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Assessment of potential biogas production from multiple organic wastes in Brazil: Impact on energy generation, use, and emissions abatement

Ivan Felipe Silva dos Santos[a,*], Nathalia Duarte Braz Vieira[b], Luís Guilherme Bruni de Nóbrega[c], Regina Mambeli Barros[a], Geraldo Lúcio Tiago Filho[a]

[a] Natural Resources Institute, Federal University of Itajubá (UNIFEI - MG), GEER – Renewable Energy Group, Brazil
[b] Energy Systems Planning University of Campinas (UNICAMP), Brazil
[c] Natural Resources Institute, Federal University of Itajubá (UNIFEI MG), Brazil

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ABSTRACT

The anaerobic digestion of organic solid waste is one of the mechanisms for sustainable development, which allows for an appropriate disposal of solid waste and the energy exploitation of biogas. Brazil has a significant organic waste production and consequently a great potential for biogas production yet to be exploited. Therefore, this study presents an evaluation of the potential energy and the emissions avoided by the utilization of biogas energy produced from the bio-digestion of seven types of organic wastes. In general, this evaluation was conducted by considering the volume of wastes generated in the country and the average biogas production of each waste. From this study it was discovered that the potential power for 2015 was between 4.5 and 6.9 GW which would have reduced CO_2 emissions by 4.93% per year. In addition, over 180,000 buses can be powered using the biogas generated in Brazil. Limitations such as economic feasibility, absence of incentive policy, and the poor development of business models, are factors that prevent the successful implementation of biogas projects.

1. Introduction

Biogas is a gas mixture generated by anaerobic digestion. It is composed mainly of methane (CH_4) and carbon dioxide (CO_2). According to Chernicharo, (2007), the anaerobic digestion can be considered as an ecosystem in which many micro-organisms work to transform complex organic matter to methane (CH_4), carbon dioxide (CO_2), water (H_2O), hydrogen sulfide (H_2S), ammonia (NH_3), and new bacterial cells. The anaerobic digestion process involves different stages of interaction between the substrate and bacteria, and can be divided into four main phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Van Haandel and Lettinga, 1994).

Biogas is considered a biofuel (Roya, 2012) and its production can be constant provided there is a continuous production of waste. Therefore, the energy it generates is referred to as a renewable energy. Biogas is considered carbon neutral because the carbon in biogas come from organic matter (feedstocks), trapped from the carbon in the atmospheric CO_2 in a relatively short time (Awe et al., 2017).

Biogas has several applications besides the generation of electricity, namely: for domestic heating, as vehicle fuel, cogeneration of electricity and heat, treatment and subsequent injection into gas grid, in chemical industry, *etc* (Al Seadi et al., 2008). As the complexity of its application increases, the degree of impurity removal required also increases. Awe et al. (2017) discussed various forms of biogas treatment as removal of CO_2 and removal of H_2S. Several studies have discussed biogas applications using different approaches. Appels et al. (2008) highlighted that the injection of biogas into gas networks was already a standard practice in some European countries (Sweden, Switzerland, Germany, France, among others), and used in the substitution of fossil fuels after appropriate purification. Other studies like Chen et al (2016) and Sibilo et al (2017) assessed the benefits of trigeneration practice (combined cooling, heating, and power generation) from biogas in different regions of the world. In the application of biogas as vehicle fuel, studies have reported the potential for its utilization in bus fleets in developed countries such as Sweden (Olsson and Fallde, 2015) and in trucks for transporting sugarcane in Brazil (Moraes et al., 2014). The possibility of using biogas as a source of fuel for buses in Brazil was investigated in 1999 by Kuwahara et al. (1999). Wei and Xin (2015) studied the life cycle of the using biogas from municipal solid wastes for vehicle fuel. According to the authors, the maximum pollution emissions is in the

* Corresponding author.
E-mail addresses: ivanfelipedeice@hotmail.com (I.F. Silva dos Santos), nathaliadbv@unifei.edu.br (N.D. Braz Vieira), luisguilherme_bruni@yahoo.com.br (L.G.B. de Nóbrega), remambeli@hotmail.com (R.M. Barros), gltiagofilho@gmail.com (G.L. Tiago Filho).

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operation phase of the vehicle, so the key target of reducing environmental pollutants is to improve biogas fuel combustion system by the creation of an advanced automotive technology.

In Brazil, as at January 2017, there are only 15 biogas power plants, which produced a total of 114.7 MW of power (The Brazilian National Electric Energy Agency ANEEL, 2017)), and it is equivalent to 0.83% of the National biomass capacity. The production of biogas in Brazil is still incipient while this renewable energy source has long been incorporated in the energy matrix European countries (Rutledge, 2005). The electricity generated from biogas in Germany was almost 27 TW h in 2013, which supplied energy to over 7.5 million houses and also generated more than 41,000 jobs (German Biogas Industry, 2017). In all of Europe, 52.3 TW h of energy was produced from biogas in 2013, with Germany as the highest producer, followed by Italy, United Kingdom, and Czech Republic. The speculation was that in 2020 the European production of electricity from biogas will be approximately 65 TW h (EUROBSERV'ER, 2014).

There is a high potential in the production of biogas globally. Ferreira et al. (2009) estimated this potential to be 1.1 TW h/y in Portugal landfills. Moreda, (2016) evaluated a minimum electric potential of 0.162 TW h/year in Uruguay, by considering the anaerobic digestion of agricultural residues, animal manure, vinasse, wastewater treatment sludge and municipal solid waste. Abdeshahian, 2016 estimated a potential electricity of 8.27 GW h/year will be obtained from animal manure in Malaysia. The biogas energy potential from biomass was projected to range from 1.2×10^3 to 2.3×10^3 PJ/y in 2030 in the EU28 countries (Meyer et al., 2017). Salomon and Lora (2009) estimated a potential of about 1 GW (approximately 7 TW h/y) in Brazil, when the population, livestock units, and landfills were lower than what is presently obtainable. Ionescu et al. (2013) also studied the potential energy of biogas at a small distribution generator. According to the authors, on the basis of a 4 person residence pattern in southern Italy, the adoption of anaerobic digestion of food waste produced by a family could generate energy of about 64 kWh_{el}/y. Also, the anaerobic digestion of sewage sludge of the wastewater produced by each family could generate 117 kWh_{el}/y. These data proves the benefit of energy generation from biogas.

One of the main barriers to the generation of electricity from biogas is its economic feasibility. Rangel (2016) estimated the minimum cost of energy produced from biogas in Brazil to be 105.3 USD/MWh, while the tariff used of conventional thermoelectric power plants was 86.9 USD/MWh. ANEEL (2016), demonstrated in a general form, the economic infeasibility of biogas thermal plants. Barros et al. (2014) and Santos et al. (2016) estimated that a small population using landfill, and anaerobic sewage treatment plant in a region, shows the economic feasibility of electricity generation from biogas produced in that region. The values obtained by the authors was 200,000 (for landfills) and 300,000 (for sewage treatment plant) inhabitants. The obtained value excluded a significant number of the Brazilian cities.

Other challenges that prevent the use of biogas as a source of energy are the absence of appropriate political framework and business models. In 2014, biogas was yet to be considered a primary energy source in Brazil (Mathias, 2014), and there is no specific program for its promotion (Brazilian Ministry of Cities, 2016). The regulation for biogas energy is new and gradually developing. A major regulation is the addition of biomethane to natural gas distribution network, which was established in 2015 by the ANP resolution nº 08, applied to agroforestry residues (ANP, 2015). Due to the significant presence of contaminants in the landfill and WWTP biogas, and the lack of technological know-how required to discover and treat this gas in Brazil, the addition of biomethane to biogas energy sources was regulated in 2017 by ANP resolution nº 685 (ANP, 2017a). In the same year, the São Paulo state established a new policy (Deliberation nº 744/2017) (São Paulo, 2017) for biomethane commercialization and injection into the gas network, through public calls and quality standards.

Recently, the Ministry of Mines and Energy has set up a program called "Renovabio", aimed at stimulating bioenergy in Brazil, through the creation of carbon reduction mandate for fuel sold by the distributors, which was fulfilled by the purchase of Emission Reduction Certificates (ERCs). The certificate was issued to ethanol, biodiesel and biogas plants that were successful in the certification process. The price of the biodiesel produced will vary depending on the level of production and the efficiency of carbon reduction (Ministry of Mining and Energy MME, 2016). Therefore, the Brazilian biogas energy sector anticipates an increase in the participation of industries.

The regulation of waste treatment in Brazil is new and has no significant incentive for use as an energy source. In 2010, Brazil established a National Policy on Solid Waste by Law 12,305/2010 (Brazil, 2010a) that was regulated by Decree 7,404/2010 (Brazil, 2010b); a regulatory framework for the solid waste sector, by integrating a series of laws. The law stated that by 2014, cities must close their dumps and properly dispose the municipal solid waste they produce. The Project of Law 2289/2015 (Brazil, 2015a) is still under debate, the Congress proposed an extension of the deadline, which could possibly be extended to 2021, depending on the number of inhabitants in the municipal. Since sanitary landfills are cheaper than dumps (Agamuthu, 2013), they have been the commonly used option for municipal solid waste disposal in the country, and their usage have been increasing in recent times (ABRELPE, 2015). The more is the number of landfills, the greater will be the potential of generating electricity from its biogas.

The Resolutions of the Brazilian National Council of Environment n º 375 and 430, in 2006 and 2011 (BRAZIL, 2006, 2011), defined the criteria and procedures for the usage of sewage sludge generated from wastewater treatment plant in agriculture, and set standards for the disposal of effluents. A summary of all the laws related to organic waste in Brazil can be obtained from Brazil, (2017a). The laws on organic waste and domestic effluents are important, because they demonstrate the Nation's effort in controlling the release of wastes into rivers and soil, which makes the bio-digestion of these wastes (in form of animal manure and sewage sludge) an important tool for reduction of organic waste when applied as a soil fertilizer.

This study presents an analysis potential biogas production from organic waste in Brazil, evaluating the application in electricity generation, bus fleet fuel, and reducing CO_2 emission. The analysis developed in this work covers the anaerobic digestion of seven types of wastes in Brazil: municipal solid waste (in landfills), wastewater (in upflow sludge blanket anaerobic reactors – UASB) and the sludge originated from its treatment (treated in anaerobic biodigesters); vinasse (residue from sugarcane industry– treated in UASB reactors); cattle, pig, and poultry manure (with profound generation in Brazil, whose economy is highly agricultural – treated in anaerobic digesters). The magnitude of these potentials in the energy matrix of Brazil and the CO_2 emission of biogas was evaluated. The cost of biogas energy deployment and its potential application as fuel for vehicles was estimated and elaborately discussed. The methodology used in this study is simple and can be applied to various regions and types of waste.

2. Methodology

To evaluate the uncertainties associated in the results, a methodology similar to that of Moreda (2016) was applied, where the potential was estimated using 3 scenarios: minimum, average and maximum, and defined in terms of the value the parameters in the calculation may assume.

2.1. Estimation of the potential biogas production from landfills

First, the domestic solid waste index and the population in each region in Brazil was obtained. Then from the obtained data, the volume of waste produced in each region annually (V_r), was calculated using Eq. (1) (Barros, 2012):