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Socio-economic hurdles to widespread adoption of small-scale biogas digesters in Sub-Saharan Africa: A review

Jecinta Mwirigi [a], Bedru Balana [b,*], Johnny Mugisha [c], Peter Walekhwa [c], Rethabile Melamu [d], Sylvia Nakami [e], Paul Makenzi [a]

[a] Egerton University, Department of Environmental Science, Box 536-20115, Njoro, Kenya
[b] The James Hutton Institute, Social Economic and Geographical Sciences, Craigiebuckler, Aberdeen AB15 8QH, UK
[c] Makerere University, Kampala, Uganda
[d] Environmental & Process Systems Engineering Group, Dept. of Chemical Engineering, University of Cape Town, South Africa
[e] Uganda Carbon Bureau, Plot 47, Lubowa Estate, P.O. Box 70480, Kampala, Uganda

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ABSTRACT

The unsustainable use of fossil fuels has led to increased awareness and widespread research on the accessibility of renewable energy resources such as biogas. Biogas is a methane rich gas that is produced by anaerobic fermentation of organic material. Despite its potential to replace biomass in Africa, where over 70% of the households use wood fuel and agricultural waste for cooking, biogas technology has not been adopted by Sub-Saharan African countries compared to their Asian counterparts. This paper examines the socioeconomic constraints to adoption of biogas in Sub-Saharan Africa and explores factors that could enhance adoption of the technology. These include standardization and quality control, as well as an approach of integrated farming using biogas and slurry. The article recommends mobilization of local and external funds to promote biogas, use of ready to use funds such as the Clean Development Mechanisms in overcoming the initial construction costs of biogas units, and formation of user and disseminator associations to reduce costs by joint procurement and linkage to finance. It further advocates the promotion of multiple uses of biogas for purposes other than cooking and lighting. It is expected that widespread adoption of the technology could lead to self-sufficiency in household energy provision for cooking. This would facilitate environmental management and economic development in Sub-Saharan Africa.

1. Introduction

In Sub-Saharan Africa (SSA), a high proportion of the population rely on traditional biomass for domestic energy; in countries, such as Liberia, Burkina Faso and Tanzania, more than 95% of the population relies on traditional biomass for cooking and heating [1]. However, the commonly used traditional biomass stoves are inefficient [2], provide a significant source of greenhouse gas emissions and are associated with

Abbreviations: SSA, Sub-Saharan Africa.

* *Corresponding author*. Tel.: +44 1224 395 290; fax: +44 1224 395 036.
E-mail address: bedru.balana@hutton.ac.uk (B. Balana).

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serious health problems due to exposure to smoke [3]. Time spent on firewood collection takes time away from other critical activities, such as farm work, nutrition, sanitation and education. Over-reliance on biomass energy has lead to the unsustainable use of fuel wood [5]. While trying to save on firewood, food is sometimes not given enough time to cook, potentially resulting in health problems [4]. The number of meals cooked decreases, and often the diet changes altogether, as foods that require long cooking periods are replaced by foods that take a short time to cook but do not have the same nutritional value.

The Advisory Group on Energy and Climate Change [6] proposed a goal of universal access to modern energy services by 2030. Access to modern energy services is defined by the OECD/IEA [7] as household access to electricity and clean cooking facilities (i.e. clean cooking fuels and stoves, advanced biomass cook stoves, and biogas systems). The Forum of Energy Ministers of Africa and several African regional economic communities proposed specific targets for increasing access to modern energy services, following similar lines to those agreed at the UN Millennium Project 2004 Workshop [8]. These targets range between 50 and 100% access to modern energy services by 2030, with the exception of rural households where the emphasis is on community services and so targets are either reduced or not given. Brew-Hammond [1] argues that if these ambitious targets set by African organisations are to be achieved, then it will be advisable to tap into the full menu of energy resources and technology options. This paper, therefore, looks at biogas as one of the energy options that can, not only improve rural livelihoods, but also assist the SSA region to achieve the Millennium Development Goals.

The unsustainable use of fossil fuels has led to increased awareness and widespread research on the accessibility of renewable energy resources, such as biogas [9]. Biogas is a methane rich gas that is produced by anaerobic fermentation of organic material. Anaerobic digestion consists of several interdependent, complex, sequential and parallel biological reactions that occur in the absence of oxygen. During this process, the products from one group of microorganisms serve as the substrates for the next, resulting in transformation of organic matter (biomass), mainly into a mixture of methane and carbon dioxide [10].

The use of biogas as a potential renewable energy is becoming more appealing as governments endeavour to boost renewable energy production, ease carbon emissions (especially from fossil fuels), and increase the use of domestic fuel sources. Biogas technology was introduced at different times in different SSA countries; in Kenya and Uganda it was introduced in 1950, in Tanzania in 1975, and in South Sudan in 2001. Biogas digesters have been installed in a large number of different SSA countries including Burundi, Botswana, Burkina Faso, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Lesotho, Namibia, Nigeria, Rwanda, Zimbabwe, South Africa and Uganda [14].

Biogas can be produced from many different sources, including animal excreta, industrial and municipal wastes, weeds and agricultural residues. However, domestic biogas digesters, that utilize animal excreta, are more commonly deployed in SSA to produce energy for cooking and to a lesser extent for lighting. Amigun and Blottnitz [9] argue that biogas production plays a significant role in controlling and collecting organic waste materials that, if untreated, could cause severe public-health and environmental pollution problems. The anaerobic digestion process converts this waste into an organic fertilizer and clean water for use in agricultural irrigation. In Kenya, owners of biogas plants use less compost and inorganic fertilizers and instead use bioslurry to fertilize their crops [11]. In Ethiopia, some households value the bioslurry produced by the biogas plant more than the energy produced [12]. This is due to the value of the bioslurry as a fertilizer that increases agricultural production and reduces input-costs.

Unlike other forms of renewable energy, biogas production systems are relatively simple and can operate at small or large scales in urban or very remote rural locations. Biogas is a more appropriate solution to SSA energy needs due to the decentralized nature of human settlements in the region, resulting in very high distribution costs for conventional centralized power systems [13]. Implementation of biogas is also favoured by the generally lower capital requirements compared to conventional, centralized power systems [13]. Fossil fuels in SSA are concentrated in just a few countries, with over 80% of the region's oil reserves and 76% of the natural gas reserves being in Nigeria and Angola, and 90% of the region's bituminous coal reserves being in Nigeria and South Africa [13]. Even if new fossil fuel resources were to be discovered, the debt burden and fragile economies of many SSA countries would limit the investments that could be made into conventional centralized energy systems [13]. By contrast, biomass energy is widely distributed across Africa, so there are no geographical limitations to the employment of this technology and it is not monopolistic.

2. Justification and objectives of the paper

Uptake of biogas technology in SSA has remained low despite significant national and international efforts to support its adoption [15]. A study carried out in 21 SSA countries on the state of biogas technology showed that biogas producing units of small/medium size (up to 100 m^3) in these countries range from few (Nigeria, Uganda and Zambia) to several (Egypt, Ethiopia, Ghana, Cote d' Ivoire, Morocco, Rwanda, Senegal, South Africa and Swaziland), to over 500 in Kenya and over 1000 in Tanzania [16]. The low adoption of the technology is against a background of a continent that has favourable temperatures for the fermentation process, coupled with abundant and diverse biodegradable materials that can be used for biogas production. In Kenya, for example, it had been estimated that, in only 5 of the counties (there are 47 counties in Kenya) with high potential to produce biogas (Kakamega, Kiambu, Kisii, Nakuru, and Nyandarua), there is a combined adoption potential of up to 38,000 biogas units [17]. Although the situation has slightly improved with the entry into the market by the African Biogas Initiative, adoption remains minimal. The African Biogas Initiative aims to construct 2 million biogas units in Africa by 2020 with a 90% operation rate [18]. The key issue for biogas technology in SSA is to understand why a large scale-up of the number of digesters has not yet occurred, despite demonstration by several programmes of the viability, sustainability and effectiveness of the technology. The main aim of this paper is thus to critically review

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the economic and social factors that hinder biogas technology adoption in SSA and to provide policy recommendations. The paper also provides a concise assessment of the adoption of small-scale biogas technology in SSA.

3. How has biogas been promoted in Sub-Saharan Africa?

In most cases, biogas has been introduced free of cost to the user through a pilot or demonstration project. Such projects have often been implemented through government structures that assumed the demonstration of the benefits of the constructed biogas plants would automatically motivate people to adopt the technology [18]. However, this approach does not seem to have led to widespread dissemination and market development for the technology. Moreover, many of the plants installed have eventually been abandoned. Generally, biogas initiatives in Africa have failed to grow from a product-based project approach, implemented by a single actor, into a market-oriented programme approach, in which various actors co-operate on the basis of institutional arrangements.

In Rwanda, the first record of the construction of domestic biogas plants dates back to 1982 when, on the invitation of the FAO, a biogas consultant from Nepal constructed 4 plants ranging in size from 8 to 20 m^3 [19]. In Kenya, biogas was introduced into the country by the white settlers in the mid 1950's; in 1958 Tunnel Technology Limited, a private company, started the construction of biogas plants in different parts of the country and by 1980 had constructed 150 biogas plants [20]. In Ethiopia, one of the first biogas units was constructed in 1979 at Ambo Agricultural College (EAEDPC & SNV/Ethiopia, 2008; quoted in Ref. [21]). The history of biogas dissemination in Tanzania dates back to 1975, when the Small Industries Development Organization (SIDO) built 120 floating-drum plants in Arusha region [22]. In Uganda, even though the first biogas plant was built over 50 years ago, the technology has not been significantly adopted. Even with demonstrations built all over the country in the last decade, the technology has not gone beyond these demonstrations. Despite these failures to achieve widespread adoption, no serious study or investigation into the factors hindering uptake has yet been completed [14].

3.1. *Success and failure stories*

The sustainability of the biogas plants that were constructed in the initial stages was not good. In Ethiopia, of the estimated 1000 initial plants, 50–60% of plants were not working 30 years after construction (EAEDPC & SNV/Ethiopia quoted in Ref. [21]). The causes of failure include the great variation in the design of biogas digesters; digesters that are too large (up to 16 m^3) in relation to the amount of cow dung and other wastes available to feed them; absence of a well-researched and standardized biogas plant technology appropriate for the socio-economic and cultural context of Ethiopian households; lack of technicians trained to give effective management and follow up; and a project-based approach mainly producing one or two stand alone or demonstration biogas plants that were not integrated into the local household economy [21]. In Kenya, of the initial 150 plants constructed in the mid 1950s, only 25% were functional by the year 2007 [20]. The technological design of a plant was found to be one of the factors affecting sustainability of plants in Kenya, with the fixed dome design being more sustainable than the floating drum and the flexible bag [11]. The same problem was experienced in Uganda with regard to the floating drum digesters installed with USAID funding in 1994 [23], with most of the 600 biogas plants that were still present in 2007 being non-operational [14].

3.2. *Rate of adoption of biogas in SSA countries and Asia*

The adoption of biogas in SSA is gaining momentum thanks to the African Biogas Initiative. For example, since 2010, Kenya has constructed over 2000 biogas units through this initiative (Table 1). This is a significant increase over the 800 plants constructed between mid 1950 and 2006. However, the uptake in SSA is still lagging behind the estimates of the potential for biogas installations. A feasibility study by Winrock International [14] estimated a potential to install 100,000 plants in Uganda between 2009 and 2011. Even this is a much slower rate of installation compared to the installation rate in Asia (Table 1). In China, 5 million biogas units were constructed in the year 2010, bringing the total number of operational biogas units to 40 million by the end of 2010 [12]. India, constructed 150,000 units in the 2010/2011 fiscal year under the National Biogas and Manure Management Programme (NBMMP), bringing the national total to 4.4 million biogas plants by March 2011. Nepal has the highest number of biogas digesters per capita at over 200,000 digesters installed since the beginning of their Biogas Support Programme (BSP) under the Netherlands Development Organisation (SNV) in 1992.

The difference between Asia and SSA could be explained in part by the number of animals available for manure production. Table 2 shows the cattle populations in the different countries. Other contributing factors include the maturity of the programme promoting the digesters; the programme in Nepal was introduced in 1992, while in Africa, the first programme to be introduced was in Rwanda in 2007 (Table 1). Other constraints include the construction costs which, as shown in Table 1, are higher for African than for Asian countries. In Uganda, the construction cost of fixed dome digesters has been brought down by 30% through use of Interlocking Stabilized Soil Blocks (ISSB) that use local soils mixed with 5% cement [12]. Cement, which is a major requirement for construction of a fixed dome biogas unit, contributes to the high cost of the units and the high investment costs. This, combined with low household disposable incomes, strongly impacts the adoption rate. The availability of loans and subsidies also affect uptake rates. In Bangladesh, 86% of all biogas plants are financed through credit, while Indonesia and Cambodia follow with 84% and 54%, respectively, of plants financed through credit [12]. In China, farmers receive as much as 69% of the construction cost in the form of subsidies [12]. Despite the efforts by the African Biogas Initiative, SSA countries are still lagging behind in adoption of biogas technology. This is clearly illustrated by a comparison of India and Kenya; India has a cattle population of about 282 million and 4 million biogas units, representing adoption of 1.5% of the potential units, as compared to Kenya with an estimated cattle population of 17 million [24] and only 2000 biogas units, representing a negligible

Table 1 – Biogas units supported by SNV programme.

	Programme commenced	Installation in 2010 (Official)	Cumulative up to 2010	Installation in 1st half of 2011(Official)	Average investment costs (USD)
Asia					
Nepal	1992	20,753	225,356	16,551	663
Vietnam	2003	24,511	100,342	8464	621
Bangladesh	2006	5688	15,707	3022	488
Cambodia	2006	3744	10,146	2854	430
Lao PDR	2007	937	1966	227	448
Pakistan	2009	520	587	420	505
Indonesia	2009	1581	1643	1500	660
Africa					
Rwanda	2007	627	1061	395	1339
Ethiopia	2008	731	859	605	800
Tanzania	2008	1021	1127	546	710
Kenya	2009	837	840	1044	947
Uganda	2009	583	626	560	741
Burkina Faso	2009	112	112	208	808
Cameroon	2009	49	72	16	858
Benin	2010	22	22	0	1211
Senegal	2010	14	14	127	898
Total		*61,729*	*360,480*	*36,539*	

Source: SNV, 2011.

adoption rate. There is, therefore, an urgent need to explore ways of increasing the biogas adoption rate in SSA.

4. Socio-economic constraints to biogas adoption in SSA

Demarest et al. [25] describe the socio-economic characteristics of a household as the level of household income, education and the occupation of the household head. These key socio-economic characteristics, as well as access to resources such as cow dung and water, may impact the decision of a household to adopt biogas. Due to their significant contribution to adoption of biogas technology, socio-economic characteristics of the farming communities in SSA have been studied extensively. One socio-economic factor that has been studied is access to water. Limited water availability poses a constraint to biogas operation because biogas units typically require water and manure to be mixed in an equal ratio. In Tanzania, Mwakaje [22] concluded that, despite a high biogas demand of 90% and favourable conditions, such as large numbers of indoor-fed cattle coupled with inadequate firewood, water availability strongly constrained adoption of biogas technology. In Uganda, age of the household head, household size, traditional fuels and level of education of the household head were contributing factors to adoption of the technology [26]; increase in age and level of education were inversely related to adoption while availability of traditional fuels and increase in household size had positive impacts on acceptance of the technology. Socio-economic surveys carried out in Uganda and Kenya, highlighted low levels of education and income as the main causes of limited, little or no involvement of women in the decision for procurement of energy sources; the decision to install biogas is mainly taken by the male heads of households who control resources and their allocation. In Uganda, the impact of education is contrary to the findings in Kenya [27] and elsewhere [28–31]; more educated people in Uganda generally have more income and thus can afford other sources of energy, such as electricity, which they consider to be more convenient. In Kenya, size of the farm, land tenure security, number of dairy cattle, farming system and the cost of a cow were positively correlated with adoption of the technology [27]. Other important socio-economic factors include low levels of awareness of the potential uses of biogas, and the small size of land-holdings, which limits the number of different types of land use unless the uses are complimentary. In addition, biogas units are expensive to construct and some biogas digester designs, such as the fixed dome, will remain operational for many years, thus necessitating the need for land tenure security. Zero grazing farming systems are more conducive to biogas technology adoption due to the ease with which cow dung can be collected to feed the digester. Thus, areas with higher numbers of zero grazing farming systems

Table 2 – Cattle population by country.

	Country	Head	Percent of world
1	India	281,700,000	28.29
2	Brazil	187,087,000	18.79
3	China	139,721,000	14.03
4	United States	96,669,000	9.71
5	EU-27	87,650,000	8.80
6	Argentina	51,062,000	5.13
7	Australia	29,202,000	2.93
8	Mexico	26,489,000	2.66
9	Russian Federation	18,370,000	1.84
10	South Africa	14,187,000	1.42
11	Canada	13,945,000	1.40
12	Others	49,756,000	5.00
	World total	995,838,000	100

Source: USDA/FAS, 2008 in Drovers, 2011 Available http://www.cattlenetwork.com/templates/newsarchive.html?sid=cn&cid=600361.

are more likely to adopt the technology. The number of dairy cattle increases availability of feedstock and the high selling cost of a cow implies that a farmer can raise sufficient funds to construct a biogas unit. In Sudan, lack of proof of economic-benefit analysis has led to low adoption [32].

Winrock International [33] carried out a financial and a holistic cost-benefit analysis of biogas technology and considered benefits such as provision of cooking and lighting energy, production of an organic fertilizer, improved health and sanitation, reduced labour requirements, reduction in greenhouse gas emissions, and improvements to the local environment. The study found a high financial and economic return and concluded that due to the multifaceted nature of these economic benefits, biogas technology has a potential to make progress simultaneously on a number of the Millennium Development Goals, thereby significantly improving the lives of poor African households. Despite all the above findings, biogas uptake in the SSA is still low and thus there is a need to explore more gaps in its adoption.

5. Discussion and recommendations

5.1. *Discussion*

Amigun and Blottnitz [9] consider that biogas technology can provide a means to overcome energy poverty, which poses one of the major barriers to socio-economic development in Africa. They also suggest that greater emphasis needs to be placed on productive uses of energy and energy for income generation in order to break the vicious circle of low incomes leading to poor access to modern energy services, which in turn puts severe limitations on the ability to generate higher incomes. They suggest that there is a need for significant increases in the numbers of organizations involved, together with more effective institutions in the energy sector. In order to implement the above recommendations, widespread adoption of the technology is needed and for that to happen a number of issues must be addressed including the socio-economic constraints and the institutional barriers to adoption.

5.1.1. *Tackle the major socio-economic constraints*

Some major socio-economic obstacles can be addressed by borrowing from the experiences of other countries. In Vietnam, the high cost of constructing biogas units was overcome through use of cheaper materials, such as plastics, by sourcing diversified funding such as the Clean Development Mechanisms, and by using highly subsidized fixed dome biogas units [34,35]. It is important to note that the use of plastic digesters in Vietnam was mainly in areas with predominately pig farming; whereas fixed dome units were used in cattle farming areas. In Nepal, a simple transparent and sustained subsidy policy was instrumental in increasing the adoption of biogas plants [14], in addition to the creation of an environment that allowed the private sector to play a significant role in the industry [23]. The same policy allowed larger subsidies for smaller plants, thus making the plants more affordable to poorer households. In India, the water issue was tackled through a community driven approach [36] and also through rain water collection methods. Kuteesakwe [37] and Bhat et al. [38] recommend use of multiple agencies in promotion of the technology, including private enterprise, promoters, catalysers and users, as well as interest groups to solve the constraint of lack of awareness. Increased literacy levels are also important in awareness creation [39,27]. Land tenure security is another important socio-economic factor that should be addressed, which improves both the supply and demand of institutional credits since land title deeds can be used as collateral for loans.

5.1.2. *Set appropriate institutional and policy frameworks*

In order to enhance adoption of biogas in SSA, there is a need to control the market supplying biogas digesters. As stated by Winrock International [14], free market conditions, particularly when regulations are weak and the customer does not have full information regarding the product, often result in competition between suppliers based on price alone at the expense of quality. For a national program, such as Nepal's Biogas Support Program (BSP), to succeed, a major prerequisite was that it be independent and free from political interference. Another major lesson learned from Nepal's experience is that standardization of technology to a single approved design makes quality control easier; similar observations are evident in other Asian countries such as Indonesia, Cambodia and Vietnam. At the same time, it allows a large number of competing companies to enter the market, with everyone working towards the same quality standards [14]. Quality control and standardization should also extend to biogas appliances and pipe connection materials and fittings. Adoption can further be enhanced by promoting integrated biogas initiatives [34]. Nyagabona and Olomi [40], for instance, recommend that governments focus on awareness campaigns through the media, translate policies into actions, and set conducive programmes and institutional frameworks to support biogas dissemination activities. Governments should also train more technicians and refrain from working in the market, instead concentrating on research and development. Associations of biogas users and disseminators should be formed to assist in reducing costs by joint procurement and linkage to finance.

5.2. *Recommendations*

Based on the results from the review, the following recommendations and policy implications are suggested.

1. African countries should carry out more effective mobilization by use of both domestic and external funding. One such example is the National Domestic Biogas Programme that is being implemented by countries such as Kenya, Ethiopia and Uganda. These programmes receive funds from the Netherlands Development Organization (SNV) [12].
2. African countries should develop and implement innovative policy frameworks, including transparent and sustained credit subsidy policies that allow larger subsidies for smaller plants thus making the technology affordable for poorer households.
3. African countries should support and promote research into biogas that is specific to conditions in SSA.
4. Governments should standardize proven technologies for use with specific raw materials such as plastics for pig manure and fixed domes for cattle dung. The

standardization of technology to a single approved design will make quality control easier and allow a large number of competing companies to enter the market, all working towards the same quality standards. This will bring an end to experimentation on farmers by competing suppliers whose basis is price alone, at the expense of quality. This will also reduce the number of failed biogas plants which gives a negative image to the technology and thus lowers its adoption. Quality control and standardization should also be extended to biogas appliances and pipe connection materials and fittings.

5. Agencies and government departments that have a stake in biogas technology should focus on overcoming constraints to adoption due to public awareness.
6. Biogas technology is a multiproduct technology and should thus be promoted as an integrated system of biogas and slurry. This not only improves the financial cost-benefit analysis but also emphasizes the other benefits of biogas technology. Biogas has multiple uses and these should also be encouraged. These applications include brooding of chicks and piglets, space heating, refrigeration, air conditioning and water heating. The various uses require different various appliances. Annex 1 shows some of the appliances that can be run using biogas.
7. Ready funding such as the Clean Development Mechanisms, that ensures sustainability through strict monitoring, should be encouraged and promoted to potential users of the technology.
8. Micro-financing institutions should also be encouraged to become involved in promotion of biogas technology.

6. Conclusion

Provision of affordable and sustainable domestic energy is one of the key components of improving the livelihoods of millions of poor people in SSA. Small scale biogas technology has huge potential to satisfy domestic energy demands in the same region. Despite the potential environmental and economic benefits, widespread adoption of biogas technology in SSA has been very slow. Institutional, financing, research and development and knowledge exchange support are required in order to enhance the widespread adoption of biogas technology in SSA.

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Annex 1. Some of the appliances used in biogas utilization

No.	Appliance	Use
1		Biogas cooker
2		Biogas stove (one burner)

– (continued)

No.	Appliance	Use
3		Biogas stove (Two burner)
4		Biogas water heater
5		Biogas lamp
6		Biogas blow pump

(continued on next page)

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– (*continued*)

No.	Appliance	Use
7		Biogas fire airbrush
8		Biogas flow meter
9		Biogas electricity generator
10		Biogas storage balloon

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