Renewable and Sustainable Energy Reviews 52 (2015) 468–476

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal

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A R T I C L E I N F O

Article history:
Received 30 July 2014
Received in revised form
18 May 2015
Accepted 26 July 2015
Available online 15 August 2015

Keywords:
Biogas
Anaerobic digestion
Sub-Saharan Africa
Sustainable development
Dissemination programme

A B S T R A C T

Biogas technology has the potential to provide benefits to three priority areas in Sub-Saharan Africa (SSA): energy supply, sanitation, and food security. Despite this, uptake of biogas systems has been slow and sporadic in the region. This review paper investigates what has prevented widespread dissemination of the technology in SSA by looking at the key barriers in the region, as well as identifying the main opportunities and the lessons that can be learned from successful biogas dissemination experiences in Rwanda, Tanzania, China, India, and Nepal. Installation costs, limited awareness and training for biogas users and insufficient follow-up services were recognised as being among the key barriers. SSA has favourable conditions for biogas technology, namely a suitable tropical climate in most parts of the region, a dominance of agricultural activities, and interest in alternatives to expensive conventional energy services. The region's favourable conditions therefore provide opportunities for increasing uptake of the technology. Experiences in other regions highlighted the importance of the government in supporting the biogas sector through suitable policies and incentives. Collaboration between research institutions, governmental departments, and biogas users, both current and future, was also recognised as being vital to improve the technology's dissemination and appropriate, long-term use.

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1. Introduction

The current energy situation in Sub-Saharan Africa (SSA) is characterised by abundance of resources, yet largely underdeveloped with a lack of appropriate domestic distribution and accessibility [1–3]. The

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http://dx.doi.org/10.1016/j.rser.2015.07.107
1364-0321/

majority of SSA countries struggle to meet their energy demand and rely on fuel imports, which are costly, therefore being detrimental to the economies of the countries, particularly those that are landlocked [2,3]. Furthermore, the average electricity price in SSA is commonly two-times that of other developing regions, with an additional cost associated to an unreliable supply [4]. The limitations of electricity supply and distribution infrastructure has left 620 million people in the region without access to electricity [5]. Rural SSA populations in particular have low electrification rates – approximately 11% – and rely heavily on diverse biomass resources, such as cow dung, crop residues, fuel wood, and charcoal [6]. These resources, in turn, have negative health and environmental impacts. The majority of households are poorly ventilated, yet use traditional open fire stoves, which propagates a build-up of smoke, particulates, carbon monoxide, sulphur, and nitrogen oxides in the home, thus posing serious health risks to its inhabitants [7,8]. The International Energy Agency (IEA) estimates that 75% of the SSA population –close to 730 million people – do not have access to clean cooking facilities [5,9]. Exposure to indoor pollution from the unimproved stoves is strongly linked to a number of diseases, including pneumonia and acute infections of the lower respiratory tract for children under the age of five, and chronic obstructive pulmonary disease in women [10]. In 2012, the World Health Organization (WHO) estimated that 581,300 people died in Africa from diseases that have been caused by exposure to indoor air pollution [6]. Aside from health impacts, the adverse effects from collection and use of these fuels on the environment and socio-economic development include: deforestation, land degradation in dry lands, aggravated soil erosion, and, associated flooding [1,11–13]. Improved energy services, including more efficient energy sources and conversion technologies, can make a positive contribution to both the livelihoods of the SSA population and the environment [14,15].

Biogas technology inherently meets most of the key requirements for addressing the energy access issues in SSA, and can be applied wherever there are sufficient organic materials. Biogas is comparable to natural gas due to its high methane content (50–70%), and can be used in the same way – for cooking, heating, electricity generation, and as a transport fuel [16,17]. It has an energy content of 21–23 MJ/m^3, which is odourless, colourless, and burns with a clear blue flame [16,18]. On an industrial level, biogas can also be fed into the natural gas grid, which occurs in some European countries, including Denmark, Switzerland, Sweden and Germany [16]. Biogas technologies are flexible in design and scale, ranging from simple household systems to high rate digesters, which are used for industrial wastewater treatment [19]. In developed regions, biogas systems commonly use a mixture of livestock manure and crop/food waste or energy crops for combined heat and power (CHP) production [20]. By contrast, biogas technology in developing regions is commonly utilised through small-scale systems, which are made from local materials or are prefabricated, as is the growing trend [21,22]. Cattle manure and/or latrine waste are used as the main feedstock; however, there is increasing interest and development of biogas systems suitable for treating organic solid waste [20]. At these smaller scales, the technology can be integrated into household, community, or commercial organic waste management systems for improved sanitation, as well as nutrient recycling [23,24]. Consequently, biogas technology has the potential to play an important role in improving energy access in the development process in SSA, particularly in rural regions [2,25–27]. SSA has significant potential for biogas production from municipal organic solid and sewage waste, as well as agricultural residues [28,29]. This is particularly important in major cities that have limited infrastructure to safely manage waste, and can convert a ‘problem’ into a profitable, recyclable product [17,28]. At the rural household scale, successful biogas technology adoption can reduce or eliminate the need to collect firewood for cooking, to provide a clean alternative, while improving sanitation, and providing the potential to increase soil fertility and crop productivity through accelerated processing of organic wastes [30].

Biogas technology is unique to other renewable energy sources. It can provide benefits to three sectors that are priority areas for SSA: energy supply; sanitation, and; food security (crop productivity). In light of such benefits, this review poses the question: what has prevented widespread dissemination of this technology in SSA? Compared to Asia, the dissemination of biogas in SSA has been slow [22]. Mwirigi et al. [31] have identified cattle population, maturity of biogas programmes, and construction costs as key contributors to lower installation rates in SSA compared to Asia. The same paper provides an overview of the socioeconomic barriers of the large-scale adoption of small-scale digesters in SSA, and explores factors that could improve dissemination [31]. We provide a literature review of the financial, technical, social-cultural, and institutional barriers to biogas dissemination (both small-scale and community scale) in SSA. Key opportunities to improve sustainable biogas technology adoption in SSA are identified using general examples from SSA, specific examples from Rwanda and Tanzania, and through lessons learned from China, India, and Nepal. The final result of our paper points to the technical, economic, policy, and social strategies recommended for application in SSA countries to improve biogas dissemination.

2. Overview of biogas dissemination in SSA

Since its first introduction in the 1950s, interest in biogas technology in SSA is a resurging phenomenon, yet its uptake has been sporadic. The launch of the “Biogas for Better Life –An African Initiative” in 2007 aimed to offer investment and business opportunities, market-orientated partnerships, and local ownership, with 2 million biogas installations by 2020 [32]. The initiative represented the first instance that the potential of biogas was evaluated for the whole continent of Africa, and provided a platform for biogas dissemination programmes in SSA through establishing the Africa Biogas Partnership Programme (ABPP). The ABPP is a partnership between two Dutch non-profit organisations, Hivos and the Netherlands Development Organisation (SNV), which currently supports domestic biogas programmes in five SSA countries: Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda [33]. The programme aims to install 100,000 biogas plants to provide sustainable energy to half a million people by 2017 [33]. In June 2013, a total of 29,500 biogas digesters were installed since the programme's commencement in 2009 [34]. The domestic programmes focus on households that have four or more cattle to provide dung as feedstock, making them less accessible to those with a lower socioeconomic standing, due to cattle ownership being linked to status and wealth in SSA [28]. In addition to the five countries currently running domestic biogas programmes through ABPP, several other SSA countries have experience with biogas technology, including: Benin, Cameroon, Lesotho, Madagascar, Nigeria, Rwanda, Senegal, South Africa, and Zimbabwe [17,28,35,36]. The oil crisis in the 1970s, along with the success of biogas use in China and India, motivated many of these countries to start development programmes for the technology, which involved scientific, technical, social and economic studies [36]. The studies were carried out precipitously and, as a result, brought disappointment, leading some administrators to believe that biogas is unsuitable for SSA [36].

2.1. National examples of biogas dissemination in SSA

2.1.1. Biogas in Tanzania

Biogas technology was first introduced in Tanzania in the 1970s. The Small Industries Development Organisation (SIDO), a parastatal organisation, installed floating-drum biogas digesters in the country between 1975 and 1984 [37]. During this time, the Arusha Appropriate