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Missed environmental benefits of biogas production in Zambia

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ABSTRACT

Biomass waste such as municipal solid waste, crop and forest residues, livestock waste and other organic wastes can be environmentally unsustainable if not properly handled. However, the same wastes could bring about environmental benefits and solve the energy poverty problem that Zambia is going through if used to produce biogas. Decomposition of livestock manure, direct combustion of woodfuel, forest residues, municipal solid waste and crop residues, chemical fertilizer production and application to managed soils emits a total of 2357 Gg CO_2 equivalents into the atmosphere (excluding biogenic CO_2 emissions) and results in nitrogen losses of 19.37 million tons per annum. Biogas production from biomass could result in conserving 10.38 million tons of nitrogen and replace (save) 13.23 million tons of biomass per annum in Zambia. The saved biomass can be used in the production of biogas and other modern bioenergy types. Biogas production could also result into production of 290×10^3 tons of organic fertilizer per annum as a by-product. Comparing this with the current chemical fertilizer consumption trends, 76% of the chemical fertilizer could be replaced. This would result into saving of forex and avoid emissions from raw material used in the processing of chemical fertilizers. An opportunity cost of approximately US$1 million per day exists if all households would engage in biogas production. There is need to create a comprehensive assessment framework for identifying and assessing environmental benefits arising from biogas implementation. The study closes data gaps that have existed for a long time and will be beneficial to policy makers, academicians and interested parties.

1. Introduction

Indiscriminate disposal and or burning of municipal solid waste in undesignated dumping places (Senkwe and Mwale, 2001; ECZ, 2008; Chifungula, 2007; KCC, 2010), burning of crop and forest residues (Baudron et al., 2007; Arslan et al., 2013), untreated sewerage going into water bodies, over utilization of biomass for cooking in a traditional manner using inefficient stoves (Gwavuya et al., 2012) and improper management of livestock manure have led to the creation of vectors where pests and virus breed, air and water pollution leading to chronic and non-chronic diseases, deforestation, land degradation and disturbances in the ecosystem (Li et al., 2009). The Sub-Saharan Africa and Zambia to be specific has not been spared by this scourge (Shane et al., 2015). Biogas production can contribute immensely towards solving these environmental problems from human activities and consequently solving the energy poverty problem (Sanches-Pereira et al., 2015; Auburger et al., 2016). The abundant biogas feedstock resources in Zambia can help in bringing about environmental sustainability and supplement the energy needs.

Rural households in developing countries depend highly on firewood, dung, crop and forest residues for their energy needs. They burn these energy resources using inefficient stoves and consequently get exposed to hazardous pollutants such as Respirable Suspended Particulate Matter (RSPM), carbon monoxide (CO) and nitrogen oxides (NOx). The women and children are the most affected as they are the ones who do the cooking chores (Kanagawa and Nakata, 2007). Semple et al. (2014) attribute high levels of exposure of fine particulate matter and carbon monoxide to combustion of biomass fuels in most parts of the world. Fullerton et al. (2008) and Xiao et al. (2015) argue that the exposure has been linked to the increased risk of respiratory, cancer and cardiovascular illness.

In sub-Saharan Africa, 90% of the population use fuelwood (charcoal/firewood), animal dung, crop and forest residues to do the cooking on three-stoned stoves which may occur indoors with

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little or no ventilation at all (Po et al., 2011). Studies in Bangladesh have shown that use of firewood, dung and jute sticks in rural household generate indoor pollution of about 60–1165 μg m^{-3} of $PM_{2.5}$ (Begum et al., 2009). In Ethiopia traditional use of biomass (wood, dung, crop residues, charcoal) for energy is about 95% and is responsible for 50,000 deaths and 5% disease burden in Ethiopia (Sanbata et al., 2014). Use of biogas from domestic digesters could avert this problem as biogas is an efficient and clean energy carrier. For these reasons, health and sanitation benefits arising from biogas production should be further investigated, assessed and quantified as would apply to Zambia.

The use of modern bioenergy has many benefits such as improved health and sanitation, creation of job opportunities, saving of time by women, replacement of chemical fertilizers by organic fertilizer and reduction in greenhouse gases (Axaopoulos and Panagakis, 2003). Biogas production provides a sustainable source of energy and the bio-slurry (organic fertilizer) enriches the soil. It also provides an opportunity to treat and re-utilize organic wastes and reduces land use problems associated with the disposal of organic waste (Batzias et al., 2005; Aggarangsi et al., 2013). Improved health and sanitation has both direct and indirect benefits on an individual household and a country as a whole. Productivity of a household or a labor force in a country directly depends on the health of individuals engaged as workers. The mortality, fertility and intellectual capacity of a country's population is indirectly affected by the health and sanitation situation in that country (Srinivasan, 2008). Construction, maintenance and operations of bioenergy plants create jobs and therefore improve the livelihood of locals as a result of an income which can sustain the family (Mengistu et al., 2015). In developing countries, the use of biomass in a traditional manner has put women and children at a health risk due to exposure to particulate matter while cooking using inefficient stoves. It is estimated that about 15 million people die every year due health risks associated with dust in kitchens (Din et al., 2014; WHO, 2015). Organic fertilizer from bioenergy such as biogas is rich in a lot of nutrients and organic matter and integrates the characteristics of both slow and quick acting fertilizers. Chemical fertilizers consume more net energy as compared to organic fertilizers (IFA, 2009) and consequently produce more CO_2 to the atmosphere (Kahrl et al., 2010). In Zambia, it is estimated that women in rural areas spend about 3 h a day collecting a head load of firewood. It has also been estimated that on a national average, 12.5 kg of firewood is consumed per day per household (CEEEZ, 2010; CSO, 2012; Chiwama et al., 2012).

This study quantifies environmental benefits that have been missed in Zambia as a result of not adopting biogas production fully. The study also estimates the opportunity cost to women who spend hours collecting loads of firewood every day. The study will be useful for policy makers, academicians, analysts, stakeholders and interested parties as it will close data gaps that have existed for a long time. The study forms one of the main justifications why Zambia should adopt and implement a biogas program and other forms of bioenergy programs seriously. If Zambia adopts and fully implements biogas production and other forms of modern bioenergy successfully, these benefits will accrue and consequently bring about rural development, reduction in greenhouse gas emissions and poverty reduction.

2. Methodology

The study uses data on bioenergy and biogas potentials from previous studies in published journals on Zambia, sub-Sahara African and other developing countries to quantify the environmental and ecological benefits. The Food and Agricultural Organization of the United Nations (FAO) database, the Central Statistics Office (CSO) in Zambia, Government of the Republic of Zambia (GRZ) ministries' official reports and Non-Governmental Organizations (NGOs) are among the sources of data used in the study.

2.1. Carbon dioxide emissions reduction

CO_2 emissions reduction of biogas is the difference between CO_2 emissions from burning of biogas and direct burning of traditional biomass such as firewood and or forest residues, livestock dung and crop residues (Wang, 1999; Pei-dong et al., 2007; Feng et al., 2009) as given in formula (1).

$$\delta C_i = C_{BMi} - C_{BG} \tag{1}$$

where: $\delta C_i = CO_2$ emissions reduction when using biogas to replace i type of bioenergy (tonne CO_2), $C_{BMi} = CO_2$ emissions from i type of bioenergy burnt in a traditional manner (tonne CO_2) and $C_{BG} = CO_2$ emissions from burning of biogas (tonne CO_2).

2.1.1. Carbon dioxide emissions from biogas

Biogas burns more efficiently compared to crop residues, livestock dung and forest residues burnt directly on an inefficient stove. Biogas burns at about 60% efficiency compared to firewood and dung at 5–8% efficiency when burnt in an open fire place (Mengistu et al., 2015). The quantity of CO_2 emissions from biogas are estimated according to formula used in Pei-dong et al. (207), Feng et al. (2009) and Zhang et al. (2010) as given in formula (2).

$$CE_B = \sum_{i=1}^{n} Q_{Bi} \times C \times EF_C \times \frac{44}{12} \tag{2}$$

where; CE_B is the CO_2 emission of biogas (tonne CO_2), Q_{Bi} is the quantity of biogas consumed from bioenergy resource type i (10^4 m^3); C is the calorific value of biogas per unit volume released (TJ $(10^4\ m^3)^{-1}$), EF_C is the carbon emission factor for biogas (tonne C TJ^{-1}). The quantity of biogas consumed and the calorific value are taken from Shane et al. (2015) who estimated the biogas potential from livestock dung and crop residues.

2.1.2. Carbon dioxide emissions from direct burning of biomass

Economic development, population increase, intensity of energy use and energy types being used are some of the main causes of CO_2 emissions. Rapid growth of economic activities demands more energy and consequently more CO_2 is emitted. Household energy consumption trends depend on size of each household and an increase in population entails increased CO_2 emissions. The intensity of energy use can lead to less or more CO_2 emissions. Energy types being consumed also dictate the amount of CO_2 emitted into the environment (Fan and Lei, 2015). In the sub-Saharan Africa and in Zambia in particular, CO_2 emissions into the atmosphere can also be attributed to not only traditional burning of biomass for energy but also burning of biomass by bush fires and field fires (Arslan et al., 2013; Shane et al., 2016).

The CO_2 emissions from burning of biogas and biomass are biogenic and end up being used by growing plants and as such have not been included in the greenhouse gas emissions accounting. Biogenic CO_2 emissions are defined as CO_2 emissions related to the natural carbon cycle, as well as those resulting from the production, harvest, combustion, digestion, fermentation, decomposition, and processing of bio-based materials. In biogenic CO_2 emission, there is carbon sequestration into the carbon cycle unlike in the CO_2 emissions from fossil fuels (USEPA, 2014). CO_2 emissions from bio-based feedstock do not increase the amount of carbon in the atmosphere unlike CO_2 emitted from fossil fuels. For this reason CO_2 from bio-based feedstock has no effect on global warming potential