Journal of Energy Technologies and Policy
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.7, No.2, 2017
www.iiste.org

Towards the Development of a Biogas Database System in Kenya – A Multi-objective Study on Biogas Usage and Potency of Various Agricultural Residues in Kenya

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The research was financed by the Humanist Institute for Development Cooperation (HIVOS) under the REDSEA Project.

Abstract
Kenya being an agricultural based economy produces vast amounts of agricultural bio-waste such as maize/corn stalks, rice and wheat straws, tea and coffee waste, sugarcane, banana and barley residues, sisal and cotton wastes as well as other forest residues. Most of these residues are regarded as of no immediate value hence they are wasted in the farms through burning or uncontrolled decay thus leading to nutrient leakage and eutrophication to the surrounding water bodies as well as contributing to odour and green-house gas emission through release of volatile and un-burnt hydrocarbons. The main objective of the present research was to identify and develop biogas data variables in Kenya through a structured use of anaerobic digestion as a means of producing biogas from agricultural bio-waste including animal manure and crop residues. The short-term target of the research project was a phased development of well defined/structured data variables suitable for a multilayered database system on biogas energy in Kenya, which could later form a basis for the development of a real time biogas information dissemination platform that can be replicated in other regions across Africa. Literature review was done by means of desk study while field surveys were conducted to gather qualitative as well as quantitative data for analysis and uploading onto a Geographic Information System (GIS) based data mapping. Direct interviews were based on a schedule that employed a combination of direct site visits, emails and phone calls. Laboratory-based physical/bio-chemical characterization of biogas feedstock was also conducted. Discussions with diverse biogas stake holders elicited 100% support from respondents in addition to yielding an array of recommendations. The bio - methane results further demonstrated the suitability of coffee pulp residue, cotton residue and maize stover as complementary biogas feedstock. The biogas quality in terms of hydrogen sulphide (H_2S) and methane (CH_4) content was quite promising. The biogas H_2S content (ppmv) for all the substrates ranged from as low as 105 (for maize stover) to 1100 (sugarcane leaves) whereas the CH_4 content varied from 40% (sugar cane leaves) to 62% (cotton residue). Generally CH_4 content is required to be above 50% whereas the presence of contaminants such as H_2S is supposed to be less than 1000ppmv. From the results, biogas from coffee pulp residue, sugarcane bagasse, maize stover, cotton residue and banana stalks can be recommended as suitable alternatives for domestic biogas production.
Keywords: Biogas database, residue potency, energy, Kenya.

1. Introduction

Energy plays a central role in national development process as a domestic necessity and hence a major factor of production. However the non-sustainability of conventional energy sources and their negative environmental impacts have necessitated a paradigm shift in energy issues and as such contributed to an increase in global interest in renewable energy technologies. Renewable energy is undoubtedly regarded as the foundation of sustainable development and its benefits in the realms of social, economic and environmental protection have been globally acknowledged.

Anaerobic digestion is considered to consist of a series of stepwise reactions which are catalysed by mixed groups of prokaryotes i.e. bacterial species and Achaea, through which organic matter is converted to methane and carbon dioxide (Deublein and Steinhauser 2008, Ranalli 2007). Biogas technology has not been fully exploited in both energy and economic strategies within the African continent (Nzila et al. 2010). In East Africa, the technology has continued to lag behind since the first biogas plant was introduced in 1950 and is still at infancy due to economical factors as well as inadequate knowledge resulting in overreliance on animal dung as the principal digester feedstock. Basing the overall biogas potential on livestock numbers alone does not present the true potential of a given region since various other substrates such as grass, abattoir residues, market waste, potato waste and food leftovers (Ranalli 2007) post better biogas potential than animal manure with its reported biogas potential of only 2-45 m^3 per tonne (Reith 2003). Kenya being an agricultural based economy produces vast amounts of agricultural waste such as corn stalks, rice and wheat straws, tea and coffee waste, sugar cane, banana and barley residues, sisal and cotton wastes as well as other forest residues. However, most agricultural residues are wasted in farms, leading to nitrogen leakage and eutrophication (Lehtomäki, Viinikainen et al. 2008) as well as contributing to odour and Green House Gas (GHG) emission through release of volatile and unburned hydrocarbons (Keppler, Hamilton et al. 2006). While various databases have been developed in the last decade (UBA 2007, CPM 2007, JEMAI 2007, Narita et al 2004, NREL 2004, RMIT 2007, Ecoinvent 2007, European Commission 2007), their close analysis reveals a need for their upgrading to incorporate more detailed data.

2. Problem Statement

The energy potential presented by available biowaste materials is yet to be fully exploited in spite of the growing interest in biogas production. Most agricultural biowaste are wasted in the farms through burning or uncontrolled decay thus leading to nitrogen leakage and eutrophication in the surrounding water bodies as well as contributing to odour and green house gas emission through release of volatile and unburnt hydrocarbons. The implementation of large-scale biogas technology in Kenya has continued to be hindered or slowed by; economical, technical, social-cultural, institutional, political and information - oriented constraints. While each of the constraints has its unique influence, the apparent lack of structured information is deemed to be one of the major bottlenecks for successful adoption of biogas technology. There is therefore a need for a concerted and coordinated multi-faceted approach to establish a locally designed knowledge exchange service. Such a service can provide the necessary biogas technology information that can inform the decision makers besides facilitating in monitoring and evaluation exercises, promotion and raising awareness pertaining to the accruing benefits and resultant impacts. A database system containing important information and data on biogas technology and feedstock such as agricultural residues and their biogas potential can serve as a one stop source of information for donor agencies, policy makers, consumers, local population as well as the academia.

3. Research Objectives

Through bio-chemistry pathways of anaerobic digestion and methane gas production, Biogas Value Chain (BVC) offers many possibilities to stabilize and add value to low value organic material thus producing clean energy and organic fertilizer in the form of methane and nutrient rich digestate, respectively. Besides, BVC bring about a net reduction of greenhouse gas emissions because methane emissions that would otherwise result from land filling as well as uncontrolled decay of biowaste are avoided (Nzila et al. 2010, Taherzadeh and Karimi 2008). The purpose of the research was therefore to contribute towards the creation of a biogas database in Kenya. Thus, the objective of the present research was to study the potency of selected agricultural residues in terms of biogas production and quality analysis. In addition, the research sought to review the existing biogas database systems as well as to survey biogas usage in Kenya.

4. Research Methodology

The scientific methodology employed in the research consisted of an integration of desk study, field survey (collection of data through site visits and questionnaires) and laboratory analysis of various plant residues to establish or confirm their potential for yielding biogas through the anaerobic digestion process.

4.1 Experimental Procedure

The test substrates consisted of agricultural biowaste from maize stalks, coffee pulp residue, cotton waste, sugarcane leaves and banana stalks. All the agricultural biowaste samples were collected from different farms in Kenya. The samples were chopped and air- dried at ambient conditions to average equilibrium moisture content of 10% (±1.5). The variables analysed during the course of screening the different biowaste for energy production and nutrient recovery included Dry Matter (DM), Volatile Solids (VS), Methane (CH_4) and Hydrogen sulphide (H_2S). The experimental set up for the BMP assay consisted of 20L and 1L mini laboratory digesters reported by Nzila et al (2008).

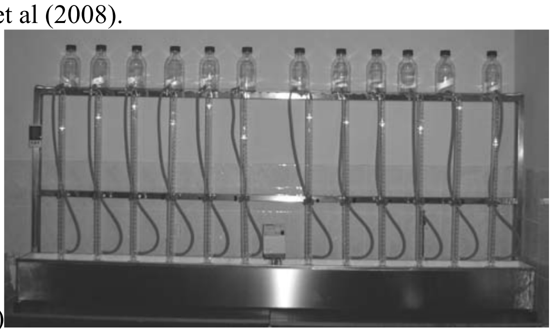
(a)  (b) 

Fig 4.1 (a) Mini digester for biogas production, (b) Gas detector

The inoculum used was a sludge mixture consisting of active suspended digested cow dung and anaerobic granular sludge. The digested cow dung with 5.0 % DM and 67.0 % VS in DM was obtained from a local mesophilic cow dung-based biogas digester whereas the granular sludge with 16.2 % DM and 77.5 % VS in DM originated from the sediments of a mesophilic anaerobic lagoon treating paper mill effluents. The

Substrate to Inoculum ratio (S/I ratio) on VS basis was kept at 0.6 to guarantee adequate presence of hydrolytic and methanogenic microbial populations.

4.2 Analytical Procedure

The parameters analyzed during to the course of the research included DM, VS, pH, gas volume and gas composition in terms of CH_4, CO_2 and H_2S. The gas volume in each reactor was measured daily through downward displacement of a water column while the pH, and gas composition were measured weekly. The characterization of the substrates in terms of DM, ash and VS were performed according to standard methods (Nzila, 2010). Gas composition was determined with a *Fisons Instruments GC* 8000 series equipped with two columns connected to a thermal conductivity detector that is a *Molsieve* column (30m X 0.53 mm X 10 µm) for measuring O_2, N_2 and CH_4 and a *Parabond Q* column (25m X 0.53mm X 10µm) for measuring CO_2. Helium was used as the carrier gas. The temperatures of the oven, injection port and flame ionization detector were 40°C, 110°C and 99°C respectively. The H_2S content was analyzed using *Antek Instruments GC 7000* series equipped with sulphur chemiluminescence detector. The oven and back inlet temperatures were 120 and 150°C respectively. All analyses were performed in duplicate.

5. Results

The results described below generally present a detailed development and selection of biogas energy database variables for Kenya as well as characterization and mapping of complementary biogas feedstock in Kenya.

5.1 Desk Study Results

5.1.1 Biomass-oriented Databases

During the desk study, three publicly accessible databases containing information about biomass were identified. These were:

- CROPGEN database - http://www.cropgen.soton.ac.uk/,
- ECN Phyllis & BIODAT - http://www.ecn.nl/phyllis/
- US Department of Energy biomass database - http://www1.eere.energy.gov/biomass/feedstock

Studies on databases focused on identifying the variables used in existing databases and critical success factors necessary for setting up of a biogas energy database. While the Cropgen database focuses on information relevant for anaerobic digestion (AD), the latter offer relevant information on thermal, biochemical, thermo chemical conversion of biomass to biofuels. Clearly, the parameters used for the three databases vary – the Cropgen database is focused on data relevant for AD only and it does not give details of ash content (as ECN Phyllis database intends). Moreover Cropgen does not go into hemi cellulose structure, while both ECN Phyllis and US Department of Energy database do. Generally database containing Bio Methane Potential (BMP) information is necessary in case biomass is to be used as feed for AD reactors. Substrate analysis has to be regularly done in order to provide constant and optimal feed to AD reactors. Moreover, standard units ought to be used for variables employed in the biogas database whereas differences in data documentation, choice of data variables and nomenclature should be minimised so as to facilitate data retrieval and exchange.

5.1.2 Methane Potential

Apart from the large databases mentioned, there are some reports and articles dealing with specific biomass information. The GTZ (2010) report dealing with biogas potential in Kenya gives an overview of theoretical data on biogas potential. An extensive review of BMP of different biomass using anaerobic digestion can be found in the review article of Gunaseelan (1997) where the writer identified biomass with the highest methane yields (m^3 /kg VS) - organic fraction of municipal solid waste (0.390-0.430). Furthermore the author listed fruit, vegetable and grass species as offering high methane yield.

5.2. Field Survey

5.2.1 Selection of Biogas Energy Database Variables for the Research

A combination of open-ended and closed-ended questions was employed to generate information from stakeholders. Discussions centred on identification of variables or datasets for the establishment of a renewable energy database system in the country. From the questionnaire responses, the following came to light:-

i) General awareness

In the Central Kenya region, about 85% respondents learnt of biogas from their relatives, friends and or biogas users who already had installed biogas facilities. The remaining 15% of the respondents learnt from groups promoting use of biogas like GTZ, livestock settlers, CBO's who were the initial propagators of the concept. On the other hand in the Western Kenya region, 14 out of 23 respondents (about 61%) learnt of Biogas from their relatives and friends who already had started using biogas. However, 9 respondents (about 39%) got information from Energy Centres and Community Based Organisations (CBOs) that worked in their areas of residence. It is therefore apparent that the flow of information from the users of biogas to potential users is vital in the adoption of the biogas technology. Between the Western and Central regions it is apparent that the information flow from biogas users is significantly higher in Central than in Western. Although the foregoing could be explained by the fact that the concept of biogas usage is older in the Central Kenya region compared to Western region, it is important to put more strategies in place to enhance information flow on biogas technology.

ii) Motivation to adopt biogas technology

In the Central region, 30 respondents (91%) were motivated by the accruing benefits enjoyed by their neighbors and friends who had installed digesters; like reduced energy costs, reduced pressure to use firewood and charcoal, and the multiple benefits from the animals. The remaining 3 respondents (about 9%) were motivated through training as pioneers of the technology. Moreover, the training and part of the facilities were being offered free of charge to them. In the Western region, motivation to use biogas was based on the following: 13 respondents (about 57%) constructed biogas because they wanted to save on costs of fuels, however 8 respondents (about 35%) sited environmental reasons in that they wanted to reduce carbon emissions. In addition 2 respondents (about 1%) were actually trained biogas masons who opted to embrace the technology.

iii) Choice of capacity

Concerning the size of biogas plants, in the Central region, 29 of the respondents (about 88%) did not have concrete information of the sizes of their digesters. They decided on the size based on what they had seen from friends or the advice of their digester constructors. The remaining 4 respondents (mainly owners of large size digesters) who form 12% indicated that when deciding on the size of digesters to construct they balanced between their energy needs and the available source of biogas feedstock (animal manure). In the Western region, all the respondents indicated that the sizes of their digesters were in principle influenced by the technicians who performed needs assessment against the available feedstock in deciding the size of the biogas plant. In reality many of these respondents didn't have any information on the different sizes of biogas plants available.

iv) Choice of type

In Central region, for all the 33 respondents, the type of digester adopted depended on who was promoting the technology or what they had seen from friends or recommendations of the digester constructor. The main types of installed biogas plants were the floating drum type and the fixed dome type. In Western region, the technician's knowledge majorly determined the type of biogas plant because they only constructed based on what they were trained on. Most initial biogas plants were the floating drum type, which were constructed under the GTZ and Ministry of Energy programs. New plants from 2007 onwards have been under the Kenya National Domestic Biogas Program (KENDBIP). One respondent actually has installed both the floating drum type and fixed dome type.

v) Choice of raw material

In the Central region, all the 33 respondents use cow dung slurry mixture as raw materials. However, among them, 2 respondents some times also add pig dung to the cow dung and they indicated that the pig dung produced more biogas compared to cow dung. Similarly in Western region, all respondents used cow dung apart from one respondent who sometimes added chicken droppings to the cow digester.

vi) Uses of biogas

100% of respondents in the Central region indicated that they use biogas for cooking. However, among them, 12% also use it for lighting. Similarly in the Western region, 100% of the respondents use biogas for cooking, but amongst them, one respondent intends to use it for lighting besides selling the excess biogas to the neighbors. All the respondents contacted both in the Central and Western Kenya regions reportedly used the digester by-product as organic manure. They concurred that this manure was far superior to raw organic manure obtained from the animal shed probably because it was already stabilized hence it does not cause damage to plants. Moreover, the respondents indicated that the digester by-product attracted less caterpillars, white ants and similar insects besides having a higher water content and hence sustaining the crops better especially during the dry weather.

vii) Alternative sources of fuel

From Central Kenya region about 97% of the respondents used firewood or charcoal for cooking prior to being introduced to the biogas, while about 3% used firewood and gas. Besides among the 12% of the respondents who use biogas for purposes of lighting purposes in addition to cooking, 75% initially used kerosene while 25% alternately used electricity and LPG gas prior to turning to biogas. All the respondents from Western region used firewood or charcoal for cooking prior to installing biogas, but among them, 52% also used kerosene, electricity or LPG gas in addition to firewood and charcoal.

viii) Digester functionality

About 85% or 28 out of 33 respondents from the Central Kenya region apparently answered NO to this question, while 5 (about 15%) answered YES. However even the affirmative respondents had no objective method or technique for measuring the excess quantities of biogas produced but they indicated they noted bubbles of gas from the digester by-product, especially in the mornings. In the Western Kenya region, 5 respondents (about 22%) responded YES. However, this question had limited answers because all the respondents didn't have any measuring unit to determine the amount of biogas produced. However they answered in relation to their daily needs. Others did not know how to tell if there is excess gas produced. All the respondents from Central Kenya and Western Kenya regions who responded 'YES' to having excess biogas reported that they had difficulties to determine and ascertain the quantity of excess biogas since they did not have measuring appliances.

ix) Challenges in biogas production

About 79% of the respondents from Central region indicated that they did not experience any problems with their biogas digester while 21% reported leakage or blockage related problems that led to reduced biogas quantities either due to age of digester or poor workmanship. Plastic pipes were reported to leak especially those exposed to sunlight for long. On the other hand, about 26% of the respondents from the Western Kenya region indicated that they did not have any problems with their biogas plants. However 17% reported that they experienced low gas production while the rest (i.e., 57%) reported that they had technical issues like formation of scum, wearing out of the drums and lack of follow ups by the technicians. Among those who had technical problems, 77% managed to have the problems solved after technicians were contacted however 33% abandoned further use of their biogas plants. From the foregoing, it is evident that the ability to obtain after-sale service is essential for the sustainability of biogas technology.

x) Information dissemination and sustainability

On the subject of development of a web-based database system dedicated to biogas giving an assortment of up-to-date free information on biogas, all respondents from the two regions responded positively and indicated that the content would be useful to them. They all indicated that the information would be valuable especially given that there is no consolidated information about biogas in the region. When explaining how the content would be of use to them, all the respondents said that the information would help potential digester investors to make informed decisions, use the contacts availed for consultations on repair and construction of digesters as well as in choosing the best technology. They also indicated that the information would assist them to get technical and technological assistance in biogas production. With respect to other content that should be included in the database, all the respondents from the Central region in addition wanted the economic benefits and convenience of using the biogas, and the materials suitable for construction documented. Moreover 18% of the respondents also wanted the quality of the feedstock emphasized as a key point for performance of the digester. On the other hand, from the Western Kenya region, 74% of the respondents were not sure of which additional content that could be incorporated however, the other 26% wanted the contacts of technicians and different experiences of other farmers around the country who use biogas to be incorporated in the envisaged database.Pertaining to Internet access, all the respondents indicated that they have Internet access in one form or another. In Central region 12% of the respondents had direct Internet access while the reminder indicated that they make use of their relatives or workers who can access information for them if and when need arises. On the hand, Internet access by the respondents from Western was rather high with 78% indicating that they had internet access either directly or by proxy i.e., using their children to obtain information for them from the internet. All the respondents with access to Internet indicated that they used it principally for information and communication.

During the course of the discussions it emerged that there is an overwhelming demand for a kind of a service where stakeholders such as biogas plant owners can contact in case of a need for help as depicted in figure 5.2.1.

Figure 5.2.1 Common problems with biogas plants in Western Kenya; low biogas production/gas leakage (left) and structural collapse (right)

The envisaged biogas database system was therefore viewed as a possible key component that can directly link the biogas plant owners with different service providers through the provision of an online help-desk service. In general, the following were highlighted as some of the data that could be captured in the database:

- A simplified presentation of biogas technology and its advantages
- Suitability of different feedstock for biogas production
- Inventory of bio-digesters in the country
- Constraints/challenges in adopting bio-gas technology

- Inventory and profile of the stakeholders in biogas technology such as government line ministries, institutions, NGO's, associations, companies, contractors, etc
- Achievements of the different stakeholders over a given period of time
- Inventory of on-going/finished biogas projects
- Sources of funding and technical assistance
- Government financing mechanism for biogas projects
- Tax exemption information for different appliances
- Biogas quality standards
- Appliance manufacturers and distributors in the region
- Biogas bulletin, manuals or fliers detailing biogas reports, statistics, latest research news etc.
- Provide links to environmental bodies, CDM, line ministries/ organizations, Facebook/twitter etc.

5.3 Potential Biogas Feedstocks in Kenya

The information was obtained from the Ministry of Agriculture Headquarters (Kilimo House) and any data gaps filled by collecting the relevant data from Provincial Crop Development Officers (PCDOs) located at provincial headquarters in the country. Generally data on crop area and production are collected by Frontline Extension Officers (FEOs) at the sub-location level and transmitted upwards ending up at the Ministry's Head Office for aggregation. The averaged crop production data for the period 2005 – 2010 were analysed for maize, coffee, cotton, sugarcane and bananas and the resultant residue production were computed using the corresponding Residue to Produce Ratios (RPR) and Dry Matter (DM) content. The RPR based on the ratios of respective crop produce and the residue generated was determined according to Nzila et al (2010). As shown in Figure 5.3.1, there is a large differentiation in the mean annual residue production and yield from maize, coffee, cotton, sugarcane and bananas for the period under consideration with maize and sugarcane showing the highest annual residue production (Tons/yr) whereas sugarcane and banana shows the highest residue yield (Tons/ha). For the period under consideration, Rift valley region was the leading producer of the crop residue followed by Nyanza and Western (Figure 5.3.2). North Eastern and Nairobi are the least producers of residue.

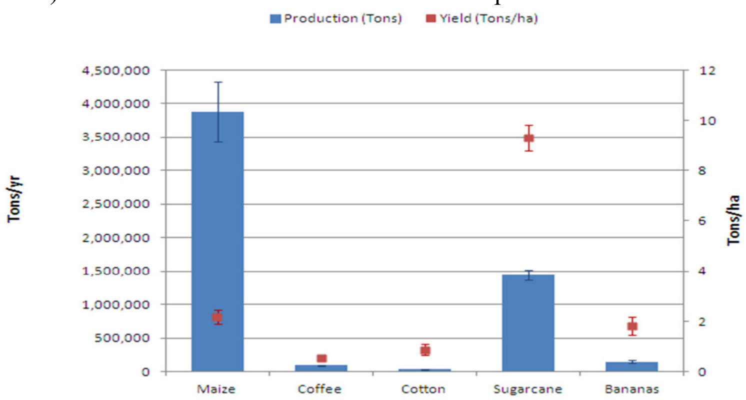


Figure 5.3.1: Countrywide mean crop residue production (Tons/yr) and yield (Tons/ha). Error bars represent 95% confidence limit (n=5 years)

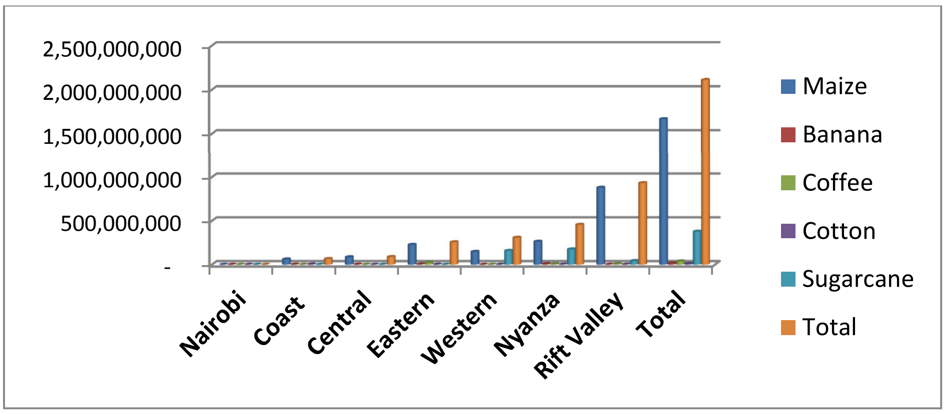


Figure 5.3.2: A comparison of the crop residue based biogas energy potential for selected streams in different

regions of Kenya

5.4 Feedstock Biogas Analysis

Biogas is a product of biological transformation of organic matter by means anaerobic digestion. High methane content is widely regarded as major indicator of biogas quality while the presence of contaminants such as hydrogen sulphide (H_2S) diminishes the quality of the biogas (Ranali 2007; Yadvika 2004). The biogas quality from the different complementary biogas feedstock flows in terms of methane content (%, volume) and hydrogen sulphide content (ppmv) is presented in Figure 5.4. The results demonstrate significantly varying levels suitability of cotton residue, maize stover, coffee pulp residue, and sugarcane bagasse as substrates for biogas production. From the results it is evident that cotton residue had the highest biogas quality while sugarcane leave residues had the lowest biogas quality. Generally, the biogas H_2S content (ppmv) for all the substrates ranged from as low as 105 (for maize stover) to 1100 (sugarcane leaves) whereas the CH_4 content varied from 40% (sugar cane leaves) to 62% (cotton residue) as depicted in Figure 5.4. Generally, one of the major contaminants of biogas is H_2S commonly ranging from 2000 – 20000 ppmv depending on the pH value and sulphate concentration of the substrate (Schieder, Quicker et al. 2003). The presence of H_2S in the biogas renders it "sour" that is malodorous and corrosive besides causing SO_2 emissions during combustion. Consequently for domestic applications such as in lighting and combustion in burners and boilers, the H_2S content is required not to be more than 0.1% or 1000 ppmv (Ranalli 2007; Amrit, Jagan et al. 2009). Removal of H_2S (desulphurisation) from the biogas, normally by means of caustic scrubbing or iron sponge beds, is required so as to render the gas suitable as a fuel (Jensen and Webb 1995). In this regard, the biogas from coffee pulp residue, sugarcane bagasse, maize stover, cotton residue and banana stalks can be regarded to be suitable for direct domestic application since it is within the required limit for H_2S content. On the other hand the biogas from sugarcane leaves is deemed to be about 10% above the allowable limit for domestic applications and hence might require desulphurisation prior to any combustion.

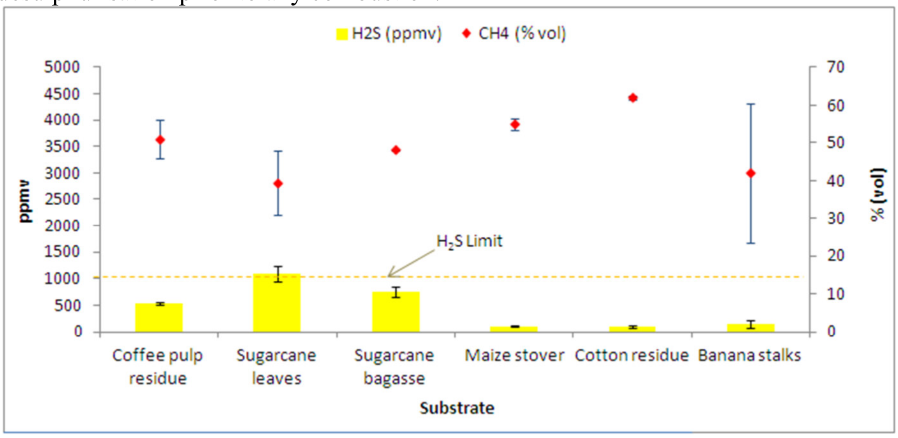


Figure 5.4: Biogas H_2S content (ppmv) and CH_4 content (%, vol.) from different substrates

6. Conclusions and Recommendations

6.1 Conclusions

Kenya produces huge amounts of agro residues such as maize stover, banana stalks, rice and wheat straws, tea and coffee waste, sugarcane leaves and bagasse, barley residues, sisal and cotton wastes, etc but the energy potential they present is yet to be exploited despite the growing interest in biogas production. It is possible to mitigate the global energy crisis in a sustainable way through innovative use of the available agricultural residues as supported by the general adaptation of biogas usage in the surveyed regions. The great number of farmers keeping dairy cattle especially those who have adopted the zero-grazing practice, dictated by the small land size, underlines this.

The core idea of the research was to identify ways and means of connecting the biogas end user to a pool of freely available well-structured information database to bridge apparent knowledge gaps. From the questionnaire responses, all the biogas plant owners were not aware of any other potential biogas feedstock apart from animal droppings! Also, it was apparent that there exist certain challenges pertaining to the determination of the amount of biogas produced.

Generally all the respondents outlined the following as benefits of using biogas: clean ready energy, conservation of trees otherwise used as firewood before, improved hygiene since every farmer can boil water for milking gear, and cook food properly without worrying about energy costs. Although a large percentage of the interviewees appeared not have direct Internet access, their motivation to use relatives or their children to access information on their behalf denotes their desire for information hence further reason why they readily accept new green energy technologies with ease. In addition it was noted that virtually all the interviewees had direct access to mobile phones, which in essence presented another avenue for conveyance of information. Moreover all the respondents acknowledged the positive contributions they were reaping from the good quality of organic manure that they obtain as by-product of the digester.

Generally, database containing BMP information can work best in the case where biomass (including animal waste and agro residues) is used as feedstock for biogas digesters. However regular analysis of the feedstock is recommended in order to provide constant and optimal feed to the biogas digesters.

Natural variability in biomass can be reduced if the data offered in databases is representative for the geographical region of the intended use. In addition it is essential for a biogas database system to package and present user-oriented data that is specifically derived based on the specific needs of the end users. Some of the key information that stakeholders recommended to be captured in the database includes:

- Downloadable brochures and fliers on best practices in biogas production.
- Published works and on-going projects/research on biogas energy.
- Profiles and links to various biogas stakeholders.
- General biogas production inventory.

The residues from maize, cotton, coffee, banana and bagasse demonstrated excellent suitability as complementary feedstock for biogas production. A system for promoting the use of the complementary biogas feedstock is therefore highly recommended. The results of this study demonstrate that coffee pulp residues, maize stover and cotton residues are most suitable for biogas production. Pertaining to biogas quality in terms of H_2S content, the biogas from sugarcane leaves is deemed to be just above 1000 ppmv which is the upper limit for domestic applications, hence it might require desulphurisation prior to any combustion. On the other hand, biogas from coffee pulp residue, maize stover and banana stalks proved to be suitable for direct domestic application since it is within the required threshold of H_2S content.

6.2 Recommendations

There is an imminent need to bridge the existing gap presented by the apparent lack of a detailed database system dedicated to biogas energy in Kenya and other developing countries. The data generated as output of this research lays requisite foundation for the implementation of the biogas database system in Kenya. However given the apparent diversity in the quality of biogas from the different subtrates in terms of H_2S content, subsequent work should seek to establish the effect of farming systems and soil properties on biogas quality in Kenya as well as to investigate novel biogas desulphurization techniques. In addition, it is essential to undertake a similar study on other sources of biowaste besides replicating the research survey in other localities in Kenya.

7. References

Agblevor, F.A., Cundiff, J. S., C. Mingle, and W. Li, Storage and characterization of cotton gin waste for ethanol production. Resources Conservation and Recycling, 2006. 46(2): p. 198-216.

Amrit, B.K., N.S. Jagan, Sundar B., and S. Isha, eds. Biogas as Renewable Source of Energy in Nepal - Theory and Development. 2nd ed. 2009, BSP - Nepal.

APME, 2007. Plastics Europe. Association of Plastics Manufacturers (APME). Life Cycle and Eco-profiles. http://www.plasticseurope.org/Content/Default.asp?PageID =392#.

Biogas-Africa 2011, Biogas for Better Life <http://www.biogasafrica.org>

CODA. 2010. The Pamba News Bulletin. A publication of Cotton Development Authority: Issue 002,

CPM, 2007. SPINE@CPM database. Competence Center in Environmental Assessment of Product and Material Systems (CPM), Chalmers University of Technology, Goteborg.

Deublein, D. and A. Steinhauser, Biogas from Waste and renewable Resources2008: Wiley-VCH.

EAA, 2007. European Aluminium Association (EAA). Environmental Profile Report and LCA Data. <http://www.eaa.net/eaa/index.jsp> (data available on request only).

Ecoinvent, 2007. Swiss Centre for Life Cycle Inventories (Ecoinvent Centre). Ecoinvent Database. European Commission, 2007. European Commission, Directorate General Joint Research Centre

(JRC), European Reference Life Cycle Database (ELCD). <http://lca.jrc.ec.europa.eu/lcainfohub/>.

FAO, 2008. The State of Food and Agriculture, in Biofuels: prospects, risks and opportunities 2008.

FEFCO, 2006. European Federation of Corrugated Board Manufacturers (FEFCO). European Database for Corrugated Board – Life Cycle Studies, FEFCO, Brussels, Belgium.

Fernandes, T.V., G.J. Klaasse Bos, Zeeman, G., Sanders, J. P. M., and J.B. van Lier, Effects of thermo-chemical pre-treatment on anaerobic biodegradability and hydrolysis of lignocellulosic biomass. Bioresource Technology, 2009. 100(9): p. 2575-2579.

GTZ, 2010. "Agro-industrial biogas in Kenya- Potentials, Estimates for Tariffs, Policy and Business Recommendations", report, p.76.

Gunaseelan V.N. 1997. "Anaerobic digestion of biomass for methane production: a review", Biomass and Bioenergy, Vol. 13, Nos.1/2, pp.83-114

Phydades Inteligent Energy, 2011. Phyllis database, dissemination, education and standardisation (10. 30. 2011; http://www.phydades.info/)
IISI, 2007. International Iron and Steel Institute (IISI). LCI data on steel production. <http://www.worldstainless.org/Aboutstainless/> (data available on request only).
JEMAI, 2007. Japan Environmental Management Association for Industry (JEMAI). JEMAI database. <http://www.jemai.or.jp/english/index.cfm> (database available in Japanese language only).
Jensen, A.B. and C. Webb, Treatment of H2S-containing gases - a review of microbiological alternatives. Enzyme and Microbial Technology, 1995. 17(1): p. 2-10.
Keppler, F., J.T.G. Hamilton, Brass, M., and T. Rockmann, Methane emissions from terrestrial plants under aerobic conditions. Nature, 2006. 439(7073): p. 187-191.
Lehtomaki, A., S. Huttunen, Lehtinen, T., and J.A. Rintala, Anaerobic digestion of grass silage in batch leach bed processes for methane production. Bioresource Technology, 2008. 99(8): p. 3267-3278.
Lubken, M., Wichern, M., Schlattmann, M., A. Gronauer, and H. Horn, Modelling the energy balance of an anaerobic digester fed with cattle manure and renewable energy crops. Water Research, 2007. 41(18): p. 4085-4096.
Mathenge, M.K., Towards increased use of fertilizer and improved seed for food security and economic growth in 6th National fertilizer conference in Kenya2009: Nairobi-Kenya.
Narita, N., Nakahara, Y., Morimoto, M., Aoki, R., Suda, S., 2004. Current LCA database development in Japan – results of the LCAproject. Int. J. Life Cycle Assess. 9, 355–359
NREL, 2004. National Renewable Energy Laboratory (NREL). US Life Cycle Inventory Database. NREL, Golden, CO. <http://www.nrel.gov/lci/>.
Nzila, C., J. Dewulf, Spanjers, H, Kiriamiti, H., and H. van Langenhove, Biowaste energy potential in Kenya. Renewable Energy., 2010. 35(12): p. 2698 - 2704.
Nzila, C., P. Wambua, Githaiga, J.,Tuigong, D., Kiriamiti, H., Aoyi, O., Kiambi L., and W. Verstraete, The Potential of a Low cost EPAD System in the Treatment of Textile Mill Effluents. Kenya Journal of Mechanical Engineering, 2008. 4 (1).
Ranalli, P., ed. Anaerobic digestion: a multi-faceted process for energy, environmental management and rural development. Improvement of crop plants for industrial end uses2007, Springer. 335 - 416.
IEA, 2011. Key World Energy Statistics. <http://www.iea.org>
Reith, J.H., R.H. Wijffels, and H. Barten, eds. Bio-methane and Bio-hydrogen: Status and perspectives of biological methane and hydrogen production. 2003, ECN, Netherlands: The Hague. 29-95.
RMIT, 2007. Centre for Design, RMIT University. Australian LCI Database, Available at: http://www.auslci.com/.
Schieder, D., P. Quicker, Schneider, R., Winter, H., Prechtl, S., and M. Faullstich, Microbiological removal of hydrogen sulfide from biogas by means of a separate biofilter system: experience with technical operation. Water Science and Technology, 2003. 48(4): p. 209-212.
Taherzadeh, M.J. and K. Karimi, Pretreatment of lignocellulosic wastes to improve ethanol and biogas production: A review. International Journal of Molecular Sciences, 2008. 9(9): p. 1621-1651.
UBA, 2007. Umweltbundesamt (UBA) (German Environmental Protection Agency). PROBAS Database. http://www.probas.umweltbundesamt.de/php/index.php (available in German language only).
Yadvika, S., T.R. Sreekrishnan, Kohli Sangeeta, and R. Vineet., Enhancement of biogas production from solid substrates using different techniques--a review. Bioresource Technology, 2004. 95(1): p. 1-10.
Yu, L., K. Yaoqiu, Ningsheng, H., Zhifeng, W., and X. Lianzhong, Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation. Renewable Energy, 2008. 33(9): p. 2027-2035.

Acknowledgements
The Humanist Institute for Development Cooperation (HIVOS) sponsored this research in view of which the author is extremely grateful. The author also wishes to appreciate the support extended to him from the dedicated staff at Moi University, Ministries of Energy, Agriculture and the Local Administration as well as to all the different biogas stakeholders in Kenya.