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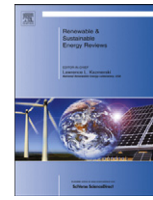

Development of bioenergy technologies in Uganda: A review of progress

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ABSTRACT

Biomass is a renewable energy resource; however, its exploitation raises concerns about its ability to sustain the growing demand and its negative impacts on the environment, particularly in developing countries. These concerns are more prominent on the African continent where high population growth rates is leading to high rates of deforestation due to expansion of agricultural land and increased demand for bioenergy. Use of traditional and inefficient bioenergy technologies and appliances also exacerbate the problem. This paper presents a review of the efforts and progress made by different organisations in promoting improved bioenergy technologies in Uganda. The study was based on an extensive review of available literature on improved bioenergy technologies introduced in the country. It was found that there is high level of wastage of biomass resources since an estimated 72.7% of the population use traditional cooking stoves with efficiency estimated to be less than 10%. Inefficient cooking stoves are also blamed for indoor air pollution and respiratory illness reported amongst its users. Modern bioenergy technologies such as biomass gasification, cogeneration, biogas generation, biomass densification, and energy-efficient cooking stoves have been introduced in the country but have certainly not been widely disseminated. The country should pursue policies that will accelerate proliferation of more efficient bioenergy technologies in order to reduce the negative environmental impacts of bioenergy utilisation and to ensure sustainability of biomass supplies.

Contents

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1. Introduction

Adequate supply of energy is crucial for the development of any nation. Currently, fossil fuels are the dominant global source of energy [1]. However, use of fossil fuels is associated with greenhouse gas emissions (GHG), which is blamed for global warming, and consequently, climate change. Therefore, emphasis is currently focused on promoting use of renewable energy sources such as biomass, solar, wind and tidal energy. Biomass, in particular, is seen as a possible substitute to fossil fuels, and many developed countries are striving to increase the proportion of their primary energy supply from it [2].

The situation in developing countries is however different because biomass has all along been the major source of energy [3]. In Africa for example, biomass accounts for about 30% of the energy consumption. Its use is more prominent in sub-Saharan Africa where it account for up to 80% of energy supply [4]. In Uganda, biomass contributes over 90% of energy requirements. However, despite the high contribution, the production and supply of biomass is still managed by the informal sector. Technologies employed from the production to consumption of biomass fuels are majorly traditional and inefficient and are associated with high levels of pollutants' emission. Extensive use of inefficient bioenergy technologies implies that biomass resources are being wasted; thus, contributing to increased rates of deforestation and related environmental concerns such undesirable change in biodiversity, degradation of soil and water resources. Improving the efficiency of bioenergy technologies could therefore, play a major role in conserving energy; hence, reducing the rate of environmental degradation.

In this perspective, the Government of Uganda, non-governmental organisations (NGOs), and several private agencies are currently promoting improved bioenergy technologies in the country. Examples of technologies promoted include improved (energy-saving) biomass cooking stoves, biogas, and biomass gasification technologies. Overtime, several independent reports of these programmes have been produced by the different actors in the sector. However, because they are made by different projects and individuals, it is very difficult to understand the overall impact of the bioenergy technology programmes in the country. Therefore, the aim of this study was to a conduct review of the progress made in the implementation of improved bio-energy technology programmes in Uganda. The objective is to present a succinct account of the level of proliferation of improved biomass technologies in the country.

1.1. Geographical, demographic and economic information

Uganda is a land locked country located in East Africa, between latitudes 01°30′S and 4°00′N; and longitudes 29°30′E and 35°00′E [5]. It is bordered by Kenya in the east, Tanzania and Rwanda in the south, Democratic Republic of Congo in the west and South Sudan in the north. Fig. 1 shows the location of Uganda on the African continent. The area of the country is approximately 241,550 km^2, out of which 41,743 km^2 is covered by open water bodies and swamps. The topography comprises plateaus in the central and northern parts of the country and mountains of Elgon and Rwenzori on the eastern and western borders, respectively. Overall, the elevation ranges from 620 m to 5110 m above mean sea level [6]

According to UBOS [7], by the year 2002, the country had a population of 24.4 million, characterised by an annual population growth rate of 3.4%. At the time, about 88% of the population lived in rural areas. Recent estimates by UBOS [6] indicate that the country's population by mid-year 2010 had grown to 31.8 million. A summary of the demographic and economic information on Uganda is given in Table 1.

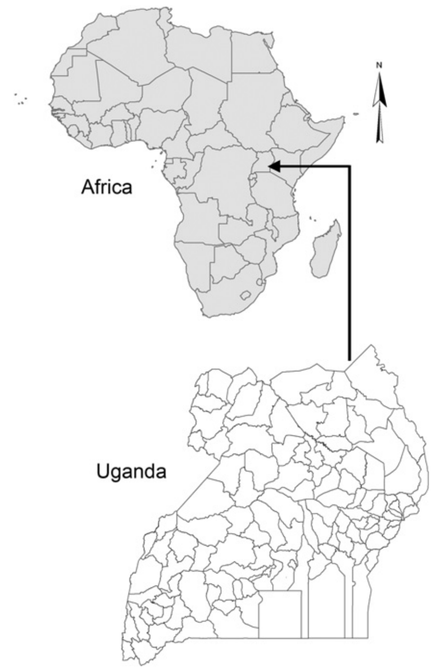

Fig. 1. Map showing the location of Uganda on the African Continent.

Table 1
Demographic information and economic indices for Uganda.

Parameter	Value	Year
Population mid-year (millions)	31.8	2010
Population density (persons per square km)	131.3	2008
Population growth rate (%)	3.3	2005 to 2010
Urban population (%)	12.8	2007
Gross domestic product (GDP)[a] (millions USD)[b]	15829.0	2008
GDP per capita (USD)	500.0	2008
Forested area (%)	17.5	2007
Energy production, primary ($\times 10^3$ TOE)[c]	121.0	2008
Energy consumption per capita (kgOE)[d]	39.0	2012
CO_2 emission estimates ($\times 10^3$ tonnes)	2704.0	2006
CO_2 emission per capita (tonnes)	0.1	2006

Sources: [8,6].
[a] GDP – gross domestic product.
[b] USD – United States Dollars.
[c] TOE – Tones oil equivalent.
[d] kgOE – kilograms oil equivalent.

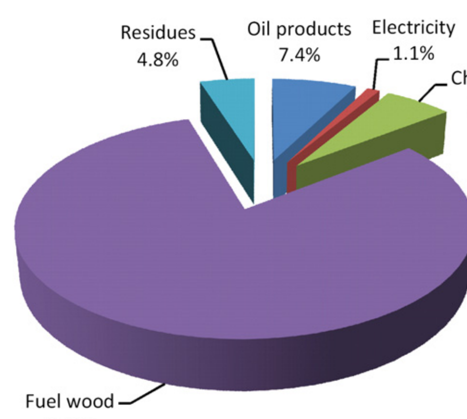

Fig. 2. Energy use by category in Uganda.

1.2. Overview of Uganda's energy sector

The per capita energy consumption of Uganda is estimated to be 39 kg oil equivalent (kgOE), which is very low compared to that of Kenya at 80 kgOE and Italy at 2959 kgOE [8]. Energy supply in the country is predominated by biomass in form of firewood, charcoal and agricultural residues. Electricity and petroleum fuels are also used, but contributes less than 10% of the total energy use. The contributions of the various forms of energy are illustrated in Fig. 2.

Electricity and petroleum fuels are considered as commercial energy in the country; however, biomass is not included in this category, probably because trade in biomass is predominantly informal, and in some cases illegal. In Uganda, biomass energy is used for cooking and heating in households, commercial and public institutions such as hotels, schools and hospitals. It is also used in small scale industries such as brick production and in various industries to supply process heat [9]. Urban households predominantly use biomass in form of charcoal, while firewood and agricultural residues are principally used by rural dwellers. Table 2 shows the distribution of biomass consumption by sector [10], from which it can be observed that the residential sector is the biggest consumer of biomass energy in the country. However, bioenergy technologies used in Uganda are mainly traditional and inefficient. Therefore, several organisations are currently promoting improved bioenergy technologies in the country. Table 3 gives a list of the organisations that are currently promoting improved bioenergy technologies in Uganda.

Petroleum fuels contribute about 7.4% of Uganda's primary energy consumption. The major forms of petroleum products used are: gasoline, diesel fuel, kerosene, fuel oil, aviation fuel and liquefied petroleum gas (LPG). Diesel fuel takes the biggest share of petroleum consumption and is mainly used to power heavy vehicles, and for electricity generation. Gasoline is used for powering light vehicles and small engines. Kerosene is mainly used by the rural households for lighting. Most petroleum products are imported into the country and their prices usually fluctuate with international rates. Recent development in the petroleum sector includes a discovery of an estimated 2.5 billion barrels of petroleum reserves in the western part of the country [11]. In the short term, the government plans to build a mini-refinery of 6000 to 10,000 barrels per day to supply the country's growing petroleum fuel needs [12].

Electricity, mainly from hydropower generation stations is also used in the country. However, the level of access to electricity in Uganda is estimated to be only 5%, making it one of the lowest in Africa. In rural areas where about 84% of the population leave,

Table 2
Bioenergy consumption in Uganda.

Sector	Type of Fuel (TOE[a] per year)		
	Wood	Charcoal	Residues
Residential	5,957,976	406,756	488,106
Commercial	1,242,267	195,855	0
Industrial	999,213	0	0
Total	8,199,456	602,611	488,106

Source: [11].
[a] TOE – tonnes oil equivalent.

Table 3
List of organisations involved in improving bioenergy technology in Uganda.

Name of organisation	Classification or description of organisation	Bioenergy technology promoted or used
Ministry of Energy and Mineral Development	Government agency	Policy formulation and regulations, and project implementation
Centre for Research in Energy and Energy Conservation	Makerere University; institution of higher learning	Research, development and dissemination of improved biomass technology
Appropriate Technology and Agricultural Engineering Research Centre	National Agricultural Research Organisation	Biogas technology
Nyabyeya Forestry College	Institution of higher learning	Training in biomass energy technology
Promotion of Renewable Energy and Energy Efficiency Programme	German Agency for International Cooperation	Improved biomass stoves
SNV Uganda	Netherlands Development Organisation	Biogas technology
Joint Energy and Environment Project	Non-Governmental Organisation (NGO)	Biogas technology, improved biomass stoves
Heifer International	NGO	Biogas technology
United Nations Development Programme	United Nations agency	Multifunctional platform based on biodiesel
Norwegian Refugee Council	NGO	Improved biomass stoves
Agency for Cooperation and Research in Development	NGO	Improved biomass stoves
CARITAS International	NGO	Improved biomass stoves
African Medical Research Foundation	NGO	Biogas technology
SEND A COW Uganda	NGO	Biogas technology
Africa 2000 Network Uganda	NGO	Biogas technology
KULIKA Community Development and Education in Uganda	NGO	Biogas technology
Sustainable Sanitation Water Renewal Systems	NGO	Biogas technology
East African Energy Technology Development Network	NGO	Bioenergy technology promotion, capacity building, networking
Pajoma Inc.	NGO	Gasifier stoves for domestic applications
Kakira Sugar Works (1985) Limited	Sugar manufacturing company	Combined heat and power generation
Kinyara Sugar Works Limited	Sugar manufacturing company	Combined heat and power generation
Sugar Corporation of Uganda Limited	Sugar manufacturing company	Combined heat and power generation, ethanol production
Uganda Stove Manufacturer's Limited	Private company	Production of improved biomass stoves
Nexus Bio-diesel Limited	Private company	Biodiesel production from jatropha
Royal Zan Zanten	Private flower growing firm	Biodiesel from jatropha
Muzizi Tea Estate	Private tea producing estate	Gasification for electricity generation
Paramount Cheese Dairies Limited	Private company	Gasification for industrial heat production
Green Heat (U) Limited	Private company	Biogas and briquetting technologies
Kampala Jillotine Suppliers Limited	Private company	Biomass briquetting technology

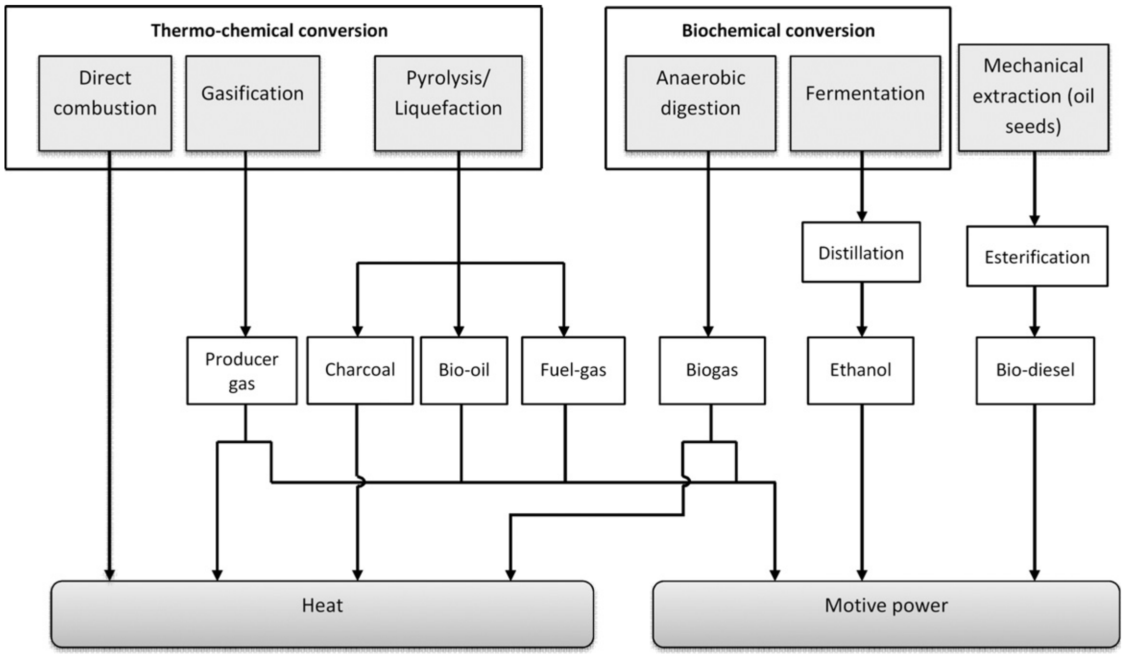

Fig. 3. Bioenergy conversion technologies. Modified from [17,18].

access to electricity is less than 2% [13,14]. Even in urban areas, with higher accessibility rates, majority of households still heavily rely on charcoal to meet their daily energy needs. The low level of access could be explained by the low generation capacity and the high capital and operating costs for developing the electricity sector, especially for less developed economies like Uganda [14]. Currently, the installed capacity of the main hydroelectric power complex located in Jinja is 380 MW. However, the effective generation capacity dropped considerably to about 100 MW in 2005, before rising eventually to about 140 MW in the year 2010 [15]. The drop in generation capacity was attributed to the drastic fall in Lake Victoria water levels as a result of prolonged drought in the East African region [6]. As a result, the country faced a major electricity crisis since the year 2005. In order to overcome the shortfall, the government contracted independent power producers, which by the year 2010, were supplying about 150 MW of electricity mainly from diesel powered generation plants to the national grid [6].

Meanwhile, to meet the shortfall, construction of a 250 MW Bujagali hydroelectric power station is currently on-going. Biomass, mainly bagasse from sugarcane processing, is also used in Uganda to produce about 22 MW of electricity through cogeneration [12]. Several stand-alone diesel and gasoline powered generators are also installed in the country by individual consumers. However, their contribution to the total electrical power consumption is not known.

Nevertheless, Uganda has high potential to produce hydroelectricity. It is estimated that the hydroelectric power potential along the river Nile alone is about 2000 MW. Additional potential of about 200 MW is available from several other smaller waterfalls distributed all over the country [16]. Uganda is also rich in other energy sources such as solar and geothermal resources. Currently, there is effort to promote solar photovoltaic (PV) and thermal systems but their contributions still remain insignificant to the country's energy supply.

1.3. Overview of bioenergy conversion technologies

There are several routes through which biomass can be converted into different forms of liquid, solid or gaseous fuels. These processes are classified broadly as thermo-chemical, biochemical and mechanical extraction [17,18]. A detailed illustration of the processes is shown in Fig. 3. In this study, we examined the level of penetration of each of these bioenergy conversion routes in Uganda. In addition, we also discussed the combined heat and power generation (CHP) and biomass densification technologies. A brief explanation of the principles behind these processes is introduced in each section followed by a detailed review of the level of penetration of each technology in Uganda.

2. State of bioenergy technologies in Uganda

2.1. Direct combustion

2.1.1. Traditional biomass combustion technologies

It is estimated that three billion people worldwide use solid fuels such as coal, wood and animal dung to meet their domestic energy needs [19]. Such fuels are mainly used in developing countries, where an estimated 2.2 billion people burn them in traditional cooking stoves. Use of traditional stoves is more prominent in sub-Saharan Africa, where it is estimated that 94% of the population use them for cooking and heating [20]. For the case of Uganda, it is estimated that 87.5% of households use traditional stoves for domestic energy conversion applications. The three-stone stoves and the traditional charcoal stoves are used by 72.7% and 14.8% of households, respectively [21]. In three-stone stoves, firewood is burnt between three stones that act as the hearth as well as support to the cooking vessel. Firewood is pushed into the hearth through the open spaces between the stones as it burns [22]. Traditional charcoal stoves, on the other hand, are locally made using scrap metal materials such as roofing sheets and oil drums, but do not have insulation lining; therefore, leading to excessive heat loss during operation. The efficiency of these stoves is reported to be less than 10% [23,2].

The tradition stove technologies, are also known to be a source of indoor air pollutants such as particulate matter and carbon monoxide [24]. Exposure to indoor air pollutants emitted by these stoves causes eye irritation and respiratory related diseases that mainly affect women and children in developing countries [19]. According to World Health Organisation (WHO), about 1.5 million people die annually due to illnesses caused by exposure to indoor air pollutants emitted by inefficient cooking stoves [19]. In sub-Saharan Africa, the mortality burden is estimated at 400,000 people annually [4,25]. Another problem associated with combustion of biomass in traditional stoves is its contribution to global warming resulting from products of incomplete combustion [20].

2.1.2. Improved biomass combustion technologies

Improved biomass stoves are built to have higher efficiencies compared to the traditional counterpart. They have been in use for at least 100 years, but recent emphasis to their use arose due to the petroleum crisis of the 1970s. Increased petroleum prices coupled with anticipated fuel wood exhaustion led to renewed emphasis on promoting improved biomass cooking stoves [26]. Recently, environmental concerns, together with the need for improved health of rural households have given more legitimacy to the promotion of improved biomass stoves [27]. Improved biomass stoves have several advantages over their traditional counterpart including increased fuel savings, reduced cooking time and costs for the health sector, increased forest conservation, and reduced emissions of air pollutants [28]. There are several designs of improved biomass stoves available on Ugandan market, examples can be found in Jetter and Kariher [22]. The principle considerations in the design of improved stoves include reducing heat loss by insulating the walls of the combustion chamber and controlling air flows during combustion. Fig. 4 illustrates a comparison between traditional charcoal stoves (Fig. 4a) and improved ones (Fig. 4b), both of which are commonly used in Uganda. The principal difference in this case is that the walls of improved stoves are insulated while that of the traditional one is not.

The Government of Uganda underscores the importance of improved biomass stoves and has a set target of installing 4 million improved wood fuel stoves and 250,000 improved charcoal stoves by the year 2017 [16]. Energy-saving stoves, based on the rocket stove principle are being promoted by the government with support of German Agency for International Cooperation (GIZ) under the "promotion of renewable energy and energy efficiency programme". Under this programme, at least 500,000 energy-saving biomass stoves have so far been installed since the year 2005 [28]. Makerere University is currently spearheading research and development of energy saving stoves in the country and several NGOs are involved in dissemination programmes through training of artisans in stove production.

The role of the private sector in the dissemination of improved biomass stoves in Uganda is also becoming important. An example of a private sector involvement is the "UGASTOVE" project that specialises in producing improved charcoal stoves for use in the domestic and commercial sectors such as restaurants, schools and hospitals. A detailed illustration of the design of the UGASTOVE biomass cooking stoves is given by Adkins et al., [24]. The UGASTOVE company also produces improved wood stoves for rural households and institutions. It was estimated that over a seven-year period, the company would sell 180,000 improved stove units resulting in a potential of saving approximately 600,000 t of carbon dioxide equivalent (tCO_2E) [29].

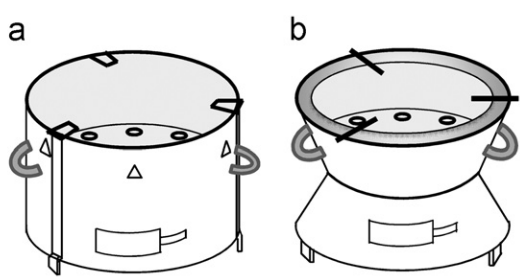

Fig. 4. Charcoal stoves: (a) traditional charcoal stove and (b) improved charcoal stove.

However, despite these efforts, the current level of adoption of improved biomass combustion technology is still low in the country. According to Byakola and Mukheibir [21], only 8.7% of Ugandan households use improved biomass stoves.

2.2. Biomass pyrolysis

Pyrolysis is the thermo-chemical conversion of biomass under limited supply of oxygen at temperatures ranging from 350 °C to 700 °C, [30]. Products of pyrolysis include charcoal, bio-oil or fuel gas, the proportion of which varies depending on the temperature and residence time of the biomass material in the reactor [17]. Explanations of the effects of temperature and residence time on the pyrolysis process and products are available in literature [30,17,18]. The most common pyrolysis method is carbonisation, which is the slow pyrolysis of biomass at temperatures of about 400 °C [17]. Carbonisation is widely used in developing countries for the production of charcoal [31]. There are several technologies available for carbonisation including traditional methods such as earth pit, and earth-mound kilns. Examples of improved technologies include brick and metal kilns [32].

Charcoal making is a major source of employment and income in Uganda and is mainly carried out by numerous small, economically weak and unorganised individuals [33]. However, these are not necessarily the poorest clusters of their communities [34]. The traditional earth-mound kiln [31] is the dominant type of carbonisation technologies in Uganda. It involves stacking wood lots in mounds of about 1.5 m high, followed by sealing with earth to limit air during carbonisation. An opening is provided for ignition of the wood, after which it is sealed off with soil. However, the sealing is not uniform and it is common for air to escape into the kilns leading to complete combustion of the biomass. Consequently, the efficiency of this method is very low, estimated to be between 10% to 15% [35]. Significant loss of the product also occurs at the production site due to the difficulty in recovering the charcoal that has been mixed with soil during the carbonisation stage. The packaging technology used also contributed to material loss through crushing into powder during transportation. Opportunities therefore exist for reducing charcoal losses both during production and transportation stages.

2.3. Biomass gasification

Gasification is the partial oxidation of carbonaceous feedstock such as coal and biomass materials, at elevated temperature, into a gaseous energy carrier [36]. Gasification takes place when biomass is heated in a gasification medium such as air, oxygen or steam [37]. The product of biomass gasification is a mixture of several gases, collectively called producer gas, or synthesis gas. Constituents of the producer gas include carbon dioxide, carbon monoxide, hydrogen, methane, steam, together with traces of higher hydrocarbons. Others are inert gases that result from the gasification agent, and contaminants such as tars, char particles, ash and oils [38]. Gasification process takes place in a reactor called gasifier, which vary greatly in design, but are broadly classified as fixed bed, fluid bed and moving bed. Other design configurations are; rotary kilns, cyclonic and vertex reactors [35]. In general, fixed-bed gasifiers are known to be the most suitable for gasification of solid biomass. Producer gas can be used as fuel in internal combustion engines, burned to produce heat, or used in the synthesis of liquid transportation fuels, hydrogen and other chemicals [39].

Gasification technology is not widely used in Uganda; nevertheless, a case of interest is reported at Muzizi tea estate, located in the western part of the country [40–42]. The company installed a GAS 250® gasifier system manufactured in India by Ankur Scientific. Biomass for the gasifier is from 99 ha of Eucalyptus (*Eucalyptus grandis*) plantation, part of which is used in a boiler to generate steam for drying black tea (*Camellia sinensis*). Though rated at 200 kW electrical power, the average power output was reported to be only 87 kW [41]. Available literature did not give an explanation for the low output reported. Nonetheless, the unit cost of electricity from the gasifier was estimated to be 0.03 United States Dollars (USD) per kilowatt hour; much lower than that of diesel generation, which was approximately 0.3 USD/kWh. The system was estimated to replace 120,000 l of diesel per year, or an equivalent of 314 t of carbon dioxide emission. The challenge of the system was that its capital cost of 2087 USD/kW was very high, especially for developing countries like Uganda. Economic analysis showed that the gasifier plant was only marginally viable with a payback period of about 9.5 years [40].

2.4. Biogas generation technology

Biogas is a mixture of gases produced during anaerobic decomposition of organic matter and is mainly composed of methane and carbon dioxide and trace gases such as hydrogen sulphide, ammonia, water vapour and volatile organic compounds [43]. Slurry, the by-products of the digestion process is a bio-fertilizer and soil conditioner, which can be used to improve crop yields [44]. The main advantage of biogas technology is that it utilises wastes from the agricultural, industrial or municipal sectors and therefore, its use does not exhaust crop production resources. Other benefits include contributions to slowing down deforestation rates, and reducing over dependence on fossil fuels [45]. The technology also reduces drudgery associated with firewood collection and leads to time savings that could be used for other economic ventures [46]. Combustion of biogas produces less pollutants; therefore, its use leads to improved indoor air quality resulting in improved health of women and children, who are the most exposed group to the risk [47]. Use of biogas for energy purposes is also an effective means of limiting methane flows to the atmosphere from decaying organic matter, thus contributing to reduction in greenhouse gas emission.

Biogas technology was introduced in Uganda in the 1950 s by the Church Missionary Society (CMS). Currently, the technology is being promoted by government agencies such as National Agricultural Research Organisation (NARO) and the Ministry of Energy and Mineral Development. Non-governmental organisations such as Heifer International Project, Adventist Development and Relief Agency, amongst others are also promoting the technology. The most commonly used type of bio-digester is the fixed-dome design that was modified from the Chinese design by the Centre for Agricultural Mechanisation and Rural Technology (CAMARTEC) in Tanzania [48]. The CAMARTEC bio-digester design that is usually constructed below ground surface is illustrated in Fig. 5.

Volumes of these digesters range from 8 m^3 to 16 m^3. The floating-dome and the tubular bio-digester designs were introduced in the country but are not commonly used [44]. The fixed-dome digester is preferred because it is more durable than the tubular design and cheaper to install than the floating dome counterpart. Costs of floating dome digesters are higher because of the high costs of steel used in the fabrication of the gas chamber. Designs of the floating dome and tubular digesters introduced in Uganda are similar to those illustrated by Nzila et al., [49].

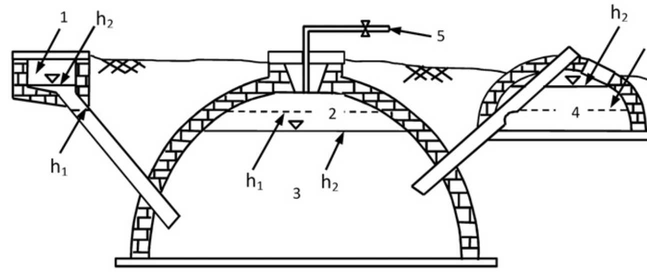

Fig. 5. The CAMARTEC biogas digester. 1: mixing tank, 2: gasholder, 3: digester, 4: compensation tank. h_1: level of slurry before gas production, h_2: level of slurry when with gas is in the holder. Source [47].

The main material used for biogas generation in Uganda is cow dung and it is estimated that the dung generated could support installation of over 250,000 family-sized digesters. The government has a target of installing 100,000 family-sized digesters by the year 2017 [11]. Overall, it is estimated that about 500 biogas digesters have so far been installed, however, less than 50% are operational [14,6]. A good case study of bio-digester installed in the country is one with a 50 m^3 capacity per day at Waga Waga School [40]. The low level of adoption of biogas technology has been attributed to limited technical skill, for installation, operation and maintenance and high capital costs [50,51].

2.5. Fermentation

Bioenergy conversion through fermentation involves production of ethanol from sugar or starch-rich biomass, and is the most widely used biofuel production method in the world [2]. The ethanol is purified through an energy-intensive distillation process [18]. The technology is widely used in Brazil, the United States and Europe for the production of fuel ethanol.

In Uganda, molasses from sugarcane processing has been identified as a possible raw material for production of ethanol with an estimated potential of 119×10^6 l per year [52]. Sugar Cooperation of Uganda Limited, a mill sugar production company, has the only ethanol production plant in Uganda with annual production of 1.5 million litres [53]. The company is expanding its production capacity to 9 million litres [54]. The ethanol produced is used as an industrial chemical, and not used widely as a bioenergy source. However, lack of appropriate policy to guide the development of this sector is reported to be a possible barrier to the development of bio-fuel in the country [55]

2.6. Mechanical extraction

Mechanical extraction is the separation oils from seeds of plants with high oil contents under pressure. Examples of seeds from which oils can be extracted include rapeseed, sunflower, and soya bean [56]. The oils can then be converted into esters through a process called esterification. The esters, also called biodiesel, can be used to substitute diesel in engines [2]. The challenge with the technology is currently the high cost of the esters compared to fossil fuels.

The use of biodiesel for motive power generation was initiated in Uganda through a pilot project supported by the United Nations Development Programme (UNDP) in 2007 [57]. The project was initiated on the basis of multifunctional platforms (MFP) that was successfully implemented in Mali [58–60]. Two MFPs, powered by oil extracted from Jatropha seeds, were installed in Masindi district [57]. The engine provided motive power source to equipment such as grinding mills, oil presses and generators. There are also small scale biodiesel production activities in Mukono district, where a flower firm and local farmers are using Jatropha oil for biodiesel production [61,62]. Another pilot project was also initiated through collaboration between GIZ and ministry of energy in Luwero district [61]. Nevertheless, biodiesel is a relatively new bioenergy conversion technology in Uganda and most trials are still on pilot scale.

2.7. Cogeneration

Cogeneration, also known as combined heat and power (CHP) generation, is the simultaneous production of mechanical or electrical and thermal energy from a single energy carrier such as oil, coal, natural or liquefied gas, biomass or solar [63,64]. The advantage of cogeneration is that it is more energy efficient compared to when mechanical, thermal or electrical energy is produced independently [65].

Biomass materials which provide opportunity for cogeneration in Uganda include bagasse; a by-product of mill sugar processing, coffee and rice husks, and wood wastes such as wood shavings, sawdust and off-cuts. Bagasse in particular provides an excellent opportunity for CHP because they are produced in large quantities, mainly in three sugar factories: Kakira Sugar Works, Kinyara Sugar Works and Sugar Corporation of Uganda Limited. The three factories process a combined average of 130,000 t of mill sugar annually [66]. According to UNDP [66], the bagasse generated from the factories has potential to generate 46 MW of electricity, in addition to process heat. Currently, the combined electricity generation from bagasse from the three factories totals 22 MW out of which 12 MW is supplied to the national grid and the rest is used internally for sugar processing [14]. However, the installed CHP capacity cannot consume all the bagasse generated during sugar processing; consequently, it is common practice to burn the excess bagasse in open fire [67].

2.8. Biomass densification

Biomass densification is the conversion of loose biomass into high density solid material through application of pressure [68]. Normally, biomass materials such as agricultural and forest residues have high moisture content, irregular shapes and sizes, and low bulk density, making it very difficult to handle, transport, store and utilise. Combustion of loose biomass is associated with low thermal efficiency, and high particulate matter emissions [69]. Biomass densification provides the solution to these problems by increasing the initial bulk density of the loose biomass making it easier and cheaper to handle, transport, and store. Densified biomass, are also easily adopted for direct combustion, gasification and pyrolysis or co-firing with coal [70]. Products of biomass densification have well defined shape and size and are broadly classified as pellets, briquettes and cubes with bulk density ranging from 450 to 700 kg m^{-3} [71]. There are a number of technologies that have been developed for biomass densification including; the piston press, screw press, hydraulic press and the roller press [69].

Biomass densification could play an important role in improving the utility of the large quantity of loose biomass materials generated in Uganda. Biomass densification is currently being employed in Uganda but the level of adoption of the technology still remains very low. Briquetting technology has in particular been taken up by poor urban communities of Kampala as an adoption strategy to increasing cost of energy in the country, and as a measure for solid waste management. The technology used by the community is very crude. It involves mixing banana peelings with charcoal dust and anthill soil to make briquettes [72,73]. At industrial scale, briquetting is being used by a private company; Kampala Jellitone Suppliers, which produces 2000 t of briquettes annually. The company uses biomass residues such as rice husks, coffee pulp, maize stalks and sawdust to make biomass briquettes, which is sold to various institutions such as hospitals, schools and universities as fuel for cooking [74]. Apart from these examples, there are several informal small scale producers of briquettes.

3. Discussions

The present review has shown that biomass remains the predominant source of energy in Uganda. The level of adoption of improved bioenergy technologies in the country is still very low. It is predicted that the in the near future, the country's demand for biomass energy will increase in line with population growth. High rate of urbanisation in the country is likely to result in increased demand for charcoal fuel. Dissemination of improved bioenergy technologies could play an important role in ensuring sustainability of biomass supply through efficiency improvement. However, despite the concerted efforts by various players in the bioenergy sector, use of modern and efficient bioenergy technologies in the country remains intangible.

The level of dissemination of improved bioenergy technology in Uganda is similar to that of other sub-Saharan Africa countries, where majority of the population still rely on inefficient traditional cooking stove technologies. However, some countries on the African continent have had very successful programs in the bioenergy technology development. An example is Mauritius where co-generation of bagasse meets over 25% of the country's electricity supply. Other countries that registered significant success in bioenergy programmes include Kenya, Malawi and Zimbabwe. The bioenergy programmes in these countries aimed at producing ethanol for blending with petroleum for use in vehicles [75]. However, the overall picture is that promotion of modern bioenergy technologies is very low on the African continent. This could probably be explained by the inadequate support to modern bioenergy technology in Africa as explained by Amigun et al., [76].

Elsewhere, it can be observed that countries that have had strong institutional support to bioenergy programmes have registered significant success in promoting improved bioenergy technologies. A good example is India, which registered significant success in modern bioenergy development through government programmes implemented by the Ministry of New and Renewable Energy. Between 1984 and 2003, an estimate of 35 million improved cooking stoves had been disseminated. The biogas programme of India also had over 3.8 million bio-digesters installed. The success was attributed to investment in research and technology development and dissemination through policy measures and incentives [77]. Brazil is another example of a country with very successful bioenergy programme based on ethanol produced for molasses. Currently, over 80% of vehicles in Brazil operate on a blend of ethanol and petroleum resulting in over 20% substitution of petroleum use in the vehicle industry [78]. The Brazilian success is attributed to state intervention in the establishment and support to the ethanol programme, infrastructural development as well as research and development [78]. In the European Union (EU), development of bioenergy technologies is being promoted by various EU policies aimed at increasing the use of renewable energy sources. Under the current EU directive, member states have targets for renewable energy use so that the overall EU renewable energy share is at least 20% of the total primary energy consumption by the year 2020 [79]. The EU policies are expected to almost double electricity generation from biomass from 22,506.44 MW in 2010 to 43,274.04 MW in 2020 [80].

In all examples of successful bioenergy development projects above, it is pointed out that favourable policies and incentives, research and development played an important role in the development of the technologies. However, there are several barriers that seem to hinder the development of bioenergy technologies. For example, Painuly [81] identified barriers to renewable energy penetration which include market failure and distortions, economic and financial constraints, institutional and technical barriers, social and cultural behaviour, lack of infrastructures, government policies, environmental barriers etc. Marie-Louise et al. [82], identified up to 13 factors that may influence the choice of renewable energy in Africa. Also, Walekhwa et al., [44] found that socio-economic and demographic characteristics of households play important roles in the adoption of biogas technology in Uganda. However, it is generally not very clear which of these factors have predominant roles in Uganda. One question that remains to be answered is whether Uganda's policy framework is favourable for promoting the development of bioenergy technology.

4. Conclusions

From this study, it can be concluded that that the rate of adoption of improved bioenergy technology remains very low in Uganda. The reasons for the slow technological adoption and diffusion have been attributed to high capital costs, and lack of technical expertise, amongst others. However, more effort is still required in developing clear understanding of the reasons for the low levels of dissemination of improved bioenergy technologies, and to developing suitable policy frameworks for bioenergy technology development.

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