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Technical Article

Geographic Information Systems based approach for assessing the locational feasibility for biomethane production from landfill gas and injection in pipelines in Brazil

Abordagem baseada em sistemas de informação geográfica para avaliação da viabilidade locacional da produção de biometano a partir de gás de aterro sanitário e injeção em dutos no Brasil

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ABSTRACT

Biomethane can readily replace fossil fuels including natural gas, which has similar physical and chemical properties. In Brazil, municipal solid waste is predominantly disposed of in landfills. Landfill gas is mostly employed for electricity generation, but still at low levels when compared to the existing potential. Production of biomethane from landfill gas may be an alternative to exploit the existing potential, but Brazil's pipeline network is rather limited and concentrated along the country's coast. In this context, the research sought to identify the locational viability of using landfill gas to produce biomethane and injecting it into pipelines, considering the available potential and its proximity to Brazil's existing pipeline network. The QGis software was used to integrate the information. Territorial arrangements with a biomethane production capacity of more than 15,000 Nm^3 day^{-1} and located up to 50 km from the pipeline network were considered feasible. The research estimated a potential production equivalent to 3,407,027 Nm^3 day^{-1} of biomethane from landfills in Brazil. This potential corresponds to 6% of country's natural gas consumption in 2019 and is almost 32 times greater than current production of biomethane from all substrates used with this purpose in that year. The results indicate the suitability of using geographic information systems to identify regions that can benefit from the production of biomethane from landfill gas using the existing natural gas pipelines as an alternative to the electricity generation and provides relevant subsidies to the formulation of more efficient public policies in both the sanitation and energy sectors.

Keywords: biomethane; landfill gas; Natural Gas pipelines; GIS approach.

RESUMO

O biometano pode substituir facilmente os combustíveis fósseis, incluindo o gás natural, que possui propriedades físicas e químicas similares. No Brasil, os resíduos sólidos urbanos são descartados predominantemente em aterros sanitários. O gás dos aterros sanitários é empregado principalmente na geração de eletricidade, mas ainda em níveis baixos quando comparado ao potencial existente. A produção de biometano a partir do gás de aterro pode ser uma alternativa para explorar o potencial existente, mas a rede de gasodutos do Brasil é bastante limitada e concentrada ao longo da costa do país. Nesse contexto, esta pesquisa buscou identificar a viabilidade locacional do uso de gás de aterro sanitário para produzir biometano e injetá-lo em dutos, considerando o potencial disponível e sua proximidade com a rede de dutos existente no Brasil. O software QGis foi utilizado para integrar as informações. Foram considerados viáveis arranjos territoriais com uma capacidade de produção de biometano maior que 15.000 Nm^3 dia^{-1} e localizados a até 50 km da rede de gasodutos. A pesquisa estimou uma produção potencial equivalente a 3.407.027 Nm^3 dia^{-1} de biometano a partir de aterros sanitários no Brasil. Esse potencial corresponde a 6% do consumo de gás natural do país em 2019 e é quase 32 vezes maior que a produção de biometano de todos os substratos utilizados com essa finalidade naquele ano. Os resultados indicam a adequação do uso de sistemas de informação geográfica para identificar regiões que podem se beneficiar da produção de biometano a partir de gás de aterro sanitário, utilizando os gasodutos de gás natural existentes como alternativa à geração de eletricidade e fornece subsídios relevantes para a formulação de políticas públicas mais eficientes, tanto no setor de saneamento quanto no de energia.

Palavras-chave: biometano; gás de aterro; gasodutos de gás natural; abordagem SIG.

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INTRODUCTION

Degradation of the organic fraction of municipal solid waste (MSW) in landfills results in the formation of biogas. When landfill gas is not captured, in addition to contributing to the aggravation of local air pollution, it also contributes, on a global level, to the intensification of climate change due to its significant methane content, which averages 50% (JAIN, 2019).

The entry into force, in 2005, of the Kyoto Protocol and its effective operation through the Clean Development Mechanism has motivated the development of many projects to capture landfill gas for its complete oxidation in burners or for electricity generation in Brazil (ALVES & ANDRADE, 2018). Recently, more refined cleaning and purification systems aimed at removing carbon dioxide, water vapor, and other constituents of landfill gas — such as siloxanes, for the production of biomethane — have been used (GARCILASSO *et al*., 2018; HOO, HASHIM & HO, 2018).

The main techniques used to remove impurities from raw biogas in the upgrading process involve the use of pressurized water (water scrubbing), absorber liquids such as amines (chemical scrubbing), membranes, and adsorption in solid media by variations in pressure (Pressure Swing Adsorption – PSA) or temperature (cryogenic upgrading) (MUÑOZ *et al*., 2015; JAIN, 2019). Specifically in Europe, where 77% of biomethane plants are located (JAIN, 2019), the use of water and chemical scrubbing technologies in larger capacity plants are predominant (PRUSSI *et al*., 2019).

Due to its high methane content, biomethane is energetically equivalent to natural gas (KOORNNEEF *et al*., 2013) and can be used, for example, either in the energy and transport sectors as a substitute for fossil fuels — such as gasoline, diesel oil or natural gas — or as a raw material in industrial processes.

Research conducted in various countries relate the potential production of biogas from different substrates to the location of the purification plants, so that it is possible to inject biomethane into the gas network. In Malaysia, a study of the spatial distribution of the plants was carried out, considering their technical and economic viability, to determine the potential of decentralized plants for the production of biomethane for injection into the gas grid (HOO *et al*., 2019). This study concluded that the most viable plants are located in densely populated regions with a higher concentration of natural gas consumers. The researchers also identified that the projects would be more viable with greater economic incentives to become more competitive with other fossil fuels. Thus, the authors concluded that spatially explicit information could contribute to the formulation of specific energy sector regulations.

Another study supported by Geographic Information Systems (GIS) modeling sought to optimize the location of biomethane plants in relation to the substrate used for their production and the injection points (O'SHEA *et al*., 2017). As a result, the research found that biomethane can replace a relevant part of the natural gas consumed in the region of Ireland.

Similarly, a survey in Finland used GIS to identify the location of the greatest potential for biomass-based biomethane production, considering the existing transport and distribution structure in that country (HÖHN *et al*., 2014). The authors concluded that GIS are important tools for the analysis and optimization of the location of plants of this type.

This tool is also used in studies aimed at optimizing, for example, the tariff charged for the distribution of biomethane, which can vary according to the distance of the plants in relation to the pipelines and the type of final consumer of biomethane (industrial or residential, for example) (HOO, HASHIM & HO, 2018).

Landfilling is the most adopted practice for final disposal of MSW in Brazil. In 2019, 59.5% of the total MSW collected was landfilled (ABRELPE, 2020). Nevertheless, landfill gas energy recovery is still incipient in the country and, where it occurs, its main use is for electricity generation (LIMA *et al*., 2018). Studies published in recent years have focused on identifying the potential of electricity generation from waste-to-energy in Brazil through comparative analysis of landfill gas recovery with other technologies, such as incineration (SOUZA *et al*., 2014; LEME *et al*., 2014; PIN *et al*., 2018). Additionally, aspects such as population density (DALMO *et al*., 2019), economic attractiveness (TIAGO FILHO & SILVA, 2014; COSTA *et al*., 2016; MAMBELI BARROS, SANTOS *et al*., 2019), and environmental indicators (LEME *et al*., 2014) have been analyzed, but few studies have considered the production of biomethane or the distribution of landfills in the territory.

An exception is the research conducted by Lima *et al*. (2018), which estimated the potential for landfill biogas production to generate electricity for different regions of the country applying a GIS-based approach. The authors considered two scenarios for electricity production: (i) landfills and open dumps currently in operation until the end of their expected lifetime; and, (ii) hypothetical territorial arrangements (TAs) consisting of municipalities clusters to estimate the potential biogas production and corresponding electricity generation.

The TAs proposed by Lima *et al.* (2018) are equivalent to municipal consortia, which in turn are groupings of municipalities that implement joint actions aimed at providing public services more efficiently. This type of arrangement, encouraged by the National Solid Waste Policy, can facilitate the implementation of projects and increase their economic feasibility.

This research aimed to integrate the potential for biomethane production from biogas that could be captured in hypothetical landfills — considering Lima *et al*. (2018) results, with their distance from the existing natural gas distribution network in Brazil. The outcome of this research reinforces the importance of promoting the implantation of consortiums for the improvement of waste management in Brazil. In addition, the results contribute to the planning of energy recovery from landfill gas and to the evaluation of the expansion of the Brazilian pipeline network.

The identification of relevant energy potentials for biomethane production highlights an additional form of energy recovery from landfill gas besides electricity generation, which has a greater impact on reducing greenhouse gas emissions, since besides oxidizing the methane emitted by landfills, it replaces fossil fuels that are more carbon-intensive than electricity in Brazil.

METHODOLOGY

The study was developed in two stages. Initially, the potential for biomethane production in landfills was calculated considering the raw biogas production estimated by Lima *et al*. (2018) in each hypothetical landfill of the TAs established by the authors. Then, based on a set of criteria better described in the next section, the number of viable plants was determined. In a second stage, the geographic information system was used to integrate the identified viable plants into the Brazilian natural gas pipeline.

Estimation of the potential of biomethane production

The raw biogas production in each hypothetical landfill of the TAs proposed by Lima *et al.* (2018) was used to estimate the biomethane production potential by these hypothetical landfills. It was assumed that just one biomethane production plant would be implemented in each TA.

In order to estimate the potential biomethane production of the plant in each TA, an efficiency of 70% of plant purification was assumed (EPE, 2014; EPE & MME, 2018)[1] as well as a plant availability of 92% (EPE & MME, 2018).

Lima *et al.* (2018) estimated the raw biogas production by each hypothetical landfill using a first-order model and considering a 30-year lifespan beginning in 2015. Based on the authors' results for raw biogas potential production, this study assumed that the processing capacity of each biomethane plant corresponded to the average production of biomethane in each TA between 2020 and 2030. This time span is consistent with the estimated lifetime of the upgrading plant equipment (EPE & MME, 2018).

Only the TAs with a biomethane production capacity of more than 15,000 Nm^3 day^{-1} were considered. According to EPE and MME (2018), biomethane production plants in landfills with a capacity of more than 6,000 Nm^3 day^{-1} are economically viable when compared to the cost of natural gas. However, the proposed analysis took into consideration the approximate value of the minimum production capacity of the three biomethane plants using biogas from landfills that are operational in Brazil (Table 1), which is equivalent to 14,400 Nm^3 day^{-1} (CIBIOGÁS, 2020; UCHIDA, 2019).

Stages of geoprocessing

The geoprocessing was done with the use of version 3.10 of the QGis Software. Whenever necessary, the processing layers were reprojected applying the South America Albers Equal Area Conic projection (ESRI:102033).

The delineation of the TAs proposed by Lima *et al.* (2018) was used. However, the attribute table of the shapefile provided by the authors did not contain the geographic location of the TAs.

The intersection function of the QGis was used to link the delineation of the TAs to the hypothetical landfill, as provided in the spreadsheet containing the calculation of biogas production potential as made available by the authors. The linkage was made since each TA was anchored to a specific Brazilian municipality. The shapefile of Brazilian municipalities was also used (IBGE, 2019). The result of this intermediary processing step was the map containing the biomethane plants of each TA.

Table 1 – Biomethane production plants from landfill gas in Brazil.

Landfill/Plant location[c]	Waste deposited (t day^{-1})	Actual production (1,000 Nm^3 day^{-1})	Installed capacity[a] (1.000 Nm^3 day^{-1})	Distribution
São Pedro da Aldeia (RJ)	600-1,000[d]	14.4[d]	16	Cylinders and pipeline[d]
Fortaleza (CE)	4,500[d]	92[d]	110	Pipeline[d]
Seropédia (RJ)	10,000[b]	72[b]	204	Cylinders[b]

Source: elaborated by the authors from [a]ANP, 2021; [b]Brasil Energia, 2019; [c]CIBiogás, 2020 and [d]Uchida, 2019.

In a second processing stage, the previous result was intersected with the Brazilian transportation pipeline map (BRAZIL, 2018). Then, data from economically viable plants were included in the attributes table, according to the criterion of minimum production capacity.

Finally, a 50 km buffer from the pipeline network was created. This criterion is justified since it is not necessary to recompress the gas delivered at this distance (HOO, HASHIM & HO, 2018). As a result, or exit layer, a map was elaborated with the economically viable plants grouped according to their processing capacity considering the default classification suggested by the software, within a buffer region of 50 km from the pipeline.

RESULTS AND DISCUSSION

The study identified 59 TAs in which the installation of biomethane plants would be viable in accordance with the adopted criteria — minimum processing capacity of 15,000 Nm^3 day^{-1}. From these 59 TAs, 42 are located within the area of influence of the pipelines — less than 50 km away from pipeline (Figure 1). The processing capacity of the 42 viable plants sums up 3,407,027 Nm^3 day^{-1} (or 88% of the total potential amongst the 59 viable TAs for biomethane production, including the ones located outside the buffer).

As a reference, in 2019, 54,278,110 Nm^3 day^{-1} of natural gas were consumed in Brazil and 103,395 m^3 day^{-1} of biomethane were produced, considering all substrates used in the country for this purpose (CIBIOGÁS, 2020). The viable processing capacity of biomethane from landfill gas within the buffer estimated by the research corresponds to 6% of the natural gas consumption in Brazil in 2019 and is almost 32 times higher than the current production of biomethane in the country.

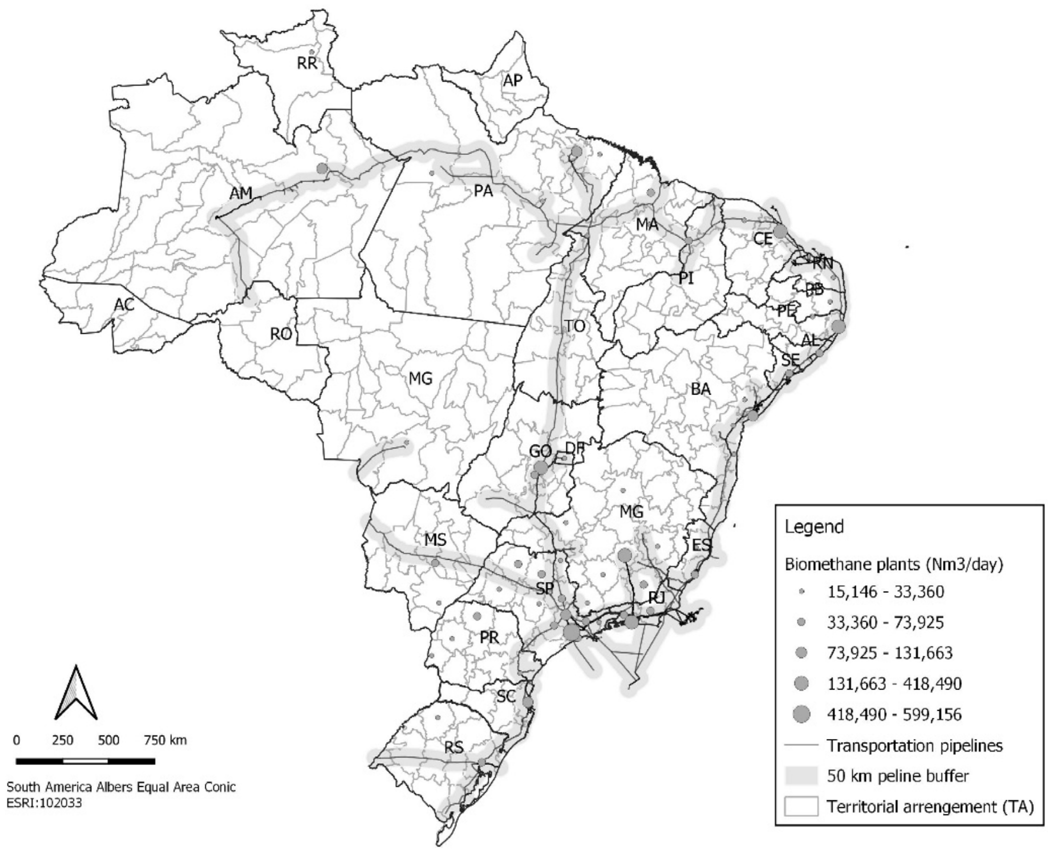
Most of the plants meeting the research criteria correspond to the lower processing capacity classes. The plant located in the TA located in the state of São Paulo (SP) significantly stands out with a processing capacity of more than 418,490 Nm^3 day^{-1}. This is justified because this region is one of the most densely populated in Brazil; consequently, more MSW is available for processing.

Other TAs with relevant biomethane production capacities — higher than 131,663 Nm^3 day^{-1} — are located in the states of Minas Gerais (MG), Goiás (GO), Pernambuco (PE), and Ceará (CE). In fact, the production of biomethane from landfill gas in Ceará is already taking place in a plant located near Fortaleza (matching the point identified by this research) which injects its production into the state's natural gas grid and accounts for 15% of the gas consumed in that state (CEARÁ, 2019).

Figure 2 shows the distribution of the plants according to the classes of processing capacity and the total processing capacity of each class.

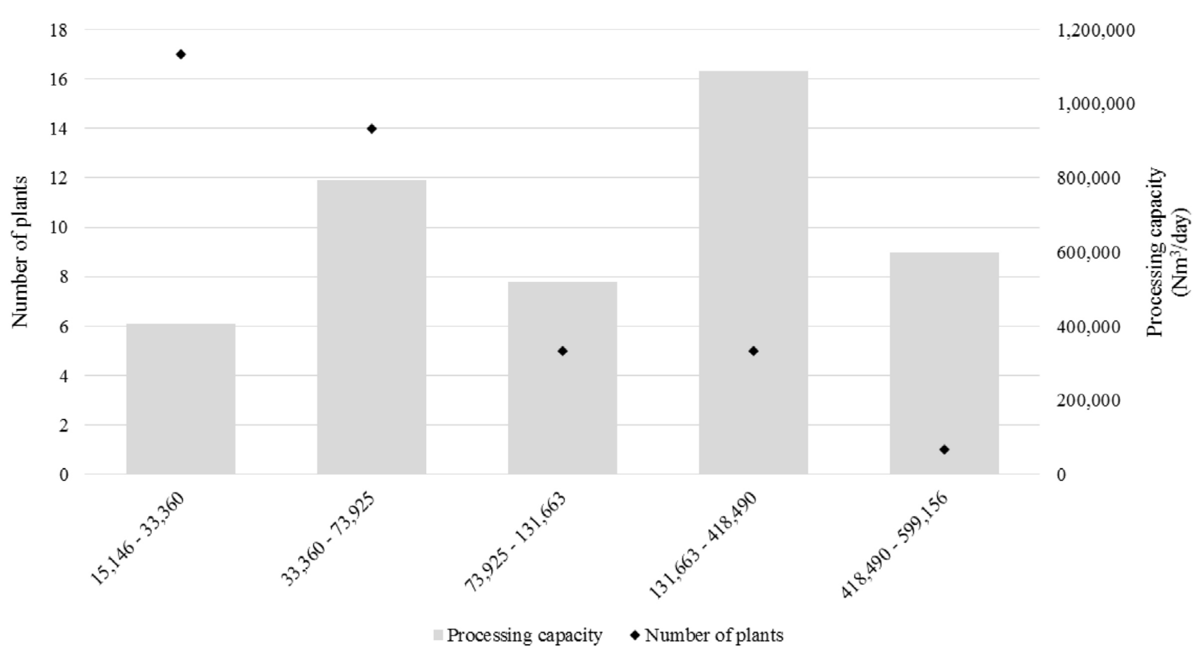
According to the largest developer of biomethane production projects from landfill gas in Brazil, financially attractive projects are located more than 500 km from gas pipelines because the price of biomethane produced in such plants is more competitive when compared to the price of fossil fuels (UCHIDA, 2019). In this context, and although the research has not focused on identifying viable plants far from existing pipelines, it is worth highlighting the plant located in the northern region of the country in the state of Roraima (RR), which may be a good option for the use of biomethane from landfill gas, especially because there are no natural gas distributors in that state (ABEGÁS, 2019).

[1]Loss of methane in the purification process.



Source: elaborated by the authors.

Figure 1 – Spatial distribution of the 59 viable biomethane plants using landfill gas.



Source: elaborated by the authors.

Figure 2 – Number of plants and total processing capacity per range of processing capacity.

CONCLUSIONS

The results obtained demonstrated the existence of a relevant potential for the energy recovery of landfill gas for biomethane production still unexplored today. In terms of locational viability, the use of spatially distributed data made explicitly evident that this potential is higher in more densely populated regions, where the MSW availability and the concentration of natural gas transportation infrastructure by pipelines are greater.

If, on the one hand, this concentration can be attractive for the development of projects, given the proximity to consumer centers and the smaller need for investment in the expansion of the pipeline network, on the other hand, it highlights the unequal distribution of infrastructure in the country.

Analyzed from another perspective, the results ratify some possibilities of development of this type of project in regions that do not have gas distribution networks, bring fossil fuels from large distances, and lack a better waste management, such as the plants located in the North and Northeast regions of Brazil.

Finally, the spatialized results of the research demonstrate the high potential for energy recovery from landfill gas that exists in the country, given the small number of projects currently in operation. Additionally, the findings described here may serve as a reference for public managers who aim to promote the interiorization of the gas distribution infrastructure or who are committed to improving the sanitary conditions of the country, possibly financed by MSW energy recovery projects.

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AUTHORS' CONTRIBUTION

VEIGA, A. P. B.: conceptualization, methodology, data curation, formal analysis, writing — review & editing. STRAMIERI SILVA, R.: conceptualization, data curation, writing — review & editing. MARTINS, G.: writing — review & editing, supervision.

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