Biogas from sugarcane vinasse: environmental, energy and regulatory issues for a political agenda in Brazil

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Abstract

Brazil is the largest sugarcane producer in the world, an important input to ethanol production, which puts the country in a privileged position in biofuel world market. Besides the importance of sugar production in the sugarcane chain, this work focuses on ethanol production (ethanol industry), particularly its main waste, vinasse. Vinasse presents several environmental risks due to its bio composition and, if dumped in rivers or lakes, causes the phenomenon of eutrophication, which promotes a high growth of aquatic plant species and spread environmental problems. In this scenario, the anaerobic digestion of vinasse (the most abundant effluent from a sugarcane biorefinery) arises as an interesting alternative because, in addition to promoting the stabilization of organic matter, it also enables energy generation from biogas (biomethane). Anaerobic digestion generates biomethane and biofertilizer from vinasse. The objective of this article is to study the biogas potential generation from sugarcane vinasse in Brazil using anaerobic digestion technology also presenting the challenges and the governmental agenda required to develop biogas systems to sugarcane sector in Brazil. This work presented a huge biogas production potential from sugarcane vinasse. It can be used in multiple ways, and this work emphasized two important energy uses: to substitute natural gas and to generate electricity in a distributed generation concept. Besides the huge potential, there is an extensive agenda to solve and overcome the multiple barriers for biogas systems implementation in Brazil. According to international experience the strong governmental involvement is necessary and sufficient condition to develop renewable energy sources. In that sense, biogas systems need to be inserted in Brazil's policy agenda.

1. OVERVIEW

In recent years Brazil has experienced a huge increase in energy demand. The supply has also grown, but it is not enough to meet the increasing demand. Historically Brazil has used large power plants with huge dams to produce cheap energy. However, in the last past years there was a crisis in the hydroelectric power sector and some environmental issues have contribute to change the nature of the new projects. It opened opportunity to thermal power (particularly natural gas), but

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essentially allowed an agenda focusing on alternative sources of energy (photovoltaic, wind, biomass, etc.) and, at same time, the distributed generation idea.

Because of its huge agricultural and livestock activity and production biomass is abundant in Brazil. Brazil is the largest sugarcane producer in the world, an important input to ethanol production, which puts the country in a privileged position in biofuel world market[4]. Among the various agricultural crop residues, sugarcane bagasse is the most abundant lignocellulosic material in tropical countries. Sugarcane straw and bagasse are mainly formed by lignocellulosic biomasses (Paoli *et al.*, 2011).

Besides the importance of sugar production in the sugarcane chain, this work focuses on ethanol production (ethanol industry), particularly its main waste, vinasse. Vinasse presents several environmental risks due to its bio composition. Because of its high levels of temperature, acidic pH, corrosivity, as well nutrients as nitrogen, phosphorus, sulfates, besides organic matter, the residue of the distillation of alcohol has a high level of oxygen demand and, if dumped in rivers or lakes, causes the phenomenon of eutrophication, which promotes a high growth of aquatic plant species and spread environmental problems.

The need to improve the sustainability of bioethanol production from sugarcane in Brazil has intensified the search for process energy optimization coupled with the environmental suitability of the generated coproducts and wastes (Moraes *et al*., 2014). In this scenario, the anaerobic digestion of vinasse[5] (the most abundant effluent from a sugarcane biorefinery) arises as an interesting alternative because, in addition to promoting the stabilization of organic matter, it also enables energy generation from biogas.

Waste management allows avoiding soil and watering pollution and, at the same time, can produce energy, particularly from biomethane production, which can be used as a substitute of natural gas, and generate heat and electricity, among other by products such as bio fertilizer. Anaerobic digestion (AD) is an alternative technology to manage several types of wastes, especially from

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[4] The 2008/09 harvest year saw a record crop estimated at 569 million tonnes of sugarcane, processed at around 423 plants nationwide. Of these, 248 were combined mills and distilleries producing both sugar and ethanol, while 159 produced just ethanol. All mills are self-sufficient in producing their own electricity needs. According to Neves et al. (2010), the sugarcane chain's GDP was, in 2008, $ 28.1 billion, equivalent to 2% of the Brazilian National GDP or almost the overall economic output produced in a country like Uruguay ($ 32 billion).The industry sold about $22.6 billion with all of the products, being $12.4 billion with ethanol,$9.7 billion with sugar, $389.6 million with bioelectricity, and $67.0 million with yeast, additives, and carbon credits. These products represent, respectively, 55%, 43%, 1.7%, and 0.3% of their sales (Neves et al. 2010).

[5]Vinasse is produced in many countries as the by-product of ethanol from different feedstocks: sugarcane in South America, beet, wine, and fruits in Europe, and corn and tequila in North America (Christofoletti et al., 2013).

agriculture and livestock wastes, and, at the end of the process produces a large amount of biogas (methane gas, biomethane) and biofertilizer. It fits especially in livestock manure (Mathias, 2014) and also agriculture crop residues and wastes.

The management and disposal of agro-industrial residues have recently received attention because of the inadequate and indiscriminate discharge of many effluents in the environment (Christofoletti et al., 2013). Due to the amount of this biomass as an industrial waste, there is great interest in developing in a biorefinery concept, methods for the production of fuels and chemicals that offer economic, environmental, and strategic advantages (Rabelo *et al*., 2011). In sum, better use of residues may significantly increase the production of biofuels, bioenergy and renewable materials using the same amount of biomass and cultivated area (Pereira *et al.*, 2014).

As pointed by literature (Mathias, 2014; Mathias and Mathias, 2015; Moraes et al. 2015), current policies and regulations that provide guidelines to develop biogas systems (AD) are inefficient and outdated. And also, there is a very important problem: the non appreciation or even consideration of biogas as an alternative fuel.

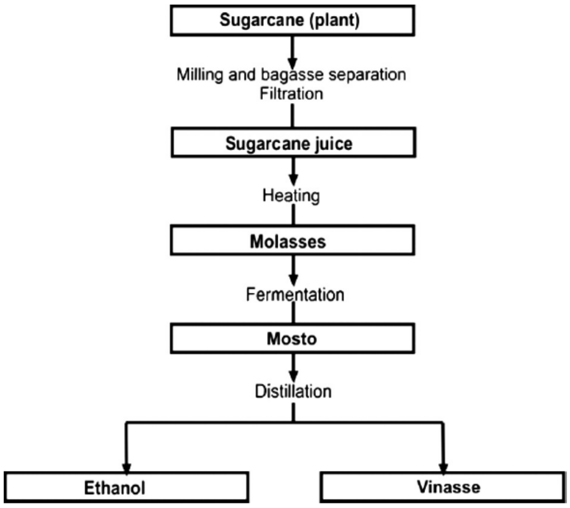
The real issue is how the huge potential of biogas production from sugarcane vinasse can be realized, used and substantially contribute to a transformation of Brazil's energy sector. Therefore, two important questions have to be considered: how much is (the potential amount of biogas produced) and how to take advantage of its multiple uses. The biogas is a source of biomethane to replace natural gas in the gas grid system. Biogas can be utilized to generate combined heat and power (CHP) on-site, at household micro and distributed or in community scales.

In this sense, the objective of this article is to study the biogas potential generation from sugarcane vinasse in Brazil and the challenges and barriers to the development of sugarcane vinasse biogas systems. The work suggests the hypothesis that distributed (decentralized) generation should be the main drive to develop biogas systems in the country.

2. METHODOLOGY

One of the most important and little discussed subjects regarding the negative impacts of sugarcane is vinasse, a by-product of ethanol industries (Figure 1). It is a residual liquid, also known in many regions of Brazil and other parts of the world as stillage, mosto, dunder or distillery pot ale (Christofoletti et al. (2013). The Figure 1, below, shows the steps to produce ethanol from sugarcane, presenting all by-products of this production.

Figure 1: Flowchart of ethanol production process and underproduction of sugarcane vinasse



Source: Christofoletti et al. (2013).

As can be seen, vinasse is a by-product from distillation in the ethanol production process. Vinasse is compounded by 93% of water, 7% of solids, and presents from low to high dark color, bad smell, acid pH, high temperature, high levels of salt (among 24,000 to 80,000 mg/l) and organic material (4,000 a 64,000 mg/l). This effluent has also high concentrations of potassium, calcium, magnesium, sulfur and nitrogen (Pereira and Pereira, 2008). These compounds remain after different steps involving the sugar cane production and processing. These hazardous substances cause the vinasse to have a very high oxygen demand and a pH of 4-5.

Studies have pointed that the main impact caused by vinasse infiltration in soil and groundwater resources is salinization and growing concentration of nitrate, nitrite, ammonia, magnesium, phosphate, aluminum, iron, manganese, chloride, and organic carbon. Metal mobilization as iron, copper, cadmium, chromium, cobalt, nickel, lead, and zinc could occur, and change of pH in soil and groundwater.

There are alternatives for the use of vinasse. The use of vinasse in fertirrigation[6] is an alternative that focuses on the rational use of natural resources, preventing the discharge of vinasse in rivers,

[6]Fertirrigation is the method through which the fertilizing substances are distributed to the plants simultaneously with the irrigation water, thus leading to significant energy and labour savings, also to significant increments in production.

while fertilizing agricultural land. Among the alternatives for the use of vinasse developed around the world, fertirrigation is the most commonly used, as requires a low initial investment (tubes, pumps, trucks, and decantation tanks), low maintenance cost, fast application, does not require complex technologies, and increases crop yield (Christofoletti et al., 2013).

The composition of this effluent is not standardized according to soil use, which is another issue of environmental concern because vinasse characterization varies significantly according to each sugarcane processing plant. For example, the chemical oxygen demand (COD) of organic matter content can vary between 10 and 65 g/l. Consequently, the impacts caused by potential GHG emissions resulting from vinasse organic matter degradation on soil, in addition to unpleasant odors generated and possibly attracting insects, are not considered but are likely to occur.

In spite of Brazilian permissive legislation, continuous fertirrigation practices could also induce impacts in the soil and groundwater. According to Madejón et al. (2001), high salt concentrations in the soil and the potential risk of salinity can occur with the continuous use of vinasse. Ribeiro et al. (2010) detected an increase in the leaching of lead in the presence of vinasse in the soil, particularly due to the soluble organic compounds in such effluent, which formed soluble complex organic matter with lead. According to this literature, special attention should be given to areas that are receiving vinasse for a long period of time and are occasionally subject to contamination by lead. Besides, Madrid and Díaz-Barrientos (1998) observed increased leaching of zinc and copper when soils were treated with concentrated sugar beet vinasse and indicated that previous removal of organic soluble compounds in effluents is necessary to minimize metal leaching. Other research also highlighted potential contamination of groundwater according to the volume and frequency of vinasse application on soil (Moraes et al., 2014).

New environmental standards restrict the use of the vinasse in the soil, due to the risk of organic and potassium soil saturation, and the protection of underground water from pollution, forcing ethanol producers to look after new safer ways of disposal (Salomon et al., 2011).

Moraes et al. (2014) agree that from an economic perspective, fertirrigation represents the least expensive and simplest solution for discharging this voluminous effluent based on Brazilian environmental legislation. However, as mentioned above, it is unclear whether one can safely assert that this action does not result in environmental impacts even though it is allowed by law. According to the authors, the lack of regulation of vinasse chemical composition for soil application allows fertirrigation with *in natura* vinasse to act as a source of potential environmental impacts.

Anaerobic Digestion (AD) offers an alternative to deal with by-products from ethanol production process. The ethanol industry produces vinasse as a residual and this waste can be used, in order to produce energy and avoid environmental damages. The organic load of vinasse can be submitted to an anaerobic biodigestion. This process consists of the biodegradation of the organic load of vinasse to produce biogas and biodigested vinasse. As it will be shown, biogas can offer a complementary alternative to the energy balance in Brazil.

To evaluate the biogas potential from sugarcane vinasse it is necessary to consider a set of parameters and data related to Brazil's sugarcane activity. Brazil's Geography and Statistics Institute (IBGE) provides the majority of data in Brazil, including information related to sugarcane and ethanol production. Another important source of data is the Brazilian Sugarcane Industry Association (UNICA). Having the data we formulate an index that allows estimating the biogas production potential from sugarcane vinasse and then comparing with Brazil's natural gas demand needs.

2.1) Anaerobic Digestion as an alternative: literature review

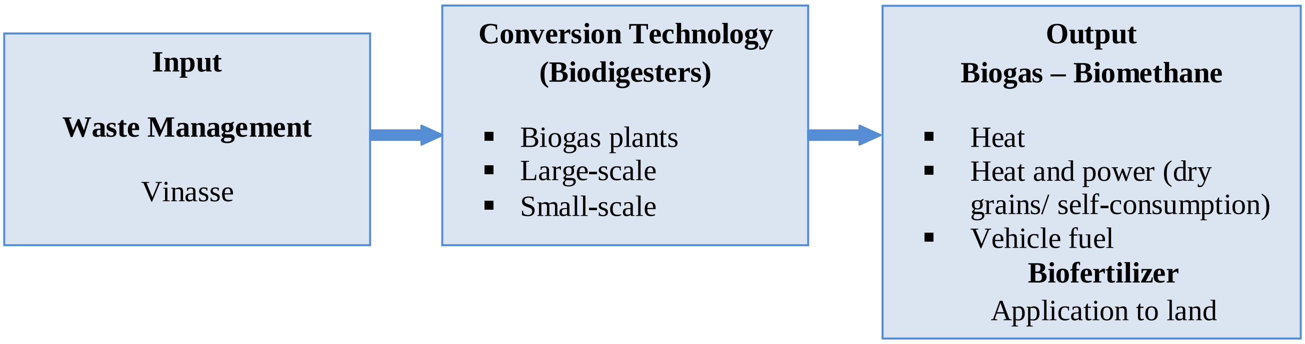
The generation of biogas from the AD of biomass is a technology which can produce sustainable energy and also reduce the environmental risks associated with manure and waste management. Biogas is produced by bacterial conversion of organic matter under anaerobic conditions and is a mixture of carbon dioxide (CO_2) and the flammable gas methane (CH_4). The biogas produced, consists of methane (50–80%), carbon dioxide (20–50%) and traces of, for example, hydrogen sulphide (0–0.4%) (Jiang et al. 2011; Lantz et al. 2007).

An overview of the waste management and biogas production from sugarcane vinasse is shown in Figure 2. In this schematic view, vinasse is the input to convert into biogas and biofertilizer, using biodigesters technology[7]. The biodigested vinasse is later used as fertilizer. Although it presents a reduced organic load, it maintains its original properties as fertilizer. On the other hand, biogas is mainly used to produce energy, due to its high methane content. In the sugar-ethanol industry, biogas can be used to: operate gas turbines combined to an electric generator; substitute part of the

[7] Anaerobic biodigestion has received more attention only after the development of high performance reactors, such as the UASB (Upflow Anaerobic Sludge Blanket), which is the most adapted to vinasse. In this type of system, the sludge at the bottom of the reactor adsorbs most of the organic matter, while gas is produced in the reaction compartment as bubbles during the anaerobic process, and removed to a separate compartment (Christofoletti et al. 2013). Choice of reactor type is determined by waste characteristics, especially particulate solid contents or total solids (TS). High TS feedstocks and slurry waste are mainly treated in (continuously flow stirred tank reactors (CSTRs), while soluble organic wastes are treated using high-rate biofilm systems such as anaerobic filters, fluidized bed reactors and upflow anaerobic sludge blanket (UASB) reactors (Karellas et al. 2010).

fuels used in the agroindustry during the harvesting time; or use in boilers to generate vapors and to mill sugarcane (Christofoletti et al. 2013).

Figure 2. Overview of the waste management and biogas from sugarcane vinasse



Considering the current available technologies for waste water treatment, anaerobic digestion stands out as an interesting alternative to be applied to the liquid wastes of sugarcane biorefineries (Moraes *et al*. 2015). Regarding energy aspects, the biogas generated from the anaerobic process would be an attractive alternative energy source due to the high heat of combustion of the methane present in the biogas. As pointed by Moraes et al. (2015: 895): "… anaerobic digestion is suitable for a sugarcane biorefinery because in addition to the environmental suitability of waste waters, it also allows energy to be generated through the use of biogas and the generation of other by-products from that biological process".

The employment of anaerobic digestion technology for waste treatment is possible and desirable given that it contributes to environmental conservation, makes modern production systems viable, and optimizes the enterprise's cost/benefit ratio. In the same way, rational use of raw material and correct waste management optimize productive systems to achieve a harmonious coexistence between man and the environment (Salomon, 2007).

The next step is to calculate the biogas (biomethane) potential from sugarcane vinasse focusing on an alternative energy source, either a natural gas substitute, or a source to produce electricity using microturbines.

2.2) Data source and Brazil's sugarcane sector state-of-the art

Brazil's exposure to the oil shock of 1970s mobilized sufficient political will to embark on a national effort to develop domestic ethanol sources and an ethanol engine to be user in vehicles.

Decades of innovation resulted in significant technical and commercial advances (IRENA, 2013). In 1975, Brazil's government created the National Ethanol Program (PROÁLCOOL) during the oil crisis as an alternative to petroleum products (Christofoletti et al., 2013). Many distilleries were built and they produced ethanol and sugar, but also vinasse as a by-product of the production. During the 1980's all cars produced in Brazil used ethanol as a fuel. The government created mechanisms to incentive both, the supply and the demand of ethanol and, as a result, Brazil became the largest producer and exporter of ethanol in the world.

Because of the expansion of the sugar-ethanol industry since 1975, distilleries began to produce ethanol but also vinasse, contributing to increase environmental pollution.

Today Brazilian vehicle industry developed an especial engine that works both with ethanol or gasoline (or any mixture of them). All the cars produced in Brazil have this engine and the consumers decide what fuel (or combination of fuel) they want to use at the gas station depending on relative prices and the engine's efficiency.[8]

All these factors contribute towards an increase in sugarcane Brazilian production (Graph 1) and the country continues to be the major world's producer (Table 1).

Table 1: Sugarcane production and harvest area: selected world majors producers (2004 and 2013)

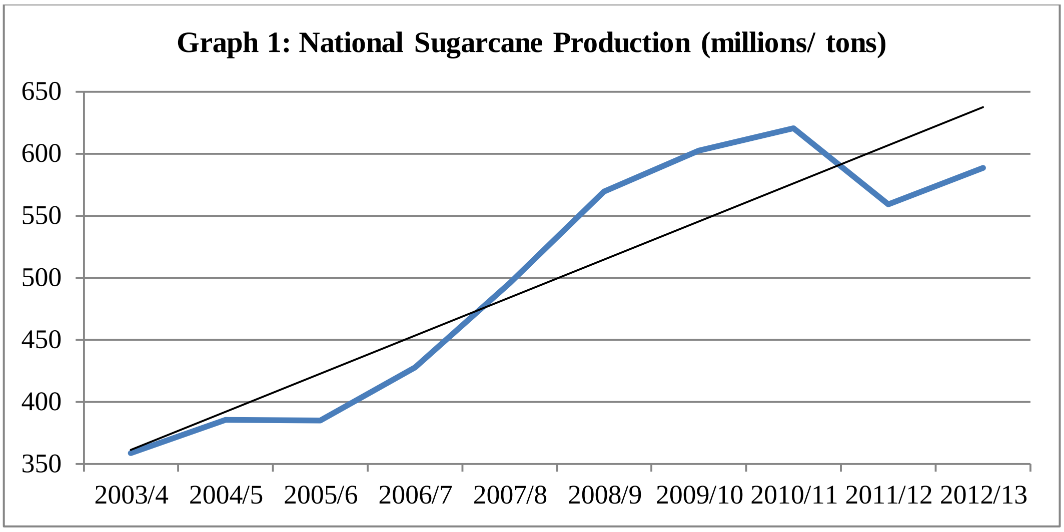
Country	Production (million tons)			Harvest Area (million ha)		
	2004	**2013**	**AnnualGrowth Rate**	**2004**	**2013**	**AnnualGrowth Rate**
Brazil	415	768	7.1%	5.63	9.84	6.4%
India	234	341	4.3%	3.94	5.06	2.8%
China	91	129	3.9%	1.39	1.83	3.1%
Thailand	65	100	4.9%	1.11	1.32	1.9%
Pakistan	54	64	1.9%	1.07	1.13	0.5%

Source: FAO Stat (2014).

Brazil's sugarcane production tends to increase, as shown in Graph 1. The Brazilian production and area harvest expanded most from 2004 to 2013, despite productivity has grown less than all others five biggest producers. In fact, if Brazilian productivity had grown the same as the average of the

[8] In Brazil, distilleries produce two different kinds of alcohol, or ethanol. The first one is called hydrated ethanol, which is use in vehicles engine directly, and de other is called anhydrous ethanol, which is blended with gasoline. The vehicle gasoline in Brazil is a blend of pure gasoline with anhydrous ethanol, which represents 27% of the mix.

others four top ranked producers, the country would have produced 840 million tons of sugarcane in 2013, revealing a yet production growth potential.

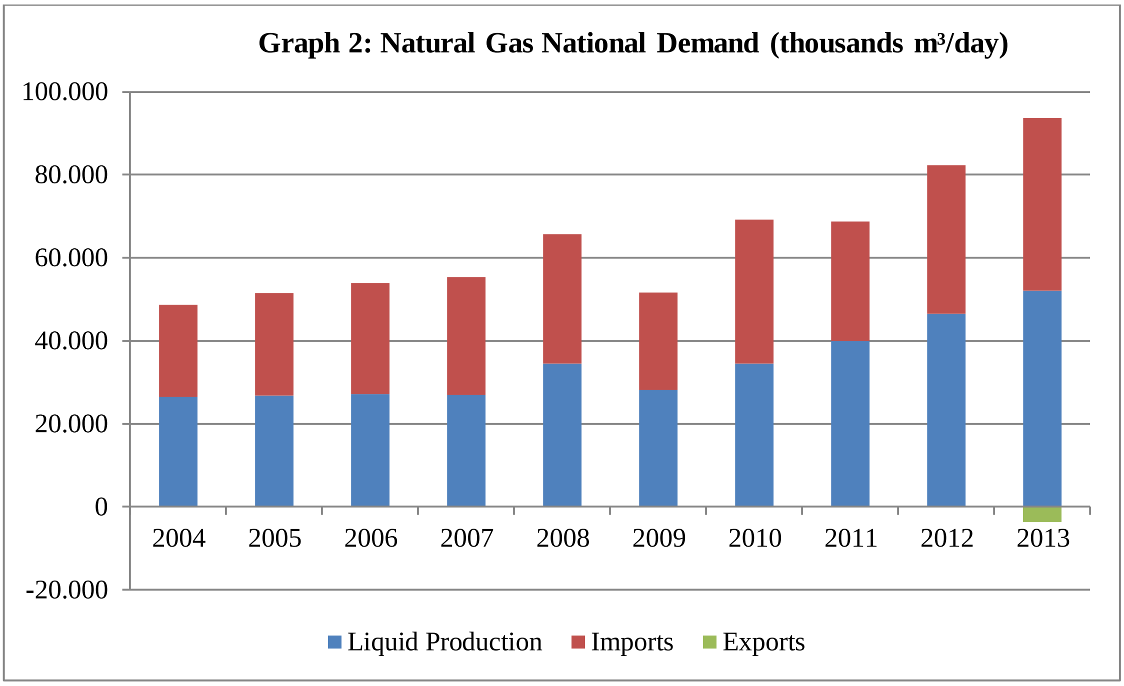


Source: UNICA (2014).

All of this data shows that Brazil has an important advantage in energy production from sugarcane. The bagasse is already used to generate electricity. The sugar juice is used to produce ethanol. Besides this, it is also possible to use the vinasse to produce biogas, which potential is still unknown.

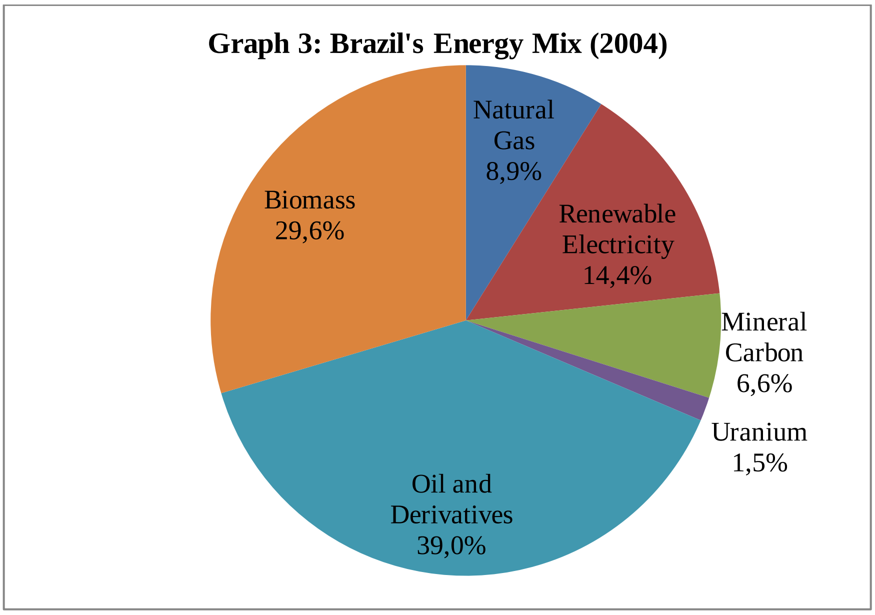
In 2001 Brazil experienced an electricity rationing and the government creates incentives to the construction of more power plants. In this context, natural gas thermo power plants appeared an interest option, once Brazil was just connected to Bolivia in a natural gas pipeline that would allow an increase in natural gas imports. Natural gas was viewed, at that time, as an abundant fuel that could be used to generate electricity.

Therefore, there was a sharp rise in natural gas consumption. In fact, while general energy consumption has grown from 523,561.64 toe/day in 2004 to 712,876.71 toe/day in 2013, corresponding to an annual growth rate of 3.5%, (the same rate of the country's GDP real growth in the period), the natural gas demand has grown from 48.6 million m³/day to 90 million m³/day, corresponding to an annual growth rate of 7.1%, as Graph 2 shows.

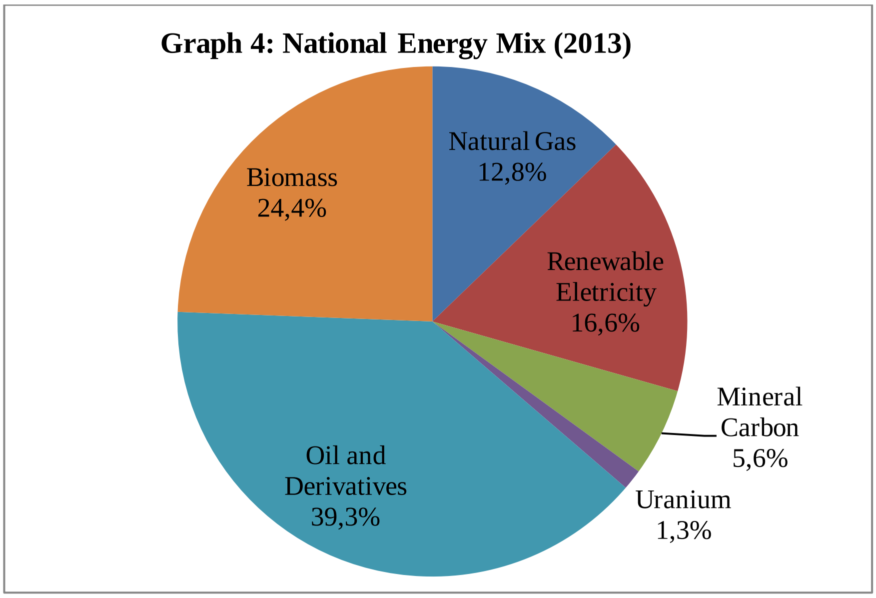


Source: ANEEL, 2005-2014

Natural gas has increased its weight in Brazil's energy supply and demand. Graphs 3 e 4 show that in the last decade this source of energy had the biggest increase in the share of national energy mix. In 2004 natural gas share in energy mix was 8.9% and in 2013 it represented 12.8% of the energy supply. Even renewable electricity, which has had an expressive expand in the last decade, had a minor increase, from 14.4% to 16.6%.



Source: ANEEL (2005; 2014).



Source: ANEEL (2005; 2014).

Nevertheless, as shown in Graph 2, natural gas imports have also had an expressive increase, from 22.15 million m³/day in 2004 to 41.56 million m³/day in 2013. It represents an impressive annual growth rate of 7.2%. This mark was very much above the energy demand growth and even above natural gas demand growth. Considering this increase and the security of supply agenda, biogas from vinasse could be an alternative to replace some of the natural gas imports, which potential we are going to estimate.

2.3) The parameters and the formula

It's common sense in literature that the distillation of 1 m³ of alcohol from about 8.9 tons of sugarcane produces from 10 to 14 m³ of vinasse (Pinto, 1999; Johansson, 1993; Salomon, 2007). There are several estimates of the biogas production potential of the biodigestion of vinasse, which depends on the scale of the process and the technology of the biodigestor, besides others factors. According to Johansson *et al*. (1993) 1 m³ of vinasse can produce about 14.23 m³ of biomethane. Brasmetano (2007) presents a close value: 14.6 m³ of biomethane for each cubic meter of vinasse. On the other hand, Salomon et al. (2011) consider the production of biogas (oxygen within) from a number of operational parameters presented in table 2.

Table 2: Operational Parameters of the Biodigestion Plant

Vinasse (m³)	5.000
Biogasproduction (m³/day)	73.125
Biogasdensity (kg/m³)	0,784
Biogascomposition	
- Methane (%)	60%
- Oxygen (%)	40%
Methandensity (kg/m³)	0,722

Source: Salomon et al. (2011).

These parameters can be used to find the volume of biomethane – the correspondent of natural gas – potentially produced in the biodigestion of vinasse with the following formula:

$$Biomethane\ (m^3) = (Biogas\ Vol. * Biogas\ Density) * \frac{\left(\frac{Methane\ (kg)}{Biogas\ (kg)}\ (\%)\right)}{Methane\ Density}$$

For the estimate of the vinasse volume we are going to use the parameters of literature applied first to estimate the residual from the production of ethanol of 2012/13 harvest, available from UNICA. Then, it is going to be able to estimate the potential biomethane production from vinasse biodigestion. Others exercises are possible, like the potential biomethane production from the distillation of all sugarcane production. Either way, we are going to be able to estimate how much of natural gas imports could be replaced by this renewable source of energy and also, the electricity potentially produced.

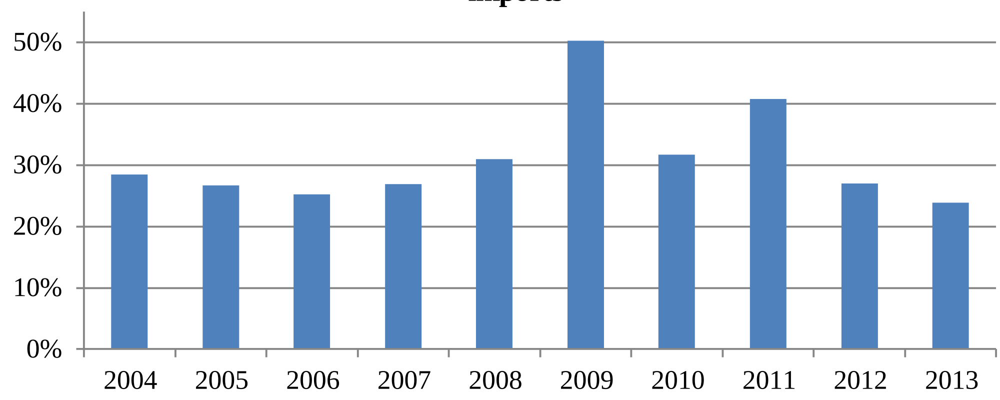
3. RESULTS: ENERGY POTENTIAL AND CHALLENGES

3.1) Estimation of biogas potential from sugarcane vinasse

Assuming that methane's density is 0.72 kg/m³, as shown in Table 1, and following the presented formula, we find that the parameters of Salomon *et al.* (2011) give us an estimate of 9.6 m³ of biomethane per cubic meter of vinasse, which is the lowest in literature, while the highest is 14.6 m³ (Brasmetano, 2007). Considering the mean of these extreme values we obtain an estimative of 12 m³ of biomethane per cubic meter of vinasse. Using the average production of 13 m³ of vinasse per cubic meter of ethanol, we obtain a potential production of 156 m³ of biomethane with the distillation of 1 m³ of ethanol. Considering that Brazil produced 63.6 thousand m³/day of ethanol in 2012/13 harvest, the production of biomethane could reach a level of 9.93 million cubic/day.

As mentioned, natural gas consumption has grown expressively in the last decade, from 48.6 million m³/day consumed in 2004 to little more than 90 million m³/ day in 2013, an annual growth rate of 7.1%. Natural gas imports have grown from 22 million m³/ day in 2004 to 41 million m³/ day in 2013, an annual growth rate of 7.2%, according to National Petroleum, Natural Gas and Biofuels Agency. So, the potential production of biomethane produced from vinasse in 2013 could replace around 20-25% (24%, in our estimative) of the natural gas imported in that year, and around 11% of the national demand of the gas. Graph 5 shows how much of natural gas imports could be replaced by biomethane each year, having its peak in 2009, when biomethane could have replaced half of natural gas imports.

Graph 5: Sugarcane Biomethane vol. potential to natural gas imports



Source: Self-elaboration.

Location gains are also a win in biomethane production in the country. Sugarcane plantations are concentrated in São Paulo, which is the biggest Brazilian state in terms of economy and energy (and natural gas) consumption. São Paulo Statistical Yearbook of 2013 shows that the state's natural gas demand reached 11.98 million cubic/day, little more than 13% of national demand. The document also highlights that the five of the fifteen most demander cities were located near oil refineries and/or whose industrial parks are in route of the Bolivia-Brazil pipeline, showing that a big part of the natural gas demanded were supplied by imports. On the other hand, UNICA data shows that, in 2012-13 sugarcane harvest, 50.9% of ethanol distillation happened in the São Paulo, what means that 5.056 million cubic/days of potential biomethane could have replaced 42.2% of the state's natural gas demand.

A further exercise is to estimate the electricity production using biomethane as the input. Several authors in literature still use raw biogas to estimate its energy potential (Salomon and Lora, 2006; Moraes et al., 2014). On the other hand we use biomethane, derived from the purification of biogas. Table 3 presents the lower heat power[9] of biogas, natural gas and biomethane, assuming a 60% of biomethane in biogas, most common estimate in literature (Salomon et. al, 2011; Swedish Gas Centre, 2012).

Table 3: Lower Heating Value (LHV) of different gases

Gas	LHV (kJ/m³)
Biogas	21,600
Natural Gas	39,600
Biomethane	34,812

Source: Self-elaboration based on Salomon et al. (2011) and Swedish Gas Centre (2012).

Using Table 3 data, it is possible to estimate the energy potential generation using biomethane from vinasse. Assuming the utilization of microturbines[10] of 30 kW (η 27%)[11], due to its advantage in smart grid, and a Lower Heat Value of 34.812 kJ/m³ of biomethane, as mentioned above, we find an estimate of 2107.9 MW of potential electricity generation in the year of 2013. This value represents 1.7% of the installed capacity of the country in that year, of 126,743 MW[12]. If we take a closer look to São Paulo, the biomethane potential energy generation in the state 1068.2 MW in 2013, which was 5.9% of its installed capacity of 18,179 MW.

3.2. Challenges and barriers to take advantage of biogas from sugarcane vinasse in Brazil

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[9] The quantity known as lower heating value (LHV) (net calorific value (NCV) or lower calorific value (LCV)) is determined by subtracting the heat of vaporization of the water vapor from the higher heating value. This treats any H_2O formed as a vapor. The energy required to vaporize the water therefore is not released as heat. LHV calculations assume that the water component of a combustion process is in vapor state at the end of combustion, as opposed to the higher heating value (HHV) (a.k.a. gross calorific value or gross CV) which assumes that all of the water in a combustion process is in a liquid state after a combustion process.

[10] Microturbines are a relatively new distributed generation technology being used for stationary energy generation applications. They are a type of combustion turbine that produces both heat and electricity on a relatively small scale. As it will be shown forward, distributed generation is one important drive to develop biogas systems.

[11] The technical specifications of a microturbine performance (high-pressure and low-pressure gas) are: 1- Full Load Power 30 kW (HP unit), 28 kW (LP unit) at ISO conditions 2- Efficiency (LHV) η = 27% +/- 2 points (HP Unit), 26% +/- 2 points (LP Unit) 3- Heat Rate (LHV) 12,600 Btu/kWh (HP Unit), 13,000 Btu/kWh (LP Unit).

[12] To compare to our estimate to the literature, we can exchange the parameters of Salomon and Lora (2006) with ours, that is, the ethanol distillation volume and the biomethane produced from vinasse, besides our utilization of biomethane rather raw biogas. Then, we find an estimate of 2,225 MW, a very close value to the one we had found.

Literature points out many obstacles to the use of biogas in Brazil. Some of them are: (i) the high investment costs, (ii) insufficient funding and little research in the area of anaerobic digestion, (iii) a lack of a national biogas program, specific financing, and government incentives, (iv) the difficulties faced by small biogas plants in selling their carbon credits, (v) a lack of information and funding for farmers, (vi) the need to define biodigestion technology for each case separately, and (vii) a lack of studies in the specialized literature for the selection and assessment of economic viability (Salomon and Lora, 2005; Bley et al. 2009, Mathias and Mathias, 2015; Christofoletti, 2013). It is also true to sugarcane AD projects (Salomon, 2007).

As previously mentioned, there are many challenges and barriers to develop biogas systems (not only from biomass, but other wastes) in Brazil. The main one seems to be the non appreciation of biogas as an alternative fuel (Moraes et al. 2015; Bley et al. 2009), considering a subaltern source of energy. Besides that, there are some other important barriers to sugarcane biogas systems:

1. **Regulatory issues**: in the specific case of sugarcane vinasse, the fertirrigation is an important process to deal with the production wastes. As remember Moraes et al. (2015), for decades, the main destination of vinasse in Brazil has been its application in sugarcane crops as fertilizer, a practice known as fertirrigation. Nevertheless, Brazilian environmental legislation only recently established criteria and procedures for vinasse application on soil[13].

2. **Economic barriers**: new technologies often have a cost disadvantage in comparison to incumbent technologies and they may not offer any direct benefits for the individual buyer or investor. A financial support and even tariffs incentives are necessary to stimulate biogas systems.

3. **Technology assessment**: it is important to develop biodigesters and biogas technologies taking into consideration the countries specificities. Laborious operation and maintenance are common in considering new technologies.

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[13] CETESB (2006), which establishes vinasse criteria and procedures for application to agricultural soil (Technical norm P4231). According to Moraes et al. (2015), such legislation can be considered superficial because vinasse application (vinasse per area) is prescribed only according to its potassium content. Its high organic matter content and the potential environmental impacts associated with it are not considered. Such impacts are mainly related to greenhouse gas emissions, soil salinization, leaching of metals and sulfate, and groundwater contamination, as well as the release of unpleasant odors and the possible attraction of insects.

To overcome the barriers is not an easy task. It depends on how the new (incumbent) system is capable to compete with the existing system. As stated by Szatow et al. (2012: pp. 2, our emphasis):

> "An alternative to change driven from within a system, for example through policy and regulation that changes incentives, is to establish ***new energy supply systems*** that organize in a fundamentally different way and ultimately compete for resources with the existing system in the long term. The idea that a new system may compete for resources successfully with an incumbent system, parallels with the idea of an invasive species that subverts the status quo within an ecosystem and establishes new resource flows".

So, it is a hard challenge to develop a biogas energy market, as it is to other renewable energies. Mathias and Mathias (2015) present a governmental agenda to develop biogas systems in Brazil. According to the authors, the challenges presented in the governmental agenda can be analyzed in two phases. In the first phase, the governmental agenda must create incentives for biogas production aimed at environmental care through the treatment of residual biomass and at energy generation (biogas and electricity) for private consumption. In a potential second phase, with more developed biogas systems and resolved technical and financial issues, it would be possible to encourage the sale of biogas excess to natural gas and/or electricity distribution networks. This phase is apparently more complex and requires more time for implementation.

One important drive to overcome the barriers to biogas systems development in Brazil is to encourage the distributed generation. It could be link to join the two phases of the governmental agenda above-mentioned.

3.3.A "drive" possibility: bioenergy and decentralized generation

Centralized production systems are dominant in most parts of the world, driven largely by economies of scale and production efficiency benefits. Large scale production systems have, however, been criticized for hiding social and environmental costs of production by distancing their activities from the consumers. When energy is produced far from consumers it requires transmission lines over long distances, resulting in the need of other investments with environmental impacts. By contrast, in decentralized systems the energy is produced close to the load they serve. There are no energy losses in the transmission process and no other investment is required. At the same time, decentralized systems use modular and more flexible technologies. In light of some of these issues, decentralized production units may provide a pathway towards a more sustainable future (Mangoyana and Smith, 2011).

Decentralized (or distributed) energy systems are typically used for renewable energy sources and it could be an important drive for sugarcane vinasse biogas. As noted above the majority of ethanol (and vinasse) production in Brazil occurs in São Paulo State, which is the main natural gas consuming area of the country.

The process of distributed (or decentralized) generation from waste biomass involves the transformation of waste into biogas with the use of biodigesters, as previously presented. This biogas can be used directly or can produce electricity. In both cases, the energy produced can be used for private consumption and the excess can be sold to distributors of natural gas or electricity, respectively. In the case of sugarcane vinasse, and also in cattle and swine waste, given their agricultural nature, one of the by-products of this process is biofertilizer, which makes its use even more advantageous.

Biogas produced from sugarcane vinasse can be included in the agroenergy concept, that is to say obtaining renewable energy through productive activities complementary to farming. In fact, the concept of agroenergy is being consolidated in connection with the idea of distributed generation. This consolidation of agroenergy as an officially recognized and stimulated economic activity gives rise to a new business and a new source of income for rural properties in addition to the revenue generated by traditional agricultural products. Through the structure of prices, periods, and firm long-term contracts with publically regulated official distributors, agroenergy constitutes new perspectives in the field. The development of biogas systems is inserted in this context (Bley et al., 2009; Mathias and Mathias, 2015).

Using a broader concept, Lilley et al. (2012) define distributed energy (includes also demand management and energy efficiency) which describes a number of technologies which use generation near the point of consumption; through maximizing the use of cleaner fuel sources such as natural gas, biogas, solar and wind; and through more efficient conversion of primary energy sources to useful energy services, including recovering heat otherwise wasted.

According to the above-mentioned authors, realizing the full value of distributed energy (DE) requires understanding and addressing the complex issues affecting key stakeholders including government, electricity and gas network businesses, energy retailers, small to medium enterprises, large energy users and domestic consumers. Critically important issues include the effects of DE on short and long term economic drivers; the effects on electrical and gas networks through introduction of local grid connected devices; environmental sensitivities resulting from the change in technology type and the location of generation; the acceptance of the technologies by all forms of society; and the complex interaction with policy and regulation (Lilley et al. 2012).

There is a recent legal framework related to distributed generation in Brazil. That is the case of Authorizing Resolution 1482/2008 and 1900/2009 of National Electricity Agency (Agência Nacional de Energia Elétrica - ANEEL). It authorizes the Program for Distributed Generation with Environmental Sanitation proposed by the Paraná State Energy Company (Companhia Paranaense de Energia – COPEL) as a pilot project for implementing low-voltage distributed generation. ANEEL Normative Resolution 390, which sets the requirements for authorization to exploit and change the installed capacity of thermal power plants and other alternative energy sources, describes procedures for registering generation plants with reduced installed capacity, and makes other provisions (Mathias and Mathias, 2015).

Of course the previous argument related to distributed generation is a necessary condition, but not sufficient to develop sugarcane biogas systems. Literature recognizes that government policy has been the major inducement mechanism to develop new technologies, particularly due to the institutional framework created (Jacobsson and Bergek, 2004). That is also the case of biogas systems (Mathias, 2014). As previously stated, there is an incipient institutional and regulatory framework in Brazil in this matter. A very recent National Petroleum Agency Resolution (ANP, 2015) specifies the biomethane use and its technical features. It is important to say that ANP establishes the quality of natural gas that can be sold in the whole country. Resolution number 8 determines the biomethane specification and allows biogas **produced from organic residues** to be used on natural gas vehicles, commercial consumers, and households. According to this Resolution there are some specific definitions related to biogas/ biomethane, as showed in Table 4, below:

Table 4 – Definitions in the Biomethane Framework Regulation in Brazil

Biogas	Raw gas obtained from biological decomposition products or organic waste
Biomethane	Gaseous biofuels consists primarily of methane, derived from the purification of biogas
Agroforestry Waste	Those generated in agricultural and forestry activities, including those related to inputs used in these activities, according to Law 12,305, of August 2nd, 2010
Commercial Waste	Waste shops and service providers, according to Law 12,305, of August 2nd, 2010

Source: ANP (2015).

It means that if the biogas produced from sugarcane vinasse meets the quality standards defined by ANP it can be used directly or mixed with natural gas. It opens new possibilities for the agroenergy business, once the biogas produced from organic residues is already recognized as a source of energy. In this context, it is possible to take the advantages of vinasse biogas production and its use in local terms, in distributed generation bases.

Nevertheless, some challenge still remains. It is necessary to start up the process, because the market does not do it by itself. IRENA (2013) proposes some stages to develop renewable energy innovation policies, which can be used to develop biogas systems: i) Establishing Governance and the Regulatory Environment, ii) Developing Infrastructure, iii) Providing Finance, and iii) Creating Markets. It seems that the biogas agenda have to focus on the initial stage, related to establishing governance and the regulatory environment. It means that it is necessary to set standards, set targets, tax negative externalities, subside positive externalities, eco-labeling and other voluntary approaches, tradable permits, among others (IRENA, 2013).

This is the first stage and where sugarcane biogas systems have to be inserted for a future development. As seen before, the biomethane production potential is huge, but it is not materialized. There is a long run to achieve the market formation, which includes feed-in tariffs, energy portfolio standards, public procurement, media campaigns, setting government requirements, taxing negative externalities, subsidizing positive externalities, among others.

One broad strategic criteria to develop innovation in renewable energy is to promote sustained multi-stakeholder engagement around an achievable, shared vision (IRENA, 2013). That is because innovation arises from a mix of social, financial, and technical factors, responsibility for innovation policy is distributed across many stakeholders within the public sector. Thus, success will be promoted insofar as innovation policy discussions are integrated into existing macro-level policy goals, as the latter will provide a level of stability and multi-stakeholder engagement that might otherwise be lacking.

The recent legal framework can be useful to develop Brazil's biogas system, including those from sugarcane vinasse. But it also depends on the engagement of the multiple stakeholders, in order to create a coalition to engage in wider political debates in order to gain influence over institutions and secure institutional alignment (Jacobsson and Bergek, 2004)[14]. The fundamental issue in the

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[14] In terms of distributed generation, there is one important coalition called Distributed Power Coalition of America (DPCA) which is an advocacy organization committed to advancing the use of distributed power. Members include: electric and gas utilities, consumers, distributed power equipment manufacturers and suppliers, natural gas transmission pipeline companies, gas and electric marketers, and research organizations. The site provides information on DCPA and its activities. Another is World Alliance for Decentralized Energy (WADE). Launched by a group of major companies and national industry associations to accelerate the development of high efficiency cogeneration and decentralized energy (DE) systems which will deliver substantial economic and environmental benefits worldwide.

application of renewable energy technologies is that most of them may be relatively small scale, but an investment and siting decision still affects a multitude of other stakeholders, as opposed to just one customer or one investor (Wustenhagen *et al.*, 2007). Hence, the decision needs approval by several stakeholders, not only by the investor.

The Table 5 consolidates the stakeholders, whether public, private or academic, and their roles in order to enable the development of sugarcane biogas systems in Brazil.

Table 5: Stakeholders to develop sugarcane biogas systems in Brazil.

	Stakeholder	**Duties and goals**
Public	National Council for Energy Policy (Conselho Nacional de Política Energética - CNPE)	To propose an energy policy that takes into account the rational use of the country's energy resources, among other aspects; to define the strategy and policies for the economic and technological development of the biofuel industry.
	Ministry of Mines and Energy (Ministério de Minas e Energia - MME)	To implement the energy policies proposed by the CNPE.
	National Electricity Agency (Agência Nacional de Energia Elétrica - ANEEL)	To regulate electricity generation from biogas; to define the rules for the injection of biogas surplus into the grid (sale to distributors).
	National Agency of Petroleum, Natural Gas and Biofuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis - ANP)	To regulate and authorize activities related to biofuel production, importation, exportation, storage, stockpiling, transport, transfer, distribution, resale, and trade.
	Ministry of Environment	Aims to promote the adoption of principles and strategies for knowledge, protection and restoration of the environment, sustainable use of natural resources, the valuation of environmental services and the inclusion of sustainable development in the formulation and implementation of public policies, cross and shared, participatory and democratic manner, at all levels and levels of government and society.
	State Regulation Agencies	To regulate the "local piped gas services" provided by the Local Distribution Companies (LDC).
Private	Natural Gas and Electricity Local Distribution Companies	To take advantage of opportunities of selling natural gas.
	Electricity companies	To take advantage of opportunities of

		selling electricity.
	Biodigesters and machines and equipment and infrastructure companies	Stakeholders of value chain in biogas systems.
	Brazilian Sugarcane Industry Association (UNICA) and similar	The largest organization in Brazil representing sugar, ethanol and bioelectricity producers. UNICA members answer for more than 50% of all ethanol produced in Brazil and 60% of overall sugar production.
Research and Academical	Energy Research Enterprise (Empresa de Pesquisa Energética - EPE)	To provide studies destined to subsidize planning in the energy sector.
	Brazilian Agriculture and Livestock Research Enterprise (EMBRAPA)	To develop and spread technologies and processes to improve the rural management
	Universities and Research Centers	To provide Research and Development (P&D) to energy sector.

Source: Self-elaboration adapted from Mathias and Mathias (2015).

4. CONCLUSIONS

It is broadly accepted in literature the importance of a “momentum” or even a “wave” to adopt new technologies. This time could be consequence of political or economic constraints. In the energy sector it is also a consequence of energy supply constraints. In that sense, in order to address the importance of a technology adoption a coalition of stakeholders should emerge in the political debate and influence the creation of new laws and an institutional framework. It is the first step required to a new technology adoption.

The above-mentioned picture seems to be the case of renewable sources of energy associated to low carbon emissions, particularly biogas systems. Because of the constraints in energy supply growth in Brazil, an opportunity window to develop alternative renewable energy has emerged. At the same time, the distributed generation solution needs to be widespread. Bioenergy, particularly, biogas and AD systems are inserted in this context.

This work presented a huge biogas production potential from sugarcane vinasse. It can be used in multiple ways, and this work emphasized two important energy uses: to substitute natural gas and to generate electricity in a distributed generation concept. The energy policy can be, in association to environmental policies, a drive to solve several pollution damages due to agricultural and livestock activities.

Besides the huge potential, there is an extensive agenda to solve and overcome the multiple barriers for biogas systems implementation in Brazil. The main drive seems to be incentive of distributed generation concept, which could solve not only biomass, but other new renewables sources of energy such as photovoltaic and wind power.

In that sense, biogas systems need to be inserted in Brazil's policy agenda. The very recent ANP Resolution specifies the features steps of biomethane. There are also recent legal efforts to promote distributed generation. It is a necessary condition to overcome the monopoly of centralized power systems and allow the development of other alternative renewable energies, as above-mentioned. But it is still not enough to develop biogas systems. According to international experience the strong governmental involvement is necessary and sufficient condition to develop renewable energy sources. Therefore, a legal framework (it can be proposed as an act) for the production of renewable energies, including biogas should be implemented.

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