Supplementary Material

S1. MSW collection and transport

Data on the collection and transportation of MSW for Lagos and Abuja were obtained from the staff of the LAWMA and the AEPB. Tables S.1 gives the input and output data used for the collection and transportation of 1t of MSW in Lagos and Abuja. The diesel consumption (L/t) is given along with the emission factors (g/L) and the emissions from the diesel combustion during the waste collection and transportation which is calculated using the equation (S1):

$$Emissions\ (kg/L) = Diesel\ Fuel\ Used\ (L/t) \times Emission\ Factor\ (Kg/L) \qquad (S1)$$

Table S1. Emission from MSW collect and transportation

Diesel Consumption for MSW Collection and Transportation (L/t)	Emissions	Emission Factors (Kg/L) (Babu et al 2014)	Emission (Kg/t)
8.8	CO_2	2.663	23.4344
	CO	0.01195	0.10516
	Hydrocarbons (HC)	0.00175	0.0154
	NOx	0.00236	0.020768
	Particulate Matter (PM)	0.00062	0.005456

S2 Electricity Output from WtE systems

Values for the electricity output generated from the WtE systems, were derived from equation S2:

$$E_p = \frac{Mi\ X\ CV\ X\ \eta}{Co} \qquad (S2)$$

From equation S2 M_i refers to the amount/volume of waste fraction involved in tonnes (t) or cubic metres (m^3), CV is the calorific value for respective technologies (Incineration: 19.34 MJ/Kg waste processed (Abuja), 20.56 MJ/Kg waste processed (Lagos); AD: 37.2MJ/m^3; Gasification: 15.68 MJ/Kg waste processed (Abuja), 14.37 MJ/Kg waste processed (Lagos), η is conversion efficiency (Incineration: 20%; AD:26%; Gasification:23% and LFGTE:33%) , and Co is the conversion factor (3.6) for MJ to kWh.

S3 Emission Calculation for the WtE systems

Landfill: the emissions in a landfill can be attributed to the degradation of the organic matter and diesel requirements by vehicles used in the compaction of the wastes. To quantify the amounts of CH_4 and CO_2 produced by the landfill, the Intergovernmental Panel on Climate Change (IPCC) Tier I methodology (IPCC, 2006) was adopted which is based upon a mass balance approach, as indicated in equations (S3) and (S4) below:

$$CH_4\ (kg\ /tonne\ of\ MSW) = W_F \times MCF \times DOC \times DOC_F \times F \times \left(\frac{16}{12} - R\right) \times (1 - OX) \qquad (S3)$$

$$CO_2\ (kg\ /tonne\ of\ MSW) = CH_4 \times \left(\frac{1-F}{F} - OX\right) \times \frac{44}{16} \qquad (S4)$$

where W_F is the wet weight of the MSW disposed at the landfill. The MCF refers to the methane correction factor and ranges between 0.4 and 1 for unmanaged and well managed landfills (Lee et al.,2017). A value of 0.6 was adopted because the landfills in most developing countries may not be perfectly managed. DOC is the percentage of the degradable organic carbon in the waste, and DOC_F is the fraction of the degradable carbon that converts to landfill gas through waste decomposition. In the

study area, the DOC of the landfilled waste comprises food, paper, and textile waste. The value 16/12 is the carbon content of methane, F refers to the methane concentration in landfill gas, R is the recovered methane fraction, and OX is the methane oxidation factor. It has been assumed that 50% of landfill gas is collected (i.e. R = 0.5) and used to generate electricity; the rest escapes into the atmosphere and contributes to GHG emissions (Sharma and Chandel, 2017). The amount of diesel fuel consumed during the compaction process of the wastes is taken as 3 L/t of MSW after Babu et al. (2014). The assumption of this calculation is that the whole amount of the degradation occurs instantaneously and that there is a steady state of continuous addition of waste to the site resulting to a steady state in terms of LFG produced.

Table S2. Emission from LFGTE per tonne of MSW for Abuja and Lagos.

Air Emissions (Kg/t of waste processed)	**Abuja**	**Lagos**
CO_2, biogenic	122.2	143.1
CH_4	44.7	52.1

AD: the emissions of CH_4 and CO_2 from AD were calculated using the Bussell equation (Odedina et al., 2017) given in equation (S5). Using elemental analysis, the chemical formula for the biodegradable fraction of MSW was formed based on the respective MSW composition of the two cities. It was assumed that 5% of biogas generated during AD would leak into the atmosphere (Richard et al.,2021). Hence, only 95% of CH_4 was assumed to be combusted to CO_2 in the energy generation. The emission of SO_2 and NOx were taken as 22 mg SO_2 Nm^{-3} and 1170 mg NOx Nm^{-3} of biogas burned after Sharma and Chandel (2017).

$$C_nH_aO_bN_c + (n–0.25a-0.5b+ 0.75c)\ H_2O \rightarrow (0.5n - 0.125a+0.25b+0.375c)\ CO_2 +(0.5n+ 0.125a -0.25b -0.375c)\ CH_4 + cNH_3 \quad (S5)$$

where ‘n’,’a’,’b' and c, are constants whose values can be determined by using the normalised mole ratio proposed by Salami et al. (2011). This was obtained as follows:

$$Mole\ Ratio = \frac{K|C,H,ON|}{M|C,H,ON|} \quad (S6)$$

where K is the mass of the Carbon (C), Hydrogen (H), Oxygen (O) and Nitrogen (N), and M is their respective Molar Mass in kg.

Incineration: the air emissions of gases such as CO_2, CO, dinitrogen monoxide (N_2O), ammonia (NH_3), NOx and non-methane volatile compounds (NMVOC) were calculated by using equations based on the IPCC methodology as given below, based on the concentration of gases and exhaust gas volume (5500 m^3/t) (IPCC, 2006). It was assumed that a wet scrubber with 95% removal efficiency would be used for SOx removal from the incinerator (Chien and Chu, 2000). During the incineration process, both biogenic CO_2 and fossil CO_2 will be generated (Chan and Lin, 2010). According to the IPCC methodology, the biogenic CO_2 and fossil CO_2 constitute 67 and 33% of CO_2 emitted, respectively (IPCC, 2006). Equation (S7) is used to calculate the CO_2 emissions for incineration:

$$CO_2\ \text{Emissions} = \sum MSW_{F(i)} \times C_i \times O_F \times \frac{44}{12} \quad (S7)$$

where $MSW_{F(i)}$ refers to the combustible portion (i = plastics, papers and textiles) of the MSW C_i is the carbon content of each combustible portion, and O_F is the oxidation fraction (0.98). At the same time,

$\frac{44}{12}$ is the carbon content of CO_2. The emissions for CO, N_2O, NH_3, NOx and NMVOC were calculated by using equations below where the values $50 mg/m^3$, $2\ mg/m^3$, $4\ mg/m^3$, $200\ mg/m^3$ and $5\ mg/m^3$ are the respective emisión factors as given by IPCC :

$$N_2O\ Emissions = 2\ mg/m^3 \times 5500 m^3/t \times MSW_F \quad (S8)$$

$$CO\ Emissions = 50 mg/m^3 \times 5500 m^3/t \times MSW_F \quad (S9)$$

$$NO_X\ Emissions = 200\ mg/m^3 \times 5500 m^3/t \times MSW_F \quad (S10)$$

$$NH_3\ Emissions = 4\ mg/m^3 \times 5500 m^3/t \times MSW_F \quad (S11)$$

$$NMVOC\ Emissions = 5\ mg/m^3 \times 5500 m^3/t \times MSW_F \quad (S12)$$

Table S3. Emission from Incineration per tonne of waste processed for Abuja and Lagos

Air Emissions (Kg/t waste processed)	Abuja	Lagos
CO_2, biogenic	519.3	604.2
CO_2, fossil	255.8	297.6
CO	0.11	0.13
N_2O	0.0045	0.0053
NOx	0.45	0.53
NH_3	0.009	0.011
NMVOC	0.011	0.013

Gasification: In the LCA model of gasification, the life cycle inventory of the LCA model has been made primarily based on the literature, report, and publications, in this case from Defra, 2013. Thus the emissions for this WtE calculated using equation (13):

Emissions (kg/t) = Amount of Waste (Kg/t waste processed) × Emission Factors (S13)

Table S4. Emission factors for Gasification (Derfa,2013).

Emissions	Emission Factor
CO_2, biogenic	0.67
CO_2, fossil	0.33
NOx	0.78
SOx	0.052
Hydorgen Chloride (HCl)	0.032
Mercury (Hg)	0.000069
Arsenic (Ar)	0.00006
Nickel (Ni)	0.00004
Cadmium (Cd)	0.0000069
Volatile Organic Compounds (VOC)	0.011
Hydrogen Fluoride (HF)	0.00034

Table S5. Emission from Gasification per tonne of waste processed for Abuja and Lagos (after Defra,2013).

Air Emissions (Kg/t waste processed)	Abuja	Lagos
CO2, biogenic	589.6	629.8
CO2, fossil	290.4	310.2
NOx	0.67	0.73
SOx	0.046	0.05
HCl	0.028	0.03
Hg	0.00006	0.00007
Ar	0.00005	0.00006
Ni	0.000035	0.00004
Cd	0.000006	0.000007
VOC	0.0097	0.01
HF	0.00029	0.0003

S4. Consumptions and emissions of backup generators

The emissions from diesel consumption for backup generators can be obtained using the equations (2) and (3) with the diesel consumption (L/kWh) emission factors (kg/L) as well as the results given below in Tables (4) and (5) respectively:

CO_2 Emissions (Kg/kWh) = 0.865× Density of Diesel Fuel (Kg/L) × $Diesel\ Fuel\ Consumption\ (L/kWh)$ × $\frac{44}{12}$ *(S13)*

where 0.865 is the amount of carbon in the diesel fuel with the density of diesel fuel being 0.85kg/L

Emissions (Kg/kWh) = $Diesel\ Fuel\ Consumption\ (L/kWh)$× Emission Factor (Kg/L) *(S14)*

Table S6 The Diesel Consumption for diesel backup generators with the pollutants and emission factors (Jarkhrani, 2017 Adeniran, 2016).

Diesel Consumption for Back-Up Generators (L/kWh)	Pollutants	Emission Factors (Kg/L)	Emission (Kg/kWh)
0.32	Carbon Dioxide (CO_2)	2.663	0.85216
	Carbon Monoxide (CO)	0.01195	0.003824
	HydroCarbons (HC)	0.00175	0.00056
	Nitrogen Oxides (NOx)	0.00236	0.0007552
	Particulate Matter (PM	0.00062	0.0001984

S5. LCIA results for the full CML-1A impact assessment method

he National Grid electricity in the Abiotic Depletion category is due to the material consumption for the grid in the Ecoinvent dataset (the materiality of the systems is not fully reflected in the results for the DGBGs or WtE systems for which materiality data was not included).

S6. Main Drivers for the Impact Categories

Tables S 9 & 10 gives the main drivers in terms of substances and processes for each impact category for the WtE systems, DBGs and Grid Electricity

Table S7. LCIA results of the full range of impact categories for the WtE system, DBGs and Grid electricity per 1 kWh of electricity for Abuja [CML-1A Impact Assessment Method]

Impact Category	Unit	AD Abuja	Incineration Abuja	Gasification Abuja	LGTE Abuja	DBGs	Grid Electricity
Abiotic depletion	Kg Sb eq	1.46E-08	1.08E-07	5.08E-07	1.54E-07	1.78E-07	1.02E-06
Abiotic depletion (fossil fuels)	MJ	0.61820734	3.1653374	6.3956894	4.5873311	14.061615	8.6675592
Global warming (GWP100a)	Kg CO_2 eq	0.50676833	0.80435293	0.85750654	9.4962535	1.0250851	0.49665014
Ozone layer depletion (ODP)	Kg CFC-11 eq	7.26E-09	3.40E-08	4.15E-08	4.96E-08	1.80E-07	2.53E-08
Human toxicity	Kg 1,4-DB eq	0.005480514	0.010225036	0.019499415	0.019035223	0.073157383	0.01172163
Fresh water aquatic ecotox.	Kg 1,4-DB eq	0.031944614	0.000848937	0.001048333	0.001237647	0.004539814	0.000493882
Marine aquatic ecotoxicity	Kg 1,4-DB eq	6.0802123	7.0422678	29.293482	10.235709	35.733645	8.5647179
Terrestrial ecotoxicity	Kg 1,4-DB eq	0.008012232	9.97E-05	0.003090534	0.000142402	0.000240638	0.000753354
Photochemical oxidation	Kg C_2H_4 eq	0.000105956	3.96E-05	4.64E-05	0.002019335	0.000198027	4.06E-05
Acidification	Kg SO_2 eq	0.000563639	0.00088947	0.000974193	0.002988768	0.012916254	0.000296188
Eutrophication	Kg PO_{4-} eq	0.000143932	0.000191536	0.000209046	0.000717046	0.003134793	6.10E-05

Table S8. Life Cycle Characterisation Results of the full range of impact categories for the WtE system, DBGs and Grid electricity per 1 kWh of electricity for Lagos [CML-1A Impact Assessment Method]

Impact Category	Unit	AD Lagos	Incineration Lagos	Gasification Lagos	LFGTE Lagos	DBGs	Grid Electricity
Abiotic depletion	Kg Sb eq	1.41E-08	1.00E-07	5.54E-07	1.22E-07	1.78E-07	1.02E-06
Abiotic depletion (fossil fuels)	MJ	0.60263408	2.8564213	6.9780682	3.6357096	14.061615	8.6675592
Global warming (GWP100a)	Kg CO_2 eq	0.50572088	0.74425049	0.93558938	8.7374896	1.0250851	0.49665014
Ozone layer depletion (ODP)	Kg CFC-11 eq	7.09E-09	3.05E-08	4.53E-08	3.93E-08	1.80E-07	2.53E-08
Human toxicity	Kg 1,4-DB eq	0.005375593	0.009236046	0.021274993	0.015086451	0.073157383	0.011721636
Fresh water aquatic ecotox.	Kg 1,4-DB eq	0.031211922	0.000759703	0.001143792	0.000980902	0.004539814	0.000493882
Marine aquatic ecotoxicity	Kg 1,4-DB eq	5.9393909	6.3180494	31.960888	8.1123569	35.733645	8.5647179
Terrestrial ecotoxicity	Kg 1,4-DB eq	0.00782836	9.17E-05	0.003371952	0.000112861	0.000240638	0.000753354
Photochemical oxidation	Kg C_2H_4 eq	0.000105803	3.57E-05	5.06E-05	0.001859974	0.000198027	4.06E-05
Acidification	Kg SO_2 eq	0.000560105	0.000825291	0.001062901	0.002368761	0.012916254	0.000296188
Eutrophication	Kg PO_4- eq	0.000143075	0.000179078	0.000228081	0.000568298	0.003134793	6.10E-05

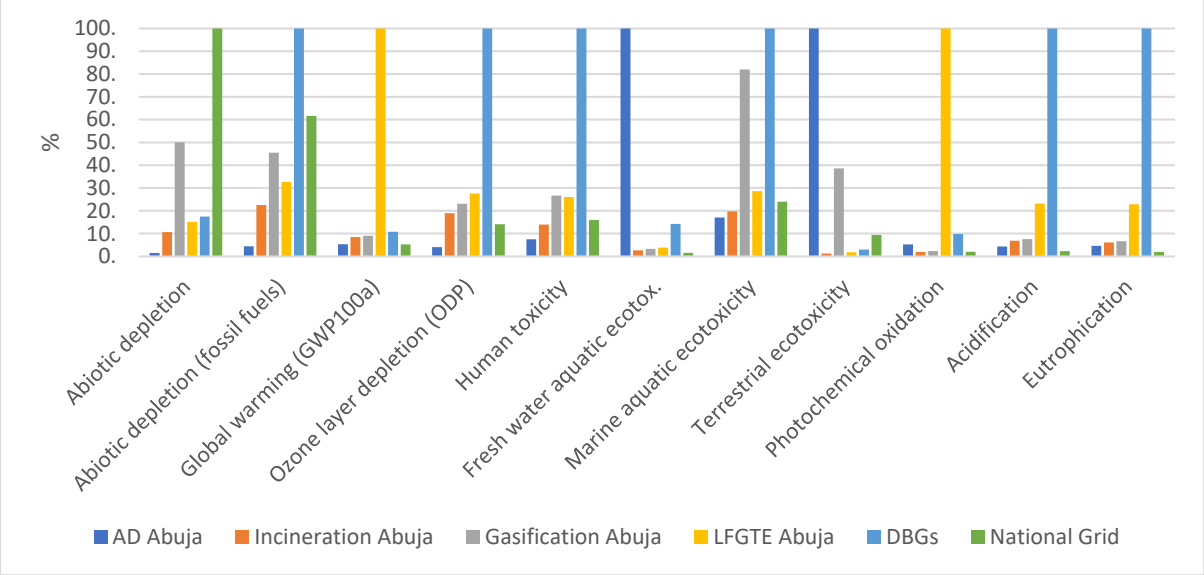


Figure S1. Abuja: Full LCA characterization results for 1kWh electricity output by WtE systems, DBG and national grid

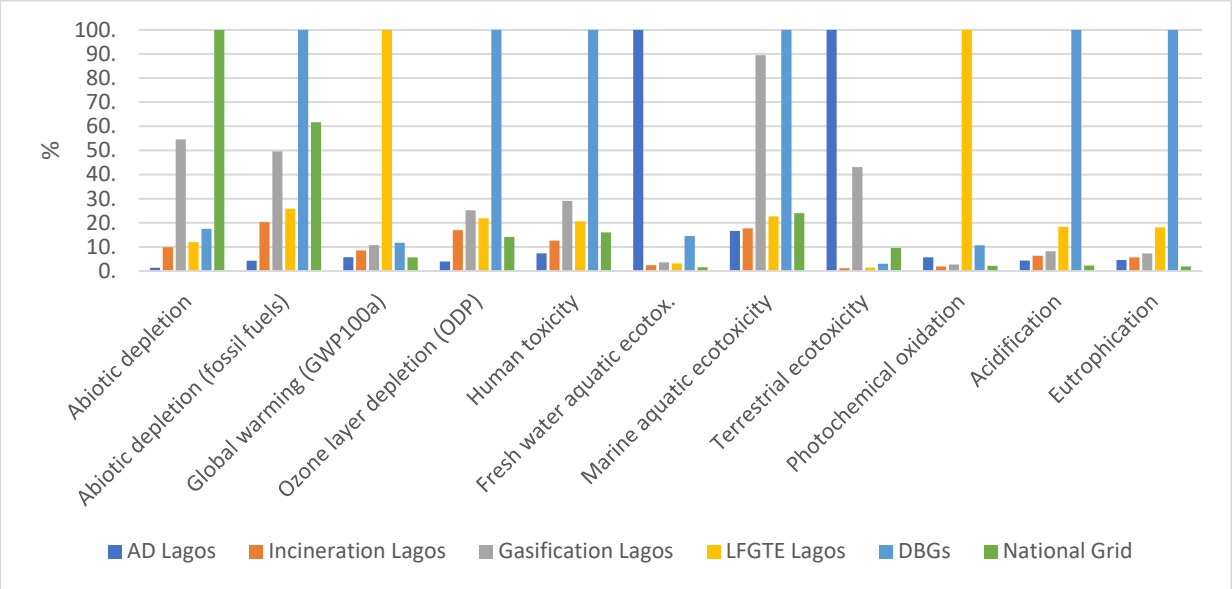


Figure S2. Lagos: Full LCA characterization results for 1kWh electricity output by WtE systems, DBG and national grid.

Table S9 The Main Drivers (Substances) for the Impact Categories for WtE Systems, DGBs and Grid Electricity (in %)

Impact Category	AD	Incineration	Gasification	LGTE	DBGs	Grid Electricity
Abiotic Depletion Potential (Fossil Fuels)	Crude Oil/Diesel (85.5)	Crude Oil/Diesel (76)	Natural Gas (64.2)	Crude Oil/ Diesel (76)	Crude Oil/Diesel (95.6)	Natural Gas (98.6)
Global Warming Potential	air/CH_4, biogenic (91.3)	air/CO_2, fossil (99.1)	air/CO_2, fossil (98.2)	air/CH_4, biogenic (94.7)	air/CO2, fossil (98.9)	air/CO_2, fossil (94.4))
Human Toxicity Potential	Soil/Cd (43.8)	air/Ni (36.4)	air/Ni (33.9)	air/NOx (33.8)	air/NOx (38.6)	air/Ni (26.6)
Photochemical Oxidation Potential	air/CH_4, biogenic (93.6)	air/CO,fossil (52.4)	air/CO,fossil (46.6)	air/CH_4, biogenic (96.1)	air/CO,fossil (73.6)	C_2H_6 (29.2)
Acidification Potential	air/NOx (91.1)	air/NOx (72.5)	air/NOx (76.3)	air/NOx (89.7)	air/NOx (91.1)	air/NOx (69.9)
Eutrophication Potential	air/NOx (93.5)	air/NOx (87.5)	air/NOx (92.5)	air/NOx (97.2)	air/NOx (97.6)	air/NOx (88.2)

Table S10 The Main Drivers (Processes) for the Impact Categories for WtE Systems, DGBs and Grid Electricity (in 10%)

Impact Category	AD	Incineration	Gasification	LGTE	DBGs	Grid Electricity
Abiotic Depletion Potential (Fossil Fuels)	Diesel Consumption (89.4)	Diesel Consumption (79.4)	Electricity Consumption (57.7)	Diesel Consumption (59.4)	Diesel Consumption (100)	Electricity Generation (100)
Global Warming Potential	AD Process (91.3)	Incineration Process (72.5)	Gasification Process (53)	LFGTE Process (94.7)	Electricity Generation (100)	Electricity Generation (100)
Human Toxicity Potential	AD Process (58.8)	Diesel Consumption (77.3)	Diesel Consumption (37.3)	Diesel Consumption (45.1)	Diesel Consumption (60.5)	Electricity Generation (100)
Photochemical Oxidation Potential	AD Process (93.6)	Diesel Consumption (48.8)	Diesel Consumption (38.3)	LFGTE Process (96.1)	Electricity Generation (70.9)	Electricity Generation (100)
Acidification Potential	AD Process (87)	Incineration Process (61.1)	Gasification Process (55.1)	LFGTE Process (84)	Diesel Combustion (89)	Electricity Generation (100)
Eutrophication Potential	AD Process (92.9)	Incineration Process (74.5)	Gasification Process (66.8)	LFGTE Process (91.1)	Electricity Generation (95.4)	Electricity Generation (100)

S7 Calculation of Total Electricity Supply for Abuja and Lagos

The results of the additional electricity from AD and total electricity for Abuja and Lagos with as the baseline year 2022 are calculated using the equations (15-17) below:

$$\textit{Additional Electricity from AD (kWh)} = \textit{Electricity from AD (kWh/t)} \times \textit{Amount of Waste (t)} \quad (15)$$

$$\textit{Additional Electricity from AD (MWh)} = \frac{\textit{Electricity from AD (kWh)}}{1000} \quad (16)$$

$$\textit{Additional Electricity from AD (MW)} = \frac{\textit{Electricity from AD (MWh)}}{8760h} \quad (17)$$

Table S11. The Electricity generated from 10% variation in conversion efficiency of WtE systems for Abuja and Lagos.

Electricity Generated (kWh/t)	Abuja	Lagos
Anaerobic Digestion	734	751
Incineration	485	603
Gasification	703	688
Landfill Gas to Energy	149	174

Table S12. The Additional Electricity from AD to Grid electricity and the Percentage Increase.

	Input Data		
	Grid Electricity Supply (MW)	**Amount of Waste (Tonnes)**	**Additional Electricity Supply from AD (kWh/t)**
Abuja	229	156881.8	667
Lagos	300	744072.4	683
Nigeria	4000	32000000	1350

	Output Data			
	Additional Electricity Supply from AD (kWh)	**Additional Electricity Supply from AD (MW)**	**Total Electricity Supply (MW)**	**Percentage Increase (%)**
Abuja	104640153.1	12	241	5.2
Lagos	744072.4	58	358	19
Nigeria	43200000000	932	4932	23.3

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