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Renewable energies in cities: Perspectives for the use of biogas in Brazil

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SUMMARY

One of the main challenges for the present and future of citiesare new energy sources that allow good efficiency and low environmental impact. In this sense, this study analyzed biogas, an energy source from the decomposition of organic matter. A theoretical essay was carried out from bibliographical research, with the aim of presenting the current scenario of the different perspectives of production and application of biogas in Brazil, in urban and rural areas of the country. The observed results showed that, in rural areas, the input for the production of biogas comes mainly from animal husbandry, and that the form of use is mainly directed towards obtaining thermal energy. In urban areas, practically all biogas production is carried out in sanitary landfills and sewage treatment plants, given the large amount of excess organic matter from the waste treatment activity. However, even though the country has relatively important indices of biogas production and use, it was clear from the theoretical framework analyzed that not only is the amount generated very low for generation potentials in Brazil, but there is also an evident lack of technologies in relation to biodigesters, in addition to a weak legislation to promote Brazilian biogas, which led to the conclusion that biogas production in the country is proceeding at a very slow pace. The study is limited in terms of detailing the barriers observed, and, therefore, it is suggested that future studies seek an in-depth analysis of these barriers.

KEYWORDS: Biogas. Cities. Brazil.

1. Introduction

Energy generation and use worldwide has been for many decades the center of discussions and global actions associated with impacts to the environment caused by such activities, from the raw material extraction– being most of these materials natural, non-renewable resources –to the installation of structures that generate the energy product, in addition to the utility itself; the impacts, in varied contexts,are related to the emission of pollutants (OMER, 2008).

According to Calvillo, Sánchez-Miralles and Villar (2016), on-going discussions associated with the world energy chain fall on the important context of the constitution of smart cities. The authors emphasize that this theme is of great complexity, oncea much relevant difficulty exists in delimiting the same energy efficiency scales for different regions. Another great challenge for the future of human populations is waste management. According to Singh (2019), the population growth that continuously accelerates in many countries, conflicting with difficulties to control the impacts of waste production, tends to stress even morethe need for new forms of managing these materials, given the logic that the greater the number of people the greater the amount of produced waste.

Brazil is a reference when it comes to the use of different biomass types for energy production. Santos, Nascimento and Alves (2017) point to the diversity of the organic waste used for energy generation – the main one being from sugar cane for ethanol production to even urban waste. Genovese, Udaeta and Galvão (2006) highlight that among the potential energy sources coming from these materials, biogas in the Brazilian context points to the possibility of several benefits to complement the national renewable energy matrices. The authors also mention the advantages in Brazilian rural areas, given the environment al and economic qualities of this by-product.

The objective of this study is the analysis of the present theoretical panorama regarding the main forms of biogas use in Brazilian rural and urban areas, as well as to present the norms in force that promote the support to this source in the context of the national energy matrix.

This study presents a theoretical reference regarding the main themes that place biogas in the discussion of energy reforms in the cities. The methodological procedures are commented, followed by the results of the bibliographical research, which are divided in different topics. Final considerations, as well as limitations of the study,and proposals of future research conclude this paper.

2. Theoretical Reference

Regarding the discussion of this theme within the conceptof intelligent cities, Albino, Berardi and Dangelico (2015) emphasize that in order to achieve efficient and sustainable energy matrices, the diversification of raw materials used for this purpose is interesting, besides the re-structuring of the way energy is distributed and the integration of this logistics to the planning of other structures that are important for the cities' dynamics. In this sense, Perea-Moreno, Hernandez-Escobedo and Perea-Moreno (2018) explain that from 1977 to 2017 there was an expressive increase of the number case studies and mappings related to tangible solutions to obstacles that the environmentally sound modernization of the energy supply has faced over time.

The International Energy Agency (IEA) revealed via the report "World Energy Balances: Overview" that in 2018 the main energy source used worldwide was petroleum (31.5%), followed by coal (26.9%), and natural gas (22.8%). These major sources are fossil; renewable energies represented only 13.9% of the world energy matrix, being biofuels the most relevant, with 9.3% (IEA, 2018a).

In this context, Kamyab, Klemeš, Fan and Lee (2020) discuss the energy supply in the world, defending the reorganization of energy matrices from the principle of intelligent energy systems. According to the authors, it is essential for the development of this logistics to elucidate the characteristics of each type of source existing in the local energy matrix and to determine which are the main energy-demanding sectors. Besides, it is inevitable to the authors to consider the reduction of CO_2 levels emitted by these matrices, and also the magnitude of the influence of the main stakeholders participating in this chain in the creation of this new system.

According to the*Balanço Energético Nacional* (National Energy Balance – BEN) of 2021, base-year 2020, the non-renewable energies represent the greatest share of sources used in Brazil, considering all the available sources and energy-demanding sectors. It is worth mentioning sugar cane biomass (19.1%) in the Brazilian energy matrix, whose use is second only to petroleum and derivatives (33.1%). According to the *Ministério de Minas e Energia* (Ministry for Mines and Energy – MME), the Central-Western region of Brazil presents the large strange of renewable energies, being 58% of its local matrix renewable. It is followed by the Southern (40.7%), Southeastern (40.5%), North (38.7%),and Northeastern (36.5%) regions (MME, 2017). Figure 1 presents the data concerning the Brazilian internal energy supply in 2020.

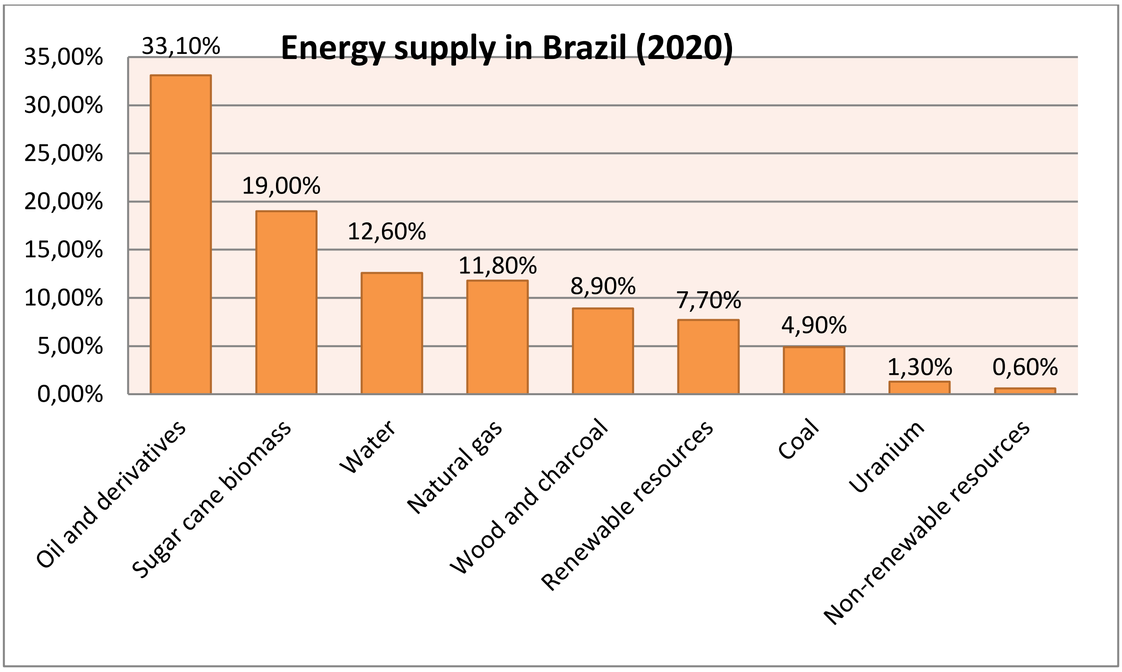


Figure 1. Energy supply in Brazil in 2019.
Source: Adapted from "*Balanço Energético Nacional*" – *Ministério de Minas e Energia & EPE – Relatório Síntese – Empresa de Pesquisa Energética*, 2020, p.16.

According to Bellote et al. (2018), Brazil constantly seeks for the modernization of the procedures to extract the energy properties from a variety of biomass types, mainly those coming from the energy cane sector for the generation of ethanol. In this sense, Tolmasquim (2016) states that the energy generation from sugar cane is influenced by environmental factors and the seasonality of the plant's own life cycle. The author also explains that regarding biogas, the influence of seasonality is not the same, given the possibilities of using different substrate types.

BEN (2020) did not contemplate biogas as a source produced and used in quantities relevant enough to be recorded in graphs. The information present in the report regarding biogas is related to the number of production plants in operation in Brazil, which in 2019 was around 186.

3. Methodology

Our bibliographical research focused on biogas production, characterization, and application (in urban and rural contexts), production technologies and legislation in Brazil. The objective of this methodological approach was to investigate in detail certain topics derived from the literature that were relevant to both the objects of study and the objective of the research (PIZZANI et al., 2012).

For the present research, a query of the databases Science Direct, Web of Science, and Scopus was performed. The following key words were used: "biogas", "biogas use rural Brazil", and "biogas use urban Brazil".

4. Results

4.1 Benefits from thereuse of organic waste

According to Das et al. (2019), there is a relevant range of opportunities for the reuse of organic waste, in the sense of transforming it in energy aiming at short- and long-term financial and environmental gains. In the context of intelligent cities, there is a premise to investigate environmental impacts related to the final destination of waste to the point of making them the basis of new solutions and ideas, such as the research carried out by Cucchiella, D'Adamo and Gastaldi (2017), who analyzed alternatives to waste management in Abruzzo, Italy, from the creation of spaces for energy generation from waste produced in the region.

As stated by Kiyasudeen et al. (2016), waste management opens the opportunity of reuse of waste discarded in rural and urban areas. According to the authors, organic waste can be converted in thermal energy: this practice allows not only the creation of a new, clean energy source, but also the reduction of the amount of litter disposed in nature.

In this context, Pleissner (2018) affirms that the benefits of organic waste reuse are directed to the decentralized production of electric energy, and also to the mitigation of atmospheric and soil pollution by land filling. The author explains that the natural decomposition of these materials releases polluting gases, and the space for landfills implies the deforesting of large green areas, besides the imminent danger of harmful substances that percolate soil layers. Another considerable advantage is the reuse of digestate by-products from the substrate applied in anaerobic digesters designed for biogas production, which was proved efficient when soil chemical and physical parameters are adapted for soil fertilization and recovery, as shown by Castro et al. (2017).

4.2 Biogas characterization and applications

Biogas is highly flammable and is produced by organic matter anaerobic decomposition, process in which bacteria – whose metabolism is adapted to function in the absence of oxygen– break down these materials, generating methane as by-product, which is the main biogas chemical component that constantly interacts with carbon dioxide and other gases and nutrients (WEILAND, 2010).

Biodigestion is a natural process by which certain organisms feed on or extract nutrients from these substances for their metabolic activities via fermentation without the presence of oxygen, thus characterizing the anaerobic digestion (DEGANUTTI et al, 2002). Digesters are basically impermeable sealed vessels or reactors in which biodigestion takes place in a controlled way. The design of these reactors depend on the quantity of organic substrate that is applied (FRIGO et al., 2015).

In this sense, it is important to distinguish biogas from biomethane. Ryckebosch, Drouillon and Vervaeren (2011) explain that biomethane is the purified product and purification basically consists of the removal of chemical components –hydrogen sulfide (H_2S), carbon dioxide (CO_2), ammonium hydroxide (NH_3), and even water – from biogas. The authors explain that this “purification” can prevent problems related to the wear of gas generation, storage and distribution equipment, once depending on the objective of the use, the combustion steps can generate different hazards, including explosions.

Anaerobic digestion – process that generates biogas –takes place in four steps: hydrolysis, acidogenesis, acetogenesis and methanogenesis.

In hydrolysis, the bacteria produce certain enzymes that start to decompose the organic matter, breaking it in smaller and simpler molecules. Compounds such as carbohydrates, fat molecules and proteins are converted in sugars, amino and fatty acids (ACHINAS; ACHINAS; EUVERINK, 2017).

Acidogenesis consists of the absorption of substances generated in the hydrolysis by bacteria characterized as fermentative and acidogenic, as from their metabolic activity fatty acids, alcohol, minerals and lactic acids are excreted, among other types of compounds (SOARES; FEIDEN; TAVARES, 2017).

Acetogenesisconsists of processes by whichacetogenic bacteria convert fatty acids and other products resulting from acidogenesis, transforming them inacetic acid molecules, carbon dioxideand hydrogen (LOHANI; HAVUKAINEN, 2018).

A particularity of methanogenesis– the last step of the anaerobic digestion – is the low tolerance to sudden changes in the environment in which the process is taking place. It is the conversion of hydrogen, acetic acid, water and carbon dioxide in methane, the latter being the main by-product of the anaerobic digestion and the main biogas compound (VALIJANIAN et al., 2018).

According to the *Associação Brasileira de Biogás e Metano* (Brazilian Association for Biogas and Methane – ABiogás), biogas is an energy source of relevant characteristics for the national energy matrix modernization, once the productivity via digesters is totally controllable and predictable (ABiogás, 2016). In this sense, the versatility of digesters stands out as a positive aspect, taking into account that the organic matter that is used as substrate is not necessarily food discarded in household waste, as animal feces and other types of organic matter can also be used.

Despite its several advantages, biogas is still a source that lacks structuring in several aspects, facing a series of important obstacles that prevent its wider diffusion, as Nevzorova and Kutcherov (2019) explain. According to these authors, the quality and quantity of produced biogas is highly influenced by the conditions under which biogas generation and use take place, fact that makes biogas dependent on the evaluation and control of variables that, in addition to not being fully known, are complex to control.

4.2.1 Biogas use in rural areas

A study by Ortiz, Pfaff and Dienst (2017) shows that for the diffusion of biogas production to be successful in rural areas of developing countries, some essential criteria must be observed. The most common, according to the authors, is that the use of biogas is directed to domestic purposes as cooking gas, animal husbandry and crop production. To obtain sustainable gains from this practice it is necessary that new technologies be accessible to the residents of these areas, and that this population be capable of drawing strategic plans for logistical integration, ranging from cultivation to generation and final use of biogas to maximize the benefits.

In Europe, biogas production in digesters is concentrated in farms. Reuse via transformation of organic waste into energy results from short-, medium- and long-term policies, which mainly aim at making European countries sustainable and efficient, when it comes to national energy matrices, as explained by Garcia et al. (2019).

In Brazil, Freitas et al. (2019) investigated the possibility of biogas production in a farm in the State of Paraná from swine manure. The authors observed that the produced biogas was of satisfactory quality, in parallel decreasing CO_2emissions to the atmosphere. The study of Bernal et al. (2017) was directed to biogas generation from vinasse. For the authors, the properties of the generated gas pointed to favorable conditions for use as biomethane, coinciding with the benefit of reusing large amounts of exceeding vinasse from sugar cane production in Brazil.

Moura et al. (2017) observed that the use of cattle manure as substrate in a digester installed in a small farm in the State of Minas Gerais proved to be of good economic viability when considering return on investment, evidencing the possibility of energy autonomy for rural producers. On the other hand, Ribeiro et al. (2018) observed that biogas production using chicken manure as substrate did not yield good cost-benefit parameters, once the production of electric energy from the biogas generated in the study was not attractive from a financial and economic point of view, attesting to the importance of the production context.

4.2.2 Biogas use in urban areas

China is a model country,when it comes to the number of biogas plants distributed throughout the country. In urban areas, biogas is mainly generated in sewage treatment plants and from industrial waste, with the reuse being directed to the buildings adjacent to the production sites. Deng et al. (2017) also point to the increasing adoption of technologies for biogas production from household organic waste in some Chinese cities, such as Chongqing from 2009 and Beijing from 2012.

In Brazil, biogas generation in urban areas is strongly linked to sanitary landfills, with a series of different techniques applied in several projects, as shown by Nascimento et al. (2019). According to these authors, the landfills that collect gas for electric energy production are mainly concentrated in the State of São Paulo, and the electricity thus produced is injected in the *AES Eletropaulo* and *Companhia Piratininga de Força e Luz* (CPFL) networks. In this context, it is worth mentioning that in urban areas the biogas production and use is primarily related to the local basic sanitation structure, once the amount of waste, its composition and form of treatment will support all the gas productive chain, being strictly important all the investment made to this type of service (OLIVEIRA; NEGRO, 2019).

Regarding Pouso Alegre, a city of the State of Minas Gerais, Raimundo et al. (2017) made economic projections on the basis of aspects such as production cost, the estimated energy value that biogas has the potential to produce, and the quantity of energy used in the city’s sewage treatment station. A conventional generic digester and a UASB-type digester were adopted in the simulations. The results pointed to the infeasibility of a project that includes energy distribution beyond the treatment plant, but conditions existed for energy reuse internally to the treatment plant installations, when the operation of the UASB reactor was simulated for energy generation.

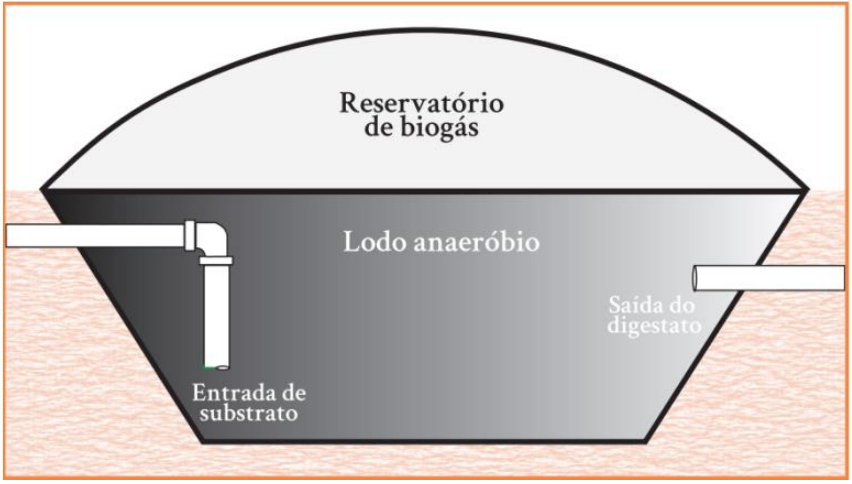
In Campinas – State of São Paulo –the cost-benefit of a project to collect biogas from a landfill was estimated by Freitas et al. (2019), taking into account waste production, population increase, budget availability and financial fluctuation between 2018 and 2038. The authors identified good opportunities of biogas production for these conditions.

4.3 Production technologies

Part of the technologies depend on the types of digesters selected for biogas production. Considering that the substrate is the basis of the anaerobic digestion and consequently of gas production, digesters with their own agitation systems play an important role in the generation capacity of a biogas plant. In this context, equipment such as the Continued Stirred Tank Reactor (CSTR) are structures capable of receiving a variety of substrates, given that some of these reactors are manufactured with internal stirring systems, thus avoiding waste pre-treatment (KRESS et al., 2018).

Amaral, Steinmetz and Kunz (2019) explain thatin Brazil the most used digesters are the covered pond, the Upflow Stirred Tank Reactor (UASB) and CSTR. The authors describe the covered pond digester as constituted by a cover placed on an excavation in the soil in which the substrate is lain. It is currently adopted in rural properties. The UASB digester is usually fed with substrates in the form of sludge. It is a cylindrical structure in which the substrate flows inside the equipment via tubes. Figure 2 illustrates a covered pond-type digester.

Figure 2: Covered pond-type digester.



Source: Recovered from “*Os biodigestores*” – Amaral, Steinmetz & Kunz (2019).

Sahota et al. (2018) describe technologies to refine biogas into biomethane in a more sustainable way. The authors name some methods, such as physical absorption by the use of water in a debugger, absorption by reaction of a chemical solvent rich in amines, which adhere and react to hydrogen sulfide (H_2S) and carbon dioxide (CO_2). They also comment that there are some emerging technologies, such as cryogenic methane separation (which involves high operation and energy costs, but very high methane concentrations obtained at the end of the process), movement of sludge for CO_2 absorption, as well as the integration of several methods applied in parallel, when possible.

Regarding distribution, biogas can be introduced in common gas distribution pipelines, being important however to observe the quantity produced and to be distributed, so as to check whether it I viable the building of a new distribution system, should it be necessary (ADNAN et al., 2019). Gustafsson et al. (2020) observe that relevant variables must be previously considered, such as the distance to the distribution grid, environmental impacts and economic viability, emphasizing that when great distances are involved in distribution, it is interesting to invest in gas liquefaction.

4.5 Legislationconcerning biogas and biomethane generation in Brazil

On 26th December 2017, law 13576/17 was put into effect, creating the National Biofuels Policy – RenovaBIO. This norm is part of the *Política Energética Nacional*(National Energy Policy), dealing with incentives related to the production of electric energy and other by-products from biomass for the integration of renewable sources to the national energy matrix (Law 13576, 2017).

The *Agência Nacional de Energia Elétrica* (National Electric EnergyAgency – ANEEL) resolutions 482/12 and 687/15 represent a milestone in the legislation to encourage the use of renewable energies to produce electricity, including biomass (ALTOÉ et al., 2017). Resolution 482/12constitutes the access systems to distributed micro-and mini-generation and compensation by energy produced in small electricity-generating units. In other words, it establishes that the consumer, in case of electricity production from certain renewable sources, can transfer part of his production to the local grid and later be rewarded with different types of credits (ANEEL, 2016). As a review of this norm, resolution 687/15 was enacted, with the objective to adequate certain aspects and establish new norms to expand the possibilities of distributed micro- and mini-generation units, authorizing the electricity production from any renewable sources, besides the orientations for the organization of consortia, cooperatives, expansion of the time interval for the use of credits, possibility of using credits in different installations of the same holder, among other benefits (ANEEL, 2018).

5. Final considerations

In general terms, biogas is a relatively emerging energy source in Brazil. In certain areas of the Brazilian territory, it has not been exploited yet. In other areas, it is an energy generation tool in varied sector practices. Scientific research has attested the potential biogas production and use throughout the country. However, the inclusion of this energy source in local energy matrices has been difficult, due to obstacles that, given the disparity of information commented here, can be generally considered as unknown.

This study aimed to present the main biogas applications in Brazil. A relevant difference was observed between the productivity techniques in urban and rural areas. In great cities, organic matter mostly comes from waste from sanitary landfills and sewage treatment plants. At this point, it is worth mentioning the possibilities of redirecting this waste to energy production, as pointed out by the authors.

In rural areas, the different ways of reuse of animal waste for biogas production are evident, fact that is opportune for agricultural producers, once the local biogas generation is a thermal energy source for various purposes.

Regarding the technological reality, Brazil is devoid of the best digesters both in cities and rural areas, besides the difficulties, which are mainly financial, when it comes to the conversion of biogas in biomethane. The Brazilian legislation in force is composed of local norms, lacking of a national plan to insert biogas in the national energy matrix. ANEEL resolutions 482/12 and 687/15, as well as RenovaBIO, represent important advances, but are still far behind the production possibilities in Brazil.

The present paper allows us to conclude that the biogas production in Brazil proceeds at a slow pace and is still from the available generation potential. The production projects in operation, both in urban and rural areas, result in successes and failures that have not been analyzed in greater depth and block further advances, which reflects the lack of consensus among the main actors involved in the logistics to promote biogas production in the Brazilian territory.

The present study is limited regarding which are the obstacles associated with biogas production and use in Brazil. We suggest that future studies aim at the identification of these obstacles in detail, as well as their contexts and ways to overcome them.

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