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Research paper

Long-life performance of biogas systems for productive applications: The role of R&D and policy

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ABSTRACT

In order to achieve the transformations required to realize sustainable development, the use of modern renewable energy has to increasingly take primacy. Biogas technology is one of listed modern RETs but despite its early introduction in Uganda, its adoption rate remains very low amidst high technology failure and dis-adoption. To investigate this, a field-based assessment was conducted to evaluate performance of productive biogas installations with an aim of determining the root cause of this poor performance. It was found out that over 50% of productive biogas installations failed within two years after their commissioning due to logistical and technological challenges. Most installations could not sustain biogas production due to deprived quality of digester feed, and lack of local technical data to utilize alternatives during scarcity of the primary feedstock. Insufficient R&D in the biogas sector is suggested to be the lead cause of such poor performance. Therefore, novel policy strategies for promoting R&D have been proposed in this paper because for success of any productive biogas system, optimization of energy recovery through R&D must be at the forefront in order to drive system outputs to better economic gain.

1. Introduction

In developing countries where cheap alternative fuels like firewood are available, widespread adoption of renewable energy technologies (RETs) largely depends on government's drive to fund technology acquisition, and make them popular to the communities. Through rigorous policy strategies, this is seen as the most feasible way to accelerate reduction in conventional energy usage, which is necessary for sustainable development. Additionally, there is need for robust investment in research and development (R&D), and training to ensure long-life performance and provision of reliable and sustainable energy services to the people. Biogas technology is among the RETs that require such multi-dimensional approach to adoption and sustainability.

Despite Uganda's low biogas technology adoption rate (about 5800 domestic biogas plant installations since technology inception in the 1950's), the same technology is being dis-adopted at a very high rate. A survey by Lwiza et al. (2017) revealed that 79% of households in Luwero district dis-adopted within 3.5 years, while in Mpigi district 29% of households dis-adopted the technology in the first 1.8 years after installation. Nabuuma and Okure (2006) reported 48% failure of biogas plants in central Uganda, of which 80% failed in less than 6 years after construction, yet the average life of a biogas plant is estimated at 25 years (Nzila et al., 2012). Kariko-Buhwezi et al. (2011) also reported a 55% failure of biogas plants in western Uganda in the first few years after installation. Reported causes of failure include among others; lack of alternative feedstock in times of scarcity of cow manure, inappropriate digester operation and maintenance practices, and unfavorable digester operating conditions. Most biogas digesters operate between 18 °C to 25 °C, which is far below optimum of 30–40 °C (Kumar et al., 2013).

Although Maji (2015) suggests that increased utilization of combustible renewables and waste contributes to long term economic growth, this is only possible if the utilization of these renewables is sustainable. Productive biogas could go a long way in accelerating sustainable energy utilization, but in Uganda, this technology has not yet received deserved attention. According to Wehkamp (2013), Productive Biogas aims to provide renewable energy services supporting economic activities of entrepreneurs. Therefore, bottlenecks to adoption and system sustainability such as high installation and operation costs (Mittal et al., 2018; Kahubire et al., 2010), technical & socio-cultural impediments (Walekhwa et al., 2009), and lack of sustainable supply of digester feedstock (Lwiza et al., 2017), could be overcome by promoting productive biogas systems. This is so because the

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productive biogas plant owner expects a return on investment and so the high upfront cost of installation and operation may not be a rate limiting step to adoption. Socio-cultural issues have less to do with productive biogas since the gas generated is not used directly for cooking but rather for running an economic activity which generates income to the plant owner. Potential sites for productive biogas deployments such as commercial dairy farms, poultry farms, abattoirs, and municipalities generate lots of waste, which offsets the risk of feedstock supply.

The purpose of this study therefore was to assess the performance of productive biogas systems in Uganda, and highlight key success factors for system sustainability to influence policy for a better future of Uganda's biogas sector.

2. Materials and methods

2.1. Data collection

Both interviews and experimental tests were conducted to collect data on performance of productive biogas installations. Prior to this, field surveys had been conducted to identify productive biogas installations for assessment in western and central Uganda. Quantitative data was collected from two biogas plants; one in Mukono district utilizing chicken droppings as digester feedstock and the other in Kampala district utilizing slaughterhouse waste as feedstock. The other two biogas plants in Kalangala and Mubende districts provided the qualitative data for this work through interviews with stakeholders. Interviews were conducted with productive biogas plant operators, who gave information related to plant operations, feedstock handling, and plant maintenance. Extended interviews were conducted with plant owners who shared their experiences with biogas technology in Uganda and gave reasons for the observed system successes and/or failures. Experimental tests included digester gas sampling and analysis for quality, digester operating conditions, and gas leakage detection. Gas samples were collected in air-tight gas bags and analyzed with a GA2000Plus digital gas analyzer for composition in order to assess the effectiveness of the digester in methane recovery. Gas leakage detection around the gas storage and the entire gas line was done using a TIF XP-1 Automatic Halogen Leak Detector. This was done to identify possible areas of gas escape to the atmosphere which not only causes loss of energy but also system pressure drops. Digester temperature measurements were taken by dipping a temperature probe into the digester and then reading the temperature on the GA2000Plus digital gas analyzer connected to the probe. Digester substrate samples were taken to the lab and determination of digester pH was done using a pH 3110 SenTix®41 meter for purposes of examining the acidity of the digester and its effect on digestion efficiency.

2.2. Energy policy review and benchmarking

Review of the Renewable Energy Policy for Uganda was done to examine its contribution in promoting biogas technology and energy utilization. Benchmarking with policies for countries that have succeeded in promoting renewable energy utilization such as China and the US was done, to draw lessons and propose policy suggestions that could propel biogas technology to a brighter future.

3. Results and discussion

3.1. Field surveys and assessment

Field survey results show that as opposed to domestic biogas, productive biogas in Uganda is a recent development with very low penetration rate. Most biogas installations are domestic with a few deployments for productive applications, 50% of which were non-functional. In Kampala, interviews with the plant operator revealed that no standard substrate mixing ratio, and no treatment mechanisms are followed during digester operation. The slaughterhouse waste material as shown in Fig. 1, is so fibrous and non-homogeneous, but was being used in its raw form as digester feed.

It should be noted that poor mixing ratio and untreated feedstock greatly affects the quality of the substrate, which in turn affects sustainability of gas production and hence the life of the plant.

In Mukono district, it was also found out that there is no standard substrate mixing ratio followed during operation of the digester. At Okweru Poultry Farm for instance, water is added to the mixing chamber, and using a stick, the chicken droppings are mixed with water until a substrate which is "porridge-like" is formed. While no gas leakage was detected on the gas line, biogas generation was detected at the expansion chamber where the digestate rests before disposal. This gas is left to escape to the atmosphere thereby reducing the amount of useful gas recovered per unit volume of the feedstock. This residual gas could be captured to storage if a mechanism is arranged downstream the digester. Gas quality was found to be low (51.4%CH_4, 46.4%CO_2); an indication of low H_2 and CO_2 utilization by methanogens. Low H_2 utilization causes its accumulation leading to reduction in pH (5.0–5.56), which was far below optimum of 6.5–8.0 (Capri and Marais, 1973; Kumar et al., 2013; Seadi et al., 2008). The measured digester temperature of 25–28.1 °C was also below optimum of 30–40 °C. This could have led to low methanogenic activity thus contributing to low utilization of H_2 (Hori et al., 2006; Lastella et al., 2002). High or low solids concentration which is a result of poor mixing ratio, results in slow digestion and could have also contributed to the poor gas quality registered. For continuously operated digesters, slow digestion means that at predetermined hydraulic retention time (HRT), the organic waste has not been fully digested but has to leave the digester. This causes not only loss of residual gas but also low CH_4 and high CO_2 concentration due to incomplete methanogenic phase.

The biogas plant in Kalangala failed due to failure to utilize alternative digester feedstock. This plant had been installed to produce power for central battery charging and agro-processing, utilizing water hyacinth as the primary digester feedstock. The plant collapsed in 2013, two years after its commissioning. Water hyacinth got submerged in Lake Victoria due to increase in water levels, which caused an acute shortage of the feedstock to date. Similar reasons for plant failure were reported from Mubende district where the productive biogas plant was deployed to utilize elephant grass silage as the primary feedstock to produce biogas for powering a maize mill. Mubende being the leading producer of maize grain in the central region (UBOS, 2017), most households could not afford to plant elephant grass at the expense of maize which generates them income. So the two biogas plants failed due to unsustainable supply of digester feedstock. Alternative feedstock such as chicken litter could have been sourced from the neighboring districts of Masaka and Wakiso, which are leading poultry farming districts according to UBOS (2014). However, in Uganda today, there is no precise technical data to support biogas generation from chicken litter. Chicken litter in Uganda has distinct characteristics caused by deep litter material

Fig. 1. Slaughterhouse waste stacked at Kampala City Abattoir.

contamination including rice husks, wood shavings and coffee husks, which according to Zheng et al. (2014) contain lignin that is resistant to biodegradation. Fig. 2 shows chicken litter snapshot taken from one of the poultry houses in Wakiso district utilizing wood shavings as deep litter material.

Such feedstock requires specialized pretreatment to lessen the effects of lignin for sustainable biogas production.

Although lack of alternative feedstock for biogas generation appears to be the lead cause of failure of productive biogas plants in Uganda, the actual problem is rather lack of technical data to support biogas generation from the enormous biomass resources available. This assertion is derived from the fact that there are a variety of alternative feedstock as is explained hereunder, but their potential for biogas is not yet developed and thus no precise technical data is available for their exploitation.

3.2. Potential feedstock and its potential for biogas generation

Uganda is well endowed with a variety of biomass resources for biogas generation. These include animal waste, chicken litter, organic fraction of municipal solid waste, and slaughterhouse waste. According to statistics, there has been steady increase in the availability of these waste streams over the years. About 1400 ton/day of municipal solid waste (MSW) is collected and landfilled, 90% of which is organic material (KCCA, 2017). This is an alternative feedstock for biogas generation equivalent to about 23 Mm^3CH_4 per year (Achina et al., 2017). In the year 2016, statistics show a tremendous increase in population of livestock especially for cattle and poultry from 2015 (UBOS, 2017). This increase has been steady for the last 10 years and is expected to continue into the future since Uganda is a beneficiary of free trade in the Common Market for Eastern and Southern Africa. Livestock has increased to about 46 Million for poultry (12.3% exotic) and 14 Million for cattle (6.7% exotic), in the year 2016. Exotic cattle rearing mainly targets milk production, and for increased farm outputs, lactating cattle is kept in dairy barns which results into cow dung being collected in a central place and usually in large quantities. The same goes for exotic poultry rearing; the flocks are kept in poultry houses for over 2 years, resulting into central collection of large quantities of poultry litter. The equivalent methane potential for the waste generated is estimated from data published by Noorollahi et al. (2015) and Achina et al. (2017) to be 0.74 Mm^3CH_4 for cattle and 142 Mm^3CH_4 for poultry. The combined total methane potential of 165 Mm^3CH_4 would not only generate about 58 MW_e at 35% efficiency, but also significantly reduce GHG emissions. Uganda's livestock GHG emissions currently stands at 0.01% of global emissions (FAO, 2018). Beef production has also had a steady increase of about 3% per annum in the past 5 years to a tune of 214,000 metric tons in 2016 (UBOS, 2017). Most of this meat is supplied by the two Ugandan Abattoirs, which generate large volumes of waste. With government plan to establish four new Abattoirs, in addition to a multi-billion modern abattoir in the Ugandan cattle corridor by Uganda Meat Producers Cooperative, there is likely going to be extra million tons of organic waste generated.

All the above observations indicate that there is a variety of biomass resources for energy generation, but due to insufficient R&D, their potential for biogas production and use has not been developed. In fact, sustainability of feedstock supply for productive biogas systems would not have been a challenge as it is today in Uganda, if there was readily available data to harness the biogas potential of the available feedstock.

3.3. Policy review

The formulation of the Renewable Energy Policy for Uganda (REPU) in 2007 was an indicator of government's commitment to renewable energy development. But whereas the policy was aimed to achieve 61% of total energy consumption from modern renewable energy, it is not clear how this goal was to be achieved. The policy did not provide energy thresholds for the different renewable energy options, which has led to over-focusing on hydroelectric power development at the expense of other alternatives like biogas, solar and wind energy. Renewable electricity installed capacity increased from 327 MW in 2008 (UBOS, 2012) to about 760 MW in 2016 (UBOS, 2017) but only from hydro resources and bagasse. Although there are other hydroelectric power plants under construction amounting to 783 MW (UEGCL, 2017), which would bring the total installed capacity to about 1.5 GW on completion, it should be noted that this does not directly guarantee a secure energy future for Uganda. This is because renewable power is very sensitive to seasonal and climate change (Wanga et al., 2010). Lessons need to be learnt from 2003 to 2006 when water levels in Lake Victoria reduced due to climate change, and caused an acute reduction in hydroelectric power generation. Therefore, in order to secure the future of energy for sustainable development, renewable energy development should expand its portfolio to equally consider other alternatives. Productive biogas is a viable option since Uganda is well endowed with enormous biomass resource as described in Section 3.2.

Policy formulation should therefore set and explicitly define energy thresholds for every promising renewable energy option. Whereas REPU just states the number of biogas plants to be installed by the end of policy period, China's renewable energy

Fig. 2. Chicken litter comprised of dry chicken droppings and wood shavings.

policy specifies the amount of biogas in million cubic meters that should be realized (NREL, 2004; Wanga et al., 2010). This should be the most appropriate way of defining a policy strategy for biogas rather than just stating the number of biogas plants to be installed. By defining the amount of biogas to be realized, the policy maker is being mindful of the efficiency of energy recovery. Efficiency improvement and sustainability would thus become part of key policy guiding principles, which gives R&D an opportunity to be prioritized at policy formulation and implementation. However, this is not the case for REPU because the policy focus is placed on the number of biogas plants rather than the amount of biogas to be generated.

According to REPU, inadequate attention to R&D was listed as one of the barriers preventing steady growth of renewable energy resource development and utilization. But whereas the policy strategy to allocate funds for R&D in RETs was established, no administrative guidelines for implementing this measure have been published. Policy formulation should influence roll out of a public fund for renewable energy development, which should mainly support R&D since it is at the center of technology development and knowledge transfer. This would improve research and innovation in the biogas sector thereby enriching the local database for energy recovery. Unavailability of local database for biogas generation from Uganda's biomass resources has been cited in this paper as one of the lead causes of poor performance of productive biogas installations, since operators are not able to utilize alternatives in times of scarcity of primary feedstock.

Finally, there is need to strengthen policy incentives for enterprises that generate waste through mandatory renewable portfolio requirements. Business enterprises such as abattoirs, medium–large scale poultry and dairy farms, institutions, and municipalities, should be made legally bound to invest in biogas generation from the wastes they generate to meet a certain percentage of their total energy demand. This is a mandatory system similar to the US's renewables portfolio standards (RPS). In the US, an RPS requires all electricity retailers to show that they have supported a certain amount of their retail load with eligible sources of renewable energy (Galen Barbose, 2018). The retail electric supplier will be penalized if it fails to comply with the requirement. Uganda may consider imposing mandatory renewable portfolio requirements on all enterprises generating substantial amounts of organic waste, but co-own the energy generation facilities and use them as demonstration centers for knowledge transfer. However, there is need to strengthen policy incentives on acquisition of biogas plants. It is important to note that the current tax incentives for investing in biogas generation only apply to imported plastic bag biogas digesters (URA, 2017). However, most biogas digesters in Uganda are locally constructed which renders this incentive to be considered unfavorable. More so, for sustainability of a productive biogas installation, monitoring and control is a state-of-art requirement. For this to be realized additional components such as micro-controllers, buffer capacity regulators and insulators, have to be integrated with the conventional system hence additional cost to the investor. The current tax incentives do not favor these developments either. This repels potential investors. Therefore, there is need to stimulate private participation in biogas investments and compliance with the RPS through custom duty exemptions on biogas plant acquisition including locally constructed digesters, and equipment for R&D. RPS compliant enterprises may be rewarded in a manner similar to tradable renewable certificates offered by the US's RPS. Such policy considerations could help Uganda diversify its energy mix and secure its energy future by shifting its overreliance on hydroelectric power and conventional use of biomass. According to Galen Barbose (2018), RPS policies have been one key driver for renewable energy generation growth.

4. Conclusion

Long-life performance of biogas systems is highly influenced by continuous supply of digester feedstock and quality of digester substrates. The duo must be optimized in order to influence success of a productive biogas installation. R&D provides tangible benefits in this direction and should therefore be prioritized both at policy formulation and implementation. Policy strategies to promote R&D in Uganda's biogas sector have thus been proposed in this paper because without robust R&D, the future of biogas technology remains uncertain, yet it is among the most prospective renewable energy options for such a developing country. Uganda is well endowed with a variety of biomass resources for biogas generation, but to a greater extent the technology has relied on imported data which is not suitable for Uganda's organic waste streams.

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