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Livestock Waste-to-Bioenergy Generation Potential in Uganda: A Review

Prosper A. Owusu, Noble Banadda
Department of Agricultural and Biosystems Engineering, Makerere University, P.O. Box 7062, Kampala, Uganda

Corresponding author: aowusu@caes.mak.ac.ug
Department of Agricultural and Biosystems Engineering, Makerere University, P.O. Box 7062, Kampala, Uganda

Livestock waste-to-energy is a unique type of an energy source which can be tapped to supplement current energy needs and also help improve the current waste management problems existing in most parts of the world. This review paper seeks to assess the potential of Uganda to convert the waste from its rich livestock production to supplement its energy demand. The amount of bioenergy potential was estimated from a number of cattle, sheep, goats, pigs and poultry based on descriptive statistics data. Other feedstock sources for biogas generation were also identified. It was estimated that Uganda has the potential to produce 25.17 PJ of biogas annually from cattle, goats, pigs, sheep and poultry wastes when treated anaerobically. This is particularly important because this potential represents about 40% of the total primary energy consumption (62.56 PJ) in Uganda. The potential biogas generation in Uganda was estimated as 17.76, 1.12, 3.82, 1.72 and 0.75 PJ y^{-1} of energy for cattle, sheep, goats, pigs and poultry wastes respectively. The Government of Uganda have set a target of installing about 100,000 biogas digesters by the year 2017, only 50% of about 500 installed digesters are in operation. It was recommended that the Government of Uganda should make biogas production a priority since it can supplement the Rural Electrification Programme.

Keywords: waste-to-energy, livestock, biogas generation, waste management, Uganda.

Introduction

Livestock waste-to-energy (WTE) is an important type of bioenergy. WTE is a unique type of an energy source in that, it produces renewable energy and also provides environmental benefits (Shehu et al. 2012, Chynoweth et al. 2000, CEC 2011, Ngumah et al. 2013). Bioenergy can have positive employment and income effects, and can increase security of energy supply (Mathias 2014, Demirel et al. 2010). Energy from livestock waste is considered as one of the main future renewable energy sources, since it can provide a continuous power generation (Appels et al. 2011). For one reason, human population is to face fossil energy privation soon. For another, biomass is common and the operation of biogas systems is simple (Afazeli et al. 2014). However, livestock by-products, a valuable resources of biogas (Bayr et al. 2012), are not efficiently used in developing countries like Uganda. There is largely untapped potential in agricultural operations where animal waste is often land applied or disposed-off without conversion to energy (Avcioglu and Turker 2012). Animal wastes also contain pathogens that are very dangerous to human health (Hussein et al. 2012).

As the development of agriculture and animal husbandry coupled with population growth increases, animal waste potential also increases (Avcioglu and Turker 2012). Besides, energy demand increases as the population increases. Animal waste can cause huge problems for enterprises and cannot be reutilised (Wilson 2013) if it is not managed properly (Mathias 2014). A small portion of this is used as a fertiliser for crop production after being left a long time in the open spaces. The use of dung as biogas fuels is not common in Uganda except in a few areas with fuel wood scarcity. Lack of control of animal waste in an orderly manner and unconscious waste disposal to arable fields, pastures and water bodies degrade soil structure as a result of contamination (Avcioglu and Turker 2012). The best way to minimise the consequences is to improve waste management through enhanced manure management. The conversion of animal wastes to bioenergy can also bring significant environmental and health benefits (GBEP 2007, Ileleji et al. 2008). The benefits range from the use of the slurry for agricultural production to improving health conditions. The slurry is very rich in nutrients, which can be used to replace the expensive inorganic fertilisers that are always imported. The use of biogas also reduces the rate at which women and children are exposed to harmful emissions during the use of fuel wood and charcoal for cooking. Besides, pathogens are controlled during the anaerobic digestion process. Other benefits include the use of biogas technology to create employment and solve public waste disposal problems.

Biogas is a mixture of 60% of methane and 40% of carbon dioxide (Alexopoulos 2012, Kasisira and Muyiiya 2009). Biogas has a wide range of applications. The use of biogas is even more relevant considering the fact that wood is the main energy source in most parts of Uganda. It can be used to supplement or replace wood fuel as an energy source for cooking and lighting in Uganda.

In this study, the amount of bioenergy potential was estimated from a number of cattle, sheep, goats, pigs and poultry. This value was compared with the amount of bioenergy generated from animal wastes in other countries. Besides, the potential application of bioenergy generated from livestock wastes was identified. Other feedstock sources in Uganda for biogas generation were also recognised. The number of biogas plants in Uganda were also discovered.

Methodology

The geographical location, livestock production and the energy situation

Uganda is a developing country bordering South Sudan to the north, Kenya to the east, Democratic Republic of Congo to the west, Rwanda to the southwest and Tanzania to the south. The estimated population is 34,856,813 (UBOS 2014). The country has a total land size of 241,550.7 km^2 (UBOS 2011). The agricultural sector of Uganda is one of the main drivers of the country's economy and employs about 66% of the workforce. This accounts for approximately 20.9% of the nation's gross domestic product (GDP). Livestock play an important role in the social and economic life (Arthur and Baidoo 2011, Mijinyawa and Dlamini 2006) in Africa. Livestock production contributes massively to food security and livelihoods. Livestock production contributes about 1.8% to the country's GDP (UBOS 2014).

In Uganda, about 90% of the populace still rely heavily on biomass (including firewood, charcoal and crop residues) as their primary energy use. It was reported in 2016 that 90% of total energy utilised in Uganda was obtained from firewood, charcoal and crop residues. Crude oil accounted for 7.2% and electricity accounted for just 1.4%. Excessive dependent on biomass as an energy source is compelled by cultural beliefs, low cost and availability of resource (Mohammed et al. 2013).

Feedstock for biogas production and estimation of biogas potential from livestock wastes

Appropriate raw material for biogas production must involve organic material that is suitable for anaerobic digestion. The energy production potential of feedstock depends on the type, level of processing or pre-treatment and concentration of biodegradable material (Vögeli et al. 2014). Biogas potential in Uganda is very large due to the vast resources that are readily available. The major sources of biogas in Uganda are animal wastes, forest residues, agricultural residues, municipal solid wastes (MSW) and wood wastes. The generation of municipal solid wastes in Kampala, capital of Uganda, is principally composed of food and kitchen wastes, papers and plastics (Komakech et al. 2014). The MSW generation in Kampala alone is estimated as 0.35 million tonnes per annum (Nabukeera and Boerhannoeddin 2014). High population growth, urbanisation and high rate of industrialisation in the capital will accelerate the generation of municipal solid wastes. This MSW can be treated anaerobically to produce biogas, which can be used for cooking and lighting purposes. Agriculture plays an important role in the economy of Uganda. Large quantities of residues such as rice husks, corncobs, straw, stover, bagasse, stem, leave, shell, stubble, peel and cane trash are produced annually. These residues are under-utilised. They are usually ploughed back into the soil, burnt, left to decompose or grazed by cattle. Rice produces straw and husks, which can be converted into energy (Mendoza and Samson 2006, Nguyen et al. 2015). Significant quantities of biomass remain in the field in the form of cobs and stubble during harvesting of maize, which can be converted into energy (Amon et al. 2007, Carpita and McCann 2008). Besides, harvesting and processing of coconut produces shells and fibres that can be processed into energy (Luukkanen 2011). Forestry residues are generated as a result of thinning of plantations, clearing for logging roads and extracting stem wood for timber. Trees damaged by fire, birds and insects are additional sources of biomass for bioenergy. Wood wastes such as sawdust, off-cuts, trims and shavings usually concentrated at the processing factories such as sawmills can be used for bioenergy (Yang and Jenkins 2008, Stecher et al. 2013, Simonyan and Fasina 2013). Sawdust is obtained from cutting, sizing, re-sawing, edging, while trims and shavings are the consequence of trimming and smoothing of wood. Uganda also has strong animal production. The biogas potential of animal manure can be harnessed through anaerobic digestion (Mustonen et al. 2013).

Livestock residues as an example are excellent material for the production of biogas. Animal residues are made up of dung and slaughter residues. The available amount of dung depends on the animal population, manure as a fertiliser (Hoogwijk et al. 2003), the quantity of fodder eaten, the quality of fodder, and the weight of animals (Duku et al. 2011). Animal manure has high water content, and it can be digested in the absence of oxygen for biogas generation.

In the quantification of energy potential of animal wastes, the daily volatile solid (VS) production per animal and biogas yield per kilogram of volatile solids must be known (Okello et al. 2013a). The method used to obtain this estimate was based on descriptive statistics data. The year 2013 was used as the baseline for estimating the number of livestock. The estimation is based on the assumption that 25% (Yamamoto et al. 2001, Swisher and Wilson 1993, Williams 1995) to 35% (Cvetković et al. 2014) of total manure from cattle, goats, sheep and pigs would be available for biogas production. This assumption is based on the fact that, in Uganda, the majority of livestock are free ranged. In the case of poultry farming, it was assumed that 15% of total manure would be available for anaerobic digestion (Cvetković et al. 2014). Biogas potential is generally based on the livestock population and quantity of waste that can be collected from animals. Data used for the estimation of biogas production from livestock residues in Uganda are presented in Table 1.

The amount of biogas generation potential from livestock residues can be determined using equation 1 proposed by Okello et al. (2013a).

$$BP_t = N \times VS \times E_t \quad (1)$$

where N is the number of livestock heads; BP_t – theoretical biogas potential (m^3 day^{-1}); VS – volatile solids per head (kg DM $head^{-1}$ day^{-1}); E_t – the estimated biogas producing rate (m^3 $(kg\ DM)^{-1}$).

Table 1

Estimated data for biogas production of livestock manure per head (Okello et al. 2013a)

Livestock	Volatile solids (kg day^{-1})	Biogas estimating rate (m^3 kg^{-1})
1	2	3
Cattle	2.67	0.20
Sheep	0.30	0.31
Goats	0.33	0.31
Pigs	0.59	0.31
Poultry	0.1	0.18

Results and discussion

Theoretical biogas production

Livestock production contributes significantly to the GDP of Uganda. Steady efforts by the government to control animal diseases and enhance livestock production systems as a result of routine effective livestock extension interventions (UBOS 2014) have led to livestock production in almost every part of the country. The population of livestock increases from year to year as shown in Table 2. Although poultry has the highest population, its waste generation rate is very low when compared with other livestock. Cattle generate the highest wastes among the livestock.

Bioenergy estimation potential leads to a range of estimated and fertile ground for debates (Slade et al. 2011). Sources of controversy and contention around bioenergy potential estimates are various. There is a very wide range of estimates that confuses policy makers, delays effective action and increases doubt and uncertainty about using biomass for energy purposes (Lynd et al. 2011). The link between bioenergy and food security is complex (Faaij 2008). On the one side, biomass production for bioenergy generation increases supply of energy and local employment, thereby promoting rural development. On the other side, biofuel industry competes with crop production for land. The fear is that the benefits obtained from increased biomass use for biofuel would threaten food security in rural areas (Eide 2008, Slade and Bauen 2015, Searchinger et al. 2008). Besides, there is no standard approach for biomass and bioenergy potential estimation. It is, therefore, important to standardise the assessment of bioenergy.

The estimation of biogas production in Uganda from different livestock wastes discussed is given in Table 3. The calorific value of biogas is approximately 20 MJ (Otim et al. n.d.).

From Table 3, the potential biogas production estimated for Uganda was 1,258.37 million m^3 y^{-1}, which is equal to 25.17 PJ of energy. In terms of biogas production, cattle contributed about 888.21 million m^3 y^{-1}. Goats contributed the second highest biogas yield (191.00 million m^3 y^{-1}) followed by pigs (85.82 million m^3 y^{-1}), sheep (55.83 million m^3 y^{-1}) and poultry (37.51 million m^3 y^{-1}).

Table 2

Population of livestock in Uganda from 2009–2013 (UBOS 2014)

Livestock	Number (1000's)				
	2009	2010	2011	2012	2013
1	2	3	4	5	6
Cattle	11,751	12,104	12,467	12,840	13,020
Goats	12,823	13,208	13,604	14,012	14,614
Sheep	3,516	3,621	3,730	3,841	3,937
Pigs	3,280	3,378	3,496	3,583	3,673
Poultry	33,819	34,834	35,879	36,956	38,064
Total	**65,189**	**67,145**	**69,176**	**71,232**	**73,308**

Table 3

Estimated biogas potential from livestock wastes in Uganda

Livestock	Biogas production (million m^3 y^{-1})	Calorific value (PJ y^{-1})
1	2	3
Cattle	888.21	17.76
Sheep	55.83	1.12
Goats	191.00	3.82
Pigs	85.82	1.72
Poultry	37.51	0.75
Total	**1258.37**	**25.17**

Okello et al. (2013a) estimated the total potential attainable from livestock waste in Uganda to be about 65 PJ y^{-1}. Comparing this potential with the one estimated by Okello et al. (2013a), this estimate is smaller. This can be attributed to the fact that Okello et al.'s (2013a) estimation was based on the assumption that all the manure generated by livestock would be harnessed for biogas production. This, however, cannot be possible since most livestock in Uganda are free ranged. The results obtained in terms of proportion by individual livestock are comparable with the estimation done by Arthur et al. (2011). Their study estimated the biogas potential in the wastes of some selected livestock (cattle, sheep, goats, pigs and poultry) in Ghana, Burkina Faso, Nigeria and Mali. They estimated that a total of about 845 Gg of methane was produced by the livestock during the period, of which cattle provided about 40%, whereas pigs, goats, sheep and chickens accounted for 21.2%, 18.7%, 13.1% and 6.6%, respectively. Massé et al. (2011) revealed that anaerobic digestion produced biogas at average rates of 0.30 and 0.48 L/g volatile solids from swine and poultry slurries, respectively. Maamri and Amrani (2014) also estimated that the maximum biogas yields from total solids (TS) concentration of 23.28 and 35.2 g L^{-1} of animal wastes yielded 0.93 and 0.231 L $(gVS)^{-1}$, respectively. This indicates that the biogas generation potential and the biogas generation rate increase with an increasing total solid concentration. Table 4 shows the comparison of biogas potential for Uganda, Africa and worldwide. Currently, the range of the global potential of animal wastes is very broad and is quantified at 25,000 PJ (Ladanai and Vinterbäck 2009, Hoogwijk et al. 2003). Kaltschmitt et al. (2009) and Cooper and Laing (2007) estimated the potential of animal wastes in Africa to be at 1,200 PJ and 1,450 PJ, respectively. Both estimations were based on Food and Agriculture Organization (FAO) data on animals. Cooper and Laing (2007) assumed 223 million cattle (Stecher et al. 2013). The potential estimate of bioenergy from only livestock wastes in Uganda accounts for an approximately 2.1% of the total potential in Africa.

The estimated biogas potential, if fully realised, could produce energy to provide lighting to the equivalent of almost 285 thousands of average Ugandan homes that use 6 bulbs with a capacity of 60–100 W for 6 h day^{-1}. In addition to the provision of light, this potential can also reduce the current rate of fuel wood consumption. It can be used to prepare 3 meals per day for average Ugandan homes (i.e., a family of 5–6 members) for a year.

Table 4

Potential biogas generation comparison

Country	Biogas production (PJ/year)	References
1	2	3
Uganda	25.17	Our Estimates
Africa	1,200–1,450	Kaltschmitt et al. (2009), Cooper and Laing (2007)
Worldwide	25,000	Ladanai and Vinterbäck (2009), Hoogwijk et al. (2003)

PJ = 10^{15} J

Current status of biogas technology in Uganda

Biogas technology was introduced in Uganda in the early 1950s. Currently, the technology is being promoted by governmental organizations, such as the Ministry of Energy and Mineral Development and the National Agricultural Research Organization. Renewable Energy Business Incubator (REBI), International Project, Adventist Development and Relief Agency are also promoting biogas technology (Okello et al. 2013b). The three most common biogas plant designs in Uganda include fixed dome, floating drum and tubular (Ocwieja 2010). The fixed-dome digester is the most commonly used because of its durability and cheaper installation cost (Sasse et al. 1991). Cow dung is the main raw material used in biogas production in Uganda. The Government of Uganda has set a target to install about 100,000 family-sized digesters by the end of the year 2017 (Veit et al. 2011). So far, about half of the 500 installed biogas digesters are in operation (UBOS 2010). High capacity biogas plants installed include the 65 m^3 productive biogas digester owned by Entomocide Enterprises (Okello et al. 2013a) and a 20 m^3 biogas plant owned by Millennium Biogas Company Limited. The rate of adoption of biogas technology in Uganda is slow like in many developing countries due to the lack of technical capacity for installation and maintenance and high initial costs of installation (Okello et al. 2013b, Komakech 2014).

Conclusions and recommendations

This study analysed the available feedstock sources and biogas technology and showed a large and unexplored potential for the use of livestock waste for biogas production in Uganda. Some of the available feedstock for biogas production in Uganda include agricultural residues such as rice husks, corncobs, stover, bagasse and cane trash, MSW such as food and kitchen wastes, papers, and plastics, and wood wastes such as sawdust and livestock wastes such as dung. Uganda has the potential to produce about 1,258.37 million m^3 of biogas annually, which is equivalent to 25.17 PJ of energy from livestock wastes. The theoretical biogas potential in Uganda is expected to increase if these animals are produced under an intensive system. The annual primary energy consumption in Uganda is estimated as 62.56 PJ (U.S. Energy Information Administration, 2012). If all of the livestock wastes are treated anaerobically, the potential for energy generation would be able to meet approximately 40% of the country's primary energy consumption needs. Treatment of livestock wastes through anaerobic digestion also generates bio-fertiliser, a by-product, which is of superior quality (Ileleji et al. 2008). It is fair to say identifying the potential is very important, but that is just the first step. How to transform the potential biogas production into practice is the most important thing. The practical production of biogas from livestock wastes in Uganda is affected by many factors. Biogas is not treated as a primary energy source. There are also political challenges; there is no specific programme to support biogas production development. Therefore, the massive potential can only become a reality if the government and other private organisations provide incentives.

It can be concluded that the promotion of biogas production is not only relevant to energy issues, but also in other policy areas, such as agricultural, environmental and waste management policies. It is therefore recommended that the production of livestock in Uganda should be intensive to increase the amount of manure that can be collected. Besides, comparing the potential of biogas generation with a country like Brazil, there is a need to have good policies that provide a good platform for private sector investment in this technology in order to meet the estimated production. The Government of Uganda should make biogas generation from livestock wastes and other available feedstocks a priority since this can supplement the Rural Electrification Programme. Livestock farms should also implement manure management systems, which treat manure with a high solids concentration. This would promote optimum biogas recovery.

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Ugandoje susidariusių gyvulininkystės atliekų ir jų bioenergijos generavimo potencialo apžvalga

Gauta:
2016 m. balandis

Priimta spaudai:
2017 m. rugsėjis

Prosper A. Owusu, Noble Banadda

Žemės ūkio ir biologinių sistemų inžinerijos katedra, Makerere universitetas, Kampala, Uganda

Gyvulinės kilmės atliekos yra unikali energijos šaltinio rūšis, kuri gali būti naudojama papildyti dabartinius energijos poreikius ir taip pat pagerinti atliekų tvarkymo problemas, egzistuojančias daugelio pasaulio šalių. Šiame moksliniame straipsnyje įvertinamas Ugandos, gyvulinės kilmės atliekų vertimas į produkciją, potencialas, kuris papildytų energijos poreikius. Bioenergetikos potencialo kiekis buvo apskaičiuotas iš kelių gyvulinės kilmės atliekų: galvijų, avių, ožkų, kiaulių ir paukščių, remiantis aprašomųjų statistikos duomenimis. Taip pat buvo nustatyti kiti žaliavų šaltiniai biodujų gamybai. Apskaičiuota, kad Uganda kasmet gali išauginti 25,17 PJ biodujų iš galvijų, ožkų, kiaulių, avių ir naminių paukščių atliekų anaerobinėmis sąlygomis. Tai ypač svarbu, nes šis potencialas sudaro apie 40% visų pirminės energijos sąnaudų (62,56 PJ) Ugandoje. Apskaičiuota galima potenciali biodujų gamyba Ugandoje 17.76, 1.12, 3.82, 1.72 ir 0.75 PJ y^{-1} energijos atitinkamai galvijams, avims, ožkoms, kiaulėms ir naminių paukščių atliekoms. Ugandos vyriausybė nustatė tikslą iki 2017 m. įrengti apie 100 tūkst. biodujų jėgainių, veikia tik 50% maždaug 500 sumontuotų biodujų jėgainių. Buvo rekomenduota, kad Ugandos vyriausybė turėtų teikti pirmenybę biodujų gamybai, nes ji galėtų papildyti kaimo vietovių elektrifikavimo programą.

Raktiniai žodžiai: atliekos, energija, gyvuliai, biodujų gamyba, atliekų tvarkymas, Uganda.