Rupf, G.V., Bahri, P.A., de Boer, K. and McHenry, M.P. (2015) The energy production potential from organic solid waste in Sub-Saharan Africa.
In: International Conference on Solid Waste 2015: Knowledge Transfer for Sustainable Resource Management (ICSW2015), 19 - 23 May, Hong Kong

THE ENERGY PRODUCTION POTENTIAL FROM ORGANIC SOLID WASTE IN SUB-SAHARAN AFRICA

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ABSTRACT. This paper presents a broad assessment of the energy production potential available from solid organic wastes when treated with anaerobic digestion in Sub-Saharan Africa (SSA). Energy production potentials were estimated by calculating the methane (CH_4) production potential based on data from the Food and Agricultural Organization (FAO), studies done in urban centres on the organic fraction of municipal solid waste (OFMSW), livestock manure, livestock food waste, crop residues normally burned, and crop primary equivalent waste. The total CH_4 production potential of organic solid wastes in SSA was estimated to be 12.8 billion m^3/yr, equivalent to 133 million GWh/yr of heat energy. Given that current domestic biogas programmes in SSA focus on cattle manure as the main feedstock, the large energy production potential from other organic waste streams highlights the opportunity to improve waste management practices through harnessing these abundant waste resources in biogas systems.

Keywords: *anaerobic digestion; solid waste; feedstock assessment; Sub-Saharan Africa*

Introduction

The treatment of organic solid waste using anaerobic digestion has the potential to improve energy access and waste management practices in both urban and rural SSA, along with making a positive contribution to health and the environment. The vast majority of installed anaerobic digesters in SSA treat cow manure and/or human sewage. To date there has been limited research on biogas production potential of other organic waste streams from the agricultural, industrial, and municipal sectors in SSA. In 2007, under the Biogas for Better Life Initiative, 18.5 million households were estimated to have the potential to install domestic, cattle manure fed biogas systems, based on the domestic livestock population, an applied cattle holding factor, and access to water sources [1]. Aside from this estimate, biogas feedstock assessments have largely been limited to a country level. This research paper presents a broad assessment on the biogas and associated CH_4 production potential of organic solid wastes in SSA. The feedstock assessment results will be used to help develop a biogas system model that aims to improve biogas dissemination by identifying optimal anaerobic digester designs for SSA applications.

Material and Methods

Determining the CH_4 production potential from OFMSW

Accurate data on waste management is not available for many SSA countries. To estimate OFMSW in SSA and CH_4 that could be produced from it, municipal solid waste (MSW) figures between 2009 and 2010 were used from studies in urban centres of Ethiopia, Namibia, Tanzania, South Africa, and Nigeria, along with data collected in Mauritius and Botswana from at least 10% of the population [2-4]. Waste generation rates have been found to be influenced by the gross domestic product (GDP) with waste generation increasing in lower income countries as their GDP increases [4]. The study by Couth and Trois [2] found that the waste generation in SSA cities is clearly linked with the GDP of the country, but no direct links were evident with the waste composition. Based on these findings, a per capita GDP range was assigned to each of the seven SSA countries and the per capita waste generation for each SSA country then being approximated to be the same for all countries that fall within the GDP ranges given in Table 1. The regional average of 56% for the organic fraction of MSW was used for all SSA countries where no data was available on the proportion of the generated waste that is biodegradable. Since most of the waste generation data was collected in urban centres, the per capita organic waste generation rate was assumed to be only applicable to the urban SSA population. To calculate the potential CH_4 production yield (MPY) from OFMSW, equation (1) was used with an average biochemical CH_4 potential (BMP) of 360 L/kg organic dry matter (oDM), dry matter content (DM) of 40% and oDM of 82.5% [5-7].

$$MPY(m^3/yr)=m(t/yr)\times DM\times oDM\times BMP(m^3/kg_{oDM}) \tag{1}$$

Table 1. Per capita GDP and GDP ranges, per capita waste generation and OFMSW for selected SSA countries used to estimate the CH_4 potential from OFMSW.

City/Country	GDP (current US$/pp/yr)	GDP range min (current US$/pp/yr)	GDP range max (current US$/pp/yr)	Per capita waste generation (kg/pp/yr)	% organic	Reference
Mauritius	7,586.97	7,501	20,000	475	N/A	[4]
Botswana	6,980.36	5,501	7,000	120	N/A	[4]
Ethiopia[a]	337.40	0.00	450	64	55%	[2]
Namibia[b]	5,113.17	3,001	5,500	242	47%	[2]
Tanzania[c]	509.52	451	1,500	531	65%	[2]
South Africa[d]	7,175.63	7,001	7,500	426	43%	[2]
Nigeria[e]	2,310.86	1,501	3,000	202	49%	[3]

a- Based on data for Addis Ababa and Arba Minch
b- Based on data for Windhoek
c- Based on data for Arusha
d- Based on data for Cape Town and Durban
e- Based on data for Lagos, Kano, Ibadan, Kaduna, Port Harcourt, Makurdi, Onitsha, Nsukka, and Abuja

Determining the CH_4 and biogas production potential from the livestock manure

The FAO provides data on the estimated CH_4 emissions from livestock manure. The livestock production systems applied in SSA differ between the various agroecological zones with humid/subhumid regions being more likely to apply mixed farming systems where livestock husbandry is combined with crop farming and manure is collected for fertilising [8]. Manure collection is most feasible where zero-grazing or night-stabling occurs. Due to an absence of accurate data on the percentage of cattle that are zero-grazed or night-stabled, ter Heegde and Sonder [1] assumed that all dairy cattle were at least kept stabled overnight and applied a land use factor to non-dairy cattle to estimate the number of cattle from which manure can be reasonably collected. For this assessment, CH_4 emissions from the dairy cattle were reduced by half to apply the overnight stabling assumption, resulting in approximately half of the manure being available for collection and use in biogas production. The land-use factor, given in equation (2), was applied to the FAO CH_4 emissions data for non-dairy cattle to account for the estimated non-dairy cattle that are night stabled, and these adjusted CH_4 emissions were then halved. West and East African households commonly also keep other domestic livestock including sheep and goats tethered during the day and in small enclosures overnight, while chickens are increasingly kept in coops [9, 10]. Based on these livestock production trends, the CH_4 emissions from all other livestock were also halved.

$$\text{Land use factor} = (\text{arable land})/(\text{arable land}+20\%\ \text{pastoral land}) \quad (2)$$

Determining the CH_4 and biogas production potential from livestock food waste and crop waste

The MPY of livestock food waste and crop waste was calculated using equation (1) for all the waste types where the BMP was known. Where the BMP was unknown, the potential biogas production yield (BPY) was first calculated by using equation (3), where BP is the biogas potential (volume of biogas that can be produced per unit mass of organic dry matter for specific feedstocks). The CH_4 potential could then be determined based on the known or estimated percentage of CH_4 by volume in biogas. The DM, oDM, BP and CH_4 content for the different types of livestock food waste and crop waste that is normally burnt are given in Table 2. Crop residues normally burnt are the crop residues left over after considering the fraction of residues removed before burning for animal consumption, decay in the field and use in other sectors [11]. Aside from crop residues normally burnt, crop wastes in this research also include crop primary equivalent waste, which includes over thirty different types of vegetables, fruit, nuts and other food crop wastes that are lost at all stages between production and the household (e.g. processing, storage and transportation). For some feedstock types, the biogas yield was found in terms of the volume of biogas per tonne of fresh matter (FM).

$$\text{BPY}\ (m^3/yr) = m\ (t/yr) \times DM \times oDM \times BP (m^3/kg\ oDM) \quad (3)$$

Table 2: DM, oDM, BPY by mass, and CH_4 content by volume for residues normally burnt.

Livestock food/crop waste type	DM	oDM	Biogas potential (m^3/ kg oDM)	CH_4 content by volume	Reference
Eggs	25%	92%	0.975	60%[a]	[12]
Milk, Whole	8%	92%	0.9	60%[a]	[12]
Milk, Skimmed	8%	92%	0.7	60%[a]	[12]
Maize	86%	72%	0.7	60%[a]	[12]
Rice, paddy	38%	83%	0.585	60%[a]	[12]
Wheat	91%	92%	0.41	52%	[13]

a -estimate

Calculating the energy potential from biogas and CH_4 potentials

To determine the energy production potential from OFMSW, the livestock industry and crop waste, the calculated volumes of CH_4 production potential were multiplied by the energy production potential of CH_4 (37.3 MJ/m^3) and converted from megajoules (MJ) to megawatt-hours (MWh). Per capita energy production potential was calculated using 2010 population data from World Bank.

Results and Discussion

The total CH_4 production potential for organic solid wastes in SSA was estimated to be 12.8 billion m^3/yr, equivalent to 133 million GWh/yr of heat energy. Crop primary equivalent waste was found to have the largest net and per capita energy production potential of 73.4 million GWh/yr and 370 MWh/pp/yr, respectively, as can be observed in Fig. 1 and Fig. 2. OFMSW was found to provide significant energy production potentials of 55.9 million GWh/yr and 266 MWh/pp/yr. Per capita, Ghana was found to have the highest energy production potential from organic solid waste out of all the SSA countries with a total of 630 MWh/pp/yr as can be seen in Fig. 3.

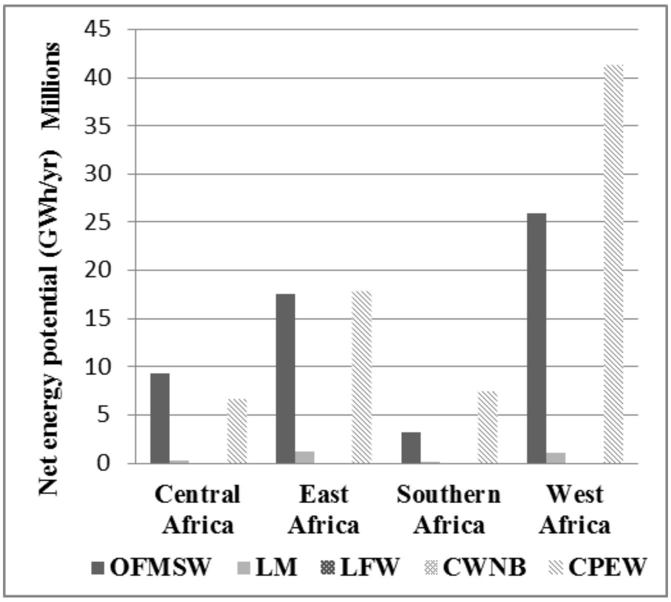

Fig.1. Net energy production potential for SSA region from organic solid waste through anaerobic digestion. OFMSW –organic fraction of solid waste, LM –livestock manure, LFW –livestock food waste, CWNB –crop waste normally burned, CPEW –crop primary equivalent waste.

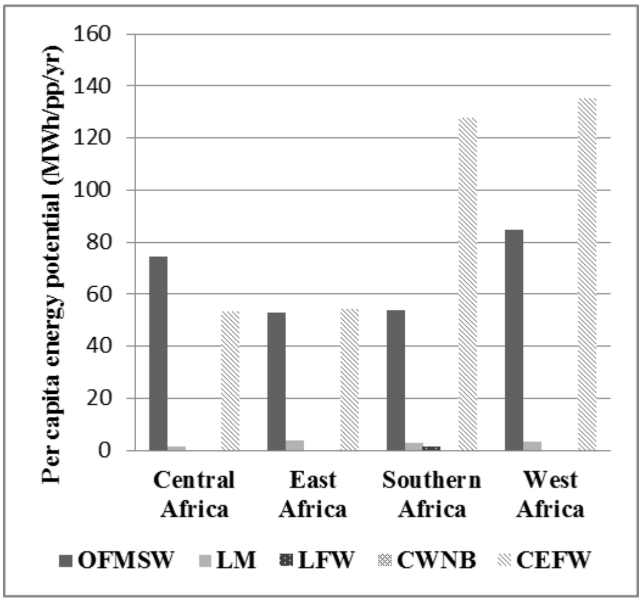

Fig.2. Per capita energy production potential for SSA region from organic solid waste through anaerobic digestion. OFMSW –organic fraction of solid waste, LM –livestock manure, LFW –livestock food waste, CWNB –crop waste normally burned, CPEW –crop primary equivalent waste.

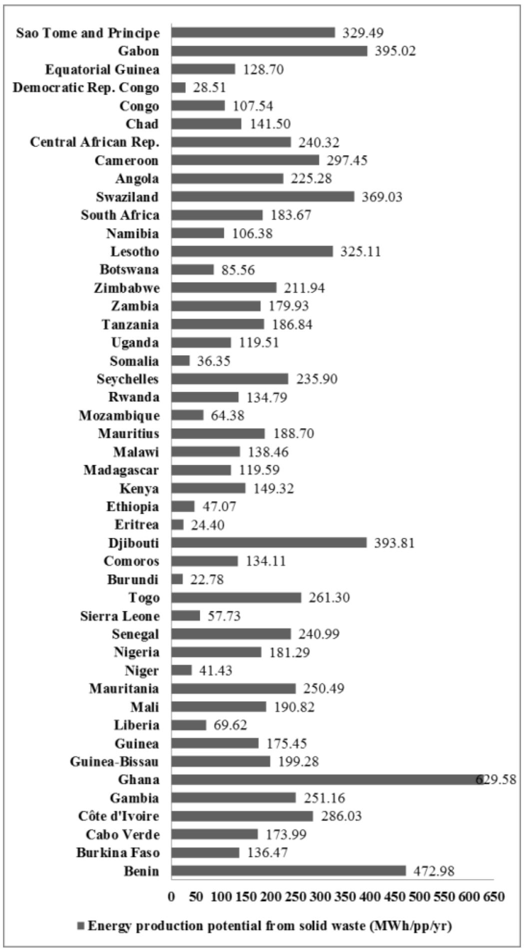

Fig. 3. Per capita energy production potential from solid waste using anaerobic digestion for each SSA county.

Conclusions

This research highlights the opportunity to improve waste management practices through harnessing additional organic waste streams in biogas systems. Increasing the use of anaerobic digestion for the treatment of OFMSW can greatly improve waste management in SSA urban centres and provide much needed energy. The authors recommend further analysis and data collection to determine the availability of the feedstocks and field testing to determine their biogas yield in each SSA region.

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