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Review

A Review of Commercial Biogas Systems and Lessons for Africa

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Abstract: Many African countries have vast biomass resources that could serve as feedstock for methane production through the adoption of commercial biogas plants. However, due to many inhibiting factors, these resources are under-utilised. This article reviews commercial biogas systems that treat organic waste from municipalities, large livestock farms, large plantations/crop farms, food/beverage production facilities, and other industries, to identify essential lessons which African countries could use to develop/disseminate such biogas systems. The review identified the critical barriers to commercial biogas development to be high initial capital costs, weak environmental policies, poor institutional framework, poor infrastructure and a general lack of willpower to implement renewable energy policies and set challenging targets. In African countries where feed-in-tariffs, quota obligations and competitive bidding programmes have been instituted, implementation has been poor, and most state-owned utilities have been unsupportive. Using knowledge from more experienced countries such as Germany and China, some key lessons have were identified. Among the key lessons is the need to institute and enforce environmental management policies to ensure that waste from medium and large livestock farms and industries are not disposed of indiscriminately, a tool China has recently used to promote commercial biogas plants to a high degree of success.

Keywords: anaerobic digestion; commercial biogas systems; bioenergy; electricity; Africa

1. Introduction

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].

This article, therefore, reviews commercial biogas systems with the aim of identifying the lessons that Africa could learn to facilitate the development/dissemination of such biogas systems. In the context of this review, commercial biogas systems are based on the definition of Rupf et al. [27], as "large-scale systems that treat organic waste from municipalities, large livestock farms, large plantations/crop farms, food/beverage production facilities, and other industries with significant quantities of organic waste". The emphasis is on biogas plants focussing on larger-scale, farm based and commercial, electricity and heat systems [29], and not domestic-scale digesters that are used to provide fuel for cooking in developing countries. The review is not restricted to large systems that only sell power and heat to the grid, but also those that provide electricity and heat for internal consumption within their premises, and which may or may not be selling excess heat and power.

The study used a systematic search of published literature to identify relevant articles that deal with ongoing biogas programmes and statistics in Africa and other regions, best practices in commercial biogas systems, biogas potential in Africa, and some of the critical barriers hindering progress in the African region. Key databases consulted include Google Scholar, Scopus, Science Direct and SpringerLink. Literature related to biogas and supporting policies from government portals was also reviewed. As much as practicable, literature published in the last three years was selected. However, where necessary, and for the sake of emphasis on historical perspectives, literature more than three years old was consulted. While the scope of the review is limted to commercial biogas systems, there were instances where for the sake of emphasis, especially in the case of China and India, efforts made to promote family-sized biogas plants are briefly captured.

2. Overview of Commercial Biogas Systems in Africa and Barriers to Dissemination

2.1. Overview of Large Biogas Systems in Africa

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 m^3 of CH_4, 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 m^3 oil palm waste digester and a 900 m^3 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 Mm^3/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 m^3

CH_4/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 1.473×10^9 m^3 biogas from animal dung and 1.819×10^9 m^3 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 (CO_2), 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 CO_2. The biomethane will be compressed and distributed as an alternative to LPG or diesel and the CO_2 liquefied and stored for the agricultural and wastewater treatment sectors [52].

Table 1. Example of commercial Biogas digesters in some African Countries [36,53].

Area	Developer or Biomass Source	Capacity (MW)	Country
Alice	University of Port Hare	0.2	South Africa
Athlone	Clean Energy Africa and Wastemart	4.0	South Africa
Bredasdorp	iBert	0.10	South Africa
Cavalter	iBert	0.50	South Africa
Cavalter	EnviroServ/Chloorkop LFG Cullinan	0.19	South Africa
Darling Uilenkraal	Uilenkraal dairy farm	0.60	South Africa
Durban	Bisasar road LFG	6.00	South Africa
Durban	Marrianhill LFG	1.50	South Africa
Grabouw	Elgin Fruit and Juices	0.50	South Africa
Jan Kempdorp	iBert	0.135	South Africa
Jan Kempdorp	Jacobsdale	0.15	South Africa
Johannesburg	WEC Projects/Northern Waste Water Treatment Works	1.20	South Africa
Johannesburg	Robinson Deep	19.00	South Africa
Klipheuwel	Farmsecure	0.60–0.70	South Africa
Mossel Bay	Biotherm Energy	4.20	South Africa
Paarl	Drakenstein municipality	14.00	South Africa
Pretoria	Bio2watt/Bronkhorst-Spruit	4.60	South Africa
Riverdale	iBert	0.10	South Africa
Riverdale	Robertson	0.15	South Africa
Springs	BiogasSA/Morgan Springs Abattoir	0.40	South Africa
Springs	Selectra	0.50	South Africa
Springs	Selectra	1.00	South Africa
Springs	Selectra	1.00	South Africa
Chaka	Afrisol	0.060	Kenya
Dagoretti	Slaughterhouse waste	0.030	Kenya
Isinya	P. J. Dave Flower Farms Ltd (PPP)	0.10	Kenya
Keekonyoike	Slaughterhouse waste	0.020	Kenya
Kericho	James Finlay Ltd	0.160	Kenya
Kilifi	Pine Power Ltd	0.150	Kenya
Naivasha	Bio-joule Kenya	2.20	Kenya
Sagana	Oilvado Company Ltd	0.340	Kenya
Simbi Roses	Ereka Holdings Ltd (PPP)	0.055	Kenya
Adeiso	Assorted fruit waste and poultry manure	0.90	Ghana
Ashaiman	Market and faecal waste	0.10	Ghana
Kwae	Oil palm waste	2.00	Ghana

PPP—Public-Private Partnership collaboration with the Ministry of Energy; LFG—Landfill gas.

2.2. Support for Commercial Biogas Systems

Over the years, some support policies have been put in place for general renewable energy development in African countries. The support policies include renewable energy targets, feed-in-tariffs (FiTs), utility quota obligations, tendering, and fiscal incentives [3]. According to the Renewables Global Status Report for 2018 [3], most African countries have some form of renewable energy target in place, either for energy, or power. Of the fifty-six (56) countries in Africa, only eleven (11) do not have any form of renewable energy targets in place. However, with regards to regulatory policies and incentives, many African countries fall short. Only ten (10) countries have FiTs or premium payment for renewable energy projects; nineteen (19) countries either have policies on tendering or at least held a tender in 2017, while twenty-three (23) countries do not have any policy or fiscal incentive support for renewables at all.

The government of South Africa first introduced a FiT scheme for renewable energy projects in 2009, but the state electricity utility and the treasury opposed this as they feared additional cost to the consumer [54]. It was rep laced by a competitive tender or auction-based-tariff (ABT) system in 2011 under the Renewable Energy Independent Power Producers Procurement Programme [55]. South Africa supports commercial biogas plants with grants. For example, the funding for one of South Africa's prominent commercial biogas facilities, the 4.6 MW developed by Bio2watt/Bronkhorst-Spruit (listed in Table 1) came from 24% equity, 11% Department of Trade and Industry (DTI) grant and 65% loan from the Industrial Development Corporation [56].

Ghana uses a mix of policies, including grid access, FiTs, competitive bidding, and Renewable Energy Purchase Obligation to promote renewable energy development, including electricity from biogas plants [46,57,58]. The Ghana Renewable Energy Act states explicitly that "an operator of a transmission or distribution system shall connect a generator of electricity from a renewable energy source within the coverage area of the transmission or distribution system where a generator of electricity from renewable energy sources so request" [59]. The Nigerian Renewable Energy Master Plan aims for 100 MW electricity generation capacity from biomass by 2030, with expected contribution from other renewables [37]. Under Nigeria's "Regulations on feed-in tariff for renewable energy sourced electricity in Nigeria" [60], the off-taker is obliged to connect to accredited plants generating electricity from eligible renewable energy sources that are within the capacity limits set by the Renewable Energy Master Plan.

Notwithstanding these policies and fiscal incentives granted by laws and regulatory documents in some of the countries, progress in the deployment of renewable energy technologies in general, and commercial biogas plants in particular, have been abysmal.

3. Barriers to Commercial Biogas Dissemination in Africa

Commercial biogas plants have enjoyed very little success in the African region. Barriers that hinder the adoption of biogas plants in Africa, mainly family-sized plants, have been discussed extensively in the literature [12,28,61]. Commercial biogas systems may have a unique set of barriers, compared to family-sized systems. Among the critical barriers, in the African context, are poor institutional framework and infrastructure, weak environmental policies, inadequate planning policies, non-implementation of the existing policies, and lack of coordination and linkages in biogas programmes. Other barriers are price distortions that have placed renewable energy at a disadvantage, high initial capital costs, weak dissemination strategies, lack of skilled human resources, and weak maintenance and after-sales services [1,12,28]. This section will discuss barriers to commercial biogas adoption in Africa under four main sub-headings: financial and economic barriers, technical and infrastructural barriers, regulatory and institutional barriers, and market barriers.

3.1. Financial and Economic Barriers

Financing is at the heart of the many challenges faced by energy and other infrastructural projects in Africa. Admittedly, commercial biogas plants are expensive, and for many livestock farmers, agro-industrial complexes and large institutions that are already struggling to finance their operations, investing into biogas plants as a waste management option is often out of the question, especially in areas where environmental policies are hardly enforced. The economy of a biogas plant consists of large investments costs and some operation and maintenance cost [28]. The initial investment cost is especially the major bottleneck to the adoption of commercial biogas technology in Africa [62,63]. Central Bank policy rates range from 14 to 17% in African countries such as Ghana, Egypt, Angola, Sierra Leone, Malawi, Mozambique and Nigeria [64,65]. This has resulted in high lending rates, which makes long-term financing options very expensive and often inaccessible, affecting the economic viability of biogas projects [66] and an entry barrier for private developers [67]. Most financial institutions are reluctant to provide financial packages because of the high risks and experiences of low recovery [10]. Government support in the form of guarantees to project developers has not been encouraging. Ghana's Ministry of Energy, for example, has indicated its reluctance to provide government guarantees in support of renewable power projects [46], leaving projects stranded. Additional barriers arise in the financing of biogas systems due to the scattered efforts initiated by investors, governments, local agencies, and policy-makers. [68]. In some countries where FiTs are in place, it has been challenging for project developers to sign Power Purchase Agreements (PPAs) with the utilities, which are in many instances, state-owned.

3.2. Technical and Infrastructural Barriers

Whereas there is a fair technical experience with family-sized biogas systems on the African continent, there is little experience in commercial systems. Commercial biogas systems are larger and more complex, requiring higher skills and expertise in their conception, design, construction and management. Technical and infrastructural challenges start with feedstock supply. The inadequate transportation infrastructure in some communities increases disruption risk of feedstock supply chains, especially in areas where feedstock is not all available at the power plant [69]. Where biogas technology has been tested, there are reports of setbacks, partly attributed to the failure of governments to support the technology through a focused energy policy, lack of information regarding its economic viability, poor designs and construction of digesters, wrong operation and lack of maintenance by users [70]. According to Gebreegziabher et al. [71], the extent to which users understand the technology is essential, and this is often lacking, leading to a situation where technical challenges are difficult to resolve, affecting the maintenance and sustainability of installed units.

Technical capacity for the construction and maintenance of commercial biogas plants is lacking in many developing countries in general, though the impact may be country specific [12,72]. The successful systems reported in South Africa, Kenya, and Ghana have depended on foreign engineering and construction companies [56], a scenario that has cost implications, as foreign labour imported to Africa is often more expensive than local labour. A study by Mukumba et al. [73] noted that there is little biogas technology education at the different educational levels on the continent.

One of the very critical infrastructural barriers is the issue of poor grid network in many African countries, which poses challenges even to existing power plants [57]. Grid infrastructure is not robust enough in some parts of the continent, and that affects their capability to grant grid access to renewable energy power plants in general. This has been reported in many countries, including Ghana [46], Kenya [66], Nigeria [74], Zambia [75] and Uganda [76].

3.3. Regulatory and Institutional Barriers

Establishing commercial biogas plants in a country or region requires organisational capability and initiative. According to Okello et al. [77], countries that have strong institutional support to biogas programmes have registered significant success in promoting the technology. Where renewable energy policies are in place in Africa, there is often a general lack of coherent strategy in place to promote commercial biogas technology [28,62]. A 300 kW MSW-to-energy plant (Taka Gas Project in Dar es Salaam, Tanzania) that underwent vigorous planning and was supposed to generate 7.08 MWh/d of electricity from 2368 m^3 of methane per day [78] failed to take off due to what Parawira [28] describe as 'bureaucracy'. The institutional structures failed to come to a consensus on the actual direction for the project, whose main aim was to produce biogas from MSW and serve as a model for other urban areas in Africa [28]. There is a reported general lack of coordination and linkup among important institutions such as local and central governments agencies, research institutions and business institutions [68].

As the case has been in South Africa, the monopolistic nature of the utility was enough to kill the FiT scheme, instead, introducing a bidding system where they had control. Unfortunately, the bidding process was expensive and complicated "with the cost to the developer being in the region of $2 million per bid, depending on the size of the contract, with the bulk of the fees due to legal costs and raising of the bid bond" [37]. For example, the 4.6 MW Bio2watt/Bronkhorst-Spruit biogas plant in South Africa encountered a problem during its development due to the tedious steps it had to take to comply with rigid environmental legislation before construction could commence, spending approximately 8 million Rand (US$ 0.8 million) in legal costs for about 7 years [56]. Notwithstanding the progress made by South Africa in the development of commercial biogas systems, legislation in the country did not permit this plant, which is grid connected, feeding surplus electricity back into the grid [56].

In Ghana, it has been reported that project developers must obtain up to eleven licenses, approvals, agreements and clearances from different institutions, with each increasing transaction costs and opening up the system for corrupt practices [66].

3.4. Market and Awareness Barriers

Among the major obstacles to the uptake of commercial biogas plants in Africa is a lack of cognisance on the viability of biogas as a source of electrical energy and/or heat production as well as sustainable waste management method [26]. Many crop and livestock farmers, as well as processing companies, are not informed about the opportunities offered by biogas technology as a dual "fuel production and waste management technology" [79]. This barrier cuts across several African countries. Electricity generated from biogas plants must compete with low-priced (often subsidised) electricity from thermal plants and other sources. Even with free substrates in most instances, biogas technology for electricity generation is expensive, especially in countries where technology is imported. Most analyses, and indeed FiTs published by governments (e.g., that of Ghana), show that other renewable sources like solar, hydro and wind are cheaper than anaerobic digestion based power generation [10,57]. FiTs have almost always been more expensive than existing electricity tariffs, and this is the main reason why South Africa's electricity utility kicked against the FiT scheme in South Africa, instead opting for competitive bidding. Poor performing public utilities in African countries such as Ghana, Zambia, Tanzania, Kenya and Niger [80], are not creditworthy, and there are too many risks engaging with them on PPAs [66]. Also, not all governments are willing to provide the needed guarantees to private investors [46].

4. Overview of Successful Commercial Biogas Programmes

4.1. Global Overview

There are currently more than 35 million biogas installations across the globe, though the majority comprises of family-sized installations in India and China [81], with commercial-scale plants mostly in Europe and North America (see Figure 1). Biogas production in Europe reached 14,120 toe in 2016 from about 7934 toe in 2009, boosted primarily by the development of favourable conditions for electricity production from biogas, such as FiTs in Germany, the obligation certification for energy renewability in the UK, and the tax policy (i.e., economic exemptions) in Sweden [82]. European countries derive their motivation from the EU legislation, which set a target of 20% renewable energy contribution by the year 2020 [83], and also to meet the organic waste management directive [68]. In some of the developed countries, for example, Denmark, Germany, the United States and Sweden, advanced technologies have been employed to upgrade biogas into advanced fuels. The process is carried out either in-situ, which involves the injection of hydrogen inside the digester, or ex-situ with hydrogen injection in a separate reactor [84]. A compilation by the United Nations Industrial Development Organisation [52] provides examples of biogas plants that have advanced upgrading technologies, including one plant in South Africa. Subsequent sub-sections will review biogas programmes in selected countries, including Germany, China, and India.

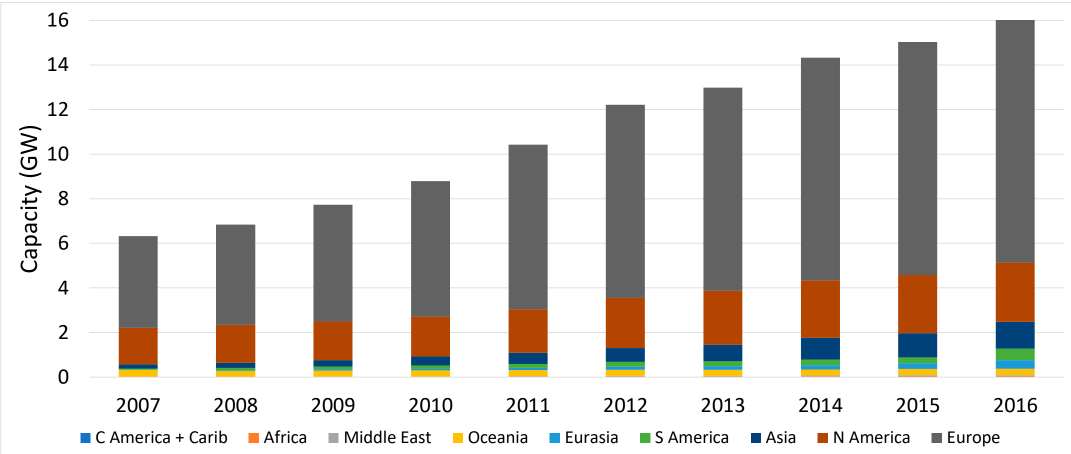

Figure 1. Global installed biogas plant capacity between 2007 and 2016 [85].

4.2. Germany

Germany is the leader of biogas production in Europe, helped by a number of support measures. As shown in Figure 2, there are more than 8000 biogas plants currently in operation in Germany, with total electricity generation capacity of approximately 5 GW as of 2016 [26,85]. Biogas production in Germany is done mostly using small to medium-scale anaerobic digesters, with an average installed capacity of about 500 kWe [86].

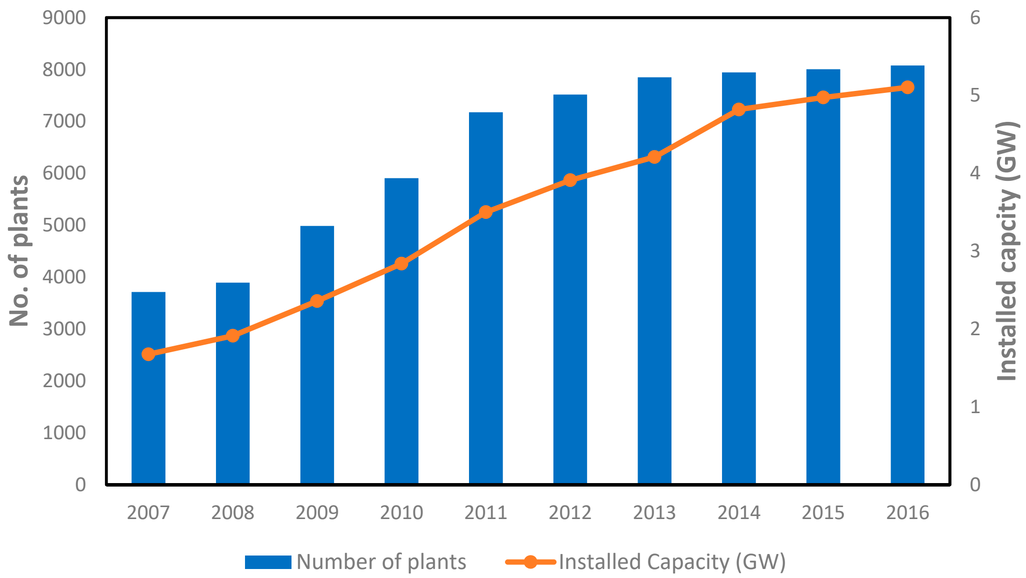

Figure 2. Details of biogas plants in Germany at the end of 2016 [85,87].

The biogas industry in Germany is supported by various policy instruments. The Renewable Energy Sources Act (EEG), which has undergone several revisions since it was first adopted close to three decades ago, outlines the critical support measures. First, there was the "Act on Feed-In of Electricity" in 1991, which set the pace for the development of biogas in Germany [88]. This metamorphosed into the Renewable Energy Sources Act of 2000 (or EEG 2000), which provided the following benefits to renewable energy developers: right of grid connection, obligation on the part of grid operators for preferential purchase, and a guaranteed minimum FiT [86]. An amendment to the Act in 2014 (EEG 2014), limited the annual expansion of biogas plant capacity to 100 MWe. The latest version, adopted in July 2017 (EEG 2017), raised the annual expansion celling to 150 MWe until 2019, and 200 MWe from 2020 onwards [89]. The 2017 version of the EEG also changed from a fixed tariff to a tender system, in response to market trends. However, biowaste digestion plants and smaller manure plants up to 75 kW_e capacity can be built outside the tenders. Also, installations with a maximum capacity of 150 kW_e may decide to either use the FiT scheme or take part in tenders.

4.3. China

Asia in general, and China in particular, is one of the pioneer developers of biogas technology but efforts in China have in the past focussed mainly on household biogas systems [90,91]. Data from Chen et al. [92] indicates that by the close of 2015, there were 111,000 commercial biogas plants in China, of which 103,898 were medium- to small-scale plants, 6737 were large-scale plants, 34 were super-large plants, and 306 were industrial waste biogas projects. Commercial biogas plants, in addition to other biomass power plants, has made China the world's largest bioelectricity producer, with an installed capacity of 14.9 GW and generation of 79.4 TWh in 2017 [3]. This compares to total grid-connected electricity generation installed capacity in sub-Saharan Africa of 36 GW (excluding South Africa) in 2013 [93].

Like Germany, China's biogas development programme is supported by a set of energy and environmental policies, as well as economic policies, laws, and the development of standards [92]. The energy policies include the Rural Biogas Projects and the 12th Five-Year Plan for Bioenergy Development (2011–2015). The laws include the Agricultural Law and the Renewable Energy Law released in 2005 (and the revised version of 2009). The 2009 revised Renewable Energy Law stipulated a full support system for power generated by renewable energy. Among the economic policies were financial support and interest-free loans for both small, medium and large biogas plants, with supports of 20,000 CNY or approximately US$ 2937 (at 1 US$ = 6.81 CNY; www.xe.com, 24 July 2018) per 100 m^3 of large- and medium-scale [92]. After 2009, the subsidy programme was enhanced, with the central government covering 25% to 45% of the total cost of biogas projects, and setting up policies similar to FiTs [94]. This consisted of a state special fund and additional renewable energy surcharge of 0.002 CNY per kWh in the sale price of power, which is used to provide a premium price for power from renewable energy generally.

4.4. India

The first anaerobic digestion plant in Bombay, India in 1859 is said to have generated biogas from a treatment facility and used for lighting streets [4]. In the 1970s, India started programmes to promote biogas in the country. Sensing the need to valorise agriculture waste, animal manure and other biomass sources, India started programmes such as the National Biogas and Manure Management Program and Off-grid Biogas Power Generation Program for providing renewable energy for cooking and lighting [95]. At the end of 2017, about 300 MW capacity of commercial biogas production has been installed in India.

Even though less successful than the Chinese biogas programme, the Indian government has provided much support to the biogas industry in India. A Ministry of New and Renewable Energy has been created to oversee biogas and other renewable energy investment programmes. The Ministry has initiated some programmes and policies, as well as instituted subsidy programmes. The National

Biogas and Manure Management Program was also initiated to tackle sub-programmes such as the "Biogas-Based Distributed/Grid Power Generation Programme", "Recovery of Energy from Industrial Wastes" and "Recovery of Energy from Urban Wastes" [1]. Incentives have been provided for the setting up of community-scale biogas plants. The Railway Company in India is currently experimenting with bio-based fuels, including biogas, on its networks [3].

4.5. Other Countries

Other major commercial biogas promotion countries include Italy, the United Kingdom, and the United States. Italy is the second largest biogas producer in Europe, with more than 1300 biogas plants and electricity generation of over 8 GWh [96]. The proliferation of biogas plants in Italy was helped in part by a high feed-in-tariff of €0.28/kWh for plants with a capacity of less than 1 MW for 20 year duration [97]. A new feed-in-tariff instituted in 2012 varies based on the kind of substrate, the installed power, the use of heat and the technology used, with an overall aim to favour small sized plants (<500 kW) using animal and agricultural waste [97]. The United Kingdom (UK) is another notable producer and user of biogas in Europe. Installed bioelectricity capacity in the UK reached 6 GW in 2017, with electricity generation of 31.8 TWh, from a combination of solid biomass fuels, anaerobic digestion and MSW [3]. At the lower end, countries with moderate biogas production in Europe include Denmark, Czech Republic, Bulgaria and Austria. Denmark is very experienced in the use of commercial biogas facilities and has been promoting technologies for treating co-digested manure, clean organic industrial wastes and source-separated municipal solid waste (MSW) for decades. Denmark uses "Green Pricing", a policy tool that provides incentives for manufacturers that use biogas to generate electricity, to promote the use of biogas [98]. The Czech Republic has a subsidy system to support the construction of agricultural biogas plants that process purpose-grown crops [99]. Bulgaria promotes biogas plants using the "credit line for energy efficiency and renewable energy sources for Bulgaria", in which projects can receive up to 20% grants [79]. Austria introduced a green electricity act and feed-in-tariff in 2002 increasing installed capacity of biogas from 15 MW at the beginning of 2002 to about 80 MW by the end of 2015 [100]. The feed-in-tariff varies, based on the capacity and technology of the plant and origin of the biogas, such as sewage gas or landfill gas [101]. In 2013, Swedish biogas production reached 1.7 TWh, with the production sources being wastewater treatment plants (40%), co-digestion plants (34%), landfill gas valorization (14%), industrial waste treatment plants (7%), and farm-scale plants (5%) [102]. Over 50% of this is upgraded and used in vehicles [102], making Sweden the world leader in the use of biogas for transportation.

Besides China and India, other Asian countries that have been promoting biogas systems include Nepal, Bangladesh, Vietnam, and Thailand. As of 2013, Vietnam had constructed more than 1 million biogas digesters, which includes 500,000 medium scale plants and 150,000 industrial plants treating industrial wastewater [1]. A policy directive launched by the Government of Thailand calls for an increase in local electricity generation from biogas from 120 MW in 2011 to 600 MW by 2021 [103]. Efforts in Japan to boost industrial biogas plants have been reported [104].

In the Americas, The United States and Brazil are among the prominent biogas developers in the region. The American Biogas Council [105] reports that there are more than 2100 operational biogas systems in the United States as of 2016, with more than 11,000 prospective sites. Biomethane potential from livestock alone is estimated at 5,128,334.6 million gallons per year, which is equivalent to 4360.41 million gallons of diesel or 4883.29 million gallons of gasoline [106]. The United States Federal and State Governments provide tax incentives, grants, performance-based incentives, soft loans, among others, for commercial biogas projects. A few examples include: tax credits worth $0.015 per kWh for ten years in Iowa; Oregon and Pennsylvania provide grants to agricultural plants of 25–50% of total project costs; Massachusetts provides grants offer of 75% for the design-phase costs and 25% for the construction-phase costs and six states provide incentives of $0.015 to $0.1 per kWh produced [107].

As of 2017, Brazil operates about 127 commercial biogas plants, fed mainly with livestock manure and municipal waste [81]. Estimates are that about 100 million m^3 methane could be generated daily from livestock manure, agricultural waste, wastewater and municipal waste Brazil [81]. Biomethane potential from livestock alone in Brazil is estimated at 1,961,171.9 million gallons per year, which could replace 1667.42 million gallons of diesel or 1848.34 million gallons of gasoline [106]. Brazil is the largest producer of bioelectricity in South America, with an estimated generation of 49 TWh [3].

4.6. Summary Lessons from Country Reviews

A number of lessons could be drawn from the commercial biogas programmes in the countries reviewed above. Virtually all the countries that have a booming commercial biogas method have one form of support or another for the sector. The support systems include priority grid access for electricity, FiT for electricity, quota schemes, tax reduction for biomethane as a fuel, investment grants, special aids for farm-based biogas from manure, tax exemption from vehicle tax, tax exemption for biomethane application from CO_2 tax and energy tax. Support systems in Germany are dynamic, and evolves with changing market trends, aiming at all times, to create a win-win situation for both the private sector and the federal government. China has drafted policies and laws to guide biogas programmes in different sections of the economy, including rural, agricultural, and industrial sectors. The same situation pertains in India, where there are separate programmes for rural areas, urban waste and industrial waste. Other countries have unique support programmes, such as the green pricing policy in Denmark, preferential FiTs based on plant sizes in Italy and federal/state government grants in the United States. A summary of the countries presented in this section is shown in Table 2.

Table 2. Summary of other countries' capacities and support systems.

Country	Installed Biogas Power Capacity in 2016 (MW) *	Support for Biogas Projects
Austria	194	Feed-in-tariff, which varies based on the capacity, the technology of the plant and origin of the biogas
Brazil	451	Incentives for energy from waste resources
Bulgaria	30	Projects receive up to 20% grant
Czech Republic	369	Subsidy to support construction
Denmark	110	Uses "Green Pricing" to provide incentives for manufacturers that use biogas to generate electricity.
Italy	1387	Fee-in-tariff, which favours smaller plants with less than 500 kW capacity
South Africa	22	Investment incentives
Sweden	2	Vehicle fleet to be independent of fossil fuels by 2030. Methane will be one of the principal fuels
Thailand	435	Increase biogas capacity to 600 MW by 2030
United Kingdom	1667	Feed-in-tariff
United States	2438	The federal government provides tax incentives, grants, performance-based incentives, soft loans. Various state governments provide tax credits and grants.

* Capacity shown is for installed power only. Some of the countries also use a large portion of biogas as a transportation fuel.

5. Lessons for Africa

Africa has been described as "the most powerful future biogas market" [68], but a lot remains to be done if this accolade is to become a reality. Indeed, there is high potential and opportunities to generate electricity from biogas, but Africa has so far failed to utilise these opportunities [63]. While Africa has a lot to learn from countries such as Germany and China where commercial biogas programmes have flourished, it is also important to note that not all such support measures can be wholly lifted and implemented in Africa. Based on the reviews of what we have termed "successful" biogas programmes, important lessons have been grouped under four principal areas: enacting energy and environmental policies; rolling out economic and policies; promoting research and development; and other support schemes.

5.1. Energy and Environmental Policies

The commitment of governments and their ministries/agencies in charge of energy, agriculture, science, technology, environment and local government are of the utmost importance to the promotion of commercial biogas projects on the African continent [108]. Setting up appropriate policy and institutional framework is needed to tackle the barriers hindering the adoption of commercial biogas projects in Africa [109]. These policies, such as FiTs, quota obligations, grid access and competitive bidding programmes, are already instituted in some African countries, but implementation has been poor, and in some cases, repulsive to investors. An example of such is the South African situation, where bidding processes alone cost about two million dollars, should be avoided. Grid access is another critical area of concern for biogas power plants. Ghana and Nigeria are examples of two countries whose laws and regulatory documents grants grid access to "approved or licensed" biogas power plants. However, South Africa may not automatically grant access to the grid, as indicated in earlier sections of this article by findings from a GIZ study [56]. As the case is in Ghana and Nigeria, other African countries that do not currently have grid access must reconsider their positions, especially for power plants that have been licensed or approved by the regulatory authorities.

Enforcement of environmental laws and policies has been a challenge in some countries, including for example Ethiopia, Malawi, Uganda and Tanzania [110,111], often leading to situations where bio-waste is disposed of indiscriminately. Commercial biogas systems can be integrated into the waste management systems, providing both sanitation and energy benefits [112]. They provide a treatment platform for decreasing large amounts of complex organic materials, converting the majority of such molecules into methane and carbon dioxide [113]. As the review has shown, countries/regions with thriving commercial biogas systems have environmental policies and directives that require proper management of bio-waste, which serves to motivate livestock farms and industries that generate bio-waste. In other words, some biogas plants in these countries are constructed in response to stringent environmental management policies. According to Chen et al. [91], China's ambition to control pollution from livestock production facilities led to the establishment of environmental regulations, which resulted in the proliferation of biogas plants for waste management. The principal regulations include: "Discharge Standard of Pollutants for Livestock and Poultry Breeding", "Management Approach for Pollution Prevention of Livestock and Poultry Farms", "Criteria for Evaluating the Environmental Quality of Livestock and Poultry Farm's' and "Technical Specifications for Pollution Treatment Projects of Livestock and Poultry Farms". These regulations recognised biogas technology as an environmentally friendly measure that, in addition to energy production, may contribute to a more efficient and safe recycling of manure to fields or fish ponds [13]. The 2010 revised version of the China Renewable Energy Law provided regulations with a focus on medium and large-scale livestock and poultry breeding farms. A deliberate attempt was made in the Law to promote biogas technology, and regulations were prepared accordingly. To reduce pollution from livestock farms and agro-process industries and provide better solid and liquid waste management, new and stricter regulations must be established in African countries. Anaerobic digestion, producing biogas, is one of only a few biotechnological processes, which utilise such wastes effectively while generating energy [1,114]. It has been used widely in the waste stabilisation process because of the need to treat waste before disposal, and the need to reduce methane emission into the environment [115,116]. A government ban on disposal of MSW to landfills in Germany increased the demand of biogas plants for MSW management [117]. Environmental policies and regulations in Africa should aim to enforce strict waste management rules and promote segregation, especially in the cities, to promote biogas technologies. This should trickle down to environmental objectives and developmental agenda of municipalities, with the mindset to assess biogas technology not only for direct economic benefits but also for broader environmental services [71]. Most important is to enforce such policies and regulations.

In countries where there are energy policies in place, implementation has been slow. Some of the countries, such as South Africa, Nigeria and Ghana and for instance, have drafted (in the case of Ghana) or approved Renewable Energy Masterplans that set targets for commercial biogas systems, but implementation has been slow. While countries such as Germany and China are ahead of their biogas targets, and in fact, Germany is controlling the rate of biogas proliferation in the latest Renewable Energy Act of 2017, African countries tend to ignore their plans and policies. Again, Germany keeps updating policy supports and targets for biogas electricity, in line with local and international trends, and in response to industry concerns. This is something that African countries could quickly adapt. Germany also switches from FiTs to tenders, as and when necessary, to always create a win-win situation for both the state and the private sector. As stated earlier, Denmark uses "Green Pricing", a policy tool that provides an incentive for manufacturers that use biogas to generate electricity [4].

In line with renewable energy, environment, and climate change policies of the European Union and other regions, it may be prudent for the African Union and other regional blocs to make commitments or follow through on targets already in place. The Economic Community of West African States (ECOWAS), for example, has set some impressive targets such as generating 10% of peak electricity load from renewables by 2020 and 19% by 2030 (minus medium and large hydro) [118]. There are similar targets by the Eastern African Countries (EAC) regional bloc. Unfortunately, progress made to date is not encouraging and cast doubts on the continent's ability to achieve these targets, unless the targets are enforced.

5.2. Economic and Financial Policies

As mentioned earlier, one of the most critical barriers to the adoption of commercial biogas plants is the high capital costs. It has been pointed out that without government mandates and favourable economic policies, it is difficult for electricity from commercial biogas plants to be competitive in the electricity market [119]. This is more pronounced in regions where environmental externalities are not associated with the final price of electricity from fossil fuels [10,120], leading to disinterest from the private sector. Due to the immaturity of commercial biogas plants in Africa, economic policies, including subsidies and favourable FiTs are needed to promote them. In a review of the Africa Biogas Partnership Programme, it was noted by Clemens et al. (2018) that none of the partner countries in East Africa has economic policies supporting biogas investment programme. As the case has been in China, financial support from central and state governments are required to bridge the viability gap and make commercial biogas plants viable [5,10]. Chinese government support for commercial biogas plant construction on livestock farms includes special 'interest-free' energy loans [13]. Between 2003 and 2009, Chinese government support to the biogas industry reached 19.0 billion Chinese Yuen (CNY), with approximately 10% going into the construction of commercial plants, and about 8% financing service systems.

A South African study has estimated that an investment subsidy of about 54% is required to make commercial biogas plants viable for piggeries in the country [121]. Many countries have provided financial support to commercial biogas plants through the use of FiTs, tax reliefs, and technology bonus. According to Seghal [1], biomethane plants in the UK enjoy FiTs of GBP 0.71/kWh and in France, EUR 69–125/MWh depending on the plant's production capacity. As shown from the country reviews, Germany uses either a fixed FiT or tender system, depending on the plant capacity, to attract commercial biogas plants. Experience from some of the other countries reviewed shows that there is a need for demand-driven and market-oriented subsidy-led programmes to increase the adoption of commercial biogas plants. Therefore, to motivate the private sector into building commercial biogas plants, African governments must consider the possibility of using monetary incentives through regulated loans or subsidies to bring down production costs [9,39].

According to Meyer [122], financial support is not a permanent issue, and that project costs reduce gradually as more projects become successful. In effect, when there is legislative support through FiTs or tendering arrangements, there is less need for project developers to receive capital aid for installation. Instead, investors become confident enough to invest in projects. Also, the provision of capital for investment goes hand-in-hand with technological support, since the establishment of new technologies needs an initial push to the market [123,124].

Apart from making the right laws, policies and regulations, African governments can provide other forms of support to commercial biogas plants. Many commercial biogas plants producing electricity and heat in European Countries were built due to the strong public support for renewable energies in general [125]. Germany supports biogas proliferation by refusing to tax biogas used as a vehicle fuel [68]. In China, instead of subsidising conventional power, the government rather surcharges them, using the additional funds to support power generation from renewable resources. The higher credit rating of governments can be used to secure low-cost funds on the local and international capital markets, which could be transferred at a relatively lower cost to commercial biogas plant developers [46,126,127]. In some situations, governments may be needed to provide capacity building support, so that private project developers can package projects to assess climate funds and other multilateral grants available to the African region and respective countries.

5.3. Research and Development

Research and development has been at the heart of commercial biogas programmes globally, and African countries cannot progress without doing the same, as part of the lessons it could take from existing biogas programmes elsewhere. In India, a "Biogas Development and Training Centre" has been instituted under the National Biogas and Manure Management Program to implement monitoring of biogas installations. Also in China, the Biogas Institute of the Ministry of Agriculture (BIOMA), a part of the Chinese Academy of Agricultural Sciences (CAAS), focuses on issues like fundamental research on anaerobic microbiology and design of biogas projects [81]. Germany and the Netherlands have emphasised the vital role that research and development has played in shaping their commercial biogas sector. In Italy, the Research Center for Alternative and Renewable Energies has particular research programmes dedicated to biomass and biofuels, with an annual budget of USD 6 million per year [1].

Research support is much less intense in African countries, as governments fail to fund research activities to support their programmes [63]. Where available, it has focussed on low-tech biogas solutions for domestic use [112,128–130]. A study on the subject by Mshandete and Parawira [11] has provided details of research needs and priorities for commercial biogas plants. Where there is research in Africa, there is a lack of coordination. A study in Ethiopia, for instance, found that "despite the existence of various research trials, both at private and institutional levels, they were fragmented and lacked continuity" [61]. Ongoing research must identify, prioritise, and coordinate relevant research activities so that the limited resource available is optimised [11]. The Africa Biogas Partnership Programme must move beyond household biogas systems and additionally venture into promoting commercial biogas programmes across the continent. The Ministries in charge of agriculture, energy, environment, innovation, science and technology, must allocate funding from their budgetary allocations to boost research into commercial biogas systems, and help scale up biogas production from rural systems into those that can provide power and create jobs. Research must also tackle issues with regards to the safety of commercial biogas systems since the industry is nascent in the African region.

5.4. Other Support Schemes

Governments must also come up with proper long-term objectives with appropriate planning and strategies for commercial biogas development on the continent [131,132]. As noted by Parawira [28], "new technologies often need to be nurtured for over decades, before sufficient socio-technical momentum emerges, and alignment between the technical, economic, regulatory and social context can provide the basis for building up momentum until the biogas technology can survive on its own". Government partnerships with the private sector will be crucial for success, as governments take necessary steps to uplift biogas utilisation through existing programmes and facilities, and improve harmonisation and communication between public and private sectors [68].

6. Conclusions and Recommendations

Africa's energy crisis is not due to lack of resources, but the inability to properly harness the resources using appropriate technologies, infrastructure and policy. Organic resources such as crop and animal waste, municipal and industrial wastewater, and municipal solid waste can be harnessed in commercial biogas plants to supplement power supply for internal consumption and excess fed to the grid. The African Union (AU) and the regional blocs have all prioritised or set targets for renewable energy development in separate strategy and policy documents. Renewable energy development is one of the critical areas of the AU's Agenda 2063, the continent's 50-year development agenda. The Economic Community of West African States (ECOWAS) is aiming to supply households with decentralised energy systems by 2030 and has set targets for electricity from biomass. Others such as the East African Community (EAC) and the Southern African Development Corporation (SADC) have targets in place. Commercial biogas plants can supplement solar, wind, hydro and other renewable energy resources towards achieving energy security in Africa and could serve as base loads in areas where the grid has yet to reach.

Like family-type biogas systems, the development of commercial biogas systems will require support from African governments as the case has been in other countries and regions. Successful development and management of commercial biogas systems require not only technical expertise but also serious attention to economic, energy and environmental policies.

Also, the various university and research campuses across the region must intensify research on the subject. Research should deal with the challenges from a multidisciplinary perspective and focus on generating practical evidence to support policy decisions, using case studies to investigate the economic, logistic and technical feasibility of commercial biogas systems. African countries must also promote commercial biogas training and capacity building programmes, and create links between research institutions and potential beneficiary industries.

The private sector will require capacity building in the development of climate-smart projects that can compete on the international financial market. Therefore, public-private partnerships are needed, so that private companies and government agencies can tap into each other's strengths and complement their weaknesses.

Ultimately, sound environmental and sanitation policies and their enforcement are crucial to the success of commercial biogas plants, and also key to ensuring environmental sustainability in African countries.

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References

1. Sehgal, K. Current State and Future Prospects of Global Biogas Industry. In *Biogas*; Biofuel and Biorefinery Technologies; Springer: Cham, Switzerland, 2018; pp. 449–472, ISBN 978-3-319-77334-6.
2. Bos, K.; Chaplin, D.; Mamun, A. Benefits and challenges of expanding grid electricity in Africa: A review of rigorous evidence on household impacts in developing countries. *Energy Sustain. Dev.* **2018**, *44*, 64–77. [CrossRef]
3. Renewable Energy Network of the 21st Century. Renewables 2018 Global Status Report. 2018. Available online: http://www.ren21.net/status-of-renewables/global-status-report/ (accessed on 12 June 2018).

4. Ahammad, S.Z.; Sreekrishnan, T.R. Biogas: An Evolutionary Perspective in the Indian Context. In *Green Fuels Technology*; Green Energy and Technology; Springer: Cham, Switzerland, 2016; pp. 431–443, ISBN 978-3-319-30203-4.
5. Lebuhn, M.; Munk, B.; Effenberger, M. Agricultural biogas production in Germany—From practice to microbiology basics. *Energy Sustain. Soc.* **2014**, *4*, 10. [CrossRef]
6. Cheng, S.; Li, Z.; Mang, H.-P.; Huba, E.-M.; Gao, R.; Wang, X. Development and application of prefabricated biogas digesters in developing countries. *Renew. Sustain. Energy Rev.* **2014**, *34*, 387–400. [CrossRef]
7. Angelidaki, I.; Treu, L.; Tsapekos, P.; Luo, G.; Campanaro, S.; Wenzel, H.; Kougias, P.G. Biogas upgrading and utilization: Current status and perspectives. *Biotechnol. Adv.* **2018**, *36*, 452–466. [CrossRef] [PubMed]
8. Roubík, H.; Mazancová, J.; Le Dinh, P.; Dinh Van, D.; Banout, J.; Roubík, H.; Mazancová, J.; Le Dinh, P.; Dinh Van, D.; Banout, J. Biogas quality across small-scale biogas plants: A case of central Vietnam. *Energies* **2018**, *11*, 1794. [CrossRef]
9. Rajendran, K.; Aslanzadeh, S.; Taherzadeh, M.J.; Rajendran, K.; Aslanzadeh, S.; Taherzadeh, M.J. Household biogas digesters—A review. *Energies* **2012**, *5*, 2911–2942. [CrossRef]
10. Mittal, S.; Ahlgren, E.O.; Shukla, P.R. Barriers to biogas dissemination in India: A review. *Energy Policy* **2018**, *112*, 361–370. [CrossRef]
11. Mshandete, A.M.; Parawira, W. Biogas technology research in selected sub-Saharan African countries—A review. *Afr. J. Biotechnol.* **2009**, *8*, 116–125.
12. Rupf, G.V.; Bahri, P.A.; de Boer, K.; McHenry, M.P. Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal. *Renew. Sustain. Energy Rev.* **2015**, *52*, 468–476. [CrossRef]
13. Jiang, X.; Sommer, S.G.; Christensen, K.V. A review of the biogas industry in China. *Energy Policy* **2011**, *39*, 6073–6081. [CrossRef]
14. Ahmad Dar, R.; Ahmad Dar, E.; Kaur, A.; Gupta Phutela, U. Sweet sorghum-a promising alternative feedstock for biofuel production. *Renew. Sustain. Energy Rev.* **2018**, *82*, 4070–4090. [CrossRef]
15. Zareei, S. Evaluation of biogas potential from livestock manures and rural wastes using GIS in Iran. *Renew. Energy* **2018**, *118*, 351–356. [CrossRef]
16. Namsaraev, Z.B.; Gotovtsev, P.M.; Komova, A.V.; Vasilov, R.G. Current status and potential of bioenergy in the Russian Federation. *Renew. Sustain. Energy Rev.* **2018**, *81*, 625–634. [CrossRef]
17. Tasnim, F.; Iqbal, S.A.; Chowdhury, A.R. Biogas production from anaerobic co-digestion of cow manure with kitchen waste and Water Hyacinth. *Renew. Energy* **2017**, *109*, 434–439. [CrossRef]
18. Wu, Q.; Qiang, T.C.; Zeng, G.; Zhang, H.; Huang, Y.; Wang, Y. Sustainable and renewable energy from biomass wastes in palm oil industry: A case study in Malaysia. *Int. J. Hydrogen Energy* **2017**, *42*, 23871–23877. [CrossRef]
19. Al-Hamamre, Z.; Saidan, M.; Hararah, M.; Rawajfeh, K.; Alkhasawneh, H.E.; Al-Shannag, M. Wastes and biomass materials as sustainable-renewable energy resources for Jordan. *Renew. Sustain. Energy Rev.* **2017**, *67*, 295–314. [CrossRef]
20. Li, K.; Liu, R.; Sun, C. A review of methane production from agricultural residues in China. *Renew. Sustain. Energy Rev.* **2016**, *54*, 857–865. [CrossRef]
21. Biosantech, T.A.S.; Rutz, D.; Janssen, R.; Drosg, B. Biomass resources for biogas production. In *The Biogas Handbook*; Wellinger, A., Murphy, J., Baxter, D., Eds.; Woodhead Publishing Series in Energy; Woodhead Publishing: Cambridge, UK, 2013; pp. 19–51, ISBN 978-0-85709-498-8.
22. Guimarães, C.; Maia, D.; Serra, E. Construction of biodigesters to optimize the production of biogas from anaerobic co-digestion of food waste and sewage. *Energies* **2018**, *11*, 870. [CrossRef]
23. Mor, S.; Ravindra, K.; Dahiya, R.P.; Chandra, A. Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environ. Monit. Assess.* **2006**, *118*, 435–456. [CrossRef] [PubMed]
24. Mantis, I.; Voutsa, D.; Samara, C. Assessment of the environmental hazard from municipal and industrial wastewater treatment sludge by employing chemical and biological methods. *Ecotoxicol. Environ. Saf.* **2005**, *62*, 397–407. [CrossRef] [PubMed]
25. Tatsi, A.A.; Zouboulis, A.I. A field investigation of the quantity and quality of leachate from a municipal solid waste landfill in a Mediterranean climate (Thessaloniki, Greece). *Adv. Environ. Res.* **2002**, *6*, 207–219. [CrossRef]

26. Mugodo, K.; Magama, P.P.; Dhavu, K. Biogas production potential from agricultural and agro-processing waste in South Africa. *Waste Biomass Valoriz.* **2017**, *8*, 2383–2392. [CrossRef]
27. Rupf, G.V.; Bahri, P.A.; de Boer, K.; McHenry, M.P. Broadening the potential of biogas in Sub-Saharan Africa: An assessment of feasible technologies and feedstocks. *Renew. Sustain. Energy Rev.* **2016**, *61*, 556–571. [CrossRef]
28. Parawira, W. Biogas technology in sub-Saharan Africa: Status, prospects and constraints. *Rev. Environ. Sci. Biotechnol.* **2009**, *8*, 187–200. [CrossRef]
29. Scarlat, N.; Dallemand, J.-F.; Fahl, F. Biogas: Developments and perspectives in Europe. *Renew. Energy* **2018**, *129*, 457–472. [CrossRef]
30. Clemens, H.; Bailis, R.; Nyambane, A.; Ndung'u, V. Africa biogas partnership program: A review of clean cooking implementation through market development in East Africa. *Energy Sustain. Dev.* **2018**. [CrossRef]
31. Kinyua, M.N.; Rowse, L.E.; Ergas, S.J. Review of small-scale tubular anaerobic digesters treating livestock waste in the developing world. *Renew. Sustain. Energy Rev.* **2016**, *58*, 896–910. [CrossRef]
32. Kemausuor, F.; Bolwig, S.; Miller, S. Modelling the socio-economic impacts of modern bioenergy in rural communities in Ghana. *Sustain. Energy Technol. Assess.* **2016**, *14*, 9–20. [CrossRef]
33. Orskov, E.R.; Yongabi Anchang, K.; Subedi, M.; Smith, J. Overview of holistic application of biogas for small scale farmers in Sub-Saharan Africa. *Biomass Bioenergy* **2014**, *70*, 4–16. [CrossRef]
34. Ghimire, P.C. SNV supported domestic biogas programmes in Asia and Africa. *Renew. Energy* **2013**, *49*, 90–94. [CrossRef]
35. Laramee, J.; Davis, J. Economic and environmental impacts of domestic bio-digesters: Evidence from Arusha, Tanzania. *Energy Sustain. Dev.* **2013**, *17*, 296–304. [CrossRef]
36. Mutungwazi, A.; Mukumba, P.; Makaka, G. Biogas digester types installed in South Africa: A review. *Renew. Sustain. Energy Rev.* **2018**, *81*, 172–180. [CrossRef]
37. Aliyu, A.S.; Dada, J.O.; Adam, I.K. Current status and future prospects of renewable energy in Nigeria. *Renew. Sustain. Energy Rev.* **2015**, *48*, 336–346. [CrossRef]
38. Suberu, M.Y.; Bashir, N.; Mustafa, M.W. Biogenic waste methane emissions and methane optimization for bioelectricity in Nigeria. *Renew. Sustain. Energy Rev.* **2013**, *25*, 643–654. [CrossRef]
39. Giwa, A.; Alabi, A.; Yusuf, A.; Olukan, T. A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renew. Sustain. Energy Rev.* **2017**, *69*, 620–641. [CrossRef]
40. REUTERS. Africa's First Grid-Connected Biogas Plant Powers Up. Available online: https://www.reuters.com/article/kenya-energy-biogas/africas-first-grid-connected-biogas-plant-powers-up-idUSL5N1EZ1KL (accessed on 9 July 2018).
41. Nzila, C.; Dewulf, J.; Spanjers, H.; Kiriamiti, H.; van Langenhove, H. Biowaste energy potential in Kenya. *Renew. Energy* **2010**, *35*, 2698–2704. [CrossRef]
42. Hamid, R.G.; Blanchard, R.E. An assessment of biogas as a domestic energy source in rural Kenya: Developing a sustainable business model. *Renew. Energy* **2018**, *121*, 368–376. [CrossRef]
43. Kiplagat, J.K.; Wang, R.Z.; Li, T.X. Renewable energy in Kenya: Resource potential and status of exploitation. *Renew. Sustain. Energy Rev.* **2011**, *15*, 2960–2973. [CrossRef]
44. Kemausuor, F.; Nygaard, I.; Mackenzie, G. Prospects for bioenergy use in Ghana using Long-range Energy Alternatives Planning model. *Energy* **2015**, *93*, 672–682. [CrossRef]
45. Kemausuor, F.; Kamp, A.; Thomsen, S.T.; Bensah, E.C.; Østergård, H. Assessment of biomass residue availability and bioenergy yields in Ghana. *Resour. Conserv. Recycl.* **2014**, *86*, 28–37. [CrossRef]
46. Sakah, M.; Diawuo, F.A.; Katzenbach, R.; Gyamfi, S. Towards a sustainable electrification in Ghana: A review of renewable energy deployment policies. *Renew. Sustain. Energy Rev.* **2017**, *79*, 544–557. [CrossRef]
47. Ofori-Boateng, C.; Lee, K.T.; Mensah, M. The prospects of electricity generation from municipal solid waste (MSW) in Ghana: A better waste management option. *Fuel Process. Technol.* **2013**, *110*, 94–102. [CrossRef]
48. GIZ. Biogas in Ghana: Sub-Sector Analysis of Potential and Framework Conditions. Available online: https://www.giz.de/fachexpertise/downloads/giz2014-en-ghana-pdp-subsector-analysis-biogas.pdf (accessed on 13 July 2018).
49. Arthur, R.; Glover, K. Biomethane potential of the POME generated in the palm oil industry in Ghana from 2002 to 2009. *Bioresour. Technol.* **2012**, *111*, 155–160. [CrossRef] [PubMed]
50. Shane, A.; Gheewala, S.H. Missed environmental benefits of biogas production in Zambia. *J. Clean. Prod.* **2017**, *142*, 1200–1209. [CrossRef]

51. Yimen, N.; Hamandjoda, O.; Meva'a, L.; Ndzana, B.; Nganhou, J.; Yimen, N.; Hamandjoda, O.; Meva'a, L.; Ndzana, B.; Nganhou, J. Analyzing of a Photovoltaic/Wind/Biogas/Pumped-Hydro Off-Grid Hybrid System for Rural Electrification in Sub-Saharan Africa—Case Study of Djoundé in Northern Cameroon. *Energies* **2018**, *11*, 2644. [CrossRef]
52. UNIDO. Biogas to Biomethane. Available online: https://www.biogas-to-biomethane.com/Download/BTB.pdf (accessed on 24 October 2018).
53. Kenya Ministry of Energy. Biogas Development in Kenya. Available online: http://energy.go.ke/biogas/ (accessed on 13 July 2018).
54. Becker, B.; Fischer, D. Promoting renewable electricity generation in emerging economies. *Energy Policy* **2013**, *56*, 446–455. [CrossRef]
55. Walwyn, D.R.; Brent, A.C. Renewable energy gathers steam in South Africa. *Renew. Sustain. Energy Rev.* **2015**, *41*, 390–401. [CrossRef]
56. GIZ. Biogas Industry in South Africa: An Assessment of the Skills Need and Estimation of the Job Potential. Available online: https://www.crses.sun.ac.za/files/research/publications/SAGEN%20Job%20Pot%20-%20Digital%20(low-res).pdf (accessed on 19 October 2018).
57. Kemausuor, F.; Ackom, E. Toward universal electrification in Ghana. *Wiley Interdiscip. Rev. Energy Environ.* **2016**, *6*, e225. [CrossRef]
58. Gyamfi, S.; Modjinou, M.; Djordjevic, S. Improving electricity supply security in Ghana—The potential of renewable energy. *Renew. Sustain. Energy Rev.* **2015**, *43*, 1035–1045. [CrossRef]
59. Parliament of the Republic of Ghana. Renewable Energy Act 2011. Available online: http://energycom.gov.gh/files/RENEWABLE%20ENERGY%20ACT%202011%20(ACT%20832).pdf (accessed on 19 October 2018).
60. Nigerian Electricity Regulatory Commission. Regulations on Feed-in Tariff for Renewable Energy Sourced Electricity in Nigeria. 2015. Available online: https://www.iea.org/media/pams/nigeria/NIGERIA_FIT_regulation2015enteringintoforceFeb2016.pdf (accessed on 19 October 2018).
61. Mengistu, M.G.; Simane, B.; Eshete, G.; Workneh, T.S. Institutional factors influencing the dissemination of biogas technology in Ethiopia. *J. Hum. Ecol.* **2016**, *55*, 117–134. [CrossRef]
62. Roopnarain, A.; Adeleke, R. Current status, hurdles and future prospects of biogas digestion technology in Africa. *Renew. Sustain. Energy Rev.* **2017**, *67*, 1162–1179. [CrossRef]
63. Mulinda, C.; Hu, Q.; Pan, K. Dissemination and problems of African biogas Technology. *Energy Power Eng.* **2013**, *5*, 506–512. [CrossRef]
64. Central Bank News Interest Rates. Available online: http://www.centralbanknews.info/p/interest-rates.html (accessed on 24 July 2018).
65. Trading Economics Interest Rate: Countries List. Available online: https://tradingeconomics.com/country-list/interest-rate (accessed on 24 July 2018).
66. Pueyo, A. What constrains renewable energy investment in Sub-Saharan Africa? A comparison of Kenya and Ghana. *World Dev.* **2018**, *109*, 85–100. [CrossRef]
67. Schmidt, T.S.; Dabur, S. Explaining the diffusion of biogas in India: A new functional approach considering national borders and technology transfer. *Environ. Econ. Policy Stud.* **2014**, *16*, 171–199. [CrossRef]
68. Yousuf, A.; Khan, M.R.; Pirozzi, D.; Wahid, Z.A. Financial sustainability of biogas technology: Barriers, opportunities, and solutions. *Energy Sources Part B Econ. Plan. Policy* **2016**, *11*, 841–848. [CrossRef]
69. Tucho, G.; Moll, H.; Schoot Uiterkamp, A.; Nonhebel, S.; Tucho, G.T.; Moll, H.C.; Schoot Uiterkamp, A.J.M.; Nonhebel, S. Problems with biogas implementation in developing countries from the perspective of labor requirements. *Energies* **2016**, *9*, 750. [CrossRef]
70. Mohammed, M.; Egyir, I.S.; Donkor, A.K.; Amoah, P.; Nyarko, S.; Boateng, K.K.; Ziwu, C. Feasibility study for biogas integration into waste treatment plants in Ghana. *Egypt. J. Pet.* **2017**, *26*, 695–703. [CrossRef]
71. Gebreegziabher, Z.; Naik, L.; Melamu, R.; Balana, B.B. Prospects and challenges for urban application of biogas installations in Sub-Saharan Africa. *Biomass Bioenergy* **2014**, *70*, 130–140. [CrossRef]
72. Kranert, M.; Kusch, S.; Huang, J.; Fischer, K. Anaerobic Digestion of Waste. In *Waste to Energy*; Green Energy and Technology; Springer: London, UK, 2012; pp. 107–135, ISBN 978-1-4471-2305-7.
73. Mukumba, P.; Makaka, G.; Mamphweli, S. Biogas technology in South Africa, problems, challenges and solutions. *Int. J. Sustain. Energy Environ. Res.* **2016**, *5*, 58–69. [CrossRef]
74. Aliyu, A.S.; Ramli, A.T.; Saleh, M.A. Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications. *Energy* **2013**, *61*, 354–367. [CrossRef]

75. Kesselring, R. The electricity crisis in Zambia: Blackouts and social stratification in new mining towns. *Energy Res. Soc. Sci.* **2017**, *30*, 94–102. [CrossRef]
76. Murphy, P.M.; Twaha, S.; Murphy, I.S. Analysis of the cost of reliable electricity: A new method for analyzing grid connected solar, diesel and hybrid distributed electricity systems considering an unreliable electric grid, with examples in Uganda. *Energy* **2014**, *66*, 523–534. [CrossRef]
77. Okello, C.; Pindozzi, S.; Faugno, S.; Boccia, L. Development of bioenergy technologies in Uganda: A review of progress. *Renew. Sustain. Energy Rev.* **2013**, *18*, 55–63. [CrossRef]
78. Mbuligwe, S.E.; Kassenga, G.R. Feasibility and strategies for anaerobic digestion of solid waste for energy production in Dar es Salaam city, Tanzania. *Resour. Conserv. Recycl.* **2004**, *42*, 183–203. [CrossRef]
79. Kolchakov, V.; Petrova, V.; Mitova, T.; Ivanov, P.; Marinova, S. Possibilities for Biogas Production from Waste—Potential, Barriers, and Legal Notices. In *Energy Solutions to Combat Global Warming*; Lecture Notes in Energy; Springer: Cham, Switzerland, 2017; pp. 181–191, ISBN 978-3-319-26948-1.
80. Trimble, C.P.; Kojima, M.; Perez Arroyo, I.; Mohammadzadeh, F. *Financial Viability of Electricity Sectors in Sub-Saharan Africa: Quasi-Fiscal Deficits and Hidden Costs*; The World Bank: Washington, DC, USA, 2016; pp. 1–105.
81. Langeveld, J.W.A.; Peterson, E.C. Feedstocks for Biogas Production: Biogas and Electricity Generation Potentials. In *Biogas*; Biofuel and Biorefinery Technologies; Springer: Cham, Switzerland, 2018; pp. 35–49, ISBN 978-3-319-77334-6.
82. Achinas, S.; Achinas, V.; Euverink, G.J.W. A technological overview of biogas production from biowaste. *Engineering* **2017**, *3*, 299–307. [CrossRef]
83. Kougias, P.G.; Angelidaki, I. Biogas and its opportunities—A review. *Front. Environ. Sci. Eng.* **2018**, *12*, 14. [CrossRef]
84. Aryal, N.; Kvist, T.; Ammam, F.; Pant, D.; Ottosen, L.D.M. An overview of microbial biogas enrichment. *Bioresour. Technol.* **2018**, *264*, 359–369. [CrossRef] [PubMed]
85. International Renewable Energy Agency. Renewable Capacity Statistics 2017. Available online: http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Mar/IRENA_RE_Capacity_Statistics_2017.pdf (accessed on 13 October 2018).
86. Daniel-Gromke, J.; Rensberg, N.; Denysenko, V.; Stinner, W.; Schmalfuß, T.; Scheftelowitz, M.; Nelles, M.; Liebetrau, J. Current Developments in Production and Utilization of Biogas and Biomethane in Germany. *Chem. Ing. Tech.* **2018**, *90*, 17–35. [CrossRef]
87. German Agency for Renewable Resources. Bioenergy in Germany: Facts and Figures 2016. Available online: content/uploads/2017/03/Bioenergy_in_Germany_facts_and_figures_2016.pdf (accessed on 19 June 2018).
88. Heffels, T.; McKenna, R.; Fichtner, W. Direct marketing of electricity from biogas and biomethane: An economic analysis of several business models in Germany. *J. Manag. Control* **2012**, *23*, 53–70. [CrossRef]
89. German Federal Ministry for Economic Affairs and Energy Renewable Energy Sources Act (EEG 2017). Available online: https://www.bmwi.de/Redaktion/EN/Downloads/renewable-energy-sources-act-2017.pdf?__blob=publicationFile&v=3 (accessed on 2 July 2018).
90. Chen, L.; Zhao, L.; Ren, C.; Wang, F. The progress and prospects of rural biogas production in China. *Energy Policy* **2012**, *51*, 58–63. [CrossRef]
91. Chen, Y.; Yang, G.; Sweeney, S.; Feng, Y. Household biogas use in rural China: A study of opportunities and constraints. *Renew. Sustain. Energy Rev.* **2010**, *14*, 545–549. [CrossRef]
92. Chen, B.; Hayat, T.; Alsaedi, A. History of Biogas Production in China. In *Biogas Systems in China*; Springer: Berlin/Heidelberg, Germany, 2017; pp. 1–15, ISBN 978-3-662-55496-8.
93. Eberhard, A.; Gratwick, K.; Morella, E.; Antmann, P. *Independent Power Projects in Sub-Saharan Africa: Lessons from Five Key Countries*; Directions in Development; World Bank: Washington, DC, USA, 2016.
94. Gu, L.; Zhang, Y.-X.; Wang, J.-Z.; Chen, G.; Battye, H. Where is the future of China's biogas? Review, forecast, and policy implications. *Pet. Sci.* **2016**, *13*, 604–624. [CrossRef]
95. Shukla, P.R. Biomass Energy Strategies for Aligning Development and Climate Goals in India. Available online: https://www.rivm.nl/bibliotheek/rapporten/500101002.pdf (accessed on 3 July 2018).
96. Valenti, F.; Zhong, Y.; Sun, M.; Porto, S.M.C.; Toscano, A.; Dale, B.E.; Sibilla, F.; Liao, W. Anaerobic co-digestion of multiple agricultural residues to enhance biogas production in southern Italy. *Waste Manag.* **2018**, *78*, 151–157. [CrossRef]

97. Torrijos, M. State of development of biogas production in Europe. *Procedia Environ. Sci.* **2016**, *35*, 881–889. [CrossRef]
98. Aryal, N.; Kvist, T.; Aryal, N.; Kvist, T. Alternative of biogas injection into the Danish gas grid system—A study from demand perspective. *ChemEngineering* **2018**, *2*, 43. [CrossRef]
99. Vochozka, M.; Maroušková, A.; Šuleř, P. Economic, Environmental and moral acceptance of renewable energy: A case study-the agricultural biogas plant at Pěčín. *Sci. Eng. Eth.* **2018**, *24*, 299–305. [CrossRef] [PubMed]
100. Stürmer, B. Biogas—Part of Austria's future energy supply or political experiment? *Renew. Sustain. Energy Rev.* **2017**, *79*, 525–532. [CrossRef]
101. Pablo-Romero, M.D.P.; Sánchez-Braza, A.; Salvador-Ponce, J.; Sánchez-Labrador, N. An overview of feed-in tariffs, premiums and tenders to promote electricity from biogas in the EU-28. *Renew. Sustain. Energy Rev.* **2017**, *73*, 1366–1379. [CrossRef]
102. Larsson, M.; Grönkvist, S.; Alvfors, P. Upgraded biogas for transport in Sweden—Effects of policy instruments on production, infrastructure deployment and vehicle sales. *J. Clean. Prod.* **2016**, *112*, 3774–3784. [CrossRef]
103. Chaiyapong, P.; Chavalparit, O. Enhancement of biogas production potential from Acacia leaf waste using alkaline pre-treatment and co-digestion. *J. Mater. Cycles Waste Manag.* **2016**, *18*, 427–436. [CrossRef]
104. Takeuchi, Y.; Andriamanohiarisoamanana, F.J.; Yasui, S.; Iwasaki, M.; Nishida, T.; Ihara, I.; Umetsu, K. Feasibility study of a centralized biogas plant performance in a dairy farming area. *J. Mater. Cycles Waste Manag.* **2018**, *20*, 314–322. [CrossRef]
105. American Biogas Council American Biogas Council Announces 2016 Biogas Industry Awardees. Available online: http://americanbiogascouncil.org/pdf/ABC%20Press%20Release-2016%20Biogas%20Award%20Winners.pdf (accessed on 4 July 2018).
106. Pasqual, J.; Bollmann, H.; Scott, C.; Edwiges, T.; Baptista, T.; Pasqual, J.C.; Bollmann, H.A.; Scott, C.A.; Edwiges, T.; Baptista, T.C. Assessment of collective production of biomethane from livestock waste for urban transportation mobility in Brazil and the United States. *Energies* **2018**, *11*, 997. [CrossRef]
107. Sam, A.; Bi, X.; Farnsworth, D. How incentives affect the adoption of anaerobic digesters in the United States. *Sustainability* **2017**, *9*, 1221. [CrossRef]
108. Wirba, A.V.; Abubakar Mas'ud, A.; Muhammad-Sukki, F.; Ahmad, S.; Mat Tahar, R.; Abdul Rahim, R.; Munir, A.B.; Karim, M.E. Renewable energy potentials in Cameroon: Prospects and challenges. *Renew. Energy* **2015**, *76*, 560–565. [CrossRef]
109. Mwirigi, J.; Balana, B.B.; Mugisha, J.; Walekhwa, P.; Melamu, R.; Nakami, S.; Makenzi, P. Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review. *Biomass Bioenergy* **2014**, *70*, 17–25. [CrossRef]
110. Salih, M.A.M.; Tedla, S. *Environmental Planning, Policies and Politics in Eastern and Southern Africa*; Springer: London, UK, 2016; ISBN 978-1-349-27693-6.
111. Colby Environmental Policy Group. *Environmental Policy Update 2012: Development Strategies and Environmental Policy in East Africa*; Colby College Environmental Studies Program: Waterville, ME, USA, 2012.
112. Lönnqvist, T.; Sandberg, T.; Birbuet, J.C.; Olsson, J.; Espinosa, C.; Thorin, E.; Grönkvist, S.; Gómez, M.F. Large-scale biogas generation in Bolivia—A stepwise reconfiguration. *J. Clean. Prod.* **2018**, *180*, 494–504. [CrossRef]
113. Meyer, A.K.P.; Ehimen, E.A.; Holm-Nielsen, J.B. Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. *Biomass Bioenergy* **2018**, *111*, 154–164. [CrossRef]
114. Budych-Gorzna, M.; Smoczynski, M.; Oleskowicz-Popiel, P. Enhancement of biogas production at the municipal wastewater treatment plant by co-digestion with poultry industry waste. *Appl. Energy* **2016**, *161*, 387–394. [CrossRef]
115. Gazda, W.; Stanek, W. Energy and environmental assessment of integrated biogas trigeneration and photovoltaic plant as more sustainable industrial system. *Appl. Energy* **2016**, *169*, 138–149. [CrossRef]
116. Tufaner, F.; Avşar, Y. Effects of co-substrate on biogas production from cattle manure: A review. *Int. J. Environ. Sci. Technol.* **2016**, *13*, 2303–2312. [CrossRef]
117. Poeschl, M.; Ward, S.; Owende, P. Prospects for expanded utilization of biogas in Germany. *Renew. Sustain. Energy Rev.* **2010**, *14*, 1782–1797. [CrossRef]

118. ECOWAS Centre for Renewable Energy and Energy Efficiency. Renewable Energy Policy. Available online: www.ecreee.org/sites/default/files/documents/ecowas_renewable_energy_policy.pdf (accessed on 22 July 2018).
119. Ojha, K. Status of MSW management system in northern India-an overview. *Environ. Dev. Sustain.* **2011**, *13*, 203–215. [CrossRef]
120. Patrizio, P.; Leduc, S.; Chinese, D.; Kraxner, F. Internalizing the external costs of biogas supply chains in the Italian energy sector. *Energy* **2017**, *125*, 85–96. [CrossRef]
121. Lutge, B.; Standish, B. Assessing the potential for electricity generation from animal waste biogas on South African farms. *Agrekon* **2013**, *52*, 1–24. [CrossRef]
122. Meyer, N.I. Learning from wind energy policy in the EU: Lessons from Denmark, Sweden and Spain. *Eur. Environ.* **2007**, *17*, 347–362. [CrossRef]
123. Emodi, N.V.; Ebele, N.E. Policies enhancing renewable energy development and implications for Nigeria. *Sustain. Energy* **2016**, *4*, 7–16. [CrossRef]
124. Frondel, M.; Ritter, N.; Schmidt, C.M.; Vance, C. Economic impacts from the promotion of renewable energy technologies: The German experience. *Energy Policy* **2010**, *38*, 4048–4056. [CrossRef]
125. Dinuccio, E.; Balsari, P.; Gioelli, F.; Menardo, S. Evaluation of the biogas productivity potential of some Italian agro-industrial biomasses. *Bioresour. Technol.* **2010**, *101*, 3780–3783. [CrossRef] [PubMed]
126. Gaworski, M.; Jabłoński, S.; Pawlaczyk-Graja, I.; Ziewiecki, R.; Rutkowski, P.; Wieczyńska, A.; Gancarz, R.; Łukaszewicz, M. Enhancing biogas plant production using pig manure and corn silage by adding wheat straw processed with liquid hot water and steam explosion. *Biotechnol. Biofuels* **2017**, *10*, 259. [CrossRef] [PubMed]
127. Shrimali, G.; Srinivasan, S.; Goel, S.; Nelson, D. The effectiveness of federal renewable policies in India. *Renew. Sustain. Energy Rev.* **2017**, *70*, 538–550. [CrossRef]
128. Surendra, K.C.; Takara, D.; Hashimoto, A.G.; Khanal, S.K. Biogas as a sustainable energy source for developing countries: Opportunities and challenges. *Renew. Sustain. Energy Rev.* **2014**, *31*, 846–859. [CrossRef]
129. Buysman, E.; Mol, A.P.J. Market-based biogas sector development in least developed countries—The case of Cambodia. *Energy Policy* **2013**, *63*, 44–51. [CrossRef]
130. Bond, T.; Templeton, M.R. History and future of domestic biogas plants in the developing world. *Energy Sustain. Dev.* **2011**, *15*, 347–354. [CrossRef]
131. Vaish, B.; Srivastava, V.; Singh, P.; Singh, A.; Singh, P.K.; Singh, R.P. Exploring untapped energy potential of urban solid waste. *Energy Ecol. Environ.* **2016**, *1*, 323–342. [CrossRef]
132. Brunner, P.H.; Rechberger, H. Waste to energy—Key element for sustainable waste management. *Waste Manag.* **2015**, *37*, 3–12. [CrossRef] [PubMed]