# Waste to energy technologies for solid waste management a case study of Uganda

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**Abstract:** Municipal solid waste management is one of the major environmental problems of developing countries. Investments in solid waste management would not only translate into jobs and income but also a cleaner environment. Over years a number of solid waste management technologies have been carried out in many developing parts of the world. Some were successful in generating lasting impacts on the improvement of solid waste management, however, many technologies failed due to unsustainability. This is partly attributed to differences in waste characteristics between developed countries and the less developed countries and the resource constraints in less developed countries. On the other hand, less developed countries are also known for being energy deprived and thus energy recovery as sustainable waste management technology is advocated for in these countries. This paper seeks to review and assess the energy recovery potential from the various sustainable waste technologies in Uganda. The advantages attached to such technologies will be assessed and evaluated. In a further step, a comparative analysis with traditional energy sources like hydro-electricity power and petroleum products powered generators is also presented and discussed. This study concludes that renewable energy sources present Uganda with a rare opportunity to elevate millions out of energy poverty.

**Keywords:** solid waste, energy, sustainable, Sub-Saharan Africa, biomass, Uganda

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## 1 Introduction

Currently, world cities generate about 1.3 billion tonnes of solid waste per year. This volume is expected to increase to 2.2 billion tonnes by 2025 (Hoornweg and Bhada-Tata, 2012). Developing countries have devised technologies to handle their waste effectively but less developed countries like Uganda are still facing major challenges with waste management. For the case of less developed countries, solid waste management is a challenge for the cities' authorities mainly due to the increasing generation of waste, the load posed on the municipal budget as a result of the high costs associated to its management (Manaf et al., 2009), the lack of understanding over a diversity of factors that affect the different stages of waste management and linkages necessary to enable the entire handling system functioning and other management barriers including limited financial powers, lack of resources and poor governance (Okot-Okumu and Nyenje, 2011). Most of the waste generated in these less developed countries is organic (Troschinetz and Mihelcic, 2009) and the main sources of wastes are households, markets, institutions, streets, public areas, commercial areas and manufacturing industries (Kaseva and Mbuligwe, 2005)

Poor waste management practices and associated public health implications remain severely problematic in many developing countries (Konteh, 2009), and increasing population levels, booming economy, rapid urbanization and the rise in community living standards have greatly accelerated the municipal solid waste generation rate in these countries (Guerrero et al., 2013). Municipalities, usually responsible for waste management in the cities, have the challenge to provide an effective and efficient system to the inhabitants. Municipal wastes constitute one of the most crucial public health,

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flooding, air pollution environmental problems in African cities and urban areas (Achankeng, 2003; Henry et al., 2006; Kaseva and Mbuligwe, 2005). There is thus the need for a more appropriate solid waste management plan for less developed countries and this should address the health, environmental, aesthetic, land-use, resource, and economic concerns associated with the improper disposal of waste (Marshall and Farahbakhsh, 2013).

According to Mahadevan and Asafu-Adjaye (2007), energy use is low in countries with low GDP. This analysis encompasses most countries in the Sub-Saharan region as most of the countries are faced with energy deprivation. Uganda has a total energy demand of 173,287 GWh (Lee, 2013) of which 90% is cartered for by biomass in form of firewood,charcoal and to a small extent crop residues. The other 10% is cartered for by electricity (1.4%) and oil products at (8.7%). The challenge in the available energy sources is the sustainability. Due to the high reliance on forest products, there is a high rate of defforestation which is detrimental to the environmnent. In addition to the reliance on firewood, energy utilisation is done at low efficiencies of 10%-12% (Okot-Okumu and Nyenje, 2011). Electricity as an energy alternative would be viable but only 15% of the population in uganda has access to electricity majorly because of the high power tariffs and low coverage of the electricity grid. Oil products are expensive to purchase and their contribution to the environmnet is so highly negative. Due to the increasing energy demands with the increase in waste generation, sustainable solid waste technologies would aim at energy recovery from the waste. This paper seeks to review, analyze, assess and put forward resources and sustainable technologies that are likely to succeed in the context of developing countries.

## 2 Current energy sources

In addition to the conventional primary woody biomass resources, a large potential exists in the form of secondary sources like agro-industrial and agricultural residues. Although it is technically possible to produce electricity from these residues by combustion through combined heat and power, it remains a matter of economic performance that determines the viability. The operational costs of using agricultural residues, the benefits of replacing grid electricity and income from the sale of excess electricity back to the national grid should provide an adequate rate of return on the capital investments in the bioenergy plant. The suitable technology depends on the size of the plant. Advanced biomass technologies such as pyrolysis are in their infancy in Uganda, possibly presenting viable bioenergy business opportunities. The Renewable Energy Policy for Uganda estimated a potential of more than 5 GW potential from renewable energy, as indicated in Table 1. Biomass could contribute 2.45 GW, almost 50%, of this potential capacity.

**Table 1 Renewable energy power potential**

| Energy source | Estimated electrical potential, MW |
|---|---|
| Hydro | 2,000 |
| Mini-hydro | 200 |
| Solar | 200 |
| Biomass | 1,650 |
| Peat | 800 |
| Geothermal | 450 |
| Wind | - |
| **Total** | **5,300** |

### 2.1 Demonstration of technology co-existence

Agriculturally endowed countries like Uganda have a wide variety of agricultural residues in sufficient quantities as summarized in Table 2. However, in order to replace and/or supplement fossil based energy carriers, cost is the critical challenge for success. It is of great importance to be conscious of how to utilize the different sources of bio-waste and for which purpose. Agriculture in Uganda is linked to energy markets through both indirect (cost of fossil-based inputs like fertilizer and insecticides) and direct costs (production, processing, and transport), and also through the competition for resources, such as land and water, for production of food, feed or energy crops. Therefore, the linkage between energy and agriculture is disproportionate, with energy prices having a far greater impact on agricultural prices than the influence that agriculture could have on the world energy. At the same time, the rising energy prices are raising the costs of agricultural production, hurting the welfare of the poorest most especially in Uganda.

**Table 2 Selected Agricultural residues in Uganda**

| Crop type | Residues | Availability for energy, % | Availability for energy, t |
|---|---|---|---|
| Cassava | 667,200 | 0 | 0 |
| Bananas | 3,604,799 | 30 | 1,081,440 |
| Beans | 273,001 | 30 | 81,900 |
| Cow peas | 26,783 | 30 | 8,035 |
| Soya beans | 55,299 | 30 | 16,590 |
| Sorghum | 478,802 | 30 | 143,641 |
| Maize | 913,002 | 30 | 273,901 |
| Rice | 108,002 | 30 | 32,534 |
| Wheat | 10,800 | 0 | 0 |
| Sun flower | 22,251 | 0 | 0 |
| Ground nuts | 144,000 | 30 | 43,200 |
| Coffee | 145,172 | 30 | 43,552 |
| **Total** | **6,449,111** | **-** | **1,724,793** |

Source:(MEMD, 2014).

Currently, accessible sustainable wood biomass supply in Uganda stands at 27.7 million tons. When crop residues, whose theoretical potential in Uganda could be 4.4 million tons, are included, there is a national net surplus. Agro-industrial residues from the sugar, coffee and rice industries amount to about 3.7 million tons a year. Sawmilling residues (440,000 $m^3$) consist of sawdust, bark, chips and other waste wood that is not suitable for further processing; most of this is used as fuel wood. Access to electricity through grid extension is unlikely to increase in many poor parts of the world, and high oil prices are already preventing diesel generators from running in villages. Therefore, there is a high potential for small-scale decentralized power generation for rural areas based on biomass conversion. The major sources of power in the East African Community (Kenya, Uganda, Tanzania, Rwanda and Burundi) include Geothermal, Wind, Hydro, Solar and Biomass. Statistics show that the East African Community (EAC) population is more that 100 million but more that 81% of this population live without access to modern energy services. The statistics in Uganda further shows that:

- Less than 30% of households use liquefied petroleum gas;
- Less than 40% of urban households have access to electricity
- Less than 5% rural households have access to electricity; and.
- Less than 10% of schools, clinics and hospitals in rural areas have access to grid electricity.

Uganda's hydro-power development is based on the increasing use of the country's hydropower potential available. Hydropower potential is estimated to be more than 200 MW, with firm annual generation 12 500 GWh/year (excluding the abundant mini and micro hydro potential). The current operating and planned hydro project are indicated in Table 3.

**Table 3 Hydropower dams in Uganda**

| Hydroelectric power station | Type | Capacity | Year of completion |
|---|---|---|---|
| Ayago Power Station | Run of river | 500 MW | 2018 |
| Bujagali Power Station | Run of river | 250 MW | 2011 |
| Buseruka Power Station | Reservoir | 9.0 MW | 2010 |
| Isimba Power Station | Run of river | 100 MW | 2017 |
| Ishasha Power Station | Run of river | 7 MW | 2012 |
| Karuma Power Station | Run of river | 750 MW | 2016 |
| Kiira Power Station | Reservoir | 200 MW | 2000 |
| Mpanga Power Station | Run of river | 18 MW | 2012 |
| Nalubaale Power Station | Reservoir | 180 MW | 1954 |
| Nyagak Power Station | Run of river | 3.5 MW | 2010 |
| Kisiizi Power Station | Run of river | 0.3MW | 2008 |
| Waki Power Station | Reservoir | 5 MW | 2015 |

Lower energy prices and/or alternative renewable energy sources decrease the cost of productive inputs like (bio)-fertilizer, which is an additional benefit to food producers that can be translated into lower food prices. The introduction of clean-burning, reliable, and assessable forms of biofuels into rural villages presents opportunities for welfare gains and provides insurance against external shocks in energy and food prices. Particularly, there are potential time savings, especially for women and children, as well as additional health benefits, through the provision of cleaner, more reliable and easily assessable forms of energy. Use of agricultural wastes for pyrolysis would allow an expansion of land for agriculture and open new markets for farmers. Significant bio-waste materials from agriculture are plant residuals such as straw, roots, leaves, stems, Stover, peels and other residues from fruit, vegetables, crop production and farming. Most straws have significant contents of a wide range of inorganic elements; those are extracted from the soil during plant growth in particular potassium, which is an important plant nutrient. Rice straw contains up to 20% of inorganic elements and is an excellent fertilizer for rice production due to high contents of potassium, nitrogen and silicon. Table 4 shows potential energy production potential for agro-residues.

**Table 4 Energy production potential from agro-residues**

| Biomass | Annual production, $\times 10^3$ t/year | MW average |
|---|---|---|
| Unused bagasse | 590 | 67 |
| Rice husks | 25-30 | 16 |
| Rice straw | 45-55 | 30 |
| Sun flower hulls | 17 | 20 |
| Maize cobs | 234 | 139 |
| Coffee husks | 160 | 95 |
| Groundnut shells | 63 | 37 |
| Cotton seed hulls | 50 | 1 |
| Tobacco dust | 2-4 | 2 |
| **Total** | | **407** |

## 2.2 Water resources

Uganda is richly endowed with water bodies and with potential hydro-energy resources like water falls and dams. Despite this, there is an existing installed capacity of 827.5 MW of the total estimated 2,000 MW potential of hydro-power. Figure 1 below is a GIS map showing the location of the various hydro power plants and their status whether planned or functional. Despite the presence of the various Hydro Electricity Power sources, 18.2% of the general population has access to electricity and the current purchase of electricity stands at 2930 GWh. If fully tapped Uganda has a full hydroelectricity potential of 2 GW amounting to 17,520 GWh in Equation (1). The red outline shows areas that are not covered by any of the HEP projects and yet this is the cattle corridor of Uganda with the largest amounts of bio-material. With the total energy demand of 173,287 GWh in 2015, Hydro-electric power can only carter for 10% of the total energy demand of the country. Assuming 100% electricity access and full hydro potential harnessing, the energy demands out rightly surpasses the energy supply as thus hydroelectricity cannot stand as an independent energy source. With a 3.3% increase both in population and energy demand, the energy demand will increase to 23578 GWh and the HEP will be able to only carter for 0.75% of the total energy demand in Equation (2). Moreover, this analysis does not include the electricity that the country exports to neighboring countries.

$$P(\text{GW}) = \frac{1}{8760} \times E\ (\text{GWh}) \quad (1)$$

$$\text{D} = \text{D}_0\ \text{e}^{rt} \quad (2)$$

Where,

P is Power,

E is Energy demand,

D is .Population after t years

$D_0$ is Initial Population at time t=0

r is Population Growth Rate

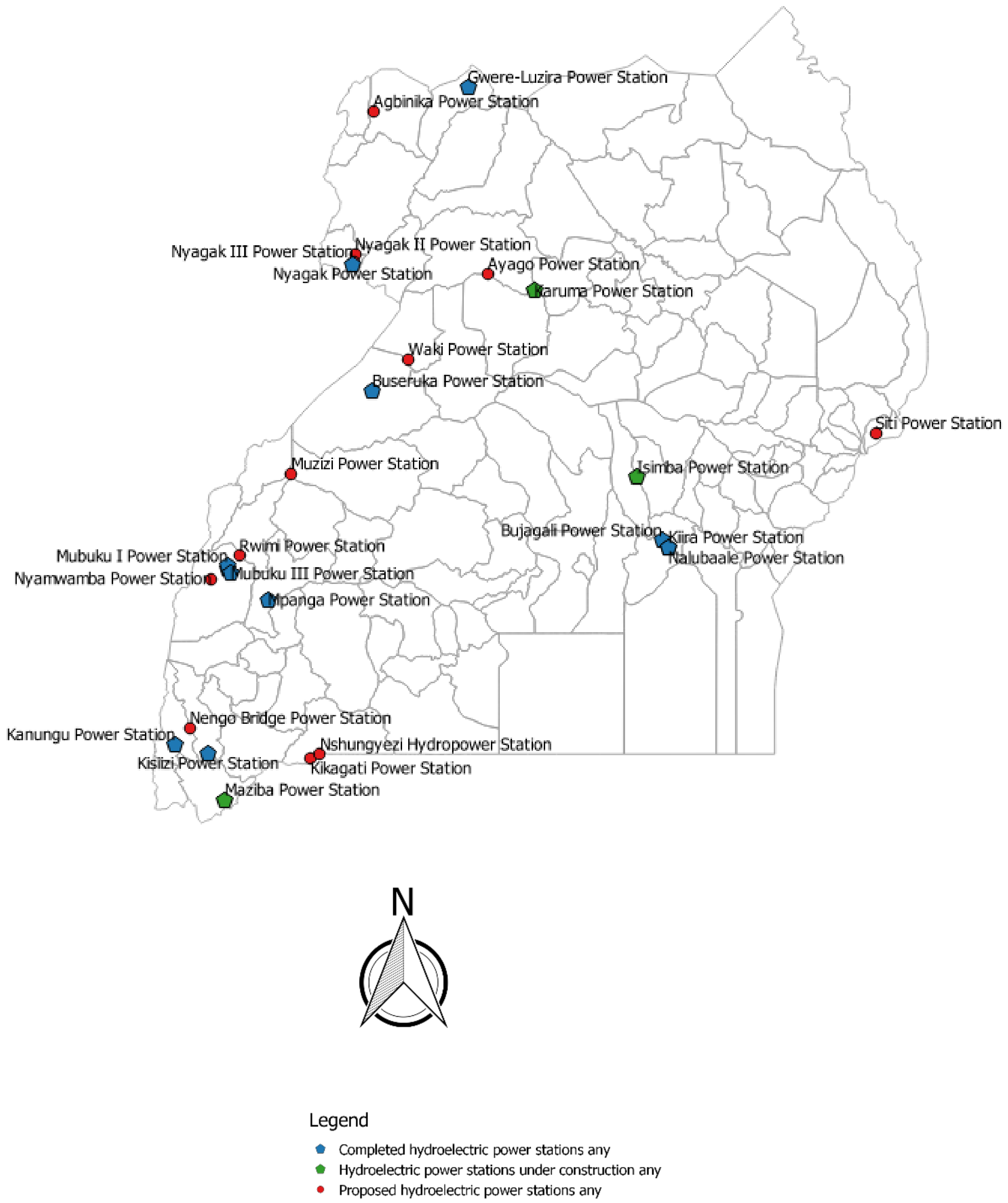


Figure 1 Major Hydroelectricity plants in Uganda with legend showing the state of the plant

### 2.3 Petroleum products

Petroleum products for energy recovery majorly find applications in automobiles and to a small scale in small power generators and light farm equipment. Uganda alone imports 1.28 million cubic meters of petroleum products (UBOS, 2014) with an energy equivalent of 13 GWh which is less than 1% of the total energy demand. To cater for all the energy demands of the country, there is a need to import more over 128 million cubic meters. Despite the fact that Petroleum alone cannot satisfy the total energy demand of the country, it is not a sustainable energy source since it's a non-renewable resource.

### 2.4 Bio Bio-resources

Biomass is the predominant type of energy use in Uganda with 94% of the total consumption. Charcoal is majorly used in urban and semi-urban areas, firewood in the rural areas and in some cases the burning of farm residues for energy recovery. Bio-resources can be subdivided into animal and crop resources.

#### 2.4.1 Animal resources

Uganda is an agricultural country and as thus engages in livestock production. According to UBOS (2014), there are 11.4 million cows, 12.5 million goats, 3.4 million sheep, 3.2 million pigs and 37.4 million chicken. Figure 2 shows a GIS map with the intensity of energy that can be obtained per district if the animal waste in Uganda is collected and energy harnessed from it. With 100% of the animal waste collection and a 3.2% increase in the animal populations will provide 1.535 $m^3$ of biogas which translates to 8.5 GWh per annum. With a 281,869 GWh energy demand of Uganda by 2040, the energy from animal resources using Anaerobic Digestion cannot cater for the energy needs sufficiently. The possibility of animal resources as a standalone technology is thus not possible as it can only contribute to 3% of the total energy demand by 2040.

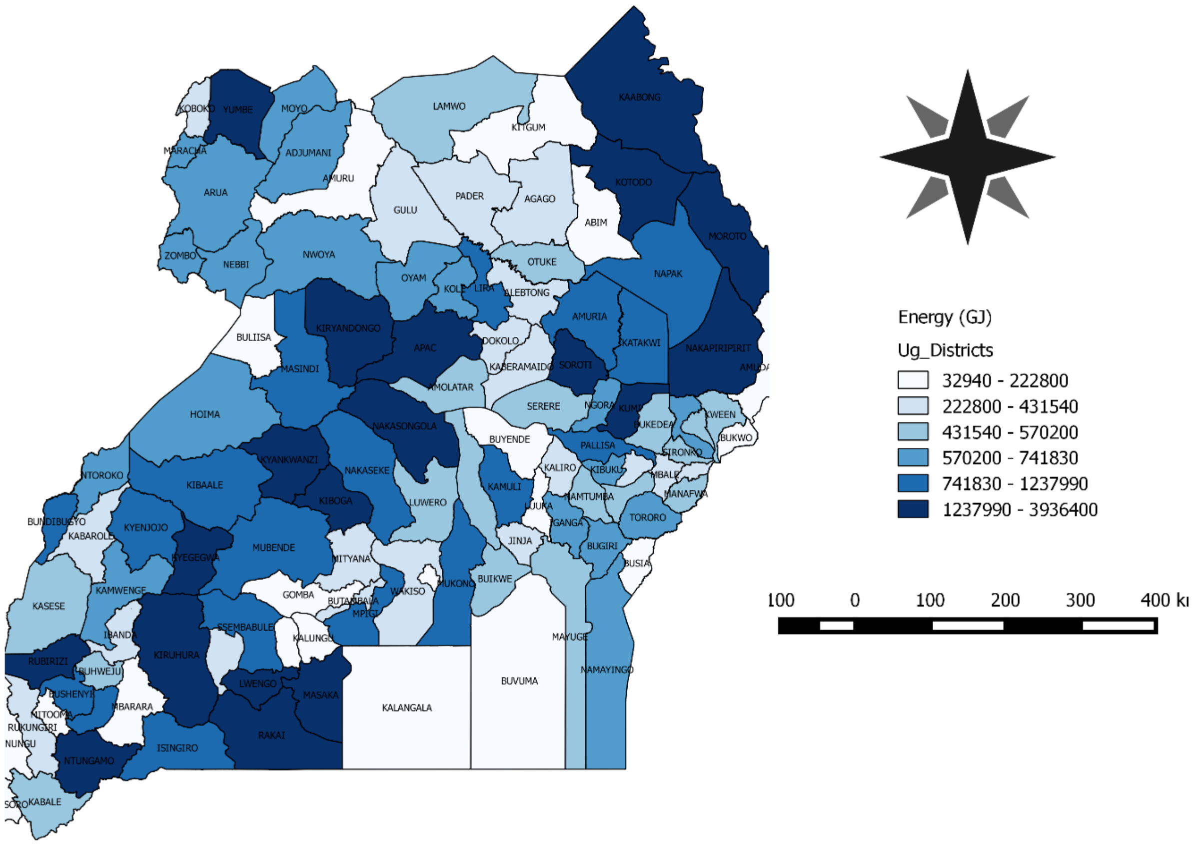


Figure 2 Animal energy potential per district of Uganda

### 2.4.2 Crop resources

Crop resources are the most common energy sources in less developed countries. The energy is mainly used in households and in food preparation by commercial vendors in urban areas. The challenge with the existing energy use is that the efficiency is low. According to Okello et al. (2013) the efficiency is 10%-12% on weight-out to weight-in basis. This suggests that about 9 kg of wood are necessary to produce 1 kg of charcoal, which translates into 22% efficiency on an energy output to energy input basis. There is a need for introduction of improved technologies in order to increase efficiency to achieve 3 to 4 kg of wood per kg of charcoal, which corresponds to 60% efficiency on an energy basis. There is little information about the energy that can be derived from crop resources but because of the high deforestation rates, this alternative is not sustainable. A solution to the deforestation in the pretext of energy is intentional grasses. This includes planting of perennial grasses on land that is rather not suitable for agriculture, harvest the grasses and then use them as energy sources. According to (Jasinskas et al., 2008), The productivity of perennial grasses under good weather conditions ranges between 6.3-8.8 t DM/ha, while under poor conditions between 2.8-6.5 t/ha. The net calorific value of the grass dry biomass ranges from 17.1 to 18.5 MJ/kg and depends on grass composition, growing conditions and cutting time, he further noted that the energy potential of tall-growing grass cultivated on light soils low in humus is 115–153 GJ/ha. This energy source can put the arable land to use while addressing energy issues in Sub-Saharan Africa.

## 3 Proposed waste to energy alternatives

### 3.1 Second generation resources

Much emphasis has been given to the 90% degradable material generated in less developed countries and less attention is allocated to the other waste compositions like plastics. Energy recovery from the first generation sources has been deemed necessary to address the energy demand but the challenge there is competition in raw materials as the first generation sources like corn are food to humans (Naik et al., 2010). Continual destruction of crops in the pretext of being energy sources if not handled with caution will lead to decrease in food supply. The second generation sources like plastics which constitute 2% of the waste generated in Uganda if treated with pyrolysis can produce diesel (Smolders and Baeyens, 2004) which can be used to address a portion of the energy demand. The fuel from pyrolysis of plastic waste has a calorific value of 22-30 $MJ/m^3$ depending on the waste material being processed. It is important to note that 2.8% of the waste in Uganda is hard plastics (Komakech et al., 2014) which are a potential for diesel extraction. According to Van Zwieten et al. (2010), from 1 kg of plastic waste, 1 L of diesel can be obtained. This can lower the reliance on the traditional energy sources. This technology is new for low developing countries as thus no cases have been cited in Uganda as of yet.

### 3.2 Landfill gas generation

When waste is deposited in landfills, the organic matter in the waste decomposes to Landfill Gas which is a mixture of about half methane and half carbon dioxide (Sel et al., 2013). The Land Fill Gas production rate steadily increases while MSW accumulates in the landfill. The gases produced within a landfill can be collected and used in various ways. The landfill gas can be utilized directly on site by a boiler or any type of combustion system, providing heat. Electricity can also be generated on site (Unnikrishnan and Singh, 2010). In Uganda, the major landfill of Kampala the capital city is 11.745 hectares which with a gas yield of 25 $m^3$/hectare (Fennell, 2013) this will yield 293.625 $m^3$ of landfill gas per day. This bio gas yield can contributes to 6 GJ of power (1667 kWh). Despite the potential, this methane has not been harnessed as of yet.

### 3.3 Bio-Methanation

Organic waste when buried in pits under partially anaerobic conditions is broken down under low oxygen conditions to give off methane and carbon dioxide which is biogas. 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 vapor and volatile organic compounds (Tsai, 2007). Biogas, which has 55%–60% methane (Molino et al., 2013), can be used directly as a fuel or for power generation. It is estimated that by controlled anaerobic digestion, 1 tonne of solid waste produces two to four times as much methane in three weeks in comparison to what 1 t of waste in landfill will produce in six to seven years with 100% of biomass collection, (Sharholy et al., 2008) this translates to 6.668 MWh which is approximately 1% of the total energy demand Slurry, the by-products of the digestion process is a bio-fertilizer and soil conditioner, which can be used to improve crop yields (Walekhwa et al., 2009). Figure 3 shows the bio-gas potential of Uganda if all the Organic matter is used as feed stock for digesters. If the energy from organic matter is harnessed efficiently, the energy situation within Sub-Saharan Africa will be improved at least. The government of less developed countries should look forward to bio-methanation technology as a secondary source of energy by utilizing municipal solid wastes. Cases of bio-methanation have been cited within institutions like schools and projects by SNV, Pamoja and CREEC have embarked on biogas projects but the spread is low and non-commercialized.

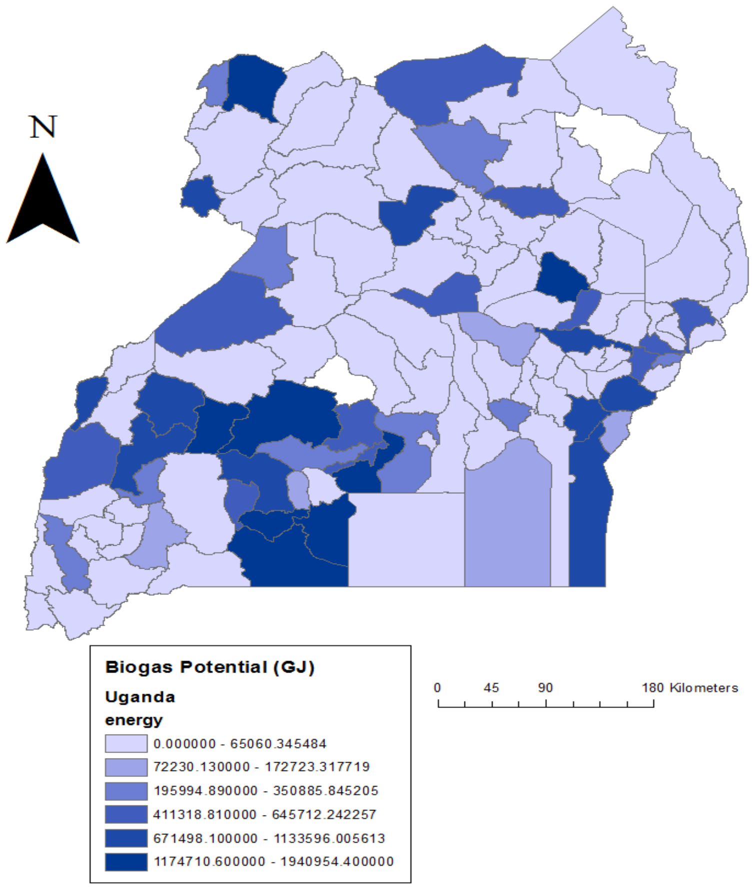


Figure 3 Biogas potential of Uganda per district

### 3.4 Fermentation, pyrolysis and gasification

Thermal treatment of waste is a technology that developed countries have adopted in the form of incineration but this technology is not very much practiced in less developed countries. This may be due to the high organic material high moisture content high inert and low calorific value content in solid waste (Sharholy et al., 2008). Less energy demanding options like fermentation, pyrolysis and gasification are probable alternatives to address the problems. 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 (Faaij, 2006). In Uganda, molasses from sugarcane processing have been identified as a possible raw material for production of ethanol with an estimated potential of 119 GJ (Jumbe et al., 2009) which is (3305 kWh). Kakira Sugar Works in Uganda has adopted the technology of molass conversion to ethanol. The possibility of other biodegradable wastes to be used for ethanol production have been studied and these include pineapple peels (Ban-Koffi and Han, 1990), banana peel (Oberoi et al., 2011) and potato peel (Arapoglou et al., 2010). According to (Kim et al., 2006), an ethanol yield of 0.31-0.43 (g ethanol/g TS) can be obtained. Which translates to an average energy content of 8.3–11.6 (kJ/g TS) could be estimated for ethanol produced from biodegradable waste based on 26.9 MJ/kg energy content of ethanol. This yield despite being low also has a role in curbing down the energy crisis in less developed countries.

Pyrolysis is the thermo-chemical conversion of biomass under limited supply of oxygen at temperatures ranging from 350℃ to 700℃ (Goyal et al., 2008). 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 (Panwar et al., 2012). Fast pyrolysis for production of bio-oil and slow pyrolysis for production of charcoal (Becidan, 2007). Gasification is the partial oxidation of carbonaceous feedstock such as coal and biomass materials, at elevated temperature, into a gaseous energy carrier (Bridgwater, 1995). Gasification takes place when biomass is heated in a gasification medium such as air, oxygen or steam. The product of biomass gasification is a mixture of several gases, collectively called producer gas, or synthesis gas. As both gasification and pyrolysis process work on carbon-based wastes, they are considered appropriate for food wastes. According to Digman and Kim (2008), both pyrolysis and gasification produce a syngas composed mainly of CO and $H_2$ (85%), with a small proportion of $CO_2$ and $CH_4$. Pyrolysis produces 75% bio-oil, of which the heating value is around 17 MJ/kg. Pyrolysis for energy recovery is still under research at the Department of Agricultural and Bio systems engineering Makerere University but preliminary studies show that the technology is sustainable. We can thus appreciate that solid waste offers a good potential for solid waste thermal treatment with the specific aim of power generation.

### 3.5 Densification

Biomass densification is the conversion of loose biomass into high density solid material through application of pressure (Katimbo et al., 2014). 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 utilize. Combustion of loose biomass is associated with low thermal efficiency, and high particulate matter emissions (Chen et al., 2009). 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. Biomass densification could play an important role in improving the utility of the large quantity of loose biomass materials generated. Biomass briquettes from organic matter have energy contents ranging from 4.48-5.95 KJ/g and with the waste production of Uganda that stands at 3.38 MT, this will yield 20 TJ of energy (5,556 MWh) (Manga et al., 2008). Even though briquetting technology has been existing in Uganda for over twenty years the wide

availability of biomass for energy purposes has meant that the extra processing steps

involved in producing briquettes have never allowed it to compete on a commercial scale (Ferguson, 2012).

## 4 Conclusions

Most of the MSW in Sub-Saharan Africa is dumped on land in an unrestrained manner. There is barely any sorting at disposal stage. Such inadequate disposal practices lead to problems that will damage human and animal health and result in economic, environmental and biological losses. Comparing the available treatment options and the energy crisis in the Ugandan scenario, perhaps the energy recovery options get the priority. Uganda as other developing countries is energy deprived and as such sustainable waste management technologies should be implemented for energy recovery. Furthermore, the largest percentage of the waste in Uganda is largely organic presenting for energy generation, as a cheap, available source, which can contribute to increasing energy access and energy consumption and reduce energy poverty. It is imperative to note that waste to energy as a standalone energy source is impossible as the energy yield are low but its coexistence with the conventional energy sources will reduce reliance on the latter. The current use of the abundant biomass is notably at low efficiencies as such more efficient technologies should be adopted to maximize the energy recovery. Uganda should invest in bioconversion technologies at small scale to match with small holder farmers' production and productivity. This will unlock the potential of millions trapped in energy poverty and deficiencies.

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