ABSTRACT

Waste is an indispensable by-product of most human daily activity. Prevailing waste management strategy, especially in developing countries such as Nigeria, is far below standard, resulting in environmental contamination and pollution which hampers sustainability. This forms the crux of the research paper which entails ascertaining how Waste-to-Energy can serve as a circular economy tool towards climate mitigation that will ensure environmental sustainability. Key challenges relate to moving beyond the perception of ‘waste as a problem’ to ‘waste as a resource’. Ultimately, both waste prevention, as well as a widespread growth in circular economy activities, will require a coherent and holistic approach that takes recovery options into account at every stage of the product life cycle. To achieve this, the study explored the potentials inherent in Waste-to-Energy (WtE) as a tool. The work is qualitative and involves a synchronic evaluation of previous research.
works relevant to the study to ascertain the viability of WtE as a circular economic tool for scaling back adverse environmental impact. Integration of results with detailed clarifications of circular economy and climate mitigation indicates WtE as an index of sustainable development. The bottom ash from combustion operations serves as feedstock to the construction industry, hence closing a potential pollution loop. Therefore, Waste-to-Energy is ascertained a viable tool that supports the circular economy while coupling with progressive externalities of climate mitigation. Thus, the study recommends that WtE as a tool should be duly considered as a key feature of climate change policy in developing countries, especially in Nigeria.

Keywords: Waste-to-energy; circular economy; climate mitigation; sustainability; environment.

1. INTRODUCTION

Waste is an indispensable by-product of most human daily activity. According to [1], the term “waste” connotes different meanings to different people. [2] defined waste as residual materials which are a result of human activities and cannot be reused or recovered as a resource, recycled into material production processes or thermally/biologically utilized for energy production. This definition contrasts with that of [3] who defined waste in Russia as “a material waiting to be reused”. In other words, wastes contain a lot of valuable resources in the form of nitrogen, phosphorus, potassium and other useful chemicals [4]. Moreover, contemporary literature is awash with the efficacy of using agro-wastes (banana peels) as a source of environmental oil spill removal [5-7]; oil palm waste as a Renewable Energy Source [8]; rice husk as useful adsorptive material [9]. Zero Waste America defines waste as a resource that is not safely recycled back into the environment or the marketplace. This definition takes into account the “value” of waste as a resource, as well as the threat unsafe recycling can present to the environment and public health [10]. Perhaps the most classical definition is the one proposed by the EU Framework Directive on Waste (91/156/EEC) as any substance or object which the holder discards or intends to discard and which falls into one of the these categories; production or consumption residue, product whose date for appropriate use has expired, contaminated or soiled materials and substances that no longer perform satisfactorily [11]. There are different sources of waste such as municipal (households, schools, offices etc), medical, agricultural, industrial or from the automobile.

Waste management can be viewed as the generation, prevention, characterisation, monitoring, treatment, handling, and reuse of solid waste for the benefit of man [12]. Solid waste generation constitutes one of the fundamental environmental issues faced by humanity in the world today. [13] posited that waste management is a serious concern due to its human health and environmental sustainability implications. To corroborate this assertion various authors have opined that waste management is a globally challenging issue faced by mankind for decades [14-16]. It implies that environmental pollution, on global, regional and local scales should be of primary concern for humanity in the modern era and the future. Human actions are fundamentally, and to a significant extent responsible for this environmental anomaly by wastes. The amount of solid waste generated in the world is steadily increasing and every government in the world is presently strategizing on methods to approach the challenges posed by Municipal Solid Waste (MSW) [17]. Rapid population growth occasioned by the industrial revolution in major towns and cities of the world has necessitated rapid urbanization and subsequent development [18], which brings about the increase in industrial, commercial, infrastructural, administration and government activities in urban cities. Thus, resulting to the rapid growth of cities population; the rate of waste generation also increases, leading to increased burning of refuse and high rate of air pollution, which in turn increased concentration of greenhouse gases that cause global warming and subsequent climate change. The volume of waste generated in any city is often a reflection of the intensity of human-induced activities such as population growth, urbanization and social development, resources exploitation and unchecked technological advancement [19] in which Imo state, Nigeria is not an exception.

In a study to ascertain the extent of solid waste management in Nigeria, [20] opined that Nigeria generates more than 32 million tonnes of solid
waste annually out of which only 20-30 per cent is collected. According to [21], Nigeria is home of 12% of the 50 largest dumpsites in the world. A global air quality evaluation between 2008-2015 by World Health Organisation (WHO), graded Onitsha, a city of about 350,000 in South-Eastern Nigeria, as the most polluted city in the world out of 3000 settlements in 103 countries [22]. The situation is aggravated by indiscriminate dumping of refuse on roadsides, streets, waterways and empty land [23]. Some of the waste deposited could decompose to odorous mud made of soil, stagnant water, and more, hence can create complementary conditions for vectors of diseases [24]. Decaying organic waste produce methane, a notorious greenhouse gas with adverse impact when released. Moreover with high proximity of dumpsites to water bodies [25-27], aquatic resources and other ecosystem services [28] could be impacted with its multiplicity on environmental receptors and media, thus eliciting danger. The impact of landfills on climate change could vary. According to [29], on a global scale, waste contributes 3% of worldwide GHG emission [29]. This may increase. Waste generation and composition are greatly correlated with population, income, economic growth, season, climate and social behaviour [30]. In Nigeria, waste streams generally consist of putrescible, plastics, paper, textile, metal and glass [31]. Improper collection and disposal of municipal wastes are one of the leading causes of environmental pollution as the country presently lacks adequate budgetary allocations, enabling legislation, and an environmentally friendly and enlightened public [32] for the implementation of integrated waste management programmes across the states. Poor waste management plan has encouraged indiscriminate dumping by the local populace.

The reckless disposal of MSW has led to blockage of sewers and drainage networks and choking of water bodies [33] with the consequent impact of flooding. To this end, a top-down approach is needed as a dire necessity to educate the public on the implication of inappropriate discarding of solid waste into the environment by highlighting the damages due to such activities [34]. It is essential to point that the environment is the nature capital from which man should organise and sustainably explore for good living. MSW generation is set to double in Asia and Africa due to rural-urban migration and increased waste per capita as the economy improves [35,36]. Issues and challenges associated with waste management are well documented in the literature. This is not surprising considering the enormous environmental, health and fiscal related implications. In industrialized nations [37] highlighted public health, environment, resource scarcity, climate change, public awareness and participation as key drivers of solid waste management strategy.

From the foregoing, it is an undeniable fact that new and innovative climate change mitigation solutions are needed for public and private actors alike to step up efforts and creativity in identifying mitigation options. Circular economy is one such approach that offers precisely this opportunity, through strategies such as recirculating a larger share of materials, reducing waste in production, light-weighting products and structures, extending the lifetimes of products, and deploying new business models based around sharing of cars, buildings, and more [38]. A circular economy can reduce CO₂ emissions, reduce the scale of the challenge of decarbonising materials production, and contain the cost of achieving an industrial base compatible with a low-carbon economy. The circular economy concept is a promising strategy to improve the way we meet the functional needs of the society whilst using fewer materials and reducing negative impacts such as greenhouse gas emissions [39]. Our dependence on fossil fuels is at the heart of the climate change challenge. Around 65 per cent of greenhouse gas emissions is carbon dioxide (CO₂) from the combustion of fossil fuels. The remains are carbon dioxide from forestry and land use (11 per cent), and methane (CH₄) and nitrous oxide (N₂O) emissions from agriculture (16 percent) and industry (6 percent). In this context, it is not surprising that a majority of climate mitigation policies focus on energy efficiency and renewable energy, as exemplified by the European Union’s 20-20-20 policy aiming for a 20 percent reduction in emissions relative to 1990 levels by 2020, based on a 20 percent share in renewables and a 20 percent increase in energy efficiency [40]. However, despite a plethora of work done by previous researchers on solid waste disposal, none has been able to systematically/holistically study how Waste-to-Energy can serve as a circular economy tool towards climate change mitigation and sustainability in Owerri, Metropolis, Imo State, hence the crux of the study.
### 1.1 The Concept of Waste-to-Energy (WtE)

WtE recovery could be understood as waste treatment process that allows for the generation of energy in the form of electricity and or heat from waste that could otherwise have been dumped or landfilled [41,42]. According to [43], WtE technologies consist of any waste treatment process that creates energy in the form of electricity, heat or transport fuels (e.g. diesel) from a waste source. WtE is a reputable alternative for municipal solid waste treatment, driven by the need to reduce the environmental stresses of landfilling and the increase of the renewable portion of energy mix [44-46]. WtE technologies are vastly evolving and enhancing livelihood with the ability to be a source of renewable energy and better solid waste management strategy [47]. This could be necessitated due to rising waste generation with high heterogeneity especially in developing countries, scarce land for landfilling, climate change, and potential reduction of criminality due to enhanced SMEs along waste streams with employment opportunities, the overall impact of poor waste management practices and the renewable nature of WtE conversion. Choice of WtE technologies could be dependent on the calorific value of waste. Combustion process such as incineration is preferred mostly on an industrialized scale where the calorific heat value of MSW is high.

Themelis [34] reported that sustained combustion without auxiliary fuel would rely on at least heat value of above 5000 KJ/Kg, moisture content below 50%, the ash content of less than 60% and a combustible component not below 40%. So incineration may be averse in most developing countries like Nigeria where the moisture content of generated waste is high like in tropical regions of South East Asia, West and East Africa. Studies indicate high organic fraction in these regions. [48] report 50-75% in Ghana, Salequzzaman et al. 78% in Bangladesh, [49] posits about 65% in Nigeria State. Furthermore, incinerators involve high capital cost and may take about five years from design to the operational stage [34]. Moreover, with improper control, waste incineration could be a source of dangerous pollutants that includes dioxins and heavy metals [50-52]. However, according to [46], the combustion process is equated nowadays as foremost and upheld waste-to-energy (WtE) technology, with over 2000 efficiently operating facilities globally, treating about a quarter of a million waste yearly.

The potential according to the International Solid Waste Association (ISWA) and UNEP is that due to the prevailing acceptance of WtE technologies by developing countries to scale down reliance on dumpsites and their associated adverse impacts, there will be fivefold increase in the number of facilities in next ten years [46]. European Directive 2008/98/EC [53] classifies WtE in the recovery category of the conceptual hierarchy of waste management options [45]. During the past decade, WtE plants have been criticized for causing negative impacts on the environment and public health, but in reality, they are equipped with sophisticated air pollution control (APC) systems to minimize air-polluting emissions, which are strictly monitored [54]. Directive 2000/76/EC on the incineration of waste made WtE, one of the most stringently regulated and controlled industrial activities. A study in the United States [55] showed that, by 2012, the dioxin emissions of the U.S. WtE industry have been reduced to 0.54% of all controlled sources. According to [46], three major non-controlled sources are responsible for 89% of total dioxin emissions: landfill fires, forest and bush fires, and backyard burning. In the last two decades, the WtE industry in Europe, North America, and Asia have developed technologies that are currently among the cleanest sources of thermoelectric energy. The dominant WtE technology by far is grate combustion of as-received or post-recycling MSW for the production of electricity and heat. This method is practised in over 2000 plants in over 45 nations. However, alternative processes, such as the circulating fluidized bed (CFB), are constantly under development. Sharma and Mishra [46] documents that one or more of these techniques may result in lower capital costs per tonne of MSW processed than grate combustion. Therefore, proposals to build WtE plants should be open to all technologies, provided they meet the total required environmental criteria. The contractual arrangement for the construction of a WtE project must include the ironclad commitment of the general contractor that the plant will operate at the specified plant availability (i.e 8000 hours per year at full capacity), deliver the specified rate of electricity per tonne of MSW processed to the grid, and continuously meet the specified environmental standards. The host municipality is also contractually committed to collect and provide the specified daily and annual...
tonnage of MSW to the WtE plant (this material must also be within the specified range of calorific values). It is strongly recommended that national governments place sustainable waste management higher up on their list of essential infrastructure projects, in addition to services such as waste removal, electricity, and wastewater treatment. The construction of the first WtE plant in a nation can motivate other cities to apply for WtE projects. Often, WtE projects are not viewed as economically profitable to private investors in the short term; however, WtE projects can develop into economic booms in the long-term, in terms of job creation, the addition of a local source of renewable energy, the enormous amount of land conserved over hundreds of years, and the environmental and greenhouse gas advantages of WtE over landfilling. Therefore, it becomes prudent for national or regional governments to participate in a public-private partnership that will allow the nation to move towards more sustainable waste management. The development of WtE facilities in nearly 45 nations across the globe has had a positive track record on improving the environment in the areas where these plants operate. Fig. 1 shows typical MSW combustion plant; Fig. 2 highlights the high acceptability of WtE in the waste management hierarchy in Europe while Fig. 3 elucidates the high domiciliation of the plants in Europe. It is essential to note that only one plant exists in Africa-the Reppie WtE plant in Ethiopia [46], which started operation in August 2018.

Fig. 1. A classic MSW combustion/WtE plant with electricity production
*Source: Waste-to-Energy International (n.d)*

Fig. 2. EEC hierarchy of waste management
*Source: Kalogirou (2017)*
Uwakwe [52] calculated the electricity generation potential from waste incineration and using landfill gas in internal gas combustion engines, opining suitability for Africa especially with their low-cost modular design. The authors stated their efficiency at 20% and 30% respectively with electricity generation potential of almost 84 TWh and 52 TWh in 2025. This could help improve access to electricity in Africa. Anaerobic digestion, a biochemical process incorporating a closed system digester also reported as a WtE strategy [47]. Suitable and currently applied in industrialized and emerging countries, it treats both high moisture content and low moisture content waste with the implication of energy production. So could be an electricity generation source. [56] researched the electricity potential from the University of Malaya biodegradable waste generation reported feasibility. However, improvement in waste composition from changes and efficient implementation of waste policies, which include incentives that could change unsustainable waste associated habits are critical for the growth of WtE in developing countries. In his study on environmental contamination and governance issues in Nigeria, [57] justified regulation internalizing externalities cost and proposed elements for institutionalizing efficient enforcement strategies. He argued that the complimentary flow of both could be countered with the direct application of the command and control approach. But with the infusion of public confidence in environmental management via continual environmental education and training. Furthermore ensuring prudence in environmental governance that promotes, implement and put into effect environmental policies and policing which highlight transparency. It is achieved with open public participation in decision making and access to relevant information including unbiased prosecution of environmental defaulters.

1.2 Climate Change Mitigation

Climate change as defined by [58] is a change of climate that is attributable directly or indirectly to human activities and, which alters the composition of the global atmosphere, in addition to natural climate variability observed over comparable periods. Climate change refers to any change in the environment due to human activities or as a result of natural processes increase in average global temperatures [59]. Plants and animals are sensitive to fluctuations in temperature and climate. In the past, the climate has varied considerably within short time scales. Evidence from fossils and paleobiological studies have indicated that these periods of rapid climate change have been associated with mass extinction [60]. Climate change is one of the main causes of terrestrial biotic change and has different effects, such as disturbances and loss of habitat, fragmentation, and increasing the incidence of photogenes. As the global mean temperature rise, it causes positive or negative effects on different processes and activities in earth systems [29]. These effects may impact on ecosystem services, biodiversity, species composition, plant growth and productivity. The various sectors including waste, contributing to climate change are highlighted in Fig. 4.
Mitigation literally means the action of reducing the severity, seriousness, or painfulness of something. Climate change mitigation also involves the reduction in emissions of many greenhouse gases that contribute to climate change. Climate mitigation can also be viewed as any human intervention to reduce the potential effects of global warming by reducing the concentrations of greenhouse gases, either by reducing their sources or enhance the sinks of greenhouse gases. The International Panel on Climate Change [29] defines mitigation as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. Examples of mitigation include switching to low-carbon energy sources, such as renewable and nuclear energy, and expanding forests and other "sinks" to remove greater amounts of carbon dioxide from the atmosphere. Reduction of the number of greenhouse gases put into the atmosphere (i.e., greenhouse gas emissions) is usually accomplished through reducing energy use and switching to energy sources that don't release greenhouse gases. Frequently discussed energy conservation methods include increasing the fuel efficiency of vehicles, making individual lifestyle changes, and changing business practices. Technologies such as hydrogen fuel cells, solar power, tidal energy, geothermal power, and wind power, along with the use of carbon sinks, carbon credits, and taxation, are aimed at countering greenhouse gas emissions more directly. Energy efficiency can also play a major role, for example, through improving the insulation of buildings. Another approach to climate change mitigation is geoengineering. Carbon capture and storage (CCS) is another method of climate change mitigation. This involves capturing carbon dioxide (CO₂) from large point sources such as power plants and subsequently storing it safely instead of releasing it into the atmosphere. According to [29], CCS could contribute between 10% and 55% of the cumulative worldwide carbon mitigation effort over the next 90 years.

2. CIRCULAR ECONOMY AND SUSTAINABILITY

Make – Take – Waste. This has been the economic and societal modus operandi for many years now. We take primary resources, make them into products for consumption and when the product no longer has a use - we simply throw it away. For too many years we have thought of our planet's resources as being unlimited, living too much in the present and not thinking about the welfare of future generations that will follow us. Waste is the final phase in a process known as 'linear economy' [61].

In tallying with the above assertion, [62] affirmed that the linear economy is a wasteful system in which many valuable materials are "lost" to landfills, and the products that are manufactured are consistently under-utilized. This is amplified in the urban context where many studies have highlighted a structural problem with waste generation and management in key sectors such as mobility, food, and the built environment. The waste generated through these ineffective processes brings about additional costs due to waste management (WM) and collection spending which increases pressure on municipal budgets and possibly harms the natural environment and society as a whole. As a result of the above lacuna and taking cognizance of the three pillars of sustainability (People, Planet and Prosperity) as enshrined in the agenda of
sustainable development goals, a new economic model was necessary. Thus the Circular Economic Model (CEM).

In contrast to a linear economy, a circular economy aims to decouple growth from finite resource consumption and is restorative and regenerative by design. The need to transition to a more circular economy is recognised as an essential element in developing a sustainable, low carbon, resource-efficient and competitive economy. Using the concepts of circularity helps progression towards a sustainable future [63]. However, such a linear economic model can only function if limitless resources are available to satisfy endless demand. Global demand is growing steadily, while the availability of both non-renewable and renewable raw materials is finite. A strictly linear economy will inevitably encounter limits.

They went further to opine that:

Central to the circular economy concept is the notion that the value of materials and products is kept as high as possible for as long as possible. This helps to minimise the need for the input of new material and energy, thereby reducing environmental pressure linked to the life-cycle of products, from resource extraction, through production and use to end-of-life [63].

Thus, a circular economic model is a model that focuses on keeping resources in use for as long as possible, extracting the maximum value out of them and recovering them into new products at the end of their life [64]. Its objective is to make economic systems and industrial processes more environmentally friendly and sustainable. The circular economic model is based on three Rs which include: Reduce, Reuse and Redistribute.

Shifting to a circular economy is not a straight forward process and requires substantial changes in the value chain, such as; adapted design, better waste and water management, greater recycling and re-use of products. It also entails providing efficient waste management systems which implement modern collection, transport and waste treatment technologies, as well as minimizing and transforming waste itself into a valuable resource. This is explicitly shown in Fig. 5.

The circular economy is a potentially viable key to sustainable waste management in Nigeria. The mechanism strategy to achieving this lies in the concept of Waste-to-Energy. Waste-to-Energy is an integral process of consolidating the three Rs (Reduce, Reuse and Recycle). It is the mechanism of converting Waste-to-Energy to ensure optimal sustainability as demonstrated in Fig. 6.

Fig. 5. Circular and linear economy
Source: (Taelman et al. 2018)
3. METHODOLOGY

New policies on conservation strategies are aligned on Sustainable Development discourse, with emphasis on local participation for resource management [65]. On this premise data work by [66] and [67] at Owerri metropolis are incorporated in assessing how the transition to an integrated waste management system with special consideration to WtE could affect sustainability, which embodies features of circular economy and climate mitigation. [66] and [67] used American Society for Testing and Material (D 5231 – 92 (Reapproved 2003) for waste characterization and estimation; to estimate methane generation from anaerobic digestion, study incorporated and adopted (Equation 1) for calculating energy recovery from incineration of MSW;

\[ \text{ERP}_i = \eta \left( \frac{M \cdot \text{LCV}_{\text{MSW}}}{1000} \right) \quad (\text{Equation 1}) \]

Where ERP = Energy recovery potential in MWh/day

M = Total mass of dry solid waste in kg/day

LCV_{MSW} = \text{Lower calorific value of the waste in kWh/kg}

Average values of the rainy and dry season in Table 1 and Table 2 were integrated into Equation 1 to ascertain potential electricity generation.

Meanwhile, [66] and [67] estimated the population increase using Nigeria’s annual growth rate of 2.47% estimate as documented by [69]. [56] used CDM methodology 111.AO./Version 01: Methane recovery through controlled anaerobic digestion, to ascertain the potential in emission reduction from the WtE project activity. This gives the Certified Emission Reduction (CER) which shows the potential emission avertable from building a WtE plant; as well it establishes the idea of tradable carbon credit in the carbon market. Furthermore in estimating the potential income from the sale of renewable electricity from the bioenergy, current tariff (t) of N 24.91/kWh ($1 = N 306.4) charged by Port Harcourt Electricity Distribution Company (PHEDC). According to [67], the unit price is utilized to multiply electricity generated as indicated in Equation 2.

\[ t_e = t_e \times E_{\text{kWh/year}} \quad (\text{Equation 2}) \]
Table 1. Waste classification and composition

| Class                  | % Composition | Class                  | % Composition |
|------------------------|---------------|------------------------|---------------|
| Rainy season           |               | Dry season             |               |
| Mixed paper            | 2.1           | Mixed paper            | 3.0           |
| Newsprint/ Corrugated  | 7.4           | Newsprint/ Corrugated  | 5.3           |
| Yard waste             | 3.6           | Yard waste             | 6.2           |
| Food waste             | 60.6          | Food waste             | 56.2          |
| Wood                   | 3.1           | Wood                   | 2.3           |
| Glass                  | 3.3           | Glass                  | 3.3           |
| Ferrous                | 2.4           | Ferrous                | 3.7           |
| Hazardous waste        | 16.2          | Hazardous waste        | 18.7          |
| Others                 | 1.3           | Others                 | 1.3           |

Source: [66]

Table 2. Waste composition vs LCV

| Composition               | Reference LCV (MJ/kg) |
|---------------------------|-----------------------|
| Paper and cardboard       | 15.6                  |
| Mixed food waste          | 4.6                   |
| Textile                   | 32.4                  |
| Wood                      | 15.4                  |

Source: [68]

4. RESULTS AND DISCUSSION

Study results and associated results of WtE are herein highlighted. Fig. 7 shows sources of waste and MSW generation rate with probably associated issues. Sustainable potential for integrated management is also indicated. WtE is a key component.

Table 3 displays ascending waste generation from an increasing population and the estimated energy generation from the associated MSW. The estimated electricity power generation from anaerobic and combustion technologies, over a decade and a half are compared in Fig. 8. On the average combustion technology signals about two folds anaerobic potential.

Table 3. Projected MSW generation and associated combustion sourced energy potential in Owerri metropolis

| Year | Population | Waste generation/annum (Tonnes) | Electricity generation (MWh/day) |
|------|------------|---------------------------------|----------------------------------|
| 2016 | 525,596    | 315,062.30                      | 1,189.45                         |
| 2017 | 538,578    | 321,961.92                      | 1,218.87                         |
| 2018 | 551,881    | 329,914.48                      | 1,247.93                         |
| 2019 | 565,512    | 338,063.11                      | 1,279.82                         |
| 2020 | 579,480    | 347,362.40                      | 1,311.43                         |
| 2021 | 593,793    | 354,969.44                      | 1,343.80                         |
| 2022 | 608,460    | 363,737.50                      | 1,376.15                         |
| 2023 | 623,489    | 372,722.00                      | 1,411.02                         |
| 2024 | 638,889    | 383,016.34                      | 1,446.00                         |
| 2025 | 654,670    | 391,361.74                      | 1,481.59                         |
| 2026 | 670,840    | 401,028.18                      | 1,518.17                         |
| 2027 | 687,410    | 410,933.67                      | 1,555.68                         |
| 2028 | 704,389    | 422,237.55                      | 1,594.11                         |
| 2029 | 721,787    | 431,484.27                      | 1,633.48                         |
| 2030 | 739,615    | 442,141.84                      | 1,673.84                         |

Okere (2018)
Fig. 7. Waste flow, estimation and externalities
Source: [66]

Fig. 8. Potential electricity power generation in Owerri metropolis (2016-2030)
Source: [66]

4.1 Certified Emission Reduction (CER) Credits and Potential for CDM Participation

The study results as indicated in Fig. 9 highlights probable and optimistic scenarios of methane emission reduction and equivalent in carbon dioxide in terms of CER. From the baseline assessment, there is a feasibility of 550,273.20 tonnes of CH₄ equalling 11,555,737.14 tonnes (Methane’s global warming potential is 21 times CO₂) of carbon dioxide equivalent in ten years crediting period as set by UNFCCC, while a very conservative estimate put at 60% of the feasible results to a total of 330,580.06 tonnes CH₄ with a corresponding carbon dioxide equivalent value of
CER credit unit of 6.94 million. There seems to be a reduction in the climate effect of MSW in Owerri with WtE. Moreover, according to [66], there is an indication that Waste-to-Energy (WtE) and Clean Development Mechanism (CDM) could be sustainable ways of utilizing waste generated to avert pollution and climate change.

4.2 Financial Accrualment from Electricity Sale

Estimated finance accruable with the two WtE technologies under study is presented in Fig. 10. Estimation is for household consumers, hence the rate as earlier stated. While anaerobic digestion would have yielded a total of about N 74 billion in ten years beginning with N 6.5 billion in 2021 to N 8.2 billion in 2030, incineration would in the same period of consideration accrued about N 137 billion from N 12.2 billion to N 15.2 billion. The research has not considered full feasibility of the project including economic parameters that include capital expenditure (CAPEX) and operational expenditure (OPEX).

4.3 WtE and Sustainability

The human need for survival and well-being is domed on our natural environment. This may be direct or indirect. To pursue sustainability is to create and maintain the conditions under which humans and nature can co-exist in productive harmony to support present and future generations as it permits fulfillment of social, economic and other necessary need for all generation [70]. So developmental activities supposedly geared towards enhancement of man and certain aspects of his environment, without adverse or parasitic implication on other developmental features, at that point and in the future could be termed as sustainable. Circular economy and Climate Change mitigation are championed in that line as they are envisioned to scale back environmental tension. Technically, they are made up of elements, processes, procedures, technologies and attitudes which aid the integrity and sustenance of nature’s capital. Thus the sustainability of essential components of varied ecosystems and their services are empowered with high resilience, enabled by consistent efforts that integrate thoughts, policies and strategies of environmental conservation, to bequeath sustainable future to the upcoming generations.

Sharma and Mishra [46] opines that the combustion of post-recycled MSW is applied with great success. It can produce steam and electricity; reduce weight and volume of MSW by 70%–80% and 90%. Furthermore, the air pollution control system of the plant neutralizes the potency of flue gases and pathogenic substances. The plant requires a very small land area with dominant WtE technology of combustion in moving grates with simple and relatively lower capital cost.

The target of this complicated physicochemical operation is the evaporation, degradation, destruction of organic elements of the MSW with the presence of oxygen (in stoichiometric proportion or surplus), and the reduction of the...
Estimated income from the sale of electricity to the household.

Source: Okere (2018)

Fig. 11. Suggestive process flow chat of WtE in the circular economy

Weight and volume of MSW. The relatively inert solid residues (mainly bottom ash, fly ash, and usually the small portion of typically hazardous waste), which represent in total the 23%–30% of the initial feed (MSW quantity) of the WtE plant, and possibly contain some important inorganic pollutants including heavy metals, may need to be further treated. After stabilization and solidification, the fly ash can be disposed of in a sanitary landfill for residuals, while the bottom ash which is relatively inert (usually after the toxicity characteristic leaching procedure (TCLP) test) and can most commonly be used for construction applications (in roads, earthworks, mines, aggregates, etc.). The implication is that from WtE, a feedstock for the construction industry is accessed. According to the American Society of Mechanical Engineers (ASME), reduction of waste volume to 10% of the original volume due to WtE is feasible. It complements recycling and reduces landfilling, truck traffic and associated emissions. Moreover, it recovers and recycles metals which scales down mining need for natural materials that could have associated environmental issues. Waste-to-Energy International (n.d) hints of WtE approval in the year 2005 by the statement of German Federal Minister for the Environment, Nature Conservation and Nuclear Safety, member of The Greens party. The approval was based on the premise that WtE significantly reduces the disposal of municipal or industrial waste and sludge, and medical or industrial hazardous waste in landfill sites. Moreover, the generated energy output results in a new revenue source which has economic benefits for the local...
community and environmental benefits in the form of cleaner air, water and soil. Waste-to-Energy reduces waste volume, need for land, pollution, and produces renewable energy. Furthermore, it could close a loop of potential waste discharge of its bottom ash as they could be utilized for road construction as practised in Europe and Japan (Waste Management International, n.d), even as the metals from the ash could be used as raw materials by the metal industries. Fig. 11 is indicative of a combustion technology in a circular economy.

So with impact on the environment reduced and the outcome of the WtE process channelled as a raw material to another industry, issues on the climate are mitigated via WtE and Circular economy.

5. CONCLUSION

Issues associated with Waste management were analysed, followed by conceptual clarifications of pivotal concepts such as Waste-to-Energy, circular economy and climate mitigation. The sustainable linkage between them was ascertained, hence study infers that WIE could be imbibed as an environmentally friendly technology and practice, with the adequate alliance with the green concept of the circular economy, which in all mitigate the impact of climate change as the environmental footprint is reduced. The government must take the lead, especially with favourable policies. This research should arm decision/policymakers with further information on the multifaceted positive integrity of WIE. So to lubricate public awareness of the benefits of the state of the art WIE plant in advancing sustainable waste management, intensive educational WIE courses should continually be organised all over Nigeria for key stakeholders and the local society.

6. RECOMMENDATIONS

I. Include WtE in the federal Renewable Portfolio Standard.
II. Consider the reduction in greenhouse gases benefits of WtE in climate change policy.
III. Direct the Regulatory agencies consider “life cycle analysis” of waste disposal options and also to consider Extreme Attainable Regulator Technology type regulations on all emission sources, as have been applied to WIE facilities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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