Potential, Barriers and Prospects of Biogas Production in Zambia

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Abstract: Despite research work and implementation of biogas having started as early as in the 1980s, Zambia has lagged behind in the adoption and use of biogas in the sub-Saharan Africa. The study established that there is a theoretical biogaspotential of 76PJ per annum from animal manure and crop residues. This is sufficient to provide energy for cooking and lighting in more than 3 million households. Lack of funding, lack of policy, regulatory framework and strategies on biogas, unfavorable investor monetary policy, inadequate expertise, lack of awareness of the benefits of biogas technology among leaders, financial institutions and locals, resistance to change due cultural and traditions of the locals, high installation and maintenance costs of biogas digesters, inadequate research and development, improper management and lack of monitoring of installed digesters, complexity of the carbon market, lack of incentives and social equity are among the challenges that have derailed the adoption and sustainable implementation of domestic biogas production in Zambia. Unless these are addressed, it is unlikely that the biogas sector in Zambia will flourish.

Key words: Biogas, Potential, Social, Technical, Economic, Challenges, Zambia.

1. Introduction

Successful implementation of biogas projects which reduce greenhouse gas (GHG) emissions and substitute fossil fuels and non-organic fertilizers can attract funding under the Clean Development Mechanism [1]. Biogas provides clean and efficient energy, reduced prevalence of chronic diseases associated with use of biomass in a traditional way and its production creates jobs [2]. Despite the health risks, 2.5 billion people globally use traditional biomass [3]. With the huge potential and abundant feedstock, biogas production can resolve energy and environmental problems in the sub-Saharan Africa [4]. Most installed domestic biogas digesters in sub-Saharan Africa are non-operational [5]. In Zambia, the National Institute for Scientific and Industrial Research installed 18 domestic digesters ranging between 4-26 m^3 during 1982 to 2004. The installations were funded by donors, but are currently non-operational [6]. From 2008 to date, the Water and Sanitation Council of Zambia and its co-operating partners have installed more than 60 biogas digesters of size between 4-80 m^3 with funding from donors, individual companies and clients [7].Biogas production projects have been unsuccessful in Zambia and it is unlikely that even with the renewed efforts they will be successful, unless adoption and implementation obstacles are addressed. The study evaluated biogas potential from animal waste and crop residues, reviewed current status of biogas production, identified obstacles to adoption and implementation of biogas production and made recommendations.

2. Methodology

The paper reviews various biogas production information and data available from scientific research reports, journal publications and organizational reports available in Zambia. The theoretical biogas potential from animal dung was determined using equation (1).

$$BP = \frac{N \times VS \times B_o \times 365 \times 1.67 \times 23}{10^6} TJ/Yr \quad (1)$$

Where: BP is the theoretical biogas potential in TJy^{-1}, N is the population of each animal category, VS is the volatile solids in $kgh^{-1}d^{-1}$, B_o is the methane potential m^3kg^{-1} VS, D is the number of days in a year and 23 is the calorific value of biogas at 60% methane in MJ^{-3}.

The bioenergy potential from residue crops was estimated using equation (2).

$$R = C_p \times RPR \quad (2)$$

$$RPR = \frac{R}{Y} \quad (3)$$

$$M = R \times TS \times VS \times MP \quad (4)$$

Where: R is the total available crop residue in tons for a given crop per annum; C_p is the amount of crop produced in ty^{-1}. RPR is the residue to product ratio; Y is the yield of the product in $tha^{-1}y^{-1}$, M is the methane produced in m3y-1, TS is the total solids as a %, VS is the volatile solids as a % and MP is the methane potential in m^3kg^{-1} VS.

Statistical data on livestock and crop production [8-9] in Zambia were used to determine the theoretical biogas potential. The objectives of the study were to estimate the biogas potential from animal waste and crop residue, review the current state of biogas production activities in Zambia and recommend practical actions of implementation to render biogas projects sustainable.

Table 1. Theoretical Biogas Potential.

Animal Name	Population (Million)	VS (kgd^{-1})	B_o (m^3kg^{-1})	BP (TJ)
Cattle	3.250	2.67	0.20	24,331
Goats	2.350	0.33	0.31	3,370
Pigs	0.725	0.59	0.31	1,859
Sheep	0.230	0.30	0.31	300
Chickens	36.500	0.02	0.18	1,842
Human	13.064	0.06	0.20	2,199
Total				**33,901**

Sources: Animal & human populations [8-9] VS & B_o [13]

3. Results and Discussion

3.1 Biogas potential

3.1.1 Biogas potential from animal dung

Using equation (1) and taking methane to be between 50 and 70% in composition of the biogas [10-11], the calorific value of the biogas as 23 MJ/m^3 [12] a total biogas potential of 33,900TJ per annum was estimated.

3.1.2 Crop residue theoretical biogas potential

Table 2 gives a list of crops whose residues were estimated along with their theoretical biogas production potential. The total potential from crop residues was estimated at 41,847TJ.

3.1.3 Total biogas potential

The total biogas potential from animal waste and agricultural crop residues was estimated to be 76 PJy^{-1}.This is equivalent to 3.507×10^9 m^3 of biogas per year. In Tanzania Ng'wandu et al. (2009) [25] estimates that on average a family of six consumes 2.55 m^3 of biogas per day. In Nigeria, a family of nine consumes 2.4 m^3 of biogas per day with three times of cooking [26]. In Cambodia, 0.8–2.5 m^3 of biogas is used per day per household having five members [27]. In Zambia a family of six requires between 2.0 to 2.5 m^3 of biogas for cooking and lighting [6]. The estimated theoretical biogas potential would serve cooking and lighting purposes for more than 3,000,000 households (6 members per household) if each household consumes 3 m^3 (18 kWh) of biogas per day. Therefore the estimated theoretical biogas potential is more than adequate to supply energy to these smallholder households as there are a total of 2,491,000 households and out of these only about 1,600,000 are actively into livestock raring and agricultural farming [9].

3.2 Technical Challenges

3.2.1 Policy and strategy

In the Sub-Saharan Africa (SSA), policy and strategy on bioenergy is not specific and the sector seems to be driven by the private sector. Governments should take a positive role in the regulation and monitoring of the bioenergy sector [28]. Although energy is crucial for a country's development, energy policy issues and debates have not been given enough attention in the developing world [29]. Biogas technology transfer requires good fiscal policies which provide incentives. There are no such fiscal policies to encourage investment in biogas technology in most sub-Saharan African Countries [30-31]. Energy policies and strategies put in place by governments are not focused and thereby fail to achieve their intended goals of attracting both domestic and foreign investments in biogas production [32-33].

In Zambia, the national energy policy makes mention of promoting renewable energy, particularly biofuels. It also makes mention of biogas and other forms of renewable energy but mostly puts more emphasis on hydroelectricity [34]. The energy regulation was amended to included energy produced by biofuels as this was missing [35]. Like the national energy policy, the fifth national development plan (FNDP) puts more emphasis on hydroelectricity rather than renewable energy. Though there is mention of promotion of biofuels development and biomass, there are no specific strategies on how this will be achieved [36]. The six national development plan (SNDP) unlike the FNDP has included the promotion of biogas for cooking, lighting and heating on its strategies but does not go further to elaborate how this will be done.

Energy policy development in Zambia has been generally slow and the role of renewable energy has been overshadowed by the dominant focus on hydroelectricity for which there is a clear investment strategy and defined targets. Adoption and implementation of modern renewable energy technologies has been hindered by inadequate policy, poor integration of renewable energy into national development plans and inadequate commitment to implement the energy policy [36].

These have had a direct impact on policy as regards to bioenergy development in Africa. For example, regulations regarding moving investment in and out of the country and reinvesting profits [37]. In Zambia, on 18th May 2012 a statutory instrument (The bank of Zambia Currency Regulation of 2012) was passed prohibiting quoting, paying or demanding to be paid in foreign currency as legal tender for goods or services for any domestic transaction [38]. On 25th June 2013, another statutory instrument called the Bank of Zambia (Monitoring of Balance of Payments) Regulations, 2013 was passed requiring that the Bank of Zambia shall monitor the value of any imported goods and services, profits or dividends paid to shareholders that are non-resident in Zambia, amounts of money remitted out of Zambia, etc. [39]. Though these regulations were designed in the best interest of the nation and the investors, some investors felt that there were a lot of risks in investing in the country due to such enormous requirements and monitoring.

Sometimes the systems are so bureaucratic that policy implementation is slow and almost impossible [33, 40]. The Taka biogas project in Tanzania is a very good example of how bureaucracy can derail developmental projects even when most preliminaries are done well in advance [41]. Bureaucracy exists in Zambia [42] and has affected both policy formulation and implementation.

3.2.2 Inadequate expertise and training

Lack of skilled and experienced masons to undertake the construction and maintenance of biogas plants is a constrain hindering the fully dissemination and adoption of biogas production in developing countries. Universities in the SSA have not designed and implemented appropriate programs to teach and train students in biogas technology [29].Sometimes there is a lack of basic technical skills to operate and maintain a biogas digester [43]. Poor quality plants due to inexperienced consultants and contractors, poor quality construction materials and lack of knowledge on biogas production systems have impacted negatively on biogas

Table 2. Theoretical biogas potential from crop residues

Crop Name	Product (10^6kg)	RPR	Residue (10^6kg)	TS (%)	VS (%)	MP (m^3/kg VS)	TBP (TJy^{-1})
Sugarcane bagasse	2,798	0.33	923.34	24	87	0.45	3,332
Sugarcane top/leaves		0.05	139.90	90	98	0.33	1,564
Maize Stalk	1,780	2	3,559.15	74	82	0.28	23,227
Maize Cob		0.3	533.87	30	94	0.6	3,470
Wheat stalk	154	1	153.60	94	87	0.26	1,254
Cassava Peels	1,115	0.15	167.31	35	97	0.377	823
Groundnut shell	108	1	108.01	94	93	0.3	1,088
Groundnut stalk		2	216.01	91	93	0.3	2,107
Other crops							4,982
Total Biogas Potential							**41,847**

Source: RPR – [14-17], TS, VS & MP – [18-24]

adoption and implementation. Sometimes operators are not properly educated, they lack credibility and technical knowledge on repairing and maintaining biogas digesters [32-33]. Poor workmanship during construction of biogas digesters has led to water and gas leakages. There has also been lack of experience in biogas digesters construction and operation leading to failure of digesters. Operators lack knowledge of what they are supposed to do in order to improve biogas production [30]. Poor design and construction of digesters, wrong operation and lack of maintenance has rendered most installed digesters unusable or non-operational [44]. In Zambia, this is the case of NISIR Chalimbana Farms digester, Nkumba Farm, Kasisi Agricultural training center and some institutional digesters in government schools which leak profusely [6].

Naik et al. (2014) [45] suggest that feedstock variability, feeding regime, temperature and pH are the most crucial parameters to be monitored in small scale applications of biogas. Where there is lack of expertise, it will be difficult for unskilled and inexperienced operators to understand these technical parameters and how they affect biogas production.

There is a lack of a coordinating framework to allow different players in biogas production to work together [5]. Lack of these different expertise and skills have resulted into the inability to carry out these multi-criteria sustainability assessments. Indeed Zambia currently lacks such skills to carry such assessment. Suitable technical training in the SSA to equip and build capacity in energy development personnel in areas such as pricing mechanisms, energy demand forecasting, demand side management, supply distribution technologies, installations and power plant management strategies is required through regular training, workshops, seminars and international collaboration [46]. At times the biogas digester beneficiaries lack the basic technical know-how [30]. Universities and other institutions of higher learning have not done enough to train and build capacity in biogas production [32-33, 40]. Zambia has not been able to adopt biotechnology due to lack of a biotechnology policy, an insufficient number of trained personnel, a poor science and technology base and very little basic research in universities and research institutions [47]. The expertise currently available in biogas production in Zambia is inadequate because the few experts that are available are expatriates or they are with learning and research institutions. The hands-on skills and experiences are inadequate.

3.2.3 Research and development

Presently, the SSAis not adequately equipped as far as renewable energy research and development is concerned. Research funds are often not adequate or are misapplied [46]. There has not been enough research in higher learning institutions on biogas technology due to non-support from responsible government ministries [30]. At times, authorities, planners and implementers of biogas projects consider universities as being too academic such that they ignore their contribution [32-33, 40]. For example, there has been inadequate research to improve livestock production [31].

The higher learning and research institutions in Zambia have not done much in renewable energy research. This has been attributed to the inadequate funding from government for research and development (R&D) [36]. Due to weakened government and donor support, there has been a continuous decline in agriculture R&D investment. The level of full time equivalent researchers and educational qualifications also dropped. This was attributed to the hiring freeze between 2002 and 2007. Government funding is mainly allocated to salaries and overheads. Funding for agricultural research has been on the decline from the 1980s [48].

3.2.4 Management and monitoring of installed biogas digesters

Surendra et al [29] argue that in some instances where subsidies were provided and biogas digesters installed they have failed to operate sustainably because of lack of proper after services management and monitoring. The beneficiaries of these biogas digesters need help in terms of how to operate these digesters, until such a time when they are ready and familiar with daily operations [30]. Due to poor management of digesters the possibility of pathogens infecting humans or crops, soil, air and water may lead to failure to adopt and implement biogas production in the SSA [49]. In Zambia, the institutional biogas digesters in schools failed because of lack of technical support and monitoring from the biogas team charged with that responsibility and improper management from school staff [6]. The school management failed to involve pupils in the day to day operations of the digesters (fetching water and dung to feed the digesters).

3.2.5 Water availability and land tenure

Inadequate water availability poses a challenge to biogas production [5, 50]. Though technically Zambia has abundant water resources, independent studies have shown that it may face an economic water scarcity due to increased economic activities and population increase exerting pressure on the Kafue river basin. Thus Zambia faces several challenges in harnessing the potential of the actually abundant water resources. The Kafue river basin supplies water for mining, industrial activities and agricultural irrigation [51]. Zambia has a surface water potential of 100 billion m^3, with the Zambezi River contributing about 60%; the average renewable ground water potential has been estimated to be 49.6 billion m^3. Of the 38.5 billion m^3 of water withdrawn, 36.3 billion m^3 is used for hydroelectricity generation [52-53].

In the SSA, land tenure plays a big role as far as to what extent one can do on a piece of land. Those who own titled land seem to be able to carry out a number of projects on their land as compared to those without. It is therefore more probable that a household with title to the land will easily put up a biogas digester as compared to those who do not [31, 50]. A survey study carried out by Smith (2004) [54] in Zambia concluded that farmers who had lease agreements or titles to their land had superior fixed investment and were more productive compared to those who did not. Those with leases or titled land owned livestock, grew more crops and had fixed investment. Squatters on state and customary land in Zambia are reluctant to invest in agriculture and land improvements because of their endemic insecurity [55].

Table 3. Water use by sector [52]

Sectorial use	Water consumption (billion m^3)	Share in overall water Consumption (%)
Agriculture	1.8	4.67
Industrial and municipal	0.4	1.03
Hydroelectric	36.3	94.30
Total	**38.5**	**100.00**

3.2.6 Feedstock availability and other technical issues

Though technically available, feedstock maybe practically inadequate due to a number of reasons, such as grazing patterns of animals, location of fields, farming practices etc. [49].Where one kind of feedstock is inadequate, co-digestion may just be the answer. Information is required on how to pretreat the manure before adding it to the digester and how much water should be used. The practice of using too much water results into high slurry volumes and less retention time resulting into high volumes of digested slurry discouraging farmers to transport it to the farms [56].

3.3 Social Challenges

3.3.1 Awareness program and strategies

There has been limited success in the promotion of biogas in rural areas of developing countries, more so the SSA countries [57]. Low education levels, living in the remote countryside, lack of access to modern media has compounded the problem of disseminating promotion strategies and awareness programs among the local rural communities [46, 49]. Poor dissemination strategies have also led to failure to adopt and implement biogas production in the SSA due to failure by African governments to introduce supportive policy [44].If biogas production is to be viable and sustainable, it is important all forms of communication channels that bring awareness and disseminate knowledge should be established and maintained [29].

Despite the potential of biogas technology to flourish in the SSA, there has been lack of promotion through both print and electronic media [31].Would-be beneficiaries are mostly not aware of the benefits that come with the adoption and use of biogas [50].Policy makers, local authorities and financial institutions lack reliable and sufficient information on potential benefits that may arise as a result of biogas production [33, 36-37], point out the absence of the department of energy in some districts of Zambia and attribute this to lack of awareness of renewable energy and its technologies among the locals. Where present, the department plays a Cinderella role and is incapacitated. For example, failure to run a biogas digester at Baambwe Palace in Namwala District of the Southern Province of Zambia because children at the palace, being of royal blood, were not allowed to feed the digesters with cow dung requires an awareness educational program. Similarly the biogas digester in Lealui, Mongu district of the western province of Zambia failed because the empowered widows could not feed the digester because women are not allowed to handle cow dung in that part of the country[6].

3.3.2 Social equity

There has been unfair distribution of opportunities as far as energy supply is concerned comparing the urban and rural areas. The impoverished normally lack good educational background, opportunity and capacity, and are more vulnerable, voiceless and powerless; they end up getting a low deal of everything including energy share [58]. In Zambia, the poverty levels are highest in the rural areas and access to electricity is lower in rural areas [36]. Poverty levels as high as 77.9% exist in rural areas and 27.5% in urban areas. Only 4.5% of the rural households are connected to electricity as compared to 53.0% for urban households [9].

3.3.3 Lack of political will

Suberu et al. (2013) [46] argue that political will is among the most important factors that have a significant impact on determining the amount of renewable energy in the national energy mix. In the SSA political will in renewable energy has lagged behind as compared to other developing countries elsewhere across the globe [5]. Political decisions or measures encouraging adoption and implementation, training and capacity building, flexible financing mechanisms and dissemination strategies are required if biogas production is to benefit the communities [49]. Naumann and Jakusch (2011) [59] in their report on the elections of September 2011 assert that there is political will in Zambia's current government but there are not sufficient resources. However, Duncan et al (2003) [60] feel that there are many practical obstacles to development and pro-poor change, one of them being political will which seem to be lacking in Zambia. In light of this, what is probably most required is to create an awareness program for the key leaders in politics and administration to educate them of the many benefits that would arise from successfully adopting and implementing a biogas program in Zambia.

3.3.4 Implementers and researchers

The researchers are normally perceived to keep a distance from implementers of energy projects and are regarded as merely doing academic exercises. And they (researchers) also do not understand why such good programs which have well been implemented elsewhere have failed in their countries [32-33]. In Zambia, researchers and implementers of energy projects meet in workshops or conferences and though a form of collaboration exists, it is not enough. There is need for close collaboration among researchers, planners and the community when a biogas project is being implemented.

3.3.5 Resistance to change

Inertia to change from use of primitive energy forms to modern energy such as biogas has been attributed to customs and traditions in some communities. The perceived unreliability of biogas also has contributed to resistance to change in some instances [58]. A study conducted in Lusaka and on the Copperbelt [61], showed that there is a tendency among urban dwellers, especially those in the peri-urban areas, to continue using charcoal or firewood because they feel it is cheaper even when their homes are connected to the grid. Institutions bringing biogas technology to an area must fully and widely understand the religious taboos and beliefs of that area. Wide consultation if not conducted, may end up in the technology being rejected. There may be a need to put up well elaborated awareness program probably using a very influential member of that community to disseminate information if people have to understand fully the benefits of the biogas technology being brought to them [43].

Due to traditional beliefs, people in the community may find it difficult to accept the use of biogas as a fuel as it is produced from dung, manure and or sometimes fecal matter. This has been a challenge in biogas technology adoption and implementation in the SSA [40].The 2006 and 2010 Living Conditions and Monitoring Surveys showed that a smaller percentage of households (16%) used electricity even though 53.0% of the urban households had access to electricity. About 80% of the households used wood fuel as a source of energy [9].Therefore the perceived low cost of firewood and charcoal, traditional and cultural beliefs and customs have contributed towards the reluctance in adoption and implementing biogas projects in Zambia. In Lealui of the Western Province of Zambia, women could not collect cow dung as it was against tradition for them to go into the Kraal and in Baambwe Palace in the Southern Province, the chief could not allow his children to collect cow dung and feed the digester because they were of royal blood and as such were not allowed to touch "dirt".

3.4 Economic Challenges

3.4.1 Trade and investment incentives

Inadequate trade policies and lack of investment incentives have failed to attract local and foreign investment in the bioenergy sector [30]. For example, Uganda has put in place a number of incentives (including tax refund), however it takes too long and is almost impossible to get a refund on imported raw materials. In Tanzania, foreign and local investors face challenges of getting permits due to inefficiencies by statutory bodies [28]. Governments in the SAA find it difficult or almost impossible to offer subsides for biogas production and as such, amortization periods are significantly longer and closer to depreciation points increasing the investment risks [57]. In the Zambian scenario, the incentives as regards to promotion of the bioenergy sector let alone biogas production are simply not there, though the Biofuels Association of Zambia has been lobbying for some incentives from the government. Bureaucracy due to growth in the size of government departments, expansion of government social services and due to the complexity of policy issues of modern government is the worst form of disincentive to both domestic and foreign would be investors in biogas production and other energy sectors[42].

3.4.2 Financing

Financial institutions often perceive the bioenergy sector as high risk, making it very challenging for investors to obtain funds [37]. Inadequate funds to finance power generation, transmission and distribution coupled with low rates of returns due to high operating costs and low consumption are some of the challenges faced by the SSA countries [62]. There have been problems in creating bioenergy financing capital in the SSA which has affected the adoption and implementation of biogas projects [31, 56]. There is a lack of political will, inadequate policy, R & D and financing from both government and the private sector in the SSA [46]. Universities and research institutions such as the University of Zambia, Copperbelt University, National Institute for Scientific and Industrial Research and many others involved in energy research are grossly underfunded and as such are unable to effectively carryout research projects [36].

3.4.3 High installation and maintenance costs

Despite the many environmental, health, sanitation, social and economic benefits, full adoption of biogas technology has lagged behind in most developing countries, especially those from the SSA because of the high installation and maintenance costs [5, 49]. Depending on the location of that developing country and type of digester, installation costs vary between US$435 to US$1,667 [29].

The renewable energy technologies cost much higher than the average income of Zambian household [36]. In Zambia, 10 m^3 and 25 m^3 biogas digesters require US$800 and US$1,918 respectively as installation costs [6]. The average income for a Zambia household is US$230 per month; rural and urban households average US$137and US$396 per month respectively [9]. After assessing that locals were not able to finance the full costs of installing a biogas digester, the recipient households were asked to contribute in terms of making burnt bricks, providing water during construction and digging the digester pits. The rest of the cost was met entirely by donors [6]. The high poverty levels in Zambia mostly in the rural areas (77.9% in rural areas and 27.5% in urban areas) could be attributed to the financial inability to adopt and implement biogas production [9, 36].

3.4.4 The carbon market

Just slightly above 2% of the CDM registered projects are located in Africa and 25% of those are in South Africa. Project developers and investors have experienced a number of obstacles as regards to carbon financing prospects of bioenergy in Africa due to a number of barriers, complexities and risks [37]. Because of all these complexities most SSA countries including Zambia have not yet benefitted much from CDM revenues as a result of the under developed bioenergy market and biogas sector to be specific.

4. Conclusion

The availability of feedstock for biogas production in Zambia is adequate. Cow dung being and maize cobs are the major feedstock sources among the animal waste and crop residues respectively. The potential of 76 PJ per annum is able to cater for more than three million households. Co-digestion is highly recommended where crop residues will be the main feedstock.

There are many technical and socioeconomic constraints that have hindered full adoption and sustainability of biogas production in Zambia. Lack of mobilization of external and local funds, the complexity of the carbon market, lack of policy, strategy and regulations in biogas production, high capital and maintenance costs, lack of trade and investment incentives, resistance to change among the beneficiaries, lack of co-operation between implementers of biogas projects and researchers, inadequate research and development due to insufficient funding, low levels of full time equivalent researchers who are qualified at PhD level, inadequate expertise and training in biogas production and unfair equity are some of the major constraints hindering adoption and implementation of biogas projects in Zambia. Though political will exists, there is need to create an effective awareness program for leaders so that they spearhead formulation of favorable policy, strategies and regulations. The awareness program should be extended to financial institutions and the beneficiaries. With appropriate policy, strategies and regulations, funding for digester installation, research and development and training of experts will follow. Like in any productive sector, the biogas sector requires incentives for both the investors and beneficiaries. There is also need to get an in depth training on the carbon market and how the Clean Development Mechanism funds operate so that Zambia can increase its benefits from this fund through biogas production. Though water resources are abundant in Zambia there is a need to make water practically available as it is very critical in biogas production.

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