Renewable and Sustainable Energy Reviews 31 (2014) 846–859

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Biogas as a sustainable energy source for developing countries: Opportunities and challenges

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A R T I C L E I N F O

Article history:
Received 24 March 2012
Received in revised form
28 November 2013
Accepted 18 December 2013
Available online 23 January 2014

Keywords:
Anaerobic digestion
Biogas
Bioenergy
Developing countries
Greenhouse gas
Manure
Wastes

A B S T R A C T

Energy is an indispensable part of modern society and can serve as one of the most important indicators of socio-economic development. Despite advancements in technology, however, some three billion people, primarily in the rural areas of developing countries, continue to meet their energy needs for cooking through traditional means by burning biomass resources (i.e., firewood, crop residues and animal dung) in crude traditional stoves. Such practices are known to be the source of significant environmental, social, economic and public health issues. To achieve sustainable development in these regions, it is imperative that access to clean and affordable (renewable) energy is made available. Within this context, upgrading existing biomass resources (i.e., animal manure, crop residues, kitchen waste and green wastes) to cleaner and more efficient energy carriers (such as biogas from anaerobic digestion) has unique potential to provide clean and reliable energy, while simultaneously preserving the local and global environment. In spite of its significant potential to serve developing nations, however, the high costs and lack of expertise in installation and maintenance of biogas technology preclude widespread adoption in geographically isolated communities. Concerted efforts from both governmental and non-governmental sectors are absolutely essential in facilitating modernization and dissemination of biogas technology to harness the inherent potential that is currently underutilized and unexploited. The intent of this paper seeks to highlight the present status, challenges, and potential of biogas technology to advocate for further research, development and dissemination of the concept in developing countries.

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http://dx.doi.org/10.1016/j.rser.2013.12.015

1. Background

Energy is an indispensable part of our daily life, often taken for granted by populations which enjoy the comforts of modern society. Despite the continually rising energy demands reported globally, however, millions of communities and households, particularly in developing countries, still lack access to basic energy services such as electricity, liquid fuels, and natural gas. For example, about 1.5 billion people (over 20% of the world population) do not have electrical power, and approximately 3 billion people (some 45% of the world population) rely on solid fuels such as firewood, crop residues, cattle dung, and coal to meet their cooking needs (Tables 2 and 3) [1]. Further, the number of households depending on traditional solid fuels is increasing as the population growths in Sub-Saharan Africa (SSA) outpaced the number of new electrical connections [2–4]. With the absence of new policies to support access to modern energy services, an additional 50–220 million people in developing countries will rely on traditional solid fuels and stoves by 2030, compared to in 2005 [5]. Biomass, which comprises 10–14% of the total global energy demand [6], accounts for over 90% of household energy consumption in many developing countries [7]. Although governments in some of these nations annually spend between 40–60 billion US dollars on the installation of power infrastructure [8], the vast majority of the people in these regions remain disconnected from the grid (Table 3) [1]. Additionally, per capita energy consumption – often viewed as part of the development index – is very low ($<$1.0 tonne of oil equivalent (toe)/year) in developing countries compared to over 4.0 toe/year in developed countries [9]. For most of developing and SSA countries like Nepal, India, Kenya, and Ghana, the per capita total primary energy supply (TPES) is 0.34 toe/year, 0.54 toe/year, 0.47 toe/year, and 0.41 toe/year, respectively; far less than the world's average per capita TPES of 1.83 toe/year [9].

As the aforesaid countries continue to grow and urbanize, waste management will be a major issue at the local and national levels [10]. In developing and underdeveloped countries in particular, a lack of effective and efficient solid waste and sewage management systems pose a significant threat to human health and the environment. In Asia alone, waste generation has reached 1 million dry tons per day [11]; up to 70% of municipal solid waste (MSW) is comprised of organic matter [12]. Despite large expenses on infrastructure, the urban areas of most developing countries are still grappling with the challenges of preventing irreparable environmental damage [11]. The absence of sustainable management of organic fractions in MSW is already responsible for various ecological problems such as soil, surface and groundwater pollution from the leachate as well as uncontrolled methane (CH_4) emissions; a potent greenhouse gas (GHG) [12].

Recently, the world energy council and the United Nations (UN) commission on sustainable development have reiterated the need for affordable, clean and renewable energy to enhance sustainable development [13]. Further, the UN declared 2012 as the 'international year of sustainable energy for all' which had the objective of providing universal access to modern energy by 2030 [14]. In this context, the use of existing biomass such as kitchen waste, cattle dung, crop residues, green wastes, and the organic fraction of industrial and municipal wastes for producing clean and renewable energy through anaerobic digestion (AD) in developing countries would improve human health, the local environment and the socio-economic conditions [15]. AD is a biological process that converts organic matter into energy-rich biogas in the absence of oxygen. Biogas – a mixture primarily consisting of CH_4 and CO_2 – can be used as a clean renewable energy source for cooking, generating heat and electricity, and can be upgraded into biomethane for use as a transportation fuel as well. Biogas digestate, a nutrient-rich residue following digestion, can be used as a soil conditioner and/or organic fertilizer. Thus, AD can play a significant role in addressing all of the aforementioned concerns plaguing underdeveloped and developing nations (i.e., energy and waste management) while simultaneously increasing agricultural productivity [16].

This manuscript seeks to highlight the current situation of energy use in developing countries and elucidates the role that AD for biogas production can and does play in meeting the energy and waste management needs of these regions. Although a detailed discussion on the basics of AD can be found elsewhere [16]; a brief description is included to build a foundation for subsequent sections. This paper includes a general discussion on biogas production process, its composition and applications, and further reviews the available biomass resources in developing nations, their biogas production potential and subsequent GHG emission reduction potential. AD is a mature technology, and consequently an emphasis has been placed on the current status of biogas, but in many cases AD technologies in developing countries remain crude. The manuscript concludes with recommendations for the development and adoption of biogas technology as a sustainable energy source in developing countries.

2. Biogas: production, composition and applications

2.1. Biogas production

The conversion of organic matter into biogas is carried out by a consortium of microorganisms through a series of metabolic stages (namely, hydrolysis, acidogenesis, acetogenesis and methanogenesis) (Fig. 1). In the first step, complex organic compounds such as lipids, proteins, and polysaccharides are converted into soluble monomers or oligomers (e.g. amino acids, long chain fatty acids, sugars and glycerol) through hydrolysis, also known as liquefaction. This process is facilitated by hydrolytic or fermentative bacteria that release extracellular enzymes. The simple soluble