In many African countries, access to electricity and modern cooking fuels is still a challenge for both residential and commercial activities. Households in sub-Saharan Africa (SSA) form the majority of over 2.7 billion people globally that rely predominantly on traditional biomass as cooking fuel [1]. With regards to electricity, only 38% of the population had access in 2014 [2]. There are vast opportunities for African countries to expand access to energy using indigenous renewable energy resources, following the growing global trend. In 2016, modern renewable energy is said to have supplied a 10.4% share of global total final energy consumption, with traditional biomass supplying 7.8% [3]. The modern renewable energy share included energy generated from biomass fuels, such as solid biomass and biogas for electricity and heat generation using modern technologies. The biogas component is produced through anaerobic digestion using feedstock sources such as livestock manure, agro-industrial residues and landfills [4]. Compared with photovoltaics and wind energy, biogas can be stored and used on demand, providing an opportunity for use as a base load [5].

In Asia and Africa, biogas installations are mainly family-sized plants [6] which generate biogas for use at the household level, though there is increasing effort in China and India to install larger

plants for electricity and heat applications. In Europe and the Americas, however, biogas installations have been restricted to large-scale plants, providing heat and electricity to municipal or national grids, with several MW scale installations. In Europe, some of the biogas produced is upgraded and fed into the natural gas grid or used as transport fuel [7]. Family-sized biogas plants are often used as cooking fuel substituting fuelwood and dung [8,9], whereas large-scale commercial biogas plants, managed by private or public-private partnerships, aim to meet internal energy needs for processing/manufacturing or yield financial benefits by selling electricity and/or heat [10]. Biogas production from agricultural residues, industrial and municipal waste/wastewater is an attractive option also in developing countries. Unlike liquid biofuels, biogas produced from the sources mentioned above does not compete with food crops for land, water and fertilisers [11], and can help improve sanitation and organic waste management at the household, community and industrial level [12].

Jiang et al. [13] report of surveys indicating that medium and large-scale biogas plants provide more benefits to the user and society than household biogas digesters. The cost per unit of gas produced is lower due to economies of scale, and the use of advanced technologies could increase financial returns [13]. Among the key benefits are job creation and improvement in technical skills, reduced fuel import leading to improved energy security, improved sanitation, improved waste and wastewater management, and reduced risk of deforestation and land degradation [12].

Feedstocks for large-scale biogas plants originate from a wide range of activities and industries such as sewage, food waste, crop waste, livestock waste, municipal solid waste (MSW), agriculture waste and agro-processing residue. Several studies point to a high potential for these resources globally and in many countries [14–21], with most of the resources directly correlating with increased population and industrial expansion. The use of some of these resources as biogas feedstock engenders multiple benefits. For example, releasing untreated municipal and industrial wastewater into the environment leads to pollution of rivers and other water bodies [22–25]. Dumping solid waste and manure in landfills is not only expensive but also leads to the emission of greenhouse gases (GHGs) into the atmosphere [26]. Biogas technologies can assist in improving the environmental management of solid and liquid waste from municipal and agro-processing facilities [27].

Notwithstanding the potential for large-scale biogas systems in Africa, its development is still emergent. Potential target users of large-scale biogas technology in Africa could be; crop and livestock farmers, small to medium and large food processing industries, wastewater and excreta management (sanitation) institutions and municipalities, and solid waste management municipalities [28]. The list also includes schools, universities, hospitals and commercial buildings. Other countries have used commercial biogas facilities for many years and gained much experience in the sector. There is an opportunity for African countries to learn from these countries in order to adopt large-scale biogas technology [11].

Africa is one of the regions with high potentials in biogas production, though it has achieved little in developing the sector. While the continent has made progress in small-scale or household

biogas systems [30–35], commercial bio-digesters are still in their infancy [27]. Several national and regional studies have been conducted on the potential of biogas in Africa, ranging from technical issues to economic and policy analysis. Studies conducted in South Africa, the country with the largest installed electricity generation capacity in Africa, noted that although about 700 biogas plants had been installed in the country, only 300 may have been in operation as of 2107 [26,36]. Of the number under operation, about 90% are household systems. The rest are commercial plants with capacities of between 30 kW and 19 MW (see Table 1), all private initiatives and generating power for internal consumption. Commercial biogas production potential in South Africa is estimated at approximately 118 million cubic meters, based on estimates of feedstock sources from the wineries industry, pig farms, poultry slaughterhouses, and from agricultural and agro-processing waste, with electricity generation potential of 148 GWh [26].

Estimates for biogas potential in Nigeria, the most populous country in Africa, is 6.8 million cubic meters per day from animal manure [37] and 913,440 tonnes of methane from MSW, equivalent to 482 MW of electricity [38]. Furthermore, Giwa et al. [39] estimated that up to 171 TJ of energy could be generated from biogas by 2030 in Nigeria. In Kenya, a 2.2 MW commercial biogas plant inaugurated in 2017 is reportedly the largest grid-connected biogas power plant in Africa [40], selling surplus power to the grid at $0.10 per kWh. The biogas plant, located in Naivasha, about 76 km from Nairobi, is operated by Bio-joule Kenya, an independent power producer. About 0.2 MW of the electricity produced is used internally, and the 2 MW surplus is fed into the grid to meet the power needs of close to 6000 rural homes. Table 1 shows other smaller commercial biogas plants installed in Kenya. Estimates of electricity generation potential from agro-industrial waste and wastewater in Kenya using biogas technology is estimated at 624 GWh [26]. Bio-waste from maize, cotton, barley, sugarcane and tea residues have biogas potential of about 3284 million m3 of CH4, with the gross annual electrical energy potential of 3.92 TWh [41]. Other notable studies that have assessed the potential and viability of commercial biogas technology in Kenya include Hamid and Blanchard [42] and Kiplagat et al. [43].

Commercial biogas plants in Ghana include a 2000 m3 oil palm waste digester and a 900 m3 fruit waste digester which process wastes from an oil palm mill and a fruit processing company respectively. The only grid-connected biogas plant in the country, a 100 kWe plant treating human faecal matter and market organic waste, began feeding electricity into the national grid in September 2016. Studies on biogas potentials have been conducted in Ghana, where a plethora of resources exist for biogas production [44]. The technical potential of biogas generation from crop residues, forestry residue, animal manure and municipal waste is estimated at 2700 Mm3/year [45]. There is considerable potential for biogas generation from MSW, particularly for cities where 600−800 tonnes of waste is generated daily [46]. Ofori-Boateng et al. [47] estimates that biogas technology can be used to produce 1–1.5 GWh electricity/year from MSW. The German Development Agency (GIZ) [48] estimates biogas production potential capacity from oil palm processing waste in Ghana as 11,755 m3 CH4/h (equivalent to 37–45 MWe), fruit processing waste as 1.6–2.7 MWe, cocoa processing waste as 2.0–2.4 MWe, and livestock waste as 7.4–9.1 MWe. Furthermore, Arthur and Glover [49] estimate electricity generation potential from palm oil mill effluent to be more than 300 GWh of electricity per year.

In Zambia, Shane and Gheewala [50] estimate about 1.473 × 109 m3 biogas from animal dung and 1.819 × 109 m3 from crop residues. A study in Cameroon showed good prospects for biogas use as fuel for rural electrification, in a hybrid configuration combining biogas with photovoltaic, wind and pumped hydro [51]. Studies on biogas potential have been done in several other African countries. Net energy potential based on estimated feedstocks available for anaerobic digestion in sub-Saharan Africa shows high potential for West and East Africa [27]. Table 1 shows some commercial biogas systems that are in operation in Africa. Except for South Africa, there is very little in the scientific literature with regards to the technologies deployed for commercial biogas systems in Africa. In South Africa, technologies used are the lagoon, plug low, and up-flow sludge blanket (UASB) [36]. There have been recent efforts to upgrade biogas in South Africa. A waste-to-energy plant opened in Athlone, near Cape Town will process up to 600 tonnes/day of Wet Trade Waste, Pure Organic Waste and Municipal Solid Waste to produce organic fertiliser, compressed biomethane, liquid carbon dioxide (CO2), recyclables and refuse-derived fuel. The biogas produced will be upgraded using Pentair Haffmans’ Advanced Plus biogas upgrading system that combines advanced membrane and cryogenic technology to split the gas into high-purity biomethane (95.5%) and liquid CO2. The biomethane will be compressed and distributed as an alternative to LPG or diesel and the CO2 liquefied and stored for the agricultural and wastewater treatment sectors [52].