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Waste to Energy Conversion: A Sustainable Electricity Production, Socio- Economic Growth and Waste Management

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ABSTRACT ***Original research paper***

The global population growth and urbanization have led to a rise in municipal solid waste, highlighting the need for sustainable energy sources amid fossil fuel depletion and climate change pressures. This paper explores waste to energy conversion as a strategic solution for managing waste and generating sustainable electricity, addressing challenges and providing reliable energy. The study highlights the socio-economic advantages of waste treatment technologies in developing regions with inadequate waste management infrastructure and energy access. It explores the mechanisms, energy conversion efficiency, environmental impacts, and applicability of water treatment empowerment systems, presenting case studies from successful countries for practical insights. Waste to energy reduces landfill use, lowers greenhouse gas emissions, creates jobs, enhances energy security, and improves sanitation, but challenges like high initial investment, public awareness, and weak regulatory support persist. The paper emphasizes the importance of integrating waste treatment empowerment into national energy and waste strategies for sustainable development, recommending stakeholder collaboration, government incentives, and public education.

1. Introduction

The global demand for energy is increasing at an unprecedented rate due to rapid industrialization, urbanization, and population growth. Traditional energy sources such as fossil fuels are not only depleting but are also associated with environmental degradation, greenhouse gas emissions, and climate change (Rahman et al., 2024). These issues have sparked a global shift toward alternative and renewable energy sources that are cleaner, more sustainable, and environmentally friendly. Among these, waste to energy (WTE) has emerged as a promising solution that addresses both the energy deficit and waste management problems concurrently (Patel & Kumar, 2025). As nations seek to meet the United Nations Sustainable Development Goals (SDGs), particularly SDG 7 (affordable and clean energy) and SDG 13 (climate action), investing in WTE technologies has become increasingly imperative.

In Nigeria, the situation is even more pressing. Despite being richly endowed with energy resources including solar, hydro, and biomass, the country continues to struggle with inadequate power generation and distribution. The national grid generates between 3,000 to 5,000 megawatts for a population exceeding 200 million people—a figure grossly insufficient for industrial, commercial, and residential demands (Ibrahim & Yusuf, 2025). The majority of rural communities and even some urban areas remain without reliable access to electricity. According to the World Bank (2024), approximately 85 million Nigerians, representing about 43% of the population, do not have access to grid electricity, making Nigeria the country with the largest energy access deficit in the world.

This persistent energy crisis has stifled economic growth, hindered educational development, and limited healthcare delivery. Small businesses operate at high costs due to the reliance on diesel generators, which are not only expensive but also harmful to the environment. As the demand for energy continues to rise, there is an urgent need to diversify the energy mix with alternative solutions that are sustainable, accessible, and capable of promoting national development. Waste to Energy provides a unique opportunity in this regard, particularly in Nigeria where large volumes of municipal solid waste are generated daily but poorly managed (Aliyu et al., 2024).

Harnessing waste as a renewable energy resource presents a dual benefit, resolving the problem of improper waste disposal while generating much-needed electricity. If properly implemented, WTE technologies can play a vital role in addressing Nigeria's energy shortfall while supporting environmental sustainability and economic development. This paper therefore explores WTE conversion as a viable and scalable solution for Nigeria's ongoing power challenges and waste management issues. In addition to the energy crisis, Nigeria is grappling with a rapidly growing solid waste problem. Urban centers like Lagos, Kano, and Port Harcourt produce thousands of tons of waste daily, much of which ends up in open dumps or poorly managed landfills. According to Nwachukwu and Eze (2025), over 32 million tons of municipal solid waste are generated annually in Nigeria, with less than 20% being properly collected and disposed of. This growing waste burden not only threatens public health and the environment but also represents a significant untapped resource for energy production. Waste to Energy (WTE) technologies offer a practical approach to convert this environmental hazard into a renewable and sustainable source of electricity, thereby addressing two major national issues simultaneously.

Countries like Sweden, Germany, and Japan have successfully adopted WTE strategies, achieving remarkable results in reducing landfill use and producing clean energy. These countries have demonstrated that WTE can be economically viable, environmentally sound, and socially beneficial when supported by strong policy frameworks and public awareness (Ahmed & Bakar, 2025). For Nigeria to follow a similar path, there must be a deliberate effort to adopt and localize such technologies, taking into consideration the country's unique socio-economic, infrastructural, and environmental realities. Integrating WTE into Nigeria's national energy and waste management policies can help mitigate the adverse effects of waste accumulation while simultaneously diversifying the energy mix.

Investing in WTE has the potential to drive socio-economic development by creating green jobs, enhancing local technological capacity, and promoting community-based waste management initiatives. It also aligns with Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement by reducing methane emissions from landfills and promoting clean energy alternatives. As the country moves toward industrialization and urban growth, embracing WTE offers a sustainable pathway to balance energy security, economic advancement, and environmental stewardship (Sharma et al., 2024). This study, therefore, positions WTE as not just a technological solution, but a strategic imperative for Nigeria's energy future.

2. Human Growth and Increase in Energy Demand

The global human population has experienced exponential growth in the last century, and projections suggest it will reach approximately 9.7 billion by 2050 (United Nations, 2023). This rapid population increase has significantly influenced energy demand worldwide. As more people require access to lighting, transportation, heating, industrial production, and electronic devices, energy consumption continues to surge. This phenomenon is even more pronounced in developing nations where urbanization and modernization are expanding swiftly (Chowdhury et al., 2024).In Nigeria, the population currently exceeds 220 million, with projections indicating over 400 million inhabitants by 2050 (National Population Commission, 2024). This surge directly affects national energy consumption, which already suffers from a considerable supply-demand imbalance. Power outages are frequent, and access to reliable electricity remains a critical challenge, especially in rural areas (Khan et al., 2024).

As industrial activities grow to meet population needssuch as food processing, housing, and health infrastructure, energy requirements intensify. According to Sharma et al. (2024), energy demand in Sub-Saharan Africa is growing at more than twice the global average. This growing demand places stress on aging and insufficient infrastructure, leading to the pressing need for alternative energy models that can scale with population dynamics.As urban areas expand, the infrastructure required to support energy consumption struggles to keep pace. Megacities in Africa and Asia are particularly vulnerable, with demand for energy outstripping available supply due to unplanned urbanization and outdated infrastructure. In Nigeria, cities like Lagos, Kano, and Port Harcourt face frequent blackouts despite being major economic hubs (Ibrahim & Yusuf, 2025). This imbalance between energy demand and supply results in inefficient power distribution, high costs, and reduced industrial productivity.

The increase in population is not only numerical but also qualitative. With rising living standards and access to modern technology, more people are using energy-intensive appliances and transportation systems. As reported by the International Energy Agency (IEA, 2023), household energy consumption in sub-Saharan Africa is projected to rise by 60% by 2040 due to population growth and lifestyle changes.The growing population also translates into increased generation of waste, especially in urban settlements. This intersection between rising population, growing energy demand, and mounting waste volumes presents an opportunity to develop integrated solutions such as WTE systems. These systems can address both challenges simultaneously, especially when designed to scale with urban population densities and energy needs (Khan et al., 2024). Human development indices such as education, health, and employment are closely linked to energy access. As the population grows, energy needs are expected to shift from basic lighting to more complex uses like e-learning, digital banking, and e-health services, necessitating a robust and sustainable energy strategy (Gupta & Shukla, 2024).

3. Need for Alternative and Sustainable Sources of Energy/Power

The overdependence on fossil fuels for energy generation has proven to be unsustainable both environmentally and economically. Fossil fuel-based energy production is responsible for a significant proportion of global greenhouse gas emissions, contributing to climate change, air pollution, and environmental degradation (Ibrahim & Yusuf, 2025). Moreover, fossil fuel reserves are finite, and price volatility in the global oil market creates economic instability in energy-reliant nations.Nigeria's energy crisis is aggravated by the inefficiency of its power infrastructure, oil theft, gas flaring, and inconsistent fuel supplies. These issues hinder national productivity and limit economic competitiveness. As a result, there is an urgent demand for a cleaner, renewable, and decentralized energy system that can support long-term sustainability (Rahman et al., 2024).

Renewable energy sources like solar, wind, hydro, and biomass present viable alternatives. They are environmentally friendly and offer long-term cost advantages and reduced reliance on imports. However, each has its limitations via solar and wind are intermittent, while hydro depends heavily on water availability. Thus, diversification within the renewable energy sector is essential.Beyond environmental and economic sustainability, energy security has become a central concern for many nations. Energy dependence on imported fuels or unstable supply chains exposes countries to market shocks and geopolitical risks. In Nigeria, the reliance on gas-powered thermal plants leaves the power sector vulnerable to vandalism and pipeline sabotage, further worsening power reliability (Rahman et al., 2024).

Moreover, energy poverty remains a major barrier to socio-economic development in Nigeria. Many communities still rely on kerosene, firewood, or diesel generators, all of which pose health and environmental risks. According to the WHO (2024), indoor air pollution from biomass fuels causes thousands of premature deaths annually in sub-Saharan Africa. Transitioning to sustainable energy alternatives like WTE not only improves access but also reduces health risks and enhances quality of life.

In rural areas, decentralized energy systems like mini-grid WTE plants can supply electricity to off-grid communities. Unlike solar and wind, which are intermittent, WTE provides a steady energy stream and is particularly well-suited to the waste management needs of small towns and semi-urban areas (Sharma et al., 2024). These factors underscore the strategic value of WTE as both an energy source and a public service intervention.Waste to energy (WTE) has gained traction as a sustainable energy alternative. It not only mitigates waste problems but also offers a continuous energy stream from an otherwise environmentally harmful resource (Aliyu et al., 2024). Implementing WTE technologies alongside other renewable sources forms a holistic approach to achieving energy security and environmental sustainability. Aligning with the United Nations SDGs, particularly SDG 7 (Affordable and Clean Energy), Nigeria and other developing countries must expand their energy sources beyond conventional means to include WTE as a strategic solution (Ahmed & Bakar, 2025).

4. Potentials in Waste Generation as a Sustainable Energy Source

Solid waste generation is often viewed solely as an environmental nuisance, yet it holds immense potential as an energy resource. With global urban populations rising, cities are generating unprecedented amounts of waste, ranging from organic matter to plastics, paper, and electronic waste. According to the World Bank (2024), over 2.24 billion tons of municipal solid waste are produced annually worldwide, and this figure is expected to rise to 3.4 billion tons by 2050.Nigeria, with its expanding urban centers, generates over 32 million tons of waste per year, much of which remains uncollected or is disposed of in open dumps (Nwachukwu & Eze, 2025). If properly harnessed, this waste could be a valuable feedstock for sustainable energy production through technologies like anaerobic digestion, pyrolysis, or incineration.Organic waste such as food scraps, agricultural residues, and sewage sludge contains a high energy content, particularly suitable for biogas production. Non-biodegradable waste like plastics can be used in thermal processes to produce synthetic fuels (Sharma et al., 2024). These processes can simultaneously reduce landfill burden and contribute to clean energy generation.

One of the unique attributes of waste as an energy source is its continuous and abundant availability, particularly in urban environments. While solar and wind are intermittent and dependent on climatic conditions, waste is generated daily and year-round. This gives WTE a distinct advantage in terms of base-load power generation (Patel & Kumar, 2025). Waste composition in Nigeria includes high volumes of organic matter, plastics, and packaging materials—all of which possess significant calorific value. When sorted properly, municipal solid waste can provide a consistent and high-energy feedstock suitable for thermal or biological energy conversion technologies (Nwachukwu & Eze, 2025).

The informal recycling sector in Nigeria, which currently thrives without institutional support, could benefit from structured WTE projects. By integrating waste pickers and recyclers into formal WTE systems, their livelihoods can be improved, and waste segregation efficiency can be enhanced (Gupta & Shukla, 2024). This approach fosters inclusivity, supports sustainable livelihoods, and maximizes the value extracted from waste. With the right infrastructure and policy frameworks, waste can be transformed from an environmental liability into a significant energy asset. The economic and environmental benefits of such a transition include reduced pollution, job creation, and improved waste handling efficiency (Gupta & Shukla, 2024).Harnessing waste for energy supports energy diversification and enhances resource efficiency, an essential pillar of the circular economy model that underpins modern sustainability goals (Rahman et al., 2024).

5. Waste to Energy Generation

Waste to Energy (WTE) involves converting waste materials into usable forms of energy such as electricity, heat, or fuel. This transformation can be achieved through a range of technologies that include thermal treatment (incineration, pyrolysis, gasification) and biological processes (anaerobic digestion). These technologies can significantly reduce the volume of waste while providing energy output that can feed into national grids or serve off-grid applications.For instance, incineration with energy recovery can generate heat and power, while anaerobic digestion can produce biogas which can be upgraded into biomethane for use as a fuel (Patel & Kumar, 2025). Gasification and pyrolysis, though more complex, can yield synthetic gas or bio-oil, which can be refined for industrial or transportation use.

Waste to energy generation is not limited to electricity production alone but, includes heat for industrial applications and synthetic fuels that can substitute diesel or gasoline. Biofuels derived from WTE processes can power vehicles, farm machinery, and backup generators, offering a clean alternative in sectors heavily reliant on fossil fuels (Chowdhury et al., 2024).In Europe and Asia, WTE facilities are being integrated with district heating systems that provide warm water and indoor heating to residential and commercial buildings. Though such systems are not common in Nigeria, they represent a potential adaptation for industries requiring process heat, such as food processing and chemical production (Chowdhury et al., 2024). Advancements in fuel upgrading technologies have made it possible to refine biogas into compressed natural gas (CNG) or liquefied natural gas (LNG), suitable for domestic and industrial use. These energy forms can be fed into national gas grids or stored for later use, increasing flexibility and reliability (Rahman et al., 2024).

In Nigeria, where over 43% of the population lacks access to electricity (World Bank, 2024), WTE offers a decentralized and scalable approach to energy provision. Small-scale biogas digesters and community-level incineration plants can serve rural and peri-urban areas that are not connected to the national grid.

The energy potential from solid waste is immense. A single ton of municipal solid waste can produce between 500 and 700 kilowatt-hours (kWh) of electricity, depending on the waste composition and technology used (Khan et al., 2024). Scaling up WTE projects across major Nigerian cities can reduce pressure on the national grid and promote energy equity.WTE reduces the environmental and health risks associated with open dumping and landfill emissions, which release methane, a potent greenhouse gas into the atmosphere (Ahmed & Bakar, 2025).

6. Waste to Energy Conversion

Waste to energy conversion refers to the series of processes through which waste materials are transformed into usable energy forms. This conversion encompasses a variety of chemical, thermal, and biological methods depending on the waste type and desired energy output. The process is not only efficient in energy recovery but also effective in minimizing waste volume and environmental pollution (Chowdhury et al., 2024).Thermal conversion methods such as incineration and pyrolysis involve the combustion or breakdown of waste at high temperatures to release energy. These methods are particularly effective for dry, high-calorific-value waste such as plastics, textiles, and paper. In contrast, biological conversion through anaerobic digestion is better suited for wet, biodegradable waste such as food scraps and animal manure (Gupta & Shukla, 2024).

An essential component of successful WTE conversion is feedstock preparation and segregation. Proper separation of organics, recyclables, and inorganics enhances process efficiency, reduces operational costs, and prevents environmental contamination. Implementing community-based waste sorting programs can increase public participation and ensure higher-quality waste input for energy recovery (Ibrahim & Yusuf, 2025). Moreover, the choice of conversion method must align with local conditions—urban areas with high plastic and paper waste are better suited for thermal technologies, while rural areas with abundant organic waste may benefit from anaerobic digestion. Flexibility and modularity in WTE plant design are critical for adapting to these localized needs (Khan et al., 2024).

Lifecycle assessment (LCA) and energy balance evaluations are necessary to ensure that the net energy gain from WTE systems justifies their implementation. Modern WTE systems are increasingly being integrated with carbon capture technologies to further minimize emissions and meet net-zero targets (Sharma et al., 2024).The integration of WTE conversion facilities within municipal waste systems can streamline waste segregation, increase recycling rates, and improve landfill diversion. Proper pretreatment of waste including sorting and drying, enhances energy efficiency and minimizes toxic emissions.WTE conversion is increasingly being combined with smart technologies such as automated waste segregation, AI-based waste tracking, and emission monitoring systems to improve efficiency and transparency. These innovations ensure that energy conversion does not compromise environmental standards (Ibrahim & Yusuf, 2025).For countries like Nigeria, adapting WTE conversion systems to local conditions—such as waste composition, economic feasibility, and technological capacity—is essential for success. Tailored systems can ensure both affordability and sustainability in achieving national energy and waste management goals.

7. Waste to Energy Conversion Technologies

Waste to Energy (WTE) technologies are diverse and tailored to different waste streams and energy needs.

The primary categories include thermal, biological, and mechanical-biological treatment systems. Each has its unique mechanisms, applications, and benefits. Thermal technologies, such as incineration, gasification, and pyrolysis, are commonly used for high-energy, non-biodegradable waste. Incineration, for instance, is the most mature and widely used method globally, with over 2,500 plants in operation (Sharma et al., 2024).

Gasification involves converting organic waste into syngas (a mix of hydrogen and carbon monoxide) at high temperatures with limited oxygen, which can then be used for electricity or fuel production. Pyrolysis, a similar high-heat process without oxygen, breaks down waste into bio-oil, gas, and char, suitable for further refinement into usable fuels (Ahmed & Bakar, 2025). These technologies are particularly effective for converting plastics, tires, and hazardous waste into energy.

Biological technologies such as anaerobic digestion and composting are ideal for organic, biodegradable waste. Anaerobic digesters, commonly used in both rural and urban areas, convert animal waste, food waste, and sewage sludge into biogas, which can be used directly or refined into biomethane(Chowdhury et al., 2024). Mechanical-biological treatments combine sorting and biological processes to separate recyclable materials and extract energy from organics.

Recent technological innovations in WTE are transforming the sector, making it more efficient, cleaner, and economically viable. For instance, plasma arc gasification uses extremely high temperatures to convert waste into syngas without combustion, thereby eliminating dioxins and other harmful emissions (Gupta & Shukla, 2024). Though capital intensive, this technology has great promise for urban centers with high waste volumes.Another development is hybrid systems that combine solar photovoltaic (PV) with WTE plants. Such systems optimize energy availability by balancing solar intermittency with consistent WTE output. Automation and AI are also being used to optimize sorting, monitor emissions, and predict equipment maintenance, reducing operational downtime and cost (Ahmed & Bakar, 2025).

Mobile and containerized WTE units are being deployed in disaster zones, refugee camps, and remote communities where conventional infrastructure is lacking. These compact systems process local waste and provide electricity for emergency services, water purification, and shelter heating—demonstrating the flexibility of WTE in various contexts (Nwachukwu & Eze, 2025).Nigeria can benefit from hybrid systems that integrate these technologies to handle the diverse waste composition found in urban centers. Such integration, supported by smart waste sorting and digital monitoring, ensures efficiency and environmental compliance (Khan et al., 2024). With proper investment and technical training, WTE technologies can be scaled to meet both urban and rural energy needs sustainably.

8. Benefits in Waste Conversion

i. Socio-Economic Growth Advantages

Waste to Energy (WTE) conversion presents substantial socio-economic benefits, especially for developing countries like Nigeria. The establishment of WTE plants creates direct and indirect employment opportunities across various sectors, including waste collection, sorting, processing, plant operations, and equipment maintenance. According to Nwachukwu and Eze (2025), every 10,000 tons of waste processed in a WTE facility can generate up to 150 direct jobs and numerous indirect roles in supply chains. Revenue generation through energy sales, carbon credits, and by-products like compost or bio-oil contribute significantly to local economies. These financial streams helped municipalities fund essential services and improved living standards. WTE initiatives also stimulate private sector investment and encourage innovation in clean energy solutions, thereby promoting economic diversification (Ibrahim & Yusuf, 2025).

Reducing reliance on imported fuels and generators, communities redirect funds towards healthcare, education, and infrastructure. Electrification of off-grid communities through decentralized WTE plants supports inclusive development and poverty alleviation (Gupta & Shukla, 2024).The establishment of WTE plants stimulates local economies through construction contracts, equipment procurement, and service provision. Local manufacturing of WTE components—such as digesters, boilers, and turbines—can foster industrial development and technology transfer. Furthermore, training programs related to WTE plant operations and maintenance create opportunities for workforce development (Aliyu et al., 2024).By powering markets, schools, and small-scale industries, WTE enhances productivity and encourages entrepreneurship. Women and youth, often excluded from formal economic sectors, can be included in waste collection, sorting, and processing enterprises, promoting inclusivity and economic empowerment (Patel & Kumar, 2025).

ii. Waste Management Solution

WTE offers a long-term solution to the waste management crisis plaguing many urban centers. Open dumping and poorly managed landfills contribute to air and water pollution, disease outbreaks, and environmental degradation. WTE helps divert waste from landfills, reducing the volume of waste by over 80% and lowering methane emissions from decomposing organic matter (Rahman et al., 2024).Modern WTE facilities are equipped with emission control systems that meet international environmental standards, making them cleaner alternatives to open burning or dumping. They also promote improved waste segregation at the source, fostering recycling and material recovery as complementary strategies (Patel & Kumar, 2025).

WTE plays a vital role in reducing illegal dumping, open burning, and uncontrolled landfilling—common practices in many Nigerian communities. These practices pollute water bodies, degrade soil quality, and attract disease vectors like rats and mosquitoes. WTE reduces these hazards by offering a structured, sanitary, and efficient disposal pathway (Rahman et al., 2024).Integrated waste management systems that include WTE promote circular economy principles. Non-combustible materials such as glass and metals can be recovered before conversion, maximizing resource efficiency and minimizing environmental impact (Chowdhury et al., 2024). By integrating WTE into municipal waste management plans, cities can maintain cleaner environments, reduce waste collection costs, and increase public health outcomes. This approach fosters community engagement in responsible waste practices and encourages environmental stewardship.

iii. Sustainable Energy and Power Generation

The most compelling advantage of WTE is its contribution to clean and sustainable power generation. Unlike solar or wind, WTE provides continuous, base-load energy that is not dependent on weather conditions. This makes it a reliable source of electricity for industrial use, hospitals, schools, and households—especially in energy-deficient regions (Ahmed & Bakar, 2025).Nigeria's electricity generation challenges can be partly mitigated by integrating WTE into the national energy mix. With consistent waste generation across cities, WTE offers a dependable and renewable energy source that complements solar, hydro, and biomass systems. A well-structured WTE system can generate hundreds of megawatts, reduce pressure on the national grid, and promote energy independence (Chowdhury et al., 2024).

9. Conclusion

The study explores the use of Waste to Energy conversion in Nigeria to address waste management issues and energy deficits caused by population growth, urbanization, and industrialization, especially in rural and peri-urban areas, and as a sustainable solution to Nigeria's energy challenges. The study discussed the benefits of WTE, including socio-economic development, effective waste management, and sustainable energy production. Waste can be harnessed for energy through technologies like incineration, gasification, pyrolysis, and anaerobic digestion, providing sustainable, clean electricity and fuels. These technologies reduce environmental pollution, improve public health, and advance climate action goals. Nigeria's integration of Waste to Energy into its energy and waste management policies can lead to sustainable development, environmental health, and inclusive economic growth, requiring government commitment, stakeholder collaboration, and investment in appropriate technologies. The work stressed the need for alternative and sustainable energy sources, emphasizing the limitations of fossil fuels and the urgency of transitioning to renewable options. It then evaluated the potential of municipal solid waste (MSW) as an abundant and underutilized energy resource, especially in urban centers where large volumes of waste are generated daily. The review presented WTE as a viable, scalable, and sustainable solution to Nigeria's energy and environmental challenges, calling for policy integration, investment in infrastructure, and public-private collaboration to realize its full potential. The summary of the review work is as stated.

i. Nigeria's growing urban population is significantly impacting its energy and waste management systems.
ii. Millions of Nigerians lack reliable electricity, highlighting the urgent need for alternative, sustainable energy sources.
iii. Nigeria generates millions of tons of solid waste annually, with most of it unmanaged, presenting a significant untapped energy resource.

iv. Waste to energy technologies provide customized solutions for various waste types and energy requirements, generating base-load power.
v. Waste to energy can lead to socio-economic benefits such as job creation, industrial development, reduced dependence on fossil fuels, and rural electrification.
vi. Proper waste conversion reduces greenhouse gas emissions, supports circular economy principles, and helps achieve the Sustainable Development Goals (SDGs).

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