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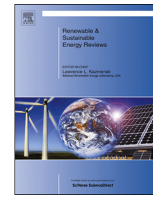

Nigeria biogas potential from livestock manure and its estimated climate value

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ABSTRACT

This paper estimates Nigeria biogas potential from livestock manure and its contribution to climate change mitigation. Findings reveal that Nigeria biogas potential from livestock manure represents a minimum of 1.62×10^9 m^3 of biogas per annum. Replacing diesel fuel with methane derived from biogas to produce electricity as well as inorganic nitrogen fertilizer with organic nitrogen from the anaerobic digester for agricultural use will lead to carbon dioxide (CO_2) emission savings of 683,600 t per annum. This amount represents the minimum contribution of biogas derived from livestock manure to climate change mitigation if harnessed for electricity and agricultural use in Nigeria.

Contents

1. Introduction

Both Rio [1] and Copenhagen [2] stress the need to cut global emissions, while Intergovernmental Panel on Climate Change (IPCC) [3] points out that an increase in greenhouse gas concentrations due to anthropogenic activities will result in the warming of the earth's surface. Specifically, the Cancun Agreements consider limiting the global average temperature to below 2.0 °C [4,5]. Worldwide, the human induced emissions of greenhouse gases have been increasing, and the growing use of fossil fuels since 1850 has led to a rapid growth in carbon dioxide (CO_2) emissions [4]. On the other hand, the earth's average temperature is projected to increase from 1.4 to 5.8 °C between 1990 and 2100, while the global average sea level is expected to rise from 9 cm to 88 cm over the same period [6,7]. Consistent with trends in other countries, CO_2 emission in Nigeria is increasing. It increased from 3.41×10^6 in 1960 to 70.23×10^6 t (tonnes) in 2009 [8]. As a result of emission impacts, agreements and protocols to limit air pollutant emissions of which CO_2 is one have been established – for example, the United Nations Framework Convention on Climate Change (UN FCCC) Kyoto Protocol [9].

Although the short to medium-term burden of climate change mitigation clearly rests on the shoulders of the Annex 1 countries, in the face of socio-economic improvements and population

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growth in other countries, efforts to abate future greenhouse gas emissions from these countries will also be needed if global atmospheric greenhouse gas emission levels are to stabilize or reduce. For example, it is projected that Africa will contribute between 1107 and 1852 × 10^6 t of CO_2 from 2010 to 2035, which is growing at an average of 1.8 per cent per annum [10]. Although Nigeria, which belongs to the non-Annex 1 countries, is not required to take any abatement action now under the UN FCCC Kyoto Protocol [9], the impact of climate change is a crucial issue for Nigeria and the Federal Government has recognized the country's vulnerability to increased climate change. For example, about 70 per cent of the Nigerian population depend on agriculture to meet their daily livelihoods which could be affected by climate change [11]. Globally, the livestock production sector is responsible for 18 per cent of the overall greenhouse gas emissions [12]. According to Tauseef et al. [13], livestock manure contributes about 240 × 10^6 t of CO_2-equivalent of methane to the atmosphere. However, there is a growing understanding that climate change will affect water quality, water quantity and water use [14,15], and also increase the risk of desertification [16]. Generally, water use, both domestic and agriculture, will rise with an increase in temperature which could have a negative impact on rain-fed farming in most rain dependent developing countries, while desertification is also a potent threat to agriculture. This implies that human livelihoods that are dependent on rain are intricately vulnerable to climate impacts [17,18]. Amidst all of these threats, the global freshwater withdrawal is expected to rise by 25 per cent by 2030 due to population growth [15].

At present, grid electricity supply in Nigeria is highly erratic. And there are cases of outages of up to 20 h a day in some localities. This situation has necessitated the call for sustainable solutions to rescue the irregular grid power situation in Nigeria in the face of growing demands. Nigeria, with a population of 162,470,737 in 2011 [8], has 5900 mega watts (MW) of installed generating capacity with grid power supply hovering around 3000 MW on an annual average in recent times. Peak demand has been estimated at over 11,500 MW, while grid power generation was as low as 1500 MW in the year 2000 [19]. To boost grid power supply the Federal Government injected about N5 trillion (US$31.45 billion) between 1999 and 2013, while grid electricity generating capacity increased from 2000 MW in 1999 to 4500 MW in 2013 [20]. In order to meet a minimum electricity demand during grid power failures in the country, most households and business organizations rely on stand-alone petrol and/or diesel fuel generators. Electricity from these sources is estimated to contribute over 6000 MW [19]. As of 2011, about 70 million generators are estimated to be in use in Nigeria, while between 60 and 70 million people in Nigeria are not connected to grid electricity or lack access to grid supply [21]. It is estimated that Nigerians spend about US$8 billion a year running the diesel generators, and the country is the largest market for generators in Africa [22]. Forecast indicates an average growth rate of 8.7 per cent per annum for generators which will drive up market volume from N71.55 billion (US$450 million) in 2011 to N151.16 billion (US $950.7 million) by 2020 [23].

However, that biogas is derived from the anaerobic digestion of organic substrates has been well illustrated in the literature (see, e.g., Al-Maliky [24], Ciotola et al. [25], Akbulut [26], Pipatmanomai et al. [27], Mohseni et al. [28], Lapp et al. [29], Bond and Templeton [30] and Tauseef et al. [13]). Essentially, anaerobic digestion consists of the decomposition of organic materials in the absence of oxygen and this process produces biogas which is rich in methane, followed by carbon dioxide, ammonia and traces of other gases, volatile fatty acids, and water. To produce electricity, many options exist. For example, the anaerobically generated (dry) biogas can be fed directly into a gas-fired combustion turbine. The combustion of biogas converts the energy stored in the bonds of the molecules of methane contained in the biogas into mechanical energy. The mechanical energy produced by biogas combustion in the engine spins the turbine that produces electricity [31]. Alternatively, carbon dioxide, water, hydrogen sulfide, nitrogen, ammonia, siloxanes, particulates and other gases can be removed from biogas to retain bio-methane for direct use in internal combustion engines to produce electricity [32]. According to von Mitzlaff [33], these unwanted gases and water do not participate in the combustion process; instead, they absorb energy from the combustion process thereby leaving the process at a higher temperature. This is consistent with the observation of Lapp et al. [29] who assert that carbon dioxide generally reduces the heat content of fuel. In general, the anaerobic digestion of organic materials (or substrates) in biogas digesters gives two main outputs: biogas and bio-manure [34,12,35].

Since efforts to cut global greenhouse gas emissions are now everybody's and every nation's business, this paper examines the amount of CO_2 that could be avoided in Nigeria by replacing diesel fuel-powered electricity generator with methane derived from biogas. It also takes a look at the amount of CO_2 emissions that could be saved if inorganic nitrogen fertilizer is replaced with spent bio-manure or digestate from the anaerobic biogas digester. This paper focuses on CO_2, because it is the most significant greenhouse gas emission that makes up nearly 77 per cent of global greenhouse gas emissions [36]. However, the literature (e.g., Sieling et al. [37], Igliński et al. [38], Asam et al. [39], Holm-Nielsen et al. [12], Ciotola et al. [25], Melikoglu [40], Huopana et al. [41] and Katuwal and Bohara [42]) agrees that harnessing energy from renewable sources could contribute to climate change mitigation. Apart from its utilization for electricity and heat production [27,29,43,30,44,45,32,35], biogas can also replace fossil fuels in the transport sector (e.g., in 2009, Sweden had about 15,000 vehicles driving on bio-methane [12]), serve as lamp fuel (e.g., biogas was used to power street lights in Exeter (UK) in 1895 [38,46]) and cooking fuel [47,29,48,30,49,50,44,35].

The rest of this paper is organized as follows: The approach to data collection and analysis is described in Section 2. Results are presented and discussed in Section 3. The challenges to realising the potential benefits of biogas for electricity generation and agricultural use in Nigeria are presented in Section 4. This is followed by conclusions and recommendations in Section 5.

2. Data collection and analysis

Secondary data on the domestic livestock population in Nigeria were obtained from FAOSTAT production database of the Food and Agriculture Organization of the United Nations in March 2013 for the period 2000–2011 [51]. The average value, which will be used in the rest of this paper, is estimated at: cattle 15,997,567; poultry (chickens) 155,630,670; goats 50,569,783; pigs 6,369,286 and sheep 32,158,042. Data on the minimum value of biogas yield per livestock were obtained from Adeoti et al. [52] as follows: cattle 78×10^{-3} m^3/day/livestock, poultry 1.54×10^{-3} m^3/day/livestock, goat and sheep 31×10^{-3} m^3/day/livestock, and pigs 59×10^{-3} m^3/day/livestock.

To estimate the amount of CO_2 emissions from diesel generators, this paper utilizes an emission factor of 2.6 kg CO_2 per litre of diesel fuel (from the calculation that diesel fuel contains about 0.695 kg of carbon). Since not all the carbons in the diesel fuel will be oxidized into CO_2 due to engine conditions, the emission factor (2.6 kg of CO_2) was adjusted to account for a small portion of the fuel that will not be oxidized into CO_2. In this paper, the oxidation factor used is 0.90 to obtain an average emission value of 2.34 kg of CO_2 per litre of diesel fuel. However, it should be noted that the