and upcycling. Recycling typically involves breaking materials down into their base components before reforming them into new products, which may sometimes be of lower quality. Upcycling, on the other hand, does not involve breaking materials down; instead, it involves creative transformation of existing products into new uses, often retaining or increasing their value.²⁰ Both processes support zero-waste objectives by extending the lifecycle of materials and reducing waste generation. Small-scale recycling facilities established in partnership with private sector operators could help divert recyclable materials from landfills. In addition, upcycling initiatives involving plastics, glass, and textiles could generate employment opportunities while reducing environmental pollution.

Technology Integration

Digital technologies and data analytics are increasingly transforming waste management systems by improving efficiency and decision-making processes. Through the use of large datasets, waste management authorities can better understand patterns of waste generation and optimise service delivery.²¹ Modern waste management systems increasingly rely on data-driven approaches. Sensors

¹⁸ Upcycle That, “Upcycle That,” accessed 2024, <https://www.upcyclethat.com>; Upcycle That, “Upcycle That,” accessed 2024, <https://www.upcyclethat.com>.

¹⁹ United States Environmental Protection Agency, “Recycling Basics and Benefits,” 2024, <https://www.epa.gov/recycle/recycling-basics-and-benefits>.

²⁰ W. McDonough and M. Braungart, *Cradle to Cradle: Remaking the Way We Make Things* (North Point Press, 2002); United States Environmental Protection Agency, “Recycling Basics and Benefits.”

²¹ R. J. J. A. Rodrigues, I. de la Torre, G. Fernández, and M. López-Coronado, “Analysis of the Use of Big Data in Smart Cities,” *Future Generation Computer Systems* 86 (2018): 143–154. <https://doi.org/10.1016/j.future.2018.03.017>; L. A.

installed on bins and waste collection trucks can monitor fill levels in real time, enabling optimisation of collection routes and reducing operational inefficiencies. Mobile applications and digital platforms can also support waste tracking, reporting of illegal dumping, and improved coordination between households and recycling centres. In addition, technology can support targeted environmental education by identifying areas with high waste generation and enabling tailored awareness campaigns. Overall, the integration of technology into waste management systems enhances transparency, efficiency, and accountability while supporting sustainable urban environmental governance.

Global Models on Zero-waste: Case Studies and Lessons from Rwanda, Sweden, The United States, and Oman

Rwanda

Rwanda is widely recognised as a leading example of effective waste governance in Africa, particularly in relation to plastic waste management. In 2008, Rwanda introduced a national ban on the production, use, and sale of plastic bags and packaging materials.²² This policy was introduced in response to increasing environmental concerns, particularly the clogging of drainage systems and widespread plastic pollution. The policy reflects a broader commitment to circular economy principles, emphasising reduction, reuse, and recycling. The ban specifically targeted single-use plastics, including plastic bags and selected packaging materials. The importation of plastic bags was also prohibited.²³ Enforcement measures were strictly implemented, with regulatory agencies and law enforcement officers deployed at borders, airports, and commercial centres to ensure compliance. Non-compliance attracted penalties, including confiscation of materials and fines.²⁴

Following the ban, the Rwandan government encouraged the use of biodegradable alternatives such as paper bags, cloth bags, and natural materials. This transition supported local industries producing eco-friendly packaging and contributed to economic diversification.²⁵ Government support for green enterprises further strengthened this transition. For example, companies such as Arth Biobags Ltd and UMUTI have contributed to the production of biodegradable packaging materials, including compostable bags and paper products derived from agricultural waste. These initiatives have supported job creation and expanded the availability of sustainable alternatives.

Guerrero, G. Maas, and W. Hogland, "Solid Waste Management Challenges for Cities in Developing Countries," *Waste Management* 33, no. 1 (2013): 220–232. <https://doi.org/10.1016/j.wasman.2012.09.008>.

²² Republic of Rwanda, "Law No. 57/2008 Relating to the Prohibition of Manufacturing, Importation, Use and Sale of Polythene Bags," 2008.

²³ Africa Check, "Yes, Plastic Bags Illegal in Rwanda, Punishment Includes Jail Time," November 14, 2019, <https://africacheck.org/fact-checks/meta-programme-fact-checks/yes-plastic-bags-illegal-rwanda-punishment-includes-jail>.

²⁴ Rwanda National Police, "RNP, REMA Operation Seize 435,000 Pieces of Banned Plastic Bags," 2016, <https://police.gov.rw/media/news-detail/news/rnp-rema-operation-seize-435-000-pieces-of-banned-plastic-bags>; Africa Check, "Yes, Plastic Bags Illegal in Rwanda, Punishment Includes Jail Time."

²⁵ United Nations Environment Programme, *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions*, 2021, <https://www.unep.org/resources/report/global-methane-assessment>; Republic of Rwanda, *Law N° 17/2019 of 10/08/2019 Relating to the Prohibition of Manufacturing, Importation, Use and Sale of Plastic Carry Bags and Single-Use Plastic Items*, Official Gazette no. 37 bis (September 23, 2019).

As a result of these interventions, Kigali (the capital of Rwanda) is frequently cited as one of the cleanest cities in Africa.²⁶ Studies further indicate a significant reduction in visible plastic waste in both urban and rural areas.²⁷ The reduction in plastic pollution has also contributed to improved drainage systems, reduced flooding, and enhanced public health outcomes. In addition, the policy has supported biodiversity protection by reducing the risk of wildlife ingestion and entanglement in plastic waste, particularly in aquatic ecosystems. It has also stimulated the growth of green enterprises and environmental awareness initiatives.

Rwanda's experience demonstrates how strong policy enforcement and public participation can drive environmental transformation. Similar approaches could be adapted in Nsukka through the regulation of single-use plastics and investment in recycling infrastructure.

Sweden

Sweden's waste-to-energy (WTE) system is internationally recognised as one of the most advanced integrated waste management models. The system is based on the principle of recovering energy from non-recyclable waste through controlled incineration processes, thereby reducing reliance on landfills and fossil fuels.²⁸ Approximately half of Sweden's household waste is processed through waste-to-energy facilities, where incineration generates heat and electricity. A key feature of the system is its integration with district heating networks. Heat generated from waste incineration is distributed to residential and commercial buildings through centralised heating systems, supplying over one million households, particularly during winter periods.²⁹

Sweden also maintains a highly efficient recycling system in which citizens separate waste into categories such as paper, glass, metal, plastics, and organic materials. As a result, only a small fraction of waste is directed to incineration, while landfill use has been reduced to approximately 1% of total waste, compared to over 60% in the 1970s.³⁰ The system has contributed to environmental and economic benefits. It has reduced dependence on fossil fuels, lowered greenhouse gas emissions

²⁶ United Nations Environment Programme, *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions*; Aimable Twahirwa, "The Cleanest City on the Planet? Kigali Scrubs Up," ONE, accessed June 26, 2026, <https://www.one.org/stories/kigali-cleanest-city/weforum>.

²⁷ Gratien Twagirayezu et al, "A Critical Review and Analysis of Plastic Waste Management Practices in Rwanda," *Environmental Science and Pollution Research* 31, no. 39 (2024): 51126–51146, <https://doi.org/10.1007/s11356-024-34572-4>; Varsha Redkar-Palepu and Sulan Chen, "Umuganda: Rwanda's Audacity of Hope to End Plastic Pollution," UNDP Rwanda, November 17, 2023, <https://www.undp.org/rwanda/blog/umuganda-rwandas-audacity-hope-end-plastic-pollution>.

²⁸ Swedish Energy Agency, "From Waste to Wealth – Sweden's Comprehensive Approach to Energy Recovery," March 9, 2025, <https://www.energimyndigheten.se/en/news/2025/from-waste-to-wealth---swedens-comprehensive-approach-to-energy-recovery/>.

²⁹ Circularity Gap Report Sweden, *The Circularity Gap Report: Sweden*, 2025, <https://cgr-assets.prod.circularity-gap.world/63469714078daaa46750fafe-The-Circularity-Gap-Report-Sweden-2b7aa8f0a6.pdf>.

³⁰ European Environment Agency. 2025. *Municipal and Packaging Waste Management Country Profiles: Sweden Municipal Waste Factsheet*. <https://www.eea.europa.eu/en/topics/in-depth/waste-and-recycling/municipal-and-packaging-waste-management-country-profiles-2025/se-municipal-waste-factsheet.pdf>.

through advanced emission-control technologies, and created economic value through energy generation and job creation.³¹

Interestingly, Sweden now imports waste from other European countries to sustain its waste-to-energy facilities, processing approximately 1.3 million tonnes annually.³² This has created a revenue-generating system in which other countries pay Sweden for waste treatment services, while Sweden benefits from energy production. Technological innovation underpins the system, with modern incineration plants operating at high temperatures and using advanced filtration systems to minimise emissions. Residual ash is further processed and used in construction, thereby reducing waste output.³³

Emissions Control and Monitoring

Sweden employs stringent emissions control measures to ensure that waste incineration processes remain as environmentally safe as possible. Modern waste-to-energy (WTE) plants are equipped with advanced scrubbers and filtration systems designed to capture harmful substances such as dioxins, heavy metals, and particulate matter before they are released into the atmosphere. Emissions are continuously monitored, and Sweden complies with strict European Union air quality standards.³⁴

Future Outlook

Circular Economy Approach

Sweden is increasingly transitioning towards a circular economy model in which resource use is minimised, and materials are continuously reused. This approach prioritises waste reduction at source, improved recycling systems, and the design of durable, repairable, and recyclable products. The overall objective is to reduce dependence on incineration by strengthening upstream waste prevention strategies.³⁵

Innovations in Waste-to-Energy

Swedish researchers and industry actors continue to advance innovation within the waste-to-energy sector. Ongoing research focuses on improving energy conversion efficiency, reducing environmental impacts, and developing more sustainable waste treatment technologies. Future WTE systems are

³¹ European Environment Agency. 2025. "Sweden." February 28, 2025. <https://www.eea.europa.eu/en/topics/in-depth/waste-and-recycling/municipal-and-packaging-waste-management-country-profiles-2025/sweden>.

³² Trading Dynamics, *Waste as a Source of Renewable Energy: Exploring Technologies, Market Trends and Global Leaders*, 2024.

³³ Arif, M. D., "Case Study: Sweden's Waste to Energy Model," *Innovative Bioenergy*, 2025, <https://innovativebioenergy.com/case-study-swedens-waste-to-energy-model/>; "The World." 2013. "Sweden Imports Waste from European Neighbors to Fuel Waste-to-Energy Program." August 14, 2013. <https://theworld.org/stories/2013/08/15/sweden-imports-waste-european-neighbors-fuel-waste-energy-program>.

³⁴ European Parliament and Council. 2010. "Directive 2010/75/EU of 24 November 2010 on Industrial Emissions (Integrated Pollution Prevention and Control) (Recast)." Official Journal of the European Union.

³⁵ International Energy Agency, "Circular Economy – Strategy for the Transformation of Sweden," 2023, <https://www.iea.org/policies/17618-circular-economy-strategy-for-the-transformation-of-sweden>; European Environment Agency, *Circular Economy Country Profile 2024 – Sweden*, 2024, https://www.eea.europa.eu/en/topics/in-depth/circular-economy/country-profiles-on-circular-economy/circular-economy-country-profiles-2024/sweden-2024-ce-country-profile_final.pdf.

expected to achieve higher energy yields with lower emissions through technological innovation and improved process design.³⁶

International Collaboration

Sweden's waste-to-energy model has influenced several countries, including Brazil, Indonesia, Ukraine, China, and Costa Rica.³⁷ Through international partnerships, Sweden shares expertise in sustainable waste management and energy recovery systems with other nations.³⁸ Overall, Sweden's waste-to-energy system demonstrates how environmental sustainability, economic efficiency, and technological innovation can be integrated within a national framework. While challenges remain, the system continues to evolve and shape global waste management discourse. Sweden therefore provides a strong example of how waste can be transformed into a valuable resource. In the context of Nsukka, the development of small-scale waste-to-energy systems, combined with reduced landfill dependence, may contribute to improved energy access and more sustainable waste management practices.

United States of America—San Francisco

San Francisco's mandatory recycling and composting programmes are among the most advanced urban waste management systems in the United States. The city has established itself as a global leader in sustainability, with policies aimed at achieving zero waste and reducing landfill dependency.³⁹ The city introduced the Mandatory Recycling and Composting Ordinance in 2009, requiring households and businesses to separate waste into recyclables, compostables, and landfill waste. Non-compliance is subject to penalties, which has contributed to high levels of participation.⁴⁰

Zero Waste Goal

San Francisco adopted an ambitious target of achieving zero waste to landfill. The strategy is centred on maximising recycling, composting, and reuse while minimising landfill disposal.

³⁶ RISE Research Institutes of Sweden AB, "Final Seminar: Waste to Energy (WtE) in Sweden's Circular Economy," 2026, <https://www.ri.se/en/event/final-seminar-waste-to-energy-wte-in-swedens-circular-economy>.

³⁷ Avfall Sverige, *Swedish Waste Management 2022*, 2022, https://www.avfallsverige.se/media/lbdg3vcp/svensk_avfallshantering_2022_en.pdf; University of Borås. "Bioconversion of Fruit Wastes into Biogas." Accessed January 26, 2025. <https://www.hb.se/en/research/research-portal/projects/bioconversion-of-fruit-wastes-into-biogas>.

³⁸ Swedish Environmental Protection Agency. "Avfallsbehandling i Sverige." Accessed January 26, 2025. <https://www.naturvardsverket.se/data-och-statistik/avfall/behandling-avfall-sverige/>.
Avfall Sverige. 2023. "Här är Svensk avfallshantering 2022." June 29, 2023.

<https://www.avfallsverige.se/aktuellt/nyheter/har-ar-svensk-avfallshantering-2022/>.

³⁹ San Francisco Environment Department. "Mandatory Recycling and Composting Ordinance." Accessed January 26, 2025. <https://www.sfenvironment.org/mandatory-recycling-and-composting-ordinance>.

⁴⁰ San Francisco Environment Department, "Mandatory Recycling and Composting Ordinance," <https://www.sfenvironment.org/mandatory-recycling-and-composting-ordinance>; United States Environmental Protection Agency, "Recycling Basics and Benefits," 2024, <https://www.epa.gov/recycle/recycling-basics-and-benefits>.

Three-Bin System

The city's waste management system is organised around a three-bin structure:⁴¹

- **Blue Bin (Recyclables):** paper, cardboard, plastics, glass, and metals.
- **Green Bin (Compostables):** food scraps, yard waste, and soiled paper.
- **Black Bin (Landfill Waste):** materials that cannot be recycled or composted.

This source separation system has significantly improved material recovery rates and reduced landfill dependence.

Public Participation and Education

San Francisco places strong emphasis on environmental education to support compliance and behavioural change. Public awareness campaigns, informational materials, and recycling guidelines are regularly provided to residents.⁴² In addition, workshops, business support programmes, and waste audits assist organisations in improving waste management practices. Given the city's cultural diversity, educational materials are made available in multiple languages to ensure inclusivity and accessibility.⁴³

Impact and Outcomes

San Francisco records one of the highest waste diversion rates in the United States, with more than 80% of waste diverted from landfills through recycling and composting.⁴⁴ This has significantly reduced landfill dependence and contributed to lower greenhouse gas emissions by limiting methane generation from organic waste decomposition.

Business and Construction Sector Participation

The recycling ordinance applies to both residential and commercial sectors, requiring businesses to comply with waste separation rules under penalty of fines.⁴⁵ The city has also implemented policies targeting waste reduction in the food service sector, including restrictions on non-recyclable packaging and mandatory composting in restaurants. In addition, construction and demolition waste is strictly regulated, with requirements for material recovery and recycling to reduce landfill disposal.⁴⁶

Composting Programme

San Francisco operates a large-scale composting system in which organic waste is collected from green bins and processed into compost for agricultural and landscaping use.⁴⁷ Food waste from households and businesses is fully integrated into this system, significantly reducing organic waste sent to landfill.

⁴¹ San Francisco Environment Department, "Mandatory Recycling and Composting Ordinance;" Recology San Francisco, "Compost, Recycle, & Landfill: Your Three Carts," 2026, <https://www.recology.com/recology/san-francisco/your-three-carts/>.

⁴² San Francisco Environment Department, "Mandatory Zero Waste Event Training," 2025, <https://www.sfenvironment.org/mandatory-zero-waste-event-training/>; Recology San Francisco, "Waste Zero Services: Education, Audits, Support," 2026, <https://www.recology.com/recology/san-francisco/specialty-services/>.

⁴³ San Francisco Environment Department, "Mandatory Recycling and Composting Ordinance."

⁴⁴ United States Environmental Protection Agency, "Recycling Basics and Benefits."

⁴⁵ San Francisco Environment Department, "Mandatory Recycling and Composting Ordinance."

⁴⁶ Ibid.

⁴⁷ Recology San Francisco. 2026. "Waste Zero Services – Recology San Francisco." February 19, 2026. <https://www.recology.com/recology-san-francisco/specialty-services>.

The resulting compost supports soil fertility, reduces reliance on chemical fertilisers, and improves water retention in soils, contributing to more sustainable agricultural practices.⁴⁸

Enforcement and Compliance

Compliance is enforced through monitoring systems and penalties. Waste collectors inspect bin contents, and repeated violations may result in fines ranging from \$100 to \$1,000 for businesses, depending on severity.⁴⁹ This enforcement mechanism has strengthened adherence to recycling and composting regulations.

Oman—Six Senses Zighy Bay: “From Glass Waste to Wealth” Initiative

The “From Glass Waste to Wealth” initiative is a sustainability programme implemented by Six Senses Zighy Bay, a luxury resort located on the Musandam Peninsula in Oman. The initiative forms part of the resort’s broader commitment to environmental sustainability and zero-waste principles. Due to its remote location, the resort faces logistical challenges in transporting waste to external recycling facilities. In response, it developed an on-site system to manage glass waste through reuse and repurposing, thereby reducing environmental impact and supporting a circular economy approach.⁵⁰

Glass Waste Processing

The initiative collects discarded glass from hotel operations, including bottles and containers. The glass is processed using on-site crushing equipment, which converts it into small reusable fragments. These crushed materials are then repurposed for construction and landscaping purposes, including pathways and building materials. This reduces the need for raw materials such as sand and gravel, thereby lowering environmental impact.

Economic and Social Benefits

The initiative generates economic value through several mechanisms:

- **Local Employment:** Residents are engaged in processing and repurposing glass waste, creating employment opportunities and strengthening community participation.
- **Artisanal Production:** Local artisans transform glass fragments into decorative items such as jewellery, ornaments, and crafts sold to guests.
- **Revenue Generation:** These products generate income while reinforcing sustainable tourism practices.

⁴⁸ Ibid.

⁴⁹ City and County of San Francisco. 2009. *Mandatory Recycling and Composting Ordinance*, Ordinance No. 100-09. Approved June 23, 2009.

⁵⁰ Sanctuary Retreats, “Oman Eco Resort & Sustainable Tourism Practices: Six Senses Zighy Bay,” accessed 2024, <https://www.sixsenses.com/en/hotels/resorts/middle-east-africa/oman/zighy-bay/sustainability/>; EcoVoice, “Six Senses Zighy Bay Unveils Its 2024 Sustainability and Community Milestones,” February 15, 2025, <https://www.ecovoice.com.au/six-senses-zighy-bay-unveils-its-2024-sustainability-and-community-milestones/>.

Environmental Benefits

The initiative contributes to environmental sustainability in several ways:

- **Reduced landfill waste** through local reuse of glass materials.
- **Lower carbon emissions** by eliminating the need for long-distance waste transport.
- **Resource conservation** through reduced demand for raw construction materials.⁵¹

Community Engagement

Guests are actively involved through workshops that demonstrate glass recycling and craft production, enhancing environmental awareness. Local communities also benefit from knowledge transfer and participation in sustainable practices, strengthening environmental stewardship.

Broader Sustainability Strategy

The initiative forms part of a wider sustainability framework at Six Senses Zighy Bay, which includes plastic-free operations, organic farming, and marine conservation programmes.⁵² The “From Glass Waste to Wealth” initiative demonstrates how the hospitality sector can contribute to circular economy objectives while generating economic and environmental benefits. By transforming waste into valuable products, the initiative reduces environmental impact and supports local livelihoods. Similar approaches could be adopted within Nigeria’s hospitality sector, including in Nsukka, to promote sustainable waste management and environmental responsibility.

Policy and Legislative Suggestions

Following Federal Government policy directives encouraging states to establish waste management authorities,⁵³ most states in Nigeria have created such agencies under their respective Ministries of Environment through enabling legislation enacted by state Houses of Assembly. In Enugu State, for instance, the Enugu State Waste Management Authority (ESWAMA) was established in 2004 with a statutory mandate to manage waste within the state, including Nsukka. The establishment of ESWAMA introduced several approaches to waste management, including conventional methods such as waste generation, collection, transportation, and disposal; waste minimisation strategies such as reduction, reuse, recycling, and recovery; and technological applications involving Geographic Information Systems (GIS), Global Positioning Systems (GPS), and remote sensing technologies.

⁵¹ UN Secretary General’s Advisory Board on Zero Waste, “From Glass Waste to Wealth: Six Senses Zighy Bay Case File,” 2024, https://unhabitat.org/sites/default/files/2024/04/from_glass_waste_to_wealth.pdf.

⁵² Six Senses Zighy Bay, “Sustainability Initiatives,” <https://www.sixsenses.com/en/hotels-resorts/middle-east-africa/oman/zighy-bay/sustainability/>; Six Senses Zighy Bay. “Sustainability Initiatives.” Accessed June 27, 2026. <https://www.sixsenses.com/en/hotels-resorts/middle-east-africa/oman/zighy-bay/sustainability/>.

⁵³ Federal Ministry of Environment (Nigeria). 2020. *National Action Policy on Solid Waste Management*.

Despite these institutional and technological frameworks, the agency continues to face significant challenges in fulfilling its mandate, as documented by Imam et al.,⁵⁴ Ogwueleka,⁵⁵ Solomon,⁵⁶ and Uwadiogwu and Iyi.⁵⁷ In the case of ESWAMA, these challenges include:

- Leadership challenges and frequent changes: Waste management requires technical and managerial expertise in environmental governance. However, appointments within ESWAMA are often influenced by political considerations, with an emphasis on revenue generation rather than service efficiency. Frequent changes in leadership also undermine institutional continuity and effectiveness.
- Limited institutional autonomy.
- Weak public perception of ESWAMA's core mandate.
- Inadequate planning processes and weak implementation frameworks.
- Insufficient empirical studies and baseline data for planning.
- General difficulties in effective policy implementation.

To promote zero-waste management in Nsukka, the following policy recommendations are proposed:

- **Strengthen waste management policies and enforcement mechanisms:** Strict enforcement of ESWAMA regulations in Nsukka, including increased penalties for illegal dumping, is essential for behavioural change and environmental compliance.
- **Strengthen administrative capacity:** Leadership positions should be filled by individuals with relevant technical expertise, professional competence, and demonstrated experience in environmental management to improve institutional performance.
- **Promote public–private partnerships:** Greater collaboration with private sector operators should be encouraged to enhance efficiency, innovation, and resource mobilisation in waste management services.
- **Improve planning and implementation systems:** Effective planning is fundamental to successful waste management. Robust data-driven planning frameworks are therefore essential for sustainable waste governance.
- **Introduce subsidies and incentives for recycling and upcycling:** Financial incentives, including tax reliefs and subsidies, should be provided to organisations and communities engaged in recycling and upcycling to encourage wider participation in sustainable practices.
- **Strengthen public education and awareness campaigns:** Environmental education should be integrated into schools, tertiary institutions, and media platforms to raise awareness of the environmental, economic, and health benefits of responsible waste management and to promote behavioural change.

⁵⁴ A. Imam, B. Mohammed, D. C. Wilson, and C. R. Cheeseman, "Solid Waste Management in Abuja, Nigeria," *Waste Management* 28, no. 2 (2008): 468–472. <https://doi.org/10.1016/j.wasman.2007.01.006>.

⁵⁵ T. C. Ogwueleka, "Municipal Solid Waste Characteristics and Management in Nigeria," *Iranian Journal of Environmental Health Science & Engineering* 6, no. 3 (2009): 173–180.

⁵⁶ U. U. Solomon, "The State of Solid Waste Management in Nigeria," *Waste Management* 29, no. 10 (2009): 2787–2788. <https://doi.org/10.1016/j.wasman.2009.06.030>.

⁵⁷ Uwadiogwu and Iyi, "An Evaluation of the Operational Efficiency of a Public Agency."

Conclusion

The pursuit of sustainable waste management in Nsukka through zero-waste practices is both an environmental necessity and a practical possibility. Although the current waste management system is constrained by infrastructural deficiencies, weak policy enforcement, and limited public compliance, the opportunities identified in this study provide a viable pathway for transformative change. Key strategies include the implementation of community-based waste management programmes, expansion of composting and recycling initiatives, integration of appropriate technologies, and adaptation of lessons from international models such as Rwanda's plastic ban, Sweden's waste-to-energy system, and San Francisco's mandatory recycling framework.

Furthermore, strengthening collaboration between public institutions such as ESWAMA and private sector actors, alongside improving administrative capacity, is critical to addressing systemic inefficiencies. Policy incentives, subsidies, and sustained public education campaigns will also play an essential role in reshaping attitudes and encouraging behavioural change at the community level. Ultimately, the adoption of zero-waste practices in Nsukka should be understood not only as an environmental intervention but also as a socio-economic and public health imperative. With coordinated efforts from government, private sector actors, and residents, Nsukka has the potential to emerge as a model for sustainable urban waste management in Nigeria, contributing to improved environmental quality, enhanced public health, and broader climate change mitigation efforts.