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ENERGY POTENTIAL OF BIOGAS FROM PIG FARMS IN THE STATE OF MINAS GERAIS, BRAZIL

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KEYWORDS

anaerobic digestion, covered lagoon biodigester, energy recovery, biogas, pig farming.

ABSTRACT

Pig farming stands out as an alternative for decentralized electrical energy production from the use of biogas energy. However, its use is still limited. Thus, this study aimed to estimate and map the biogas production, as well as determine the electric power originated by the use of biogas produced in covered lagoon biodigester from pig farms of different sizes in the state of Minas Gerais, Brazil. The research was based on data provided by the Instituto Mineiro de Agropecuária (IMA). Three forms of electric power were estimated, as follows: (i) total, (ii) current, and (iii) installed. They were estimated from the volume of manure generated at each development stage of the animals. The total electric power corresponded to 31 MW, while the current electric power was equal to 20 MW. The installed electric power was still low and corresponded to 35.4% of the current electric power. The results showed that 55% of the current electric power was concentrated in only two mesoregions (Triângulo Mineiro/Alto Paranaíba and Zona da Mata). Therefore, the use of biogas contributed to providing energy self-sufficiency in pig farms and the generation of decentralized electrical energy.

INTRODUCTION

The significant depletion of fossil fuels, associated with the environmental impacts of climate change, has encouraged some countries, such as Brazil, to diversify their energy matrices (Chinnici & Pecorino, 2015). Among the alternatives, energy from biomass has gained more and more prominence.

Energy recovery from biomass can come from several organic residues, which are classified into the forest, agro-industrial, urban, and agricultural residues (Freitas et al., 2019). According to the Brazilian Electricity Regulatory Agency (ANEEL), 8.6% of the Brazilian energy matrix comes from biomass energy, and only a small portion (0.08%) comes from energy recovery from biogas (ANEEL, 2017).

Although energy recovery from biogas is still incipient in Brazil, the primary source of energy use occurs in domestic sewage treatment plants (Freitas et al., 2019). Many studies have pointed to the energy sustainability of domestic sewage treatment plants from the recovery of biogas as an energy source (Udaeta et al., 2019, Santos et al., 2018, Rosa et al., 2016, Lobato et al., 2012).

According to Santos et al. (2018), the energy viability of domestic sewage treatment plants is associated with the organic load of effluents, in which the pig farming activity has great potential due to their high organic loads compared to those found in the treatment of sewage.

Pig farming is relevant in Brazilian agribusiness, being responsible for the production of 3.75 million tons of pork in 2017, with the state of Minas Gerais responsible for about 11% of its production (ABPA, 2018).

Pig farming activity is responsible for the generation of a large amount of manure resulting from animal confinement. One of the most widespread and indicated technologies for the treatment of these agricultural residues is the use of plug-flow digesters, also called Canadian digesters (Calza et al., 2015). This configuration stands out for the low costs of construction and operation and the possibility of using its by-products, such as biogas and biofertilizer (Cheng & Wei, 2018).

Ferreira et al. (2018) pointed out that the low utilization of biogas energy potential is associated with the limitation of legislation, economic incentives, and specific regulations for this purpose. Other factors, such as the lack of strategic planning in the production of biogas to be

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explored and adaptation of technologies for decentralized generation in Brazil, can also be highlighted.

According to Reis & Reis (2017), the spatialization of the energy potential of possible electrical energy generating units using the geographic information system (GIS) tool is of high relevance for studies of diversification of the energy matrix, as it assists in identifying the regions with potential for energy production, decision making, and management by companies in the electricity sector.

Some studies have carried out the determination of the total energy potential of biogas from the pig farming sector (Reis & Reis, 2017) and by mesoregions of Minas Gerais (Ferrarez et al., 2015). However, these studies have not considered the volume of residues generated at the different stages of animal development and electricity generation conditions from the operation of moto-generation systems, which gives this study a high detailing in the estimation of the energy potential and a more careful analysis of the biogas recovery. Thus, this study aimed to estimate and map the biogas production, as well as determine the electric power resulting from the use of the biogas produced in covered lagoon biodigester from pig farms of different sizes in the state of Minas Gerais.

MATERIAL AND METHODS

The diagnosis of pig farms in the state of Minas Gerais was carried out based on the data provided by the Instituto Mineiro de Agropecuária (IMA), quantifying the herd by stage of animal development and size of pig farms. The volumetric production of methane, electric power, and electrical energy generated from the biogas energy utilization from the pig farms were then estimated. Subsequently, the rural population that could have its daily energy demand supplied in the corresponding macro-regions was determined, followed by the construction of thematic maps of the data referring to the diagnosis of the pig farms, electric power, and electrical energy from the biogas energy recovery.

Acquisition of data from pig farms in the state of Minas Gerais

The data used to estimate the energy potential of pig farms in the state of Minas Gerais were obtained from IMA. The information used in this study is related to the location of the pig farms by geographic coordinates and the number of animals per development stage. The data provided by IMA on the pig farming activity in the state of Minas Gerais were compiled for January 2019.

Diagnosis of pig farms in the state of Minas Gerais

The data provided by IMA allowed quantifying the pig herd by stage of animal development in the state of Minas Gerais, considering the animals as piglets, boar, dam, and fattening.

Pig farms were classified according to the polluting size, following the criterion for the definition of sizes indicated in COPAM no. 217/2017, as follows: small size (200 ≤ animals < 2,000), medium size (2,000 ≤ animals ≤ 10,000), and large size (> 10,000) (COPAM, 2017). These farms were evaluated for the presence of a covered lagoon biodigester, using the Google Earth Pro tool. Pig farms with fewer than 200 animals were not considered in this study due to their reduced energy potential.

Volumetric methane production

The daily volumetric methane production was obtained using [eq. (1)] (CETESB, 2006) from the volume of manure generated by the development stage of the animals (Oliveira, 1993). Volumetric methane production was determined for two conditions: (i) total methane flow (Qi_{total}), associated with the number of animals in all pig farms classified as small, medium, and large, and (ii) current methane flow ($Qi_{current}$), calculated only from pigs on farms that have installed plug-flow digesters.

According to Leitão & Silva (2018), the percentage of CH_4 in the biogas of pig farms ranges from 55 to 75%. However, Machado et al. (2015) reported a daily variation of the percentage of CH_4 in the biogas of 75 to 77%. For the present study, the biogas was considered with 75% of methane.

$$Qi = \frac{(Pbi \times \%CH_4 \times Qt \times Mt)}{VE} \tag{1}$$

Where:

Qi is the daily (total–Qi_{total} or current–$Qi_{current}$) methane flow (m^3 CH_4 day^{-1});

Pbi is the biogas production according to Motta (1986) (0.062 kg biogas kg^{-1} manure);

$\%CH_4$ is the methane concentration in the biogas (75%);

Qt is the number of animals per category;

Mt is the volume of manure per animal for piglets (0.35 kg manure day^{-1} $animal^{-1}$), boars (3.0 kg manure day^{-1} $animal^{-1}$), dams (3.6 kg manure day^{-1} $animal^{-1}$), and fattening (2.3 kg manure day^{-1} $animal^{-1}$) (Oliveira, 1993), and

VE is the specific volume of methane according to Motta (1986) (0.670 kg CH_4 m^{-3} CH_4).

Estimation of the theoretical volumetric biogas production

The estimation of the theoretical volumetric biogas production per development stage of the animals was obtained using [eq. (2)].

$$PV_{bio} = \frac{\frac{Qi}{\%CH_4}}{Qt} \tag{2}$$

Where:

PV_{bio} is the volumetric biogas production by animal category (m^3 biogas $animal^{-1}$);

Qi is the methane flow (m^3 CH_4 day^{-1});

$\%CH_4$ is the methane concentration in the biogas (75%), and

Qt is the number of animals per category.

Energy potential from biogas in pig farms

Different concepts associated with the biogas potential for pig farming activity was also determined in this study. They were indicated as the electric power (PE), being defined by the following criteria:

(i) Total electric power

The total electric power (PE_{total}) corresponded to the total energy potential of the biogas produced in pig farms classified as small, medium, and large. For this, the total number of animals in pig farms with the effluents treated or not using covered lagoon biodigester was considered.

(ii) Current electric power

The current electric power ($PE_{current}$) was calculated considering only the biogas from pig farms of the three types of sizes that already had installed covered lagoon biodigester.

The total (PE_{total}) and current electric power ($PE_{current}$) was calculated using [eq. (3)], adapted from CETESB (2006). For this, the fraction of the output power of moto-generators relative to the system capacity (η_r), fuel conversion efficiency (η_c), and alternator efficiency (η_g) were considered, as defined in [eq. (3)].

$$PE = Qi \times Pc \times \eta c \times \eta g \times \eta r \quad (3)$$

Where:

PE is the electric power (total–PE_{total} or current–$PE_{current}$) (kW);

Qi is the daily methane flow (total–Qi_{total} or current–$Qi_{current}$) (m^3 CH_4 day^{-1});

Pc is the calorific power of methane (35,900 kJ m^{-3}) (Rosa et al., 2016);

η_c is the fuel conversion efficiency (33.0%) (CETESB, 2006);

η_g is the alternator efficiency (91.5%), and

η_r is the value adjusted by the operator of the electric power output of the moto-generator (80%).

(iii) Installed electric power

The installed electrical power ($PE_{installed}$) corresponded to the maximum installed electric power per pig farm. These data were obtained from the Brazilian Electricity Regulatory Agency (ANEEL, 2019). The sum of the installed electric power per mesoregion considered only the pig farms that had the generation modality in the consumer unit itself.

Electrical energy generated from the energy utilization of biogas

The data of the current electric power ($PE_{current}$) allowed considering a daily operating time of the moto-generator set for 22 hours (8,000 hours $year^{-1}$), which allows providing a time interval for the moto-generator maintenance, as well as possible system shutdowns. Equation (4) presents the calculation of the daily electrical energy available for consumption (E) based on the energy utilization of biogas for all pig farms of small, medium, and large sizes that have digesters.

$$E = PE_{current} \times t \quad (4)$$

Where:

E is the available electrical energy per day (kWh);

$PE_{current}$ is the current electric power (kW), and

t is the operating time of the moto-generator (22h d^{-1}).

Then, the rural population that could have its daily energy demand met in the corresponding macro-regions if electrical energy was generated from pig farms that treat their effluents using plug-flow digesters was determined (Equations 5 and 6).

$$population_{supplied} = \frac{E}{Cp} \quad (5)$$

Where:

$population_{supplied}$ is the population supplied by the generated electrical energy (inhabitants);

E is the available electrical energy per day (kWh), and

Cp is the per capita consumption (6.9 kWh $inhabitant^{-1}$ day^{-1}) (EPE, 2017).

$$\%population_{rural} = \frac{population_{supplied}}{population_{IBGE}} \quad (6)$$

Where:

$\%population_{rural}$ is the rural population supplied by the generated electrical energy (%);

$population_{supplied}$ is the population supplied by the generated electrical energy (inhabitants), and

$population_{IBGE}$ is the rural population made available by the last survey carried out by IBGE (IBGE, 2010) (inhabitants).

Thematic maps

Microsoft Excel spreadsheets containing data on the geographic locations of pig farms and their respective potentials were imported and converted into the shapefile (*shp) format. Thus, the data referring to the diagnosis of pig farms, electric power, and electrical energy resulting from the energy recovery of this by-product were evaluated for the mesoregions of the state of Minas Gerais, as shown in Figure 1.

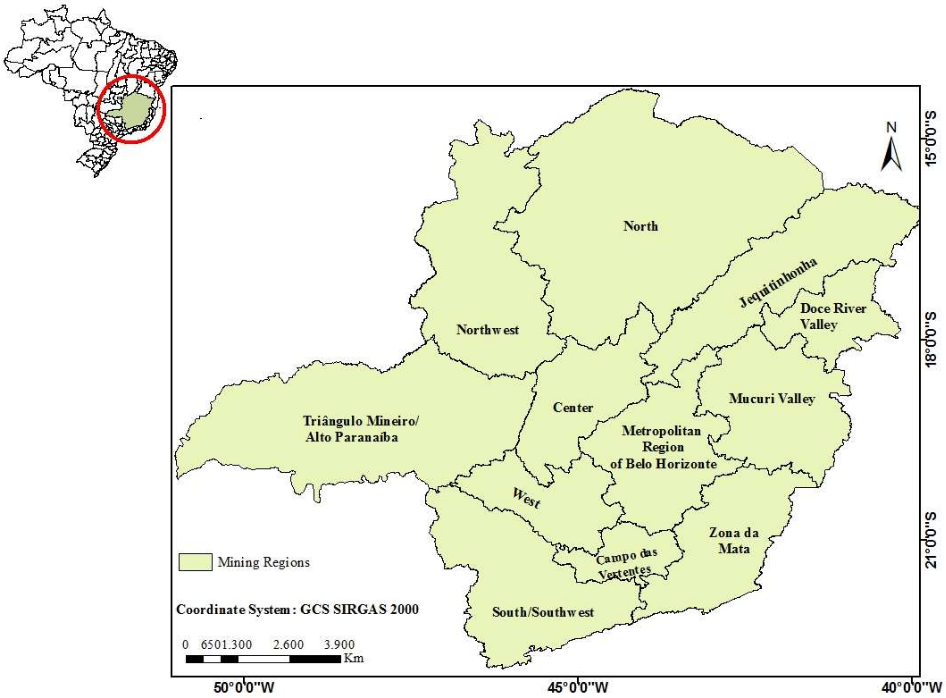


FIGURE 1. Mesoregions of the state of Minas Gerais evaluated in the study.

RESULTS AND DISCUSSION

Diagnosis of Pig farms in the state of Minas Gerais

According to a survey carried out by IMA for January 2019, the state of Minas Gerais has 4,739 pig farms, totaling a herd of around 3.4 million heads. The number of piglets is predominant, followed by animals at the fattening stage (Table 1).

The mesoregions of Triângulo Mineiro/Alto Paranaíba and Zona da Mata stand out as the main hubs of pork production in Minas Gerais. Also, 39% of the herd is located in the Triângulo Mineiro/ Alto Paranaíba, followed by 25% in the Zona da Mata (Table 1).

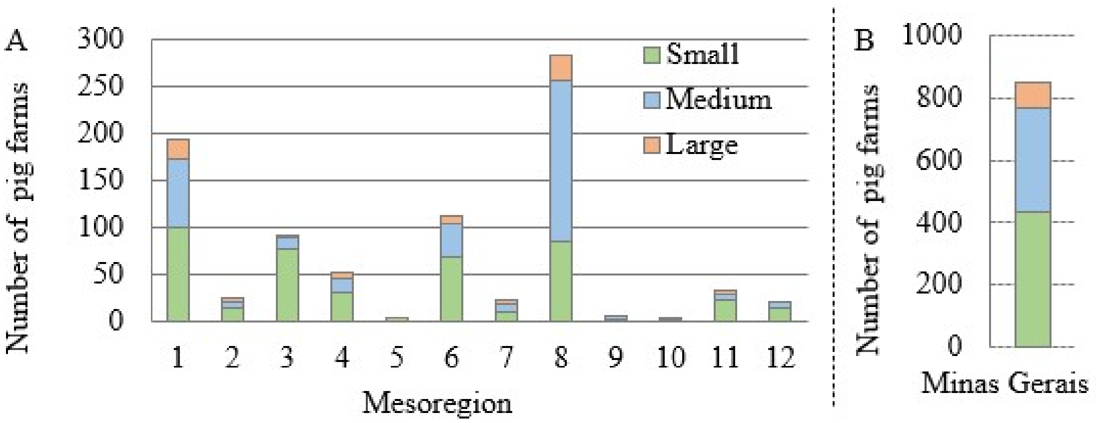
TABLE 1. Distribution of the pig herd in the state of Minas Gerais in January 2019.

Mesoregion	Piglet	Boar	Dam	Fattening	Total
Doce River Valley	1,163	116	714	2,227	4,220
Mucuri Valley	3,228	61	336	1,569	5,194
Jequitinhonha	3,180	79	987	5,515	9,761
North	11,521	257	3,242	29,319	44,339
Campo das Vertentes	29,360	374	5,510	16,245	51,489
South/Southwest	47,616	537	18,470	98,930	165,553
Center	55,689	254	12,807	100,872	169,622
Northwest	75,811	2,234	14,171	78,250	170,466
East	114,663	488	24,441	103,872	243,464
Metropolitan Region of BH	146,847	1,309	37,864	206,849	392,869
Zona da Mata	437,310	917	87,881	339,998	866,106
Triângulo/Alto Paranaíba	998,243	4,148	94,736	247,386	1,344,513
Total	1,924,631	10,774	301,159	1,231,032	3,467,596

Among the pig farms, 82.1% fall into properties of up to 200 animals, although they represent only 1.8% of the total number of animals. Among those classified as small, medium, and large (Figure 2), there is a predominance of small pig farms, corresponding to 9.2% of the properties (436), while only 1.6% were classified as large (77). However, large pig farms are responsible for 45.3% of the herd in the state of Minas Gerais.

Triângulo Mineiro/Alto Paranaíba and Zona da Mata are the mesoregions with the largest number of pig farms, comprising 56.2% of the farms in the state of Minas Gerais (Figure 2). This high concentration of pig farms in the Triângulo Mineiro/Alto Paranaíba region is due to the high availability of inputs and consumer markets that favor this activity (ABCS, 2017).

Among these pig farms classified as small, medium, and large, 79.2% of large farms (61), 46.7% of medium farms (156), and 17.9% of small farms (78) treat their residues using covered lagoon biodigester.



Zona da Mata (1), Campos das Vertentes (2), South/Southwest (3), West (4), Doce River Valley (5), Metropolitan Region of Belo Horizonte (6), Center (7), Triângulo Mineiro/Alto Paranaíba (8), Mucuri Valley (9), Jequitinhonha (10), North (11), Northwest (12).

FIGURE 2. (a) Distribution of the number of pig farms as a function of different sizes in mesoregions (b) and in Minas Gerais.

The daily manure generation of confined animals per category in small, medium, and large pig farms is estimated at 4.504.8 tons of residues. However, only 65.4% of this amount is treated using covered lagoon biodigester model in 295 properties in the mesoregions of Triângulo Mineiro/Alto Paranaíba (126 properties), followed by Zona da Mata (58) and Metropolitan Region of Belo Horizonte (38) (Figure 3). In addition, Figure 3 also indicates the ranges with the estimation of the current methane flow production (from pig farms with installed digesters), as well as the classification of farms according to their size, considering the indication in the ranges of COPAM no. 217/2017.

The volumetric methane production in farms with installed digesters is estimated at 203,976.3 m^3 methane day^{-1} (Figure 3), with an estimated production of 271,968.4 m^3 biogas day^{-1}. The North, Mucuri Valley, and Jequitinhonha Valley mesoregions had no presence of digesters in the pig farms (Figure 3). This absence is associated with the reduced number of intensive farms, as these regions have the predominance of large properties, commonly occupied by pastures, the monoculture of eucalyptus, or bananas (Dayrell et al., 2017).

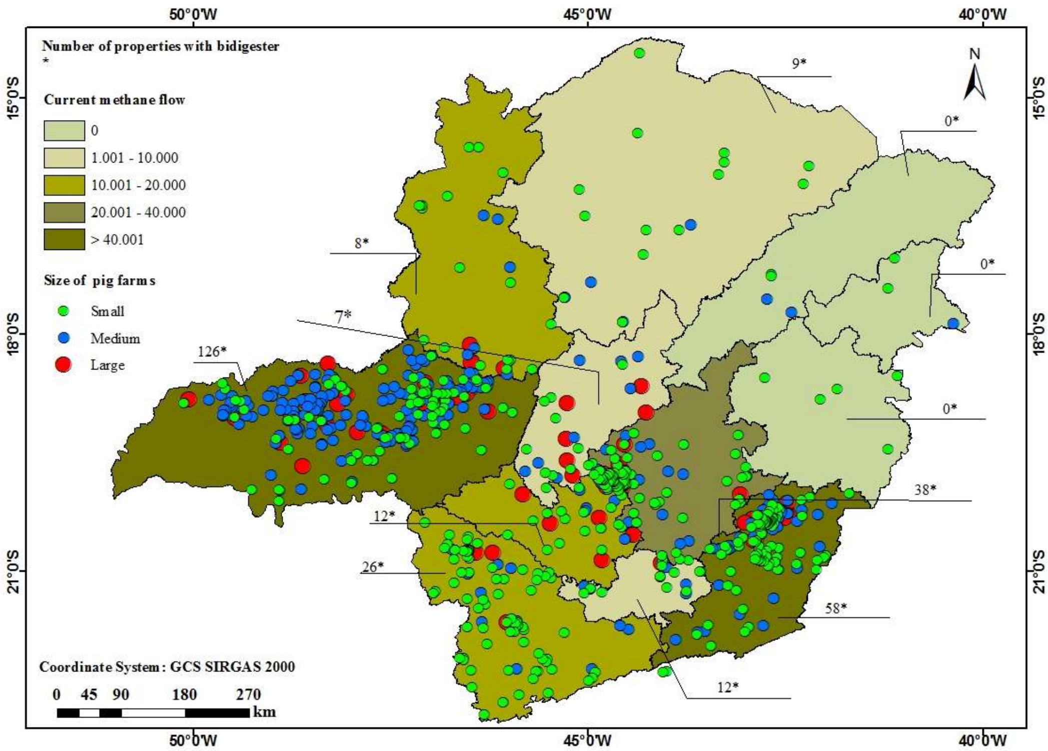


FIGURE 3. Spatial distribution of pig farms in the state of Minas Gerais by size, as well as the total methane flow grouped by mesoregion, considering pig farms with installed digesters.

The volumetric biogas production by animal category – $PV_{(bio)}$ is estimated at 0.33 m^3 biogas animal^{-1} day^{-1} for dams, 0.03 m^3 biogas animal^{-1} day^{-1} for piglets, 0.28 m^3 biogas animal^{-1} day^{-1} for boars, and 0.21 m^3 biogas animal^{-1} day^{-1} for fattening (growth and finishing).

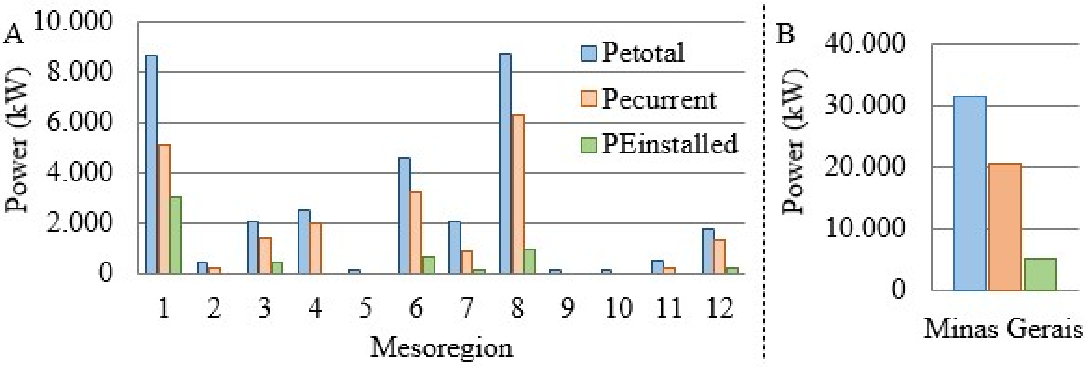
The estimated value of biogas production for piglets was lower than that reported by Coelho et al., (2018), who considered a generation of 0.10 m^3 biogas animal^{-1} day^{-1} for pigs in the nursery stage. The estimated values for pigs at the fattening stage were within the range found by Silva et al. (2018) and Oliveira (1993), who obtained a biogas production ratio ranging from 0.10 to 0.24 m^3 biogas animal^{-1} day^{-1}.

Energy potential of pig farms

Figure 4A shows that most mesoregions have a current electric power of up to 1,000 kW. However, only two mesoregions (Triângulo Mineiro/Alto do Paranaíba and Zona da Mata) represent 55% of the current electric power in the state of Minas Gerais.

The Zona da Mata region stands out for having 11 municipalities with concession, totaling an installed electric power of 3,004.84 kW, followed by Triângulo Mineiro/Alto Paranaíba, with seven municipalities, totaling an installed electric power of 922.8 kW (ANEEL, 2019) (Figure 4A).

The total electric power (PE_{total}) from pig farms evaluated in this study was 31,392.1 kW, while the current electric power ($PE_{current}$) corresponded to 20,479.9 kW. The installed electric power ($PE_{installed}$) in the state of Minas Gerais is still low, with a value of 5,278 kW (ANEEL, 2019), i.e., 35.4% of the current electric power (Figure 4B).



Zona da Mata (1), Campos das Vertentes (2), South/Southwest (3), West (4), Doce River Valley (5), Metropolitan Region of Belo Horizonte (6), Center (7), Triângulo Mineiro/Alto Paranaíba (8), Mucuri Valley (9), Jequitinhonha (10), North (11), Northwest (12).

FIGURE 4. Electric power of pig farms (a) by mesoregions (b) in the state of Minas Gerais.

The reduced energy utilization can be associated with the lack of motivation to implement projects due to technological barriers, availability of technical information, and trained professionals to guarantee control of the process (Ferreira et al., 2018).

The implementation of the biogas generation system and its utilization requires high initial investments, and the small number of successful projects makes the investment risk a barrier to be faced (Mariani, 2018).

Still, according to Mariani (2018), other barriers found in this sector are related to the technology for the energy utilization of biogas, which is often imported, leading to high costs for its acquisition, as well as prolonged periods for the maintenance of electrical energy conversion equipment, resulting in a low yield for the pig farmer. This author also pointed out that the lack of organization and dissemination of existing information and the training of people to be able to operate it satisfactorily are also other challenges to be faced.

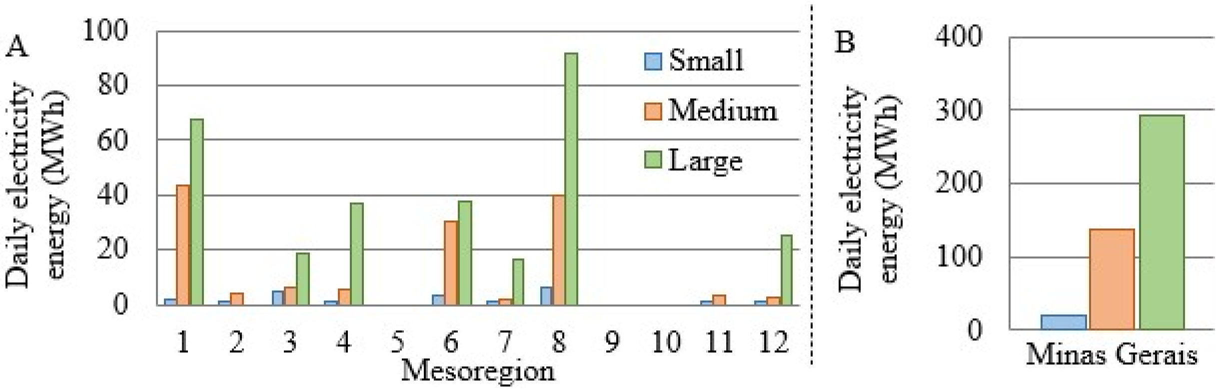
Thus, a more promising energy utilization requires to (i) increase the efficiency of biodigestion systems, which, as a rule, are not instrumentalized; (ii) improve the moto-generators so that they can operate by burning biogas, as they are usually equipment adapted from their operation by diesel and, when converted to biogas, they present low efficiency compared to similar imported moto-generators; (iii) improve the operation of filters to remove H_2S gas in order to increase its efficiency, as this gas has an unpleasant odor and is corrosive, in addition to reducing the useful life of the equipment.

Reis & Reis (2017) surveyed the energy potential of various sectors and considered for the pig farming activity the input data referring to the total number of animals obtained from IBGE for 2015, not considering the specificities related to the number of animals per stage of development and the generation of residues by type of animal at its different stages of development. It is believed that the methodological proposal and the input data of the present study are more consistent with the real conditions, thus reporting data on the energy potential of biogas in the pig farming activity for the state of Minas Gerais closer to reality.

Daily electrical energy generated from the energy utilization of biogas

The data of the current electric power and the mean operating time of the electrical energy moto-generation system of 22 hours day^{-1} allowed determining the daily electrical energy generated from the energy utilization of biogas.

Also, the current electric power data allowed observing a predominance of pig farms classified as medium, totaling 156 properties. However, 61 properties classified as large represent 65% of the daily electrical energy generated in pig farms with plug-flow digester (Figure 5). It evidences that the size of the pig farm has a higher influence on energy utilization than the number of pig farms.



Zona da Mata (1), Campos das Vertentes (2), South/Southwest (3), West (4), Doce River Valley (5), Metropolitan Region of Belo Horizonte (6), Center (7), Triângulo Mineiro/Alto Paranaíba (8), Mucuri Valley (9), Jequitinhonha (10), North (11), Northwest (12).

FIGURE 5. (a) Daily available energy from the energy utilization of biogas for different sizes of pig farms in mesoregions and (b) the state of Minas Gerais.

Figure 6 shows that the mesoregions Triângulo Mineiro/Alto Paranaíba, followed by Zona da Mata, Metropolitan Region of Belo Horizonte, West, and South/Southwest have the highest number of municipalities conducive to contributing to an increase in the energy matrix of the state of Minas Gerais, generating a total of 394 MWh of electrical energy per day.

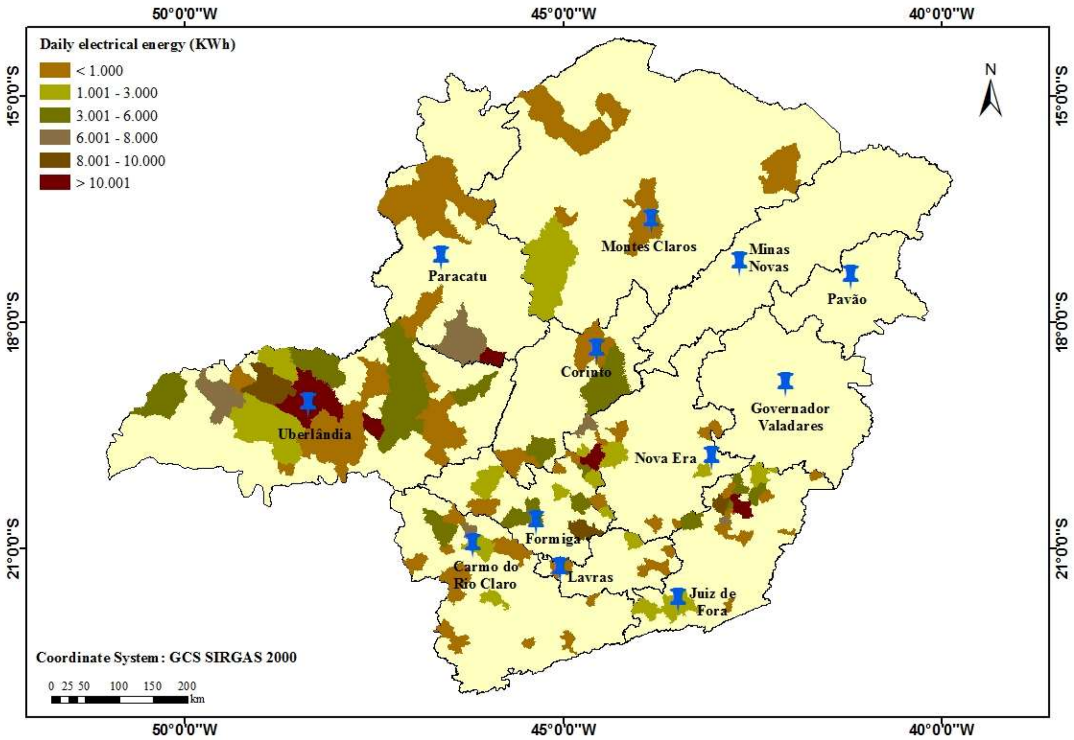


FIGURE 6. Estimation of the daily electrical energy generation available in the state of Minas Gerais from the energy utilization of biogas in pig farms.

The daily electrical energy available in pig farms that currently have a digester would be able to supply the energy demand of 65 thousand inhabitants in the state of Minas Gerais. The Triângulo Mineiro/Alto Paranaíba and Zona da Mata would be the mesoregions with the highest potential, supplying a population of 19,873 and 16,296 inhabitants, respectively (Table 2).

The data from the rural population of the state of Minas Gerais made available by the last IBGE survey conducted in 2010 show that among all mesoregions, Triângulo Mineiro/Alto Paranaíba presented a potential capable of supplying 10.8% of its rural population, followed by the West region of the state of Minas Gerais (5.5%).

TABLE 2. Rural population supplied with the energy utilization of biogas from pig farms.

Mesoregion	Rural population IBGE (inhabitants)	Population (inhabitants)	Supplied rural population (%)
Zona da Mata	417,323	16,296	3.9
Campo das Vertentes	85,608	658	0.8
South/Southwest	458,389	4,380	1.0
West	112,408	6,193	5.5
Doce River Valley	319,661	ne	ne
Metropolitan Region of BH	291,247	10,320	3.5
Center	52,365	2,699	5.2
Triângulo/Alto Paranaíba	184,454	19,873	10.8
Mucuri Valley	124,489	ne	ne
Jequitinhonha	264,251	ne	ne
North	492,119	562	0.1
Northwest	79,800	4,074	5.1
Total	2,882,114	65,054	2.3

ne – no electrical energy production.

CONCLUSIONS

The pig herd of the state of Minas Gerais counted in January 2019 by IMA showed a predominance of pigs at the piglet stage, followed by animals at the growth stage for fattening.

Among the evaluated pig farm sizes, the state of Minas Gerais showed a predominance of properties with the number of animals below 200, followed by small-sized farms.

The Triângulo Mineiro/Alto Paranaíba and Zona da Mata mesoregions were the highest hubs of pig production in the state of Minas Gerais, being responsible for concentrating the highest number of pig farms and animals. Also, these mesoregions presented most of the properties that have covered lagoon biodigester and installed electric power.

Most pig farmers in the state of Minas Gerais still do not use the anaerobic biodigestion process as an alternative for the treatment of residues.

The spatialization of the biogas generating units using the geographic information system (GIS) tool allowed identifying the mesoregions with the potential for producing electrical energy.

Electrical energy generation through the biogas recovery was evidenced and may indicate the improvement of energy self-sufficiency of pig farms and the decentralized energy generation. In addition, the use of digesters and biogas utilization to generate electrical energy contributes to minimizing the release of polluting loads into the environment and reducing the emission of greenhouse gases.

Improvements in terms of operation and monitoring of biodigesters, the development of more efficient moto-generators that operate with biogas, the development of filters to remove H_2S, and the training of professionals who work in this sector are required for the pig farming activity to become more sustainable in terms of energy and more attractive to pig farmers who have not yet used the biogas energy.

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