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Broadening the potential of biogas in Sub-Saharan Africa: An assessment of feasible technologies and feedstocks

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ABSTRACT

This paper aims to provide a broad review and assessment of the feedstocks and applicable biogas technologies that are feasible in Sub-Saharan Africa (SSA). Biodigesters and feedstocks available in SSA were identified according to scale and application – household, community, institutional, and commercial. Aside from livestock manure, suitable feedstocks for household, community, and institutional biodigesters include crop residues, night soil/domestic sewage, and the organic fraction of municipal solid waste (OFMSW). Significant untapped feedstocks exist from SSA agro-processing and food production industries. Biodigesters available in SSA for household, community, and institutional installations include variations of fixed dome, plug flow, and floating cover digesters. Commercial digester designs applicable to the region include continuously stirred tank reactors and fixed film digesters. The key factors that need to be considered in selecting suitable biodigester designs for specific applications include: feedstock availability, water supply, energy demand, local materials and labour, and the level of commitment to operate and maintain the biodigester effectively.

Contents

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1. Introduction

Biogas dissemination in Sub-Saharan Africa (SSA) has focused mainly on using cow dung as the primary feedstock even though a wide range of feedstocks can be used in biodigesters. Agricultural feedstocks include animal manure, crop residues, and energy crops; municipal feedstocks include sewage and the organic fraction of municipal solid waste (OFMSW); and feedstocks from industry include wastewater and residues from food and agro-processing of both animal and plant origin [1,2]. The potential for biogas technology in SSA, extends beyond household scale, animal manure fed biodigesters. Institutional systems in Rwanda demonstrated the potential of biodigesters treating night soil (human faeces and urine) at schools and prisons [3]. In South Africa, the mixed organic waste source fed Bronkhorstspruit Biogas Plant stands as the first industrial scale biogas plant in the country with its expected 4.2 MW electricity production to be consumed by a nearby motor assembly plant [4–6]. For urban centres in SSA, a prototype in Nigeria has demonstrated the potential of converting domestic septic tanks into biodigesters, while a new design of biogas septic tanks has been proposed in Ghana [7,8]. Biogas technology can also play an important role in the safe management of slaughterhouse waste and this approach has been applied in Kenya, Nigeria, and Uganda [9–13]. This paper aims to provide a broad review and assessment of the biogas technologies and associated feedstocks that are feasible in SSA.

2. Rural and urban household potential

2.1. Feedstocks available to households

The feedstocks available to SSA households for biogas production are dependent on the location and socio-economic status of the households. Agricultural feedstocks, particularly livestock manure and crop residues, and municipal feedstocks such as night soil, are common for rural households, while domestic sewage and the organic fraction of municipal solid waste (OFMSW) are the main feedstocks available to urban households. Aside from the estimate of cow dung available for household scale systems conducted under the "Biogas for Better Life—An African Initiative" [14], other comparable country-level feasibility assessments are available for household digesters. For example, the potential number of household digesters from selected assessments are 1.8 million in Tanzania, 175,000-400,000 in Senegal, 110,267 in Burkina Faso, and 216,000 in Uganda [15–18]. Broadening the potential from assessments based primarily on cattle manure and night soil, the FAO provides country specific data on the methane emissions from the management of livestock manure, referring to the emissions from aerobic and anaerobic manure decomposition processes in the capture, storage, treatment, and utilisation of manure [19]. For the whole of SSA the methane production potential from livestock manure (dairy and non-dairy cattle, chickens, ducks, turkeys, goats, pigs, sheep, asses, camels, horses, and mules) is 681 million m^3/yr which is equivalent to 7056 GWh/yr of energy based on 2012 FAO data [19]. The manure from this data can be assumed to be feasible for use as feedstock in biodigesters as it already is collected.

Given that 70% of agricultural production in SSA is subsistence farming and little commercialised farming occurs, much of the methane production potential from crop residues can be attributed to rural households [20]. Crop residues that are normally burned, specifically maize, wheat, and rice from paddies, are estimated to have the potential to produce a total of 15.6 billion m^3/yr of biogas and 9.35 billion m^3/yr of methane for the whole of SSA, equivalent to 96.9 TWh/yr of energy based on 2012 FAO data [21]. The FAO data is given as the total tonnes of crop residues burnt on-site, which is the amount left over after considering the fraction of crop residues removed before burning for animal consumption, decay in the field, and use in other sectors [22]. Sugar cane crop residues are also included in the FAO data, although the methane and biogas production potential from this crop is not considered in this assessment due to the high cellulose, hemicellulose, and lignin content making it unsuitable for anaerobic digestion unless it is pre-treated and co-digested with easily degradable substrates like manure [23–25]. The biogas yields (*BY*) for the crop residues was calculated by applying Eq. (1), with the dry matter content (*DM*), the organic fraction of the dry matter (*oDM*), and biogas potential (*BP*) values of maize, rice, 4mm wheat straw given in Table 1. To determine the methane yields of maize and rice crop residues, it was assumed that 60% of the volume of biogas produced from these sources would be methane, while a methane content by volume of 52% was assumed for wheat [26,27].

Table 1
Dry matter and organic dry matter content, biogas yield by mass, and methane content by volume for crop residues that are normally burned.

Crop type from FAO data	Crop definition for biogas yield	DM (%)	oDM (%)	Biogas yield (m^3/kg oDM)	CH_4 content by volume	Reference
Maize	Maize straw	86	72	0.70	60% (estimate)	[26]
Rice, paddy	Rice straw	38	83	0.59	60% (estimate)	[26]
Wheat	Wheat straw (4 mm)	91	92	0.41	52%	[27]

$$BY\ (m^3/yr) = m\ (kg/yr) \times DM \times oDM \times BP\ (m^3/kg\ oDM) \quad (1)$$

The methane production potential from domestic wastewater is 2.4 billion m^3/yr, equivalent to 25.2 TWh/yr of energy, for households with improved sanitation. Improved sanitation facilities include flush/pour flush systems to a piped sewer, septic tank, or pit latrine, as well as ventilated improved pit (VIP) latrine, pit latrine with slab, and composting toilet [28]. The population with improved sanitation facilities was chosen exclusively to derive this estimate of methane production potential as the sewage from these facilities is most likely to be feasibly collected for anaerobic digestion. The assumed contribution from urban and rural households to the total is 51% and 49%, respectively. In dense urban centres, a community scale biodigester is likely to be more suitable for treating domestic wastewater; therefore, not all of this potential methane production is applicable to household digesters alone. Eq. (2) is applied to calculate the estimated methane production potential from wastewater (MP_{ww}) where U_i is the fraction of the population that is either urban or rural, T_i is the fraction of the urban or rural population that has improved sanitation facilities, *Pop* is the total population, *BOD* is the country-specific per capita biological oxygen demand (BOD) in a given year, B_O is the maximum methane producing capacity, and *MCF* is the methane correction factor, which is an indicator of the degree to which a treatment system is anaerobic [29]. Data on the urban and rural population in 2012 as well as access to improved sanitation was obtained from the World Bank [28]. As the country specific per capita BOD and B_O values were not available for SSA countries, the estimated BOD value of 0.037 kg/pp/day and the default value of 0.6 kg CH_4/kg BOD was used for each SSA country [29].