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Assessing the Potential for Energy from Waste Plants to Tackle Energy Poverty and Earn Carbon Credits for Nigeria

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Abstract: A major challenge for Nigeria is poor energy access and limited energy mix; relying mostly on gas and hydro power plants. Energy from Waste could provide a bridge for this problem. Fuel needed to power these plants is abundant and in unsanitary dumpsites across major cities in the country. This paper brings to the fore the potential for using energy from waste as an option for reducing energy poverty in Nigeria. The analysis presented here is based on waste generation data for strategic cities of Abuja and Lagos. After removing sizeable recyclable fraction from solid waste, it is estimated that the residual waste in Abuja and Lagos can generate 54GWh/year and 475GWh/year respectively; sufficient to power over 11,000 and 94,000 homes; reducing emissions by as much as 324 million kgCO2e and 2,835 million kgCO2e; and earning carbon credits of $7 million and $113 million per years respectively. The additional supply of waste from neighbouring cities can further enhance electricity generation capacities and carbon credit earnings. This papers concludes that energy from waste plants can help Nigeria effectively deal with the menace of growing waste generation, reduce greenhouse gas emissions and earn carbon credits, and very importantly improve her energy mix.

Keywords: Energy From Waste, Electricity, Energy Policy, Solid Waste Management, Carbon Credits, Nigeria

1. Introduction

In 2017, the International Energy Agency estimated that 1.1 billion people do not have access to electricity and more than 3 billion people rely on the traditional fuelwood for cooking, mostly using inefficient stoves in poorly ventilated spaces [1]. In Nigeria, the National Bureau of Statistics estimates that 55% of Nigerian lack access to electricity and those who have access suffer erratic supply in Nigeria [2]. Furthermore, the World Energy Outlook 2012 reported that of 80 countries, Nigeria ranks 66th with an energy development index (EDI) of 0.11. Such lack of access to modern energy limits income generation and creates a vicious cycle of deprivation that trap people in poverty and any projected economic growth could be hindered [3, 4]. According to Mary Robinson, "this lack of access to energy is an intolerable failure of human solidarity" [5]. It becomes imperative to provide modern and reliable energy services (as prescribed in goal 7 of the Sustainable Development Goals) for the eradication of poverty and rising living standards targeted in Goal 1.

Beyond bridging poverty, energy supply is an engine for development. It is understandable that energy holds life transforming benefits-lighting up schools, powering lifesaving equipment, refrigerating food to minimize wastages, pumps water for better hygiene and sanitation, and creates opportunities for greater income generation. Sadly, Nigeria is energy poor. Energy poverty has been conceptualised as having a direct link with poor educational attainment and poor housing quality [6]. This conceptualization is based on energy poverty definition given as the inability of a household to acquire adequate energy services for 10% of their income [7]. For this paper, energy poverty in Nigeria is viewed from a broader perspective and the aim is not to calculate the overall national energy poverty percentage that could be lifted out of poverty but to assess energy from waste potential for Nigeria.

While successive National government have given priority to the electric power sub-sector (EPS) which has been identified as the key driver to achieving its developmental goals, there has been little improvement in electric power supply especially considering Nigeria's exponential population growth.

With a growing population numbering 95.6 million in 1990 and 190.9 million in 2017, and rapid urbanisation-35% in 1990 and 52% in 2015, the demand for energy services will continue to increase [8, 9]. Thus, bridging current energy supply-demand gaps will require new technologies supported by drastic policy measures to boost Nigeria's energy mix.

In Nigeria, there is an energy source that is almost never discussed and is not contained in any government energy policy document – energy generation from waste. Any waste treatment process that generates energy in the form of electricity, heat, or transport fuels is considered as energy recovery. Termed energy from waste (EfW) or waste to energy (WtE). It is estimated that from 2025, 2.3 billion tonnes of municipal solid waste (MSW) will be generated annually [10]. This amount of waste is equivalent to 2.58 x 1023 MJ of energy. EfW is a very promising alternative energy option for the future because with this amount of energy, 10% of global annual electricity need can be satisfied [10].

In Nigeria, thousands of tonnes of residual solid waste are generated daily across many cities. Figures from different source show that waste generation per capita range from 0.31kg/capita/day to 1.2kg/capita/day depending on location [11-16]. The large amount of waste generated in Nigeria makes energy from waste a viable waste management technology [17]. Unfortunately, waste to energy is not listed in the Nigerian National Energy Policy document. And the prospect of waste to energy is compounded by the poor waste management practice of 'collect and dump' in unsanitary open dumpsites that are often set on fire with deadly health and environmental concerns. Some of the pollutants contained in the fumes from open waste burning include dioxins, furans, arsenic, volatile organic compounds (VOCs), heavy metals, carbon monoxide and nitrogen oxides. Exposure to dioxins and furans has been linked to some types of cancer; livers problems; impairment of the immune system, the endocrine system, and reproductive systems among other health effects [18]. Furthermore, current poor waste management practice defaces streets, block waterways, disrupts ambient air quality, use up large arable land, and the leachate poison nearby surface and ground water sources.

Clearly, energy from waste technology can improve electricity generation and sustainable waste management in Nigeria. The supporting argument for EfW is 'if we must burn waste, let's burn it in a controlled environment for developmental benefits'. In essence energy generation. Energy recovery from solid waste holds great potentials for improved energy mix in Nigeria [17].

Incinerating residual faction of municipal solid waste (MSW) especially the high caloric value portion, electricity, heat and other materials can be recovered [19]. This technology is gaining global acceptance. The European Union waste framework directive (WFD) counts efficient energy recovery as recycling, and the West Africa Forum for Clean Energy Financing (WAFCEF) [1] considers EfW as a clean energy technology.

This paper takes a look at the current energy scenario in Nigeria reviewing how electricity is currently being produced and how the underlining issues can be addressed by developing local capacity in energy from waste technology. It is hoped that this will give an idea of how energy from waste technology can bridge the current energy poverty gap in Nigeria. It explores waste management practice in Nigeria and how EfW can improve existing SWM practices. The study use Abuja and Lagos as study location, because these two locations have growing populations and are strategically important locations in Nigeria. With Abuja as the seat of the federal government and Lagos the commercial capital of the country.

2. Current Electricity Scenario in Nigeria

Electricity generation dates back to the pre-amalgamation era when the first generating power plant with 60KW capacity was installed in Lagos, in 1898 only 15years after its introduction in England [20]. While the total installed generating capacity of Nigeria stands at 12,522MW with actual generation of about 3900MW, the United Kingdom generated electricity in excess of 337TWh in 2015 [2, 21]. Electricity industry estimates that with Nigeria's current GDP, growing population and global trends, electricity consumption should be four to five times more than what it currently is [2]. In simple terms, the current energy generation in Nigeria is grossly inadequate for its teaming population [22].

The problems associated with the power sector in Nigeria are evidential in the entire value chain; from generation, fuel source, transmission and distribution to bills collection. Currently, the majority (over 80 percent) of the country's installed capacity is powered by natural gas, plagued by the problems of insufficient gas production, economic disincentives for gas production, inadequate gas pipeline network and frequent vandalism contributes to making actual generation less than a third of installed capacity [2, 23, 24]. In terms of transmission network, Nigeria's capacity stands at below 5,300MW and often disrupted by system collapses and forced outages. At the distribution end, the Nigerian power

1 WAFCEF is promoted by African Development Bank, the Climate Technology Initiative – Private Financing Advisor Network (CTI-PFAN), Regional Clean Energy Investment Initiative (RCEII) together with ECOWAS Regional Centre for Renewable Energy and Energy Efficiency, Banque Ouest Africaine de Dèveloppement (BOAD) and the African Biofuels and Renewable Energy Company (ABREC), which is affiliated with the ECOWAS Bank for Investment and Development (EBID).

sector is plagued by erratic supply, improper pricing of power driven by poor metering, non-settlement of tariffs, non-payment of bills, illegal connections, theft and vandalisation of essential equipment, worn-out installations and resultant over-loading. With these, distribution companies suffer significant losses of up 46 percent of power transmitted [2].

With Nigeria sitting over the world's ninth-largest proven gas reserves estimated at 192tcf and having many large rivers traversing the length and breadth of the country, it is understood why gas and hydropower are currently the major power generating source for the grid [25]. The country has twenty two (22) gas-fired and three (3) large hydropower plants totaling 12,522MW [2].

Furthermore, different sources show that between 45% – 55% of the population have no access to grid electricity and those who are connected to the grid are burdened by erratic power interruptions [2, 26-28]. The problem is worse in rural area with an estimated 18 percent electricity penetration [24].

Resulting from the huge electric power shortfall from the grid, massive amount of power is self-generated. The power sector white paper by CBO Capital estimates that Nigerians generate about 6,000MW of electric power from countless number of fossil fuel powered generators to augment the huge lag in grid power [23]. In addition, electricity consumers involved in captive power generation pay as much as 62-94/kWh as compared to grid-based power costing between 26-54/kWh [2]. Households not only deal with this high financial cost but also the environmental and health costs associated with small scale power generators which are usually located within their living spaces. All of these factors make per capita electricity consumption in the country very low at 144kWh/capita [29]. Table 1 provides comparative per capita electricity consumption with selected African countries.

Table 1. *Electric power consumption status in selected African countries.*

S/No	Country	% Population with access in 1990	% Population with access in 2012	kWh per capita electric power consumption (2014)
	Nigeria	41.8	55.6	144.48
1	Angola	28.2	37	312.48
2	Cote d'Ivoire	36.5	55.8	276.15
3	Cameroun	29	53.7	280.67
4	Botswana	36.7	53.2	1,748.62
5	Ethiopia	10	26.6	69.72
6	Gabon	73	89.3	1,172.89
7	Ghana	30.6	64.7	354.71
8	Morocco	49.2	100	901.13
9	Mauritius	96.6	100	2,182.51
10	Tunisia	92.6	100	1,444.11
11	South Africa	65	85.4	4,198.40
12	Kenya	10.9	23	166.74
13	Zambia	13.3	22.1	707.19

Source: World Bank 2017 (https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC).

Since the coming of democratic governance in 1999, efforts by successive federal governments to boost energy generation, transmission and distribution led to the 2005 Electric Power Sector Reform which resulted in the decentralization of the electricity sub-sector into six (6) generating companies (Gencos), eleven (11) distribution companies (Discos), and the Transmission Company of Nigeria (TCN) which is 100% owned by the Federal Government [2, 30]. However, these reforms have not yielded the expected results.

3. Waste Management in Nigeria: Brief Overview

Globally, waste generated is treated using six different approaches; landfill, incineration, energy recovery, material recovery, composting and recycling [31]. In Nigeria, the most common method used to treat residual waste is 'end-of-pipe' disposal in open dumpsites. With growing population, increasing urbanisation and changing consumption patterns, it is projected that the associated increase in volume and complexity of waste will continue to pose threats to human health, ecosystems and the economy [13]. Unaegbu opines that achieving goals 3, 7, 11 and 13 of SDGs which include 'good health and wellbeing', 'affordable and clean energy', 'sustainable cities and communities' and 'climate action' respectively will depend on effective waste management practices [32]. But with the growing need for sustainability, opportunities exist to green the waste sector [31].

More worrying is the lack of well-engineered landfills and the plethora of unsanitary open dumpsites. It is argued that the choice to operate open dumps practices is as a result of the huge technical, financial, complex engineering system involved in constructing engineered landfills [33]. Available information show that there is only one dumpsite gas capturing facility in the country, the barely operational facility in Olusosun, Lagos state. Interestingly, the Abuja master plan make provision for a well-engineered 505ha solid waste treatment site which includes an engineered landfill, a composting and recycling facility and three (3) energy from waste plant to generate a total of 120MW of electricity [34].

In Nigeria, heaps of refuse are seen in open spaces, along street corners, underneath bridges, in drainage channels etc. [35, 36, 33, 37]. Illegal dumping of refuse in drainage systems has influenced flood events [38].

Another common but unsustainable waste management practice in Nigeria is open burning of refuse [35, 32]. Within households and communities, open burning refuse is done for a number of reasons; either because it is easier than hauling it to the local collection point or to avoid regular waste collection service fees, or the non-existent or poor waste collection service. To deflate the decomposing stench and growing volume of waste, these refuse heaps are set on fire. And this comes with damning consequences on the ecosystem and human health. Heavy metals like mercury and other poisonous gases including polychlorinated biphenyls (PCBs), dioxins and furans which are released remains in the environment for a long time and tend to bio-accumulate in predators at the top of the food chain-humans [18].

Waste recycling is mostly done by the informal sector – scavengers – who often have no formal education, vocational training or access to appropriate equipment and do not have alternative employment opportunities in the formal sector [31, 15, 37]. This appears to be a common practice in low and middle income countries. It is estimated that there are about 1 million and 10 million waste scavengers in India and China respectively [39].

In Nigeria, scavengers go from house-to-house to trade metals, plastics, glass bottles and newspapers for cash. Others go from dumpsters to dumpsites to pick recyclables. These informal sector collectors sell the recovered materials to middlemen, who in turn sell to processing industries. According to Adewole, scavengers are an essential part of the waste collection socio-economic structure [33]. But in recent times, there has been an upsurge of small but organised recyclables collection firms mostly in Lagos and Abuja. They offer cash or valuables as incentives for recyclables. These firms are mostly managed by young educated people who also make their presence felt on social media.

4. The Energy from Waste Option

Energy from waste plants are very complex systems. In simple term, the process of energy recovery from waste entails harnessing the chemical energy stored in waste materials by converting it to thermal energy at temperatures exceeding $900^{O}C$ to generate steam, the produced high temperature, high pressure dry steam is converted to mechanical energy by rotating the blades of the turbine, and finally to electrical energy via the generator connected to the turbine [40]. Efficiency waste to energy plants reduce the volume of waste by up to 95%, producing residual solid material (slag) made of non-combustible waste faction including glass, porcelain, iron scrap, gravel etc. [41]. For health and environmental safety, a proper energy from waste plant is fitted with air pollution control equipment [42].

Energy from waste plants can be used to generate power and/or heat [19, 41-43]. When they are used to produce only power, they have efficiency ranging from 18 – 27% [44]. The best operational example for energy from waste technology is the Afval Energie Bedrijf (AEB) CHP plant in Amsterdam which started operation in 2007. With a net electricity generation efficiency of 30% and capacity of 1 million MWh, it is the most efficient and largest EfW plant in the world able to covert 99% of the 1.4 million tonnes of MSW delivered yearly into sustainable electricity, district heating and high-quality construction materials [45]. AEB's Amsterdam facility employs about 400 people and avoids 172,500 tonnes of CO_2 annually.

Table 2. *Overall Greenhouse Effect of selected techniques.*

Selected Waste Management Techniques	Overall Greenhouse Effect (KgCO_2 per tonne)
Dumpsite	976
Land fill with biogas engine	328
Conventional Energy from Waste	-15
Optimised Energy from Waste	-219
Energy from Waste (heat only)	-153

Source: Marcel van Berlo, 2007.

The United Kingdom, Department for Environment, Food and Rural Affairs (DEFRA) in 2004, commissioned a detailed report on the health impacts of the different waste disposal methods [46]. The report which is one of the most extensive available on the subject, concludes that well managed, modern incinerators are likely to have only minimal effect on human health. This is further buttressed by a UNEP publication which argues that energy from waste can promote a green economy [31]. It is calculated that optimised energy from waste plant has significant negative overall emission of between 200 to 300kg CO_2 per tonne of waste [19]. This is a clear departure from traditional end-of-pipe treatment for Nigeria-open dumping in unsanitary spaces.

While it is a legitimate concerns that energy from waste will consume materials which could otherwise be managed higher up in the waste hierarchy especially recycling, we argue here that if the needed separation is done up stream, then the highlighted concern is effective addressed. It is the opinion of the authors that energy from waste should complement and not compete with effective recycling.

With pledges made to global environmental sustainability agreements and landfill spaces diminished alongside growing waste generation, the next best technology is energy recovery. And there is a growing trend in energy generation from waste globally. In 2010, it was estimated that the total power generated from waste was about 71,600GWh via the incineration of 192 million tonnes of municipal waste globally with a total installed capacity of 54GW [31]. Records from 2015 shows that there are over 2,200 active EfW plants worldwide, processing about 280 million tonnes of waste annually [48]. It also projects that 550 new plants will be added by 2024 processing more than 150 million tonnes of waste yearly.

In Sweden, for example, approximately 1.9TWh and 2.3TWh of electricity is generated from waste in 2011 and 2015 respectively [41]. In addition, energy from waste accounted for 48.6% of waste treated in Sweden. And in the Republic of Korea, there is a target to generate 4.16% of energy consumed from waste and biomass by 2020 [49]. This is expected to result in a reduction of GHG emissions to the tune of 44.82 million tonnes. Even so, as one of the new 300 waste-to-energy plants that the Chinese government plans to build in the next three years, the Chinese city of Shenzhen plans to manage its serious waste problem by incinerating 5,000 tonnes daily in what will become the largest waste-to-energy plant in the world, due to go live in 2019 [50].

5. Methodology

The study exploited the MSW generation data for Federal Capital Territory (FCT), Abuja and Lagos states in Nigeria. For Abuja, the data used were sourced from a 2014 field study [51]. Futuristic projection where taken from Environmental Protection Board (AEPB). In Lagos, data was sourced from the Lagos Waste Management Authority (LAWMA). It is projected that the amount of waste generated in Abuja and Lagos will increase over the years considering the growing population, increasing rural-urban migration, and changing consumption pattern requiring packaging.

Importantly, the calculation for the potential amount of waste feed took cognisance of recycling effort. Research on energy from waste potential did not consider the removal of recyclable fraction of waste [17, 52, 53]. It is known that a large amount of recyclables are removed from waste either at household level or at dumpsites by scavengers [33, 37]. For Abuja, a 30% recycling rate is considered. While for Lagos, a 50% recycling rate waste was considered based on growing incentive driven recycling initiatives now making headlines. This paper projects that collection rate will be improved from its current poor status which at best stands at 60% [54].

The energy conversion model used to calculate the energy potential in kWh per tonne is taken from Marcelo van Berlo [47]. An optimised EfW plant operating at 800KWh per tonne is the basis of calculation. The result of the carbon emission model are taken from the estimated amount of carbon dioxide equivalent (CO2e) in each tonne of waste that end up in a dumpsite. For the carbon reduction calculations, the energy source displaced is insufficient electricity generation. In addition, it substitutes the waste having to end up in open dumpsites. Box 1 and Box 2, shows the electricity generation potential in GWh, emissions reduction capacity in CO2e and earnings for operating the EfW incineration facilities in dollars for Abuja and Lagos.

6. Electricity Generation and Carbon Credit Earnings Calculations

Previous research show that as much 700Kwh to 1000KWh of electricity can be generated by incinerating one tonne of waste [41, 47, 52, 55]. Standard electricity generation capacity from selected waste management techniques are shown in Table 2. For this paper, the assumption is an 800kWh of electricity per tonne optimized grate combustion plant. Box 1 and Box 2 details the electricity generation calculations and carbon credit calculation for Abuja and Lagos respectively.

Box 1: Electricity generation capacity and emission reduction from waste incineration in Abuja.

Electricity Generation Calculation.

Estimated waste generation in Abuja = 387,040 tonnes per year; all of which end in unsanitary dumpsites across the city [51].

Assuming a 30% recycling rate, residual waste = 387,040 × 0.7 = 270,928 tonnes

Thus, electricity generation capacity (EGC) = residual waste (in tonnes) × generation rate per tonne

EGC = 270,928 × 800 = 216,742,400kWh = 216,742MWh per year (ideal case)

But assuming plant capacity factor of 25% [44]. Actual EGC =

216,742 × 0.25 = 54,185MWh (approximately 54GWh) per year

At an average household consumption of 5,000kWh per year, this amount of electricity is sufficient to power nearly 11, 000 homes.

More so, considering that EfW plants may not be fully profitable in neighbouring cities like Kaduna, Minna, Lokoja, Keffi, Suleja etc, residual waste generated in these cities can be transported to Abuja using the rail network that is current being developed cross the country. This additional waste will ensure sufficient, reliable and increased amount of waste to fuel the plant. If supply of waste from these cities can be secured, a 500,000 tonne per year plant can be developed and built in Abuja.

This means that 100GWh of electricity can be generated from such a plant. An amount of power sufficient for 20,000 homes assuming a consumption average of 5000kWh/yr.

Emission Reduction Calculation

Considering current practice of heaping refuse in open dumpsites, average greenhouse gas emission is calculated to be 976kg CO2e per tonne of waste [47].

Using optimized energy from waste, GHG emission is calculated to be negative 200 – 3ookg Co2e per tonne of waste. For this paper a figure of-219kg CO2e per tonne of waste is used.

Overall emission reduction = emission from dumpsites – emission from optimized EfW

= 976 – (-219) = 1,195kg CO2e per tonne of waste (using

Using the residual waste generation figures in Abuja of 270,928 tonnes, total CO2e savings

= 270,928 × 1,195 = 324 million kg CO2e per year.

Carbon Credit Earnings per tonne of waste = 323,758.96 × 40 = $7,122,697

Based on this amount of CO_2 reduction in the different waste treatment method, Abuja City Management can earn approximately $7 million in Carbon Emission Reduction (CER)

Assumption: Lower limit carbon price projected by the World Bank Commission of Carbon Pricing which is put at $40 per tonne of CO_2 saved by 2020 [56].

Box 2: Electricity generation capacity from waste incineration in Lagos.

Electricity Generation for Lagos:

With an estimated population of about 23 million (National Population Commission, 2016) and a per capita waste generation of 0.5kg/cap/day to 0.6kg/cap/day, the Lagos Waste Management Agency (LAWMA), estimates that about 13,000 metric tonnes of solid waste is generated daily in the State.

It means that yearly generation = 13000 × 365 = 4,745,000 tonnes

With recycling already existing in Lagos, the assumption here is that 50% recycling is attainable.

Thus, balance residual waste of 50% = 4,745,000 × 0.5 = 2,372,500 tonnes

Again, at 800Kwh of electricity per tonne of waste incinerated,

Approximate Electricity Generation Capacity (EGC) =

2,372,500 × 800 = 1.898 million MWh (1,898GWh) yearly

Assuming plant capacity factor of 25% [44]. Actual EGC =

1,898 × 0.25 = 475GWh/year

This is enough to power over 94,000 homes at an average of 5000Kwh/year consumption.

Emission Reduction Calculation for Lagos

Using the same CO2e emission differential from the two different waste management technique, overall emission reduction = 1,195kg CO2e per tonne

Using the residual waste generation estimates in Lagos of 2,372,500, total CO2e savings

= 2,372,500 × 1,195 = 2,835 million kg CO2e per year.

Carbon Credit Earnings per tonne of waste = 2,835,137.5 × 40 = $113,405,500

Based on this amount of CO_2 reduction in the different waste treatment method, Lagos State Management can earn approximately $113 million in Carbon Emission Reduction (CER).

Assumption: Lower limit carbon price projected The Commission of Carbon Prices which is put at $40 per tonne of CO_2 saved by 2020 [56].

7. Discussion of Results

From the above calculations, assuming effective waste recycling rate and an optimized EfW plant with electricity generating rate of 800kWh per tonne of waste, about 54GWh of electricity can be generated per year in Abuja while about 475GWh of electricity can be generated per year in Lagos. Furthermore, emission reduction using optimized EfW in Abuja is 324 million kg CO2e per year with possible CER earning of USD 7 million while in Lagos it is calculated to be 2,835 million kgCO2e per year with possible CER earning of USD 113 million. These calculations are made based on waste collected. Thus, if collection which stands at between 50 and 60% can be improved, significantly more power could be generated. The 36 states and the federal capital territory have capacity for energy from waste plant (though many of them small scale), poor collection and lack of political will constraints there development [17]. But following the above calculation, energy from waste plants with varying capacity can be installed in each of the six geo-political zones in the country.

The electricity generation capacity of any country has significant impact on both its productivity and economic advancement. The review current electricity scenario in Nigeria clearly shows that actual electricity generation is far below installed capacity with grid electricity dependent on two sources – gas and hydro. In other words, Nigeria lacks a sustainable energy mix. This has led many Nigerian to depend on small scale generators for self-generated power. These self-generating power plants are not only expensive to maintain but also pose significant human health and environmental consequences that have not been adequately measured. Nigeria can overcome this challenge by developing localized grid networks from small to medium scale renewable power generating sources. Though Nigeria's NDC targets a 55% emissions reduction from electricity generation, it made no mention of the use of energy from waste to meet this target. Thus a new policy direction is required as current policies do not factor the contribution of energy from waste. Generating electricity from waste avoids GHG emission when fossil fuel generated electricity is substituted and methane from waste heaped at dumpsites [57, 58].

With current waste generation, EfW can form a major source of power in Nigeria if the constraints of 'collect and dump' by state agencies, fly tipping by households and open burning are addressed. These three waste disposal methods have devastating consequences for human health, the ecosystem and ultimately the economy. Furthermore, energy from waste provides an efficacious opportunity for Nigeria to reduce her greenhouse gas emission and meet her international commitments. Waste, the fuel to power these plants are abundant and increasing. Importantly, Nigeria must not miss this trend as she missed the global trend in coal fired plants in the early 1900s. Thus, with the right policy and political will, appropriate investments can be attracted to convert municipal solid waste (currently stashed in dumpsites) into a 'precious' resource for sustainable energy mix.

Importantly, the financial implication of developing an EfW plant can be sourced from the global climate fund with Nigeria earning huge amounts in the form of Carbon Emissions Reduction (CER). In comparison with other source on electricity, energy from waste is identified as one of the eight reliable, affordable and clean source of power for now and the future [59, 60]. Below is a levelised cost of electricity from different source. The naira values are derived at NGN360 to the US dollar.

Table 3. *Levelised cost of electricity in USD/MWh 2013 estimates.*

Energy Source	Levelised cost of electricity (USD/MWh)	Levelised cost of electricity (NGN/kWh)
Wind-Offshore	147 – 367	52.9 – 132
Wind – Onshore	47 – 136	16.9 – 49
Natural Gas	60 – 150	21.6 – 54
Coal	35-172	12.6 – 61.9
Hydropower-Large	24-302	8.6 – 108.7
Solar PV	79-226	28.4 – 81.4
Energy from Waste	65-200	23.4 – 72

Source: World Energy Council (2013c).

Nigeria's inability to adapt new electric power development technologies and strategies has resulted in low energy generating capacity and consumption. These low consumption means that many of its citizens will be trapped in energy poverty [62]. This poverty trap is exacerbated by the high cost household's self-generation. Thus, scaling energy poverty in Nigeria involves the complex interaction of lack of access to clean and modern energy and the high cost various households have to bare for self-generation.

Finally, while improving Nigeria's waste management system is an important objective for proposing energy from waste technologies, the major motivation is for increased energy mix and access. This will draw Nigeria closer to meeting target set in Goal 7 of SDGs-"*expanding infrastructure and upgrading technology for supplying modern and sustainable energy services for all in developing countries by 2030*".

Benefits of Energy from Waste for Nigeria

In Nigeria, the benefits of energy from waste include:

1. Increased localized generation of electricity which is currently low. This will significantly improve Nigeria's energy mix and contribute to energy access for the future.
2. A sustainable waste management strategy that will end the practice of 'collect and dump' in uncontrolled open dumpsites.
3. As a renewable energy source it can also contribute to Nigeria meeting her national determined contribution (NDC) decarbonisation targets.
4. A driver to ensure availability of feedstock (waste) for energy from waste plant will improve waste collection and reduce the amount of waste heaps and litter that defaces cities.
5. A source for carbon credits earning for the country.
6. Increased recovery of ferrous and non-ferrous metals which otherwise will be covered up in refuse heaps.
7. The creation of new skilled and unskilled jobs for thousands of people especially for waste collectors.

8. Conclusions

Energy poverty is not just another terminology in Nigeria but a living reality. It involves the complex scaling of lack of access to clean and modern energy and the high percentage of household income expended on self-generation. With a fast growing population and need for improved human development, improvement in electricity consumption and production in Nigeria is imperative. Having signed the Paris agreement, Nigeria needs to bridge current negative patterns by promoting clean energy development which will also improve the quality of life for her citizens. Fortunately, this is the best time Nigeria has to develop its electricity power sub-sector as no time in history has the government priortised the development of the sector than in the last decade and half. Furthermore, the global drive for improved livelihood for all which is enshrined in the sustainable development goals serves as motivator to equitably pursue clean energy. It is understood that technology alone is insufficient, and barriers may arise in deploying new technologies including energy from waste which can expand Nigeria's opportunity to meet her growing energy demand.

Energy from waste will help Nigeria effectively deal with the menace of growing waste generation, reduce greenhouse gas emissions and earn carbon credits, and very importantly improve her energy mix. With the capacity to generate electricity sufficient to power over 11,000 homes and 94,000 in Abuja and Lagos respectively, localised energy from waste can bridge the current energy poverty gap in Nigeria and improve living standards. Furthermore, by maximizing recycling and incinerating residual waste, Nigeria will be conforming to the principles of circular economy. And to ensure adequate supply of fuel, waste can be transported from neighbouring cities (where energy from waste plant will not be profitable) to the plant site. But achieving this will require a sound waste-to-energy policy which is completely absent from all relevant strategic development frameworks in the power sector. While this paper did not itself review the economic feasibility of energy from waste plant in Nigeria, one option that improves the economics of such plant would be for the government to obtain low interest loan or grant from an international organization or create the enabling environment for the development of EfW through the United Nations Green Climate Fund.

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