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Biogas Generation from Bovine Confinement: An Energy Policy Option for Brazil

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Abstract

Brazil has the largest commercial beef herd in the world and is one of the most important players in the global agricultural market, notably for soybeans. Agriculture has an important demand for energy and emits significant quantities of greenhouse gases (GHG). To minimize the effects generated by livestock activities, from both the energetic and environmental perspectives, there exists the possibility of the use of biogas generated from beef cattle confinement. This productive system allows the reduction of methane emissions from enteric fermentation and from manure through the production of biogas. This has become an option for energy policy by contributing to the offer of energy and the reduction of the demand of agriculture for fossil fuels. With a renewable energy resource, the agricultural sector dependent on non-renewable resources, also reduces its dependence on exhaustible resources, so that a policy aimed at the use of biogas and partial energetic autonomy becomes strategic for the sector. The article analyses biogas production potential from waste throughout the entire beef production chain in more intensive systems (total or partial confinement of beef cattle). These solutions can contribute both to the offer of electric energy to the agricultural sector in the country, increasing its productivity, and to the reduction of greenhouse gases.

Keywords: Bovine confinement, GHG emissions, biogas, energy policy

1. Introduction

With one of the largest cattle herds in the world, with almost 215.2 million heads¹ according to FAO [1] and IBGE data [2], with almost 90% of this being beef cattle (approximately 193.5 million heads of cattle) and almost 22 million head of dairy cattle, in 2015, the production of beef and dairy products, largely based on extensive systems, has a significant environmental impact, including with a large demand for energy resources, most of which is non-renewable and of fossil origin. The **Figure 1** shows countries with the largest cattle herds, 2000-2014.

¹ Emissions generated by other animals will not be analyzed, only those from the raising of cattle. In the case of analyses and the scenarios proposed, the author uses data for the confinement of beef cattle, not considering the herd of dairy cattle which belong to the entirety of the bovine herd.

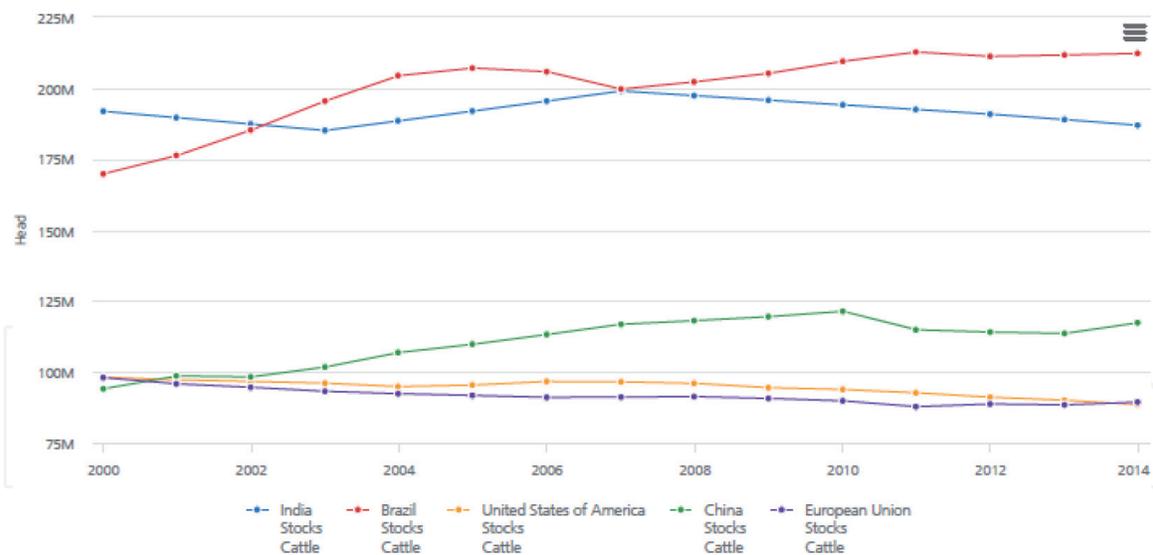


Figure 1. Countries with the largest cattle herds, 2000–2014, in millions of heads. Source: Prepared by the authors, based on FAO [1].

Agriculture is one of the principal GHG emitting activities in Brazil due to, for example, the methane resulting principally from enteric fermentation and the handling of waste, and nitrous oxide from feces and urine deposited by animals [3]. In the last emissions inventory, agriculture was responsible for around 32% of greenhouse gas emissions in the country, without taking into account the emissions created from the use of energy, measured in the part of energy whose contribution is almost 29%, but which includes a part related to the demand of the agricultural sector for energy and energy resources, as well as emissions from the conversion of forests into pasture, calculated in the part related to changes in land use. Agricultural thus contributes, directly or indirectly, to most greenhouse gases produced in the country, as seen in **Figure 2**.

In relation to the demand for energy, the agricultural sector demanded around 14.08% of the total diesel oil used in the country (approximately 7460,000 m³) and almost 11.48% of firewood (more than 9000 tons) [4]. In the case of the use of electric energy, the agricultural sector consumed around 5.14% of the final total consumption of electricity in 2015, or 26,870.89 GWh [4].

Despite have a majority renewable energy matrix, as D'Avignon [5] highlights, this does not impede the need for the implementation of complementary renewable energy programs, above all with short-term energy policies, given the environmental limitations on the construction of new hydro-electric power plants with large reservoirs², which include the majority of those constructed in Brazil, or the hydric crises which have occurred in recent years, causing serious problems with the supply of electric energy, imposing the need, for example, for rationing and the introduction of non-renewable sources of energy and more sources of GHG emissions, following the insertion of thermoelectric power plants (above all, coal and oil) [6–10]. A way to reduce dependence on hydroelectricity for the generation of electric energy and with a lower environmental impact is a policy of complementarity with new sources of renewable energy generation [5]. One of the possible renewable energy sources is biogas produced through the confinement of cattle.

² It should be emphasized the hydroelectricity continues to be the principal source in the Brazilian energy matrix. According to BEN, hydraulic energy was responsible for 64% of the total offer of electric energy in 2015 [6].

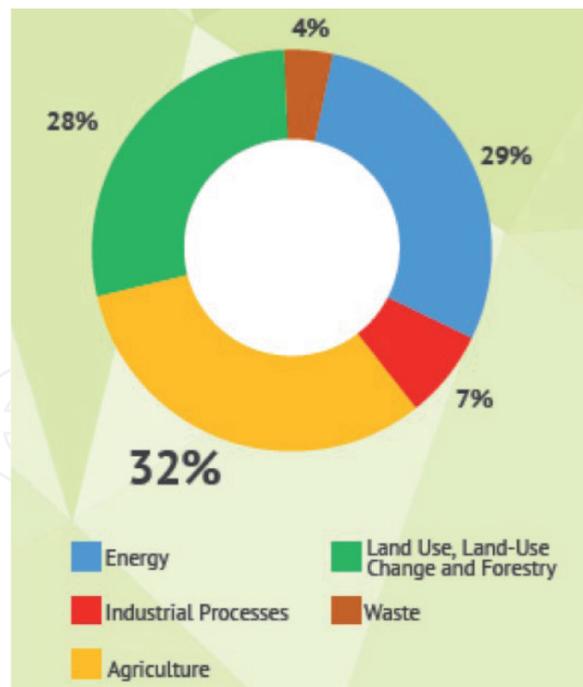


Figure 2.
Participation of each sector in the GEE emissions, in CO₂e, in 2010. Source: [12], p. 18.

2. Biogas produced from cattle confinement as a complementary and strategic energy resource in Brazilian energy policy

According to the FAO [11], it is estimated that livestock emit around 7.1 GgCO₂eq per year or 14.5% of total global emissions. The same study demonstrates that most emissions are related to the production of beef (41%) and milk (20%). Emissions are also linked to the production and processing of animal feed, enteric fermentation, the handling of waste and the remnants of processing, and the transport of products of an animal origin [11]. In the Brazilian case, in the last inventory, emissions related to enteric fermentation accounted for 11,158 GgCH₄ or around 66.9% of total methane emissions in the country in 2010 and in the case of animal waste, this value was 3.6% of total methane emissions, 608.1 GgCH₄ [12].

Confinement can contribute to the generation of electric energy with lower GHG emissions. This reduction is due to the conversion of methane generated during the beef production process into biogas as a source of energy for the energy sector, slaughterhouses, and abattoirs in particular, part of the highly energy intensive agricultural sector. At the same time, as it is a system with higher production costs in relation to the extensive system³, biogas also contributes to reducing these costs. The **Figure 3** shows how the confinement rate in Brazil is still very low.

Biogas is a gaseous mix produced by the anaerobic decomposition of organic material whose characteristics and typical composition, according to Persson et al. [14], is around 53–70% methane and 30–47% carbon dioxide, with

³ Feeding the beef cattle herd in Brazil is based on pasture, the most economic and practical means of feeding cattle. This contribute to the lower costs of beef production which are competitive in relation to the United States, Australia, and various European countries. In the latter, the predominant system is confinement, dependent on other economic factors which oscillate, such as variations in the prices of grains or fossil fuels [3, 7–10, 12, 13]. The generation of biogas help to minimize the costs associated with confinement.

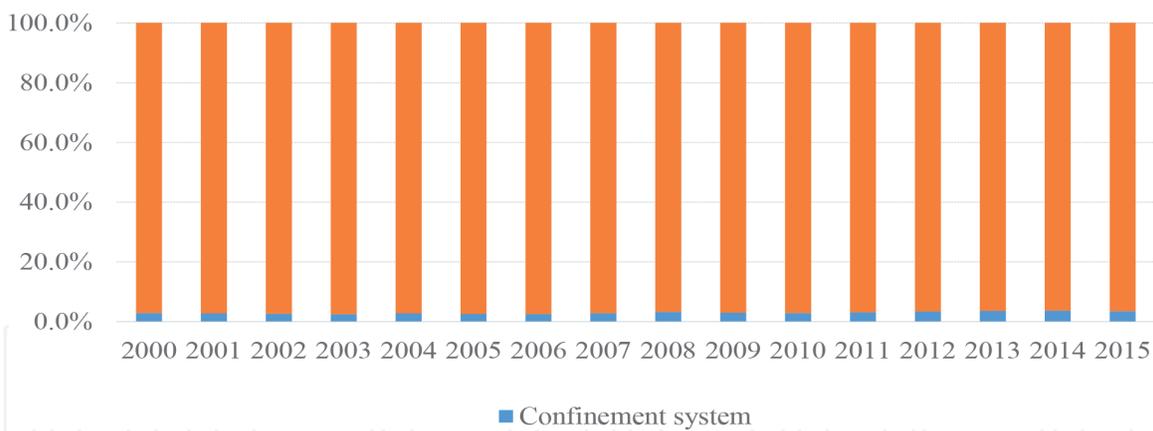


Figure 3. Participation of cattle in confinement system and cattle in extensive system or rational grazing system on the total Brazilian cattle herd, 2000-2015. Source: Prepared by the authors, based on FNP (2002, 2005, 2012 and 2016).

traces of at least 1000 ppm of sulfuric acid and at least 100 ppm of ammonia. Agricultural waste treatment systems are principally responsible for the use of the anaerobic digestion process [15].

Biogas is widely used in some countries, such as China and India, for cooking and lighting in rural areas. In Brazil, the use of this energy source was intensified in the 1970s, through governmental programs in small rural properties to reduce the dependence on LPG and the negative impacts of raising animals, as well as to increase the income of landowners. However, the lack of technical knowledge to construct and operate bio-digesters was one of the principal problems of the use of biogas in the country [16–18]. Usually, the most common uses of biogas, seen in a wide variety of countries, is its use for heating and the generation of electricity. In the case of the use of biogas for electricity generation, various technologies are available, with the principal applications being gas turbines and internal combustion generators [19].

The generation of biogas from animal waste depends on different factors: temperature, pH, alkalinity, the characteristics of animal waste, and how it is handled in the production system. As a result, animal diet gives the waste distinct potentials to produce gas [16–18]. The production of biogas is possible with the confinement of cattle before slaughter and from effluents from the production process in slaughterhouses and abattoirs.

Two types of confinement are practiced in Brazil [12]. Confinement and semi-confinement during the dry periods of the year, from May/June to October/November. For the confined cattle, the fattening period lasts on average four months, and two for semi-confined. **Table 1** shows the growth of the confinement system in the country in recent years. In 2000, the number was 4.39 million, of which 55.6% were semi-confined and 44.4% confined. In 2015, it reached a little more than 6.7 million, with approximately 40.3% being semi-confined cattle and almost 59.7% confined. In the 2000–2015 period, there was an increase of 34.6% [20–23].

The largest producers of beef in the world, the United States and Australia [24], have an average rate of confined cattle of around 50%, some years some US states, such as Texas, have an even higher rate. In the Brazilian case, this rate was 3.5% in 2016. Few states had rates much higher than the national average, notably São Paulo with 4.8% of the national herd and a confinement rate of 10.4% of its total herd. However, in many states there is little or no confinement though they have, at the same time, a large share of the national herd, as is the case of the state of Pará with approximately 10.1% of the total of the national beef herd in 2015 and

Type of production system	2000	2001	2002	2003	2004	2005	2006	2007
Confinement	1,950,000	1,868,000	1,906,000	2,039,000	2,427,000	2,305,000	2,317,999	2,572,984
Semi-confinement	2,440,000	2,565,000	2,432,000	2,310,000	2,726,000	2,481,000	2,365,160	2,504,000
Total (confinement +semi-confinement)	4,390,000	4,433,000	4,338,000	4,349,000	5,153,000	4,786,000	4,683,159	5,076,984
Type of production system	2008	2009	2010	2011	2012	2013	2014	2015
Confinement	2,989,008	2,901,734	2,756,201	3,377,311	3,670,401	4,068,628	4,201,734	4,008,764
Semi-confinement	2,804,000	2,533,191	2,583,042	2,564,146	2,653,589	2,730,584	2,800,802	2,702,774
Total (confinement +semi-confinement)	5,793,008	5,434,925	5,339,243	5,941,457	6,323,990	6,799,212	7,002,536	6,711,538

Source: Prepared by the authors, based on FNP [20–23].

Table 1.
 Quantity of confined cattle, semi-confined cattle and total cattle herd with some type of confinement in Brazil, 2000–2015.

with less than 1% of the cattle in the state being confined. This panorama shows the possibility of expanding beef cattle confinement in Brazil in comparison with the rates of confinement in some Brazilian states, but above all in various other countries.

The greater economic competitiveness of the extensive pasture system in relation to the intensive one with confinement can be compensated by the increase of beef production and the reduction of costs through the production of a new energy source (biogas), as well as the reduction in the emissions produced using this source of energy, and a lower dependence on electricity by the agricultural sector. Biogas can thus be an interesting and strategically positive energy policy.

3. Methodology

To calculate the potential to generate biogas from waste created during the beef production chain and the reduction of GHG in different scenarios, various hypotheses and parameters were considered based on the ultimate inventory of Brazilian greenhouse gas emissions [12, 25] and the research carried out by D'Avignon [26], as described below.

The slaughter age of animals fed only on pasture is around 36 months⁴, and is inversely proportional to the increased intensification of the productive system, being reduced to 18 months with confinement or 26 months with semi-confinement.

In Brazil, the average time of confinement after weaning is 4 months, though it is possible to expand this to six months, in the driest period, between May and October, while for semi-confinement, the average time can be increased by two months, rising to three months.

It is estimated that biogas with 60% methane is generated because of animal waste per day ($4.05 \text{ m}^3/\text{animal}/\text{day}$). This value was calculated based on the methane information emitted per head of cattle, in accordance with the latest national inventory of greenhouse gas emissions [12].

For the generation of biogas from the effluents produced during animal slaughter, the value of $7,4872 \text{ m}^3/\text{head slaughtered}$ ⁵ was estimated by D'Avignon [26], for a large part of abattoirs existing in the country in 2010, responsible for approximately 90.8% of cattle slaughtered in the country. In this research the need for electric energy in the productive process was estimated at 39 kWh per head of cattle slaughtered.

Biogas can thus be generated by two distinct sources: the waste produced by the animal and the effluents generated during animal slaughter. However, with the use of bio-digesters, neither are altered in relation to enteric fermentation, irrespective of changes in the productive system. Intensive and extensive systems emit methane, but with a difference in the number of days. The lower the number of days, the lower the emission of methane due to enteric fermentation. Considering all parameters and hypothesis, biogas production potential is given by the following equation:

⁴ There are cases in some parts of Brazil with a slaughter age above 36 months, and even reaching 44 months. However, in most of Brazil, with an extensive system, the slaughter age is around 36 months.

⁵ This calculation was based on the sum of the potential of biogas with cattle fat and rumen of around $3.45 \text{ m}^3/\text{head slaughtered}$ and with blood, approximately $4.04 \text{ m}^3/\text{head slaughtered}$.

$$g_{\text{biogas}} = \left[(N_{\text{conf}}) * (\text{number of days}) * (q_{\text{ent_fer}}) + (N_{\text{ab}}) * (q_{\text{abat}}) \right] / FC(\text{m}^3) \quad (1)$$

where:

- g_{biogas} = biogas production potential, in MW.
- $FC(\text{m}^3)$ = conversion factor of m^3 to MWh, in which case the value is 0,00043909.
- N_{conf} = number of confined cattle heads.
- $q_{\text{ent_fer}}$ = amount of biogas produced through manure management. In the article, the authors propose $4,05 \text{ m}^3/\text{animal}/\text{day}$.
- number of days = number of days with confined cattle. For example, cattle confined for 4 months, total days of confinement, 120 days.
- N_{ab} = number of slaughtered cattle in the year.
- q_{abat} = amount of biogas produced through abatement. In the study, this value is $7,4872 \text{ m}^3/\text{slaughtered head}$.

If the biogas is applied to the generation of electricity, there is an increase in the abatement of emissions through the reduction of the use of non-renewable sources and many GHG emitters, normally used by a large part of the agricultural sector. This potential reduction also should be calculated in relation to the grid. The use is proposed of the emission factors calculated by MCTI [27] and applied in the inventories existing for the 2006–2015 period. To analyze the years between 2000 and 2005, the factor observed in 2006 was applied, and for future scenarios the authors proposed the use of the MCTI study [25] which calculated the factors for 2020, 2025, and 2030, while for 2015–2020, 2020–2025, and 2025–2030, the calculation will be based on the linear tendency in each period, measuring the annual rates of emission factors in the initial and end years. From this the emission factor results are obtained for the national grid, as described in **Table 2**.

In the case of projections for electricity demands, it is proposed to use the average rate calculated by EPE [4] with a growth in energy sources projected until 2050 for the agricultural sector. According to EPE [28], per year, the electricity consumption of the agricultural sector will be almost $47,101,500 \text{ MWh}^6$. This is equivalent to an increase of around 42.95% in electricity consumption in the 2015–2030 period. Between 2015 and 2030, the annual rate of growth in the consumption of electricity is estimated at 3.81%. These estimations are important to measure how biogas can contribute to meet the growing demand for electricity in the agricultural sector.

⁶ In the study made of projections for energy demand, EPE [10], the total consumption of energy (without detailing the type of source) is given in millions of TEP for the year 2030. In the distribution chart for each source, it is shown that the share of electricity will be 27% in 2030. Based on this information and knowing that the conversion of TEP to kWh is 11.63×10^3 , the result is obtained in kWh and afterwards multiplied by 103 to determine the final value in MWh.

Factor emission – national grid - tCO ₂ /MWh	2000–2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	0.0323	0.0293	0.0484	0.0246	0.0512	0.0292	0.0653	0.0960	0.1355	0.1244	0.0960	0.0740	0.0571
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
	0.0441	0.0340	0.0421	0.0521	0.0646	0.0799	0.0990	0.1106	0.1235	0.1379	0.1540	0.1720	

Source: Prepared by the authors, based on MCTI [25] and MCTI [27].

Table 2.

Emission factor of the national grid (tCO₂ / MWh) in Brazil (2000–2015).

However, the use of biogas produces GHG emissions, as indicated by Gómez et al. [28]. According to IPCC, the burning of biogas results in CH₄ and N₂O emissions, which are considered by subtracting them from the reduction. The standard values supplied by Gómez et al. [13] of 1 and 0.1 kg GHG/TJ biogas for methane and nitrous oxide, respectively, were used. These values will be considered in the final calculation of total emissions in each of the scenarios proposed in the article.

In the case of emissions avoided using biogas, the result is the difference between the emissions generated during the beef production process, irrespective of the system, discounting the emissions avoided using biogas as electricity. Then, emissions with the use of biogas are given by the following:

$$E_{\text{biogas}} = (g_{\text{biogas}} * FE_{\text{CH}_4} * FC(TJ)) / 1000 + (g_{\text{biogas}} * FE_{\text{N}_2\text{O}} * FC(TJ)) \quad (2)$$

where:

E_{biogas} = biogas burning emission, in tCO₂e,

g_{biogas} = biogas generation potential, in MW.

FE_{CH_4} = methane emission factor with the use of biogas (1 kg/TJ).

$FC(TJ)$ = conversion factor from TJ to MWh (0,003599712).

$FE_{\text{N}_2\text{O}}$ = nitrous oxide emission factor with the use of biogas (0,10 kg/TJ).

For emissions abated with biogas, the equation is represented by:

$$E_{\text{abat}}^{\text{biogas}} = g_{\text{biogas}} * f_{\text{grid}} \quad (3)$$

where:

$E_{\text{abat}}^{\text{biogas}}$ = emission abated using biogas in tCO₂e,

g_{biogas} = biogas generation potential, in MW.

f_{grid} = grid emission factor, in tCO₂/MWh (see **Table 2**).

So, the final abated emissions (EF_{biogas}) using biogas are given in the formula:

$$EF_{\text{biogas}} = E_{\text{abat}}^{\text{biogas}} - E_{\text{biogas}} \quad (4)$$

To analyze the impact of increased confinement times and rates due to the use of biogas for the generation of energy for the agricultural sector and the reduction in GHG emissions, three different intensification scenarios are proposed, in addition to the reference one. One with the increased confinement time, another with the elevated confinement rate, and finally joining all the scenarios for the intensification of livestock raising through confinement.

4. Scenarios

4.1 Reference scenario

In this scenario, from 2016 until 2030, an average growth rate equal to all the variables seen in the 2000–2015 period is proposed.

In the reference scenario, confinement rates will follow the linear growth tendency observed between 2000 and 2015. In other words, semi-confined cattle will grow at an average annual rate of 0.35%, equal to the growth observed in the

period, 9.7%, and confined cattle at an average annual rate of 4.9%, with a growth of around 51.4% occurring during the period. At the same time, the same hypothesis of linear growth of confinement will be applied to both the size of the beef herd and the number of animals slaughtered in the country. In the case of the beef herd, during this period there was an increase of around 1.6% per year (21.4% in the period as a whole) and in the number of slaughtered animals a little less than 1% per year (13.4% between 2000 and 2015).

As **Table 3** shows, the number of heads of cattle confined will rise from a little over four million, in 2015, to just over 8.2 million in 2030. By 2030, the number of semi-confined heads of cattle will be a little over 2.8 million, while in 2015, there were around 2.7 million. If we compare the number of heads with some type of confinement in relation to the total heads of the beef herd, the more intensive beef production system rises from almost 3.5%, in 2015, to 4.5%, in 2030. Finally, the total cattle herd, without dairy cows, will rise from almost 193.5 million, in 2015, to a little more than 246.2 million in 2030.

In relation to slaughter, the values range from a little above 41 million head of cattle in 2015, to around 47.4 in 2030. The demand for energy for the beef slaughter process will rise from 1600.3 GWh to around 1847.1 GWh (**Table 3**).

4.2 Scenario 1: increase in confinement time

From 2016 until 2030, in relation to the reference scenario, in scenario 1 confinement time increases from 4 to 6 months, and from 2 to 3 months for semi-confinement. The only change in relation to the reference scenario is the confinement time.

The increase in confinement does not result in changes to the initial values calculated for the reference scenario. For this reason, the values of numbers of heads of confined, semi-confined, slaughtered, and total cattle, demand for energy remain the same, as described in **Table 3**. This parameter will alter the potential of the generation of biogas, as will be observed in the results, and consequently the emissions presented reduced somewhat the total emissions generated by animal slaughter over the years, with these small changes in emissions being observed in relation to the reference scenario in the results present in the next item.

4.3 Scenario 2: increase in the confinement rate

In the period 2016–2030, in scenario 2 there is an increase in the rate of cattle with some type of confinement from the rate seen in 2000–2015, rising from 3.5% to 10.9% by 2030, an annual rise of around 9.7%. This hypothesis will allow the rate of cattle with some type of confinement to reach by 2050 the minimum rate practiced in some countries, such as Australia, or as seen in the state of Texas in the US, of approximately 50% in relation to the total beef herd.

With this, as shows, the value of confined and semi-confined cattle will be altered, and the others maintained in accordance with the calculations made for the reference scenario. Since the confinement rate does not indicate the type of confinement, the hypothesis used to calculate the number of confined and semi-confined cattle from 2015 onwards was the average rate of confined and semi-confined cattle in relation to the total cattle with some type of confinement between 2012 and 2015. The reason for this hypothesis is the tendency for these rates to stabilize in recent years, with little variation, as seen in **Figure 4**.

Between 2012 and 2015, the average of this rate for confined cattle was around 59.4%, with an oscillation lower than 2%, also seen in semi-confined cattle.

Baseline scenario/Scenario 1							
	2000	2005	2010	2015	2020	2025	2030
Confinement (cattle heads)	1,950,000	2,305,000	2,756,201	4,008,764	5,097,248	6,481,284	8,241,122
Semi-confinement (cattle heads)	2,440,000	2,481,000	2,583,042	2,702,774	2,750,324	2,798,710	2,847,948
Cattle herd (cattle heads)	151,990,505	186,530,771	186,616,195	193,448,415	209,643,506	227,194,417	246,214,652
Abatement (cattle heads)	35,550,700	44,319,921	40,848,429	41,033,569	43,043,047	45,150,932	47,362,043
Energy demand (MWh)	1,386,477.3	1,728,476.9	1,593,088.7	1,600,309.2	1,678,678.8	1,760,886.3	1,847,119.7

Source: Prepared by the authors, based on FNP [20–23] and D’Avignon [26].

Table 3.

Number of confined heads, semi-confined heads, total heads and slaughtered heads, and energy demand (MWh) for the baseline scenario and scenario 1, in Brazil, in 2000, 2005, 2010, 2015, 2020, 2025 and 2030.

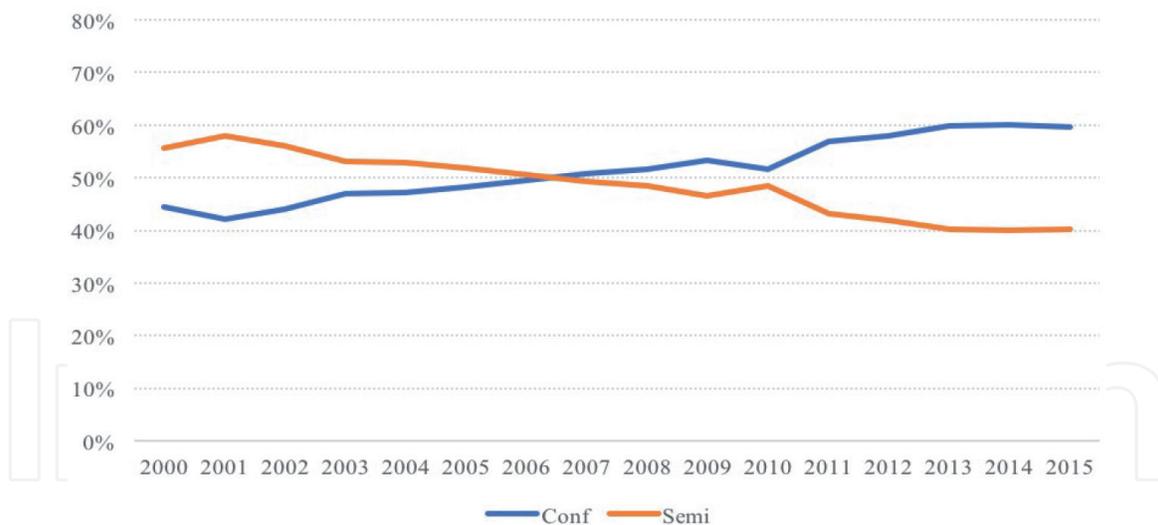


Figure 4.

Rate of number of confined cattle on total cattle with some type of confinement and number of semi-confined cattle on total cattle with some confinement in Brazil, % (2000–2015). Source: Prepared by the authors.

For semi-confined cattle, this average rate was 40.6%. Therefore, the number of confined cattle will rise from a little over four million in 2015 to around 15.9 million in 2030. Semi-confined cattle will increase from almost 2.7 million (2015) to almost 10.9 million. Total cattle with some type of confinement in 2030 will be around 26.8 million, representing an increase of 74.2% in relation to 2015.

4.4 Scenario 3: increases in the rate of cattle with some form of confinement and the time of confinement

Joining scenarios 1 and 2 creates scenario 3, thus, as has been seen in the previous scenarios, only the basic values for the calculation of the creation of biogas and emissions are altered. Permitted in this scenario is the analysis of all the proposed possibilities for the intensification of livestock raising through the confinement of cattle, and through the increase in both confinement time and the total rate of cattle in some form of confinement.

After the analysis of each of the proposed scenarios and how the basic variables are modified in the three scenarios, the biogas generation potential and to what extent this can meet the demand for energy of slaughterhouses and abattoirs, and the agricultural sector, is examined, as well as the impact on emissions of the insertion of biogas in the energy matrix. In short, it shows how cattle confinement can contribute to energy policy as a complementary renewable source capable of guaranteeing energy security from the point of view of supply without harming the environment.

5. Results

There is a high potential for the use of biogas. Even without any intensification policy it will be possible to meet almost 80% of the energy demands of abattoirs and slaughterhouses in 2015. In 2030, not only will it be possible to meet all energy demands necessary for animal slaughterhouses, but also energy can be offered to the Brazilian electricity system with an addition of around 371.1 GW/h year. In the case of the agricultural sector, first, it is estimated that the demand for electricity of slaughterhouses and abattoirs will represent almost 6% of the total electricity consumed by the sector in 2015. By 2030 it is estimated that this value will be approximately 4%. The insertion of biogas as a source of electricity can be noted that renewable resources

can meet approximately 14.9% of the electricity demands of the agricultural sector in 2030, in a scenario with both an increase in the confinement rate and an expansion of time spent in confinement (Scenario 3). The importance of the use of biogas as an alternative energy source is so relevant that without any alteration in the country's beef productive system in 2015 biogas could generate sufficient electricity to meet about 4.8% of the demands of the agricultural sector, and in 2030 this value would be practically the same, a little more than 4.7% (Figure 5). Changes in confinement time or in the confinement rate can increase the offer of biogas and can increase even more the additional offer to the grid with an addition of almost 1402.4 GW/h (scenario 1), 2867.1 GW/h (scenario 2), or 5146.3 GW/h (scenario 3). As Figure 6 shows, it is possible to create more than three times the energy demand necessary for animal slaughter (offer of biogas/energy demand = 378.6%) in 2030.

It can be noted that increased confinement time (scenario 1) creates a lower increase in the offer of biogas for electric energy when compared to the increase

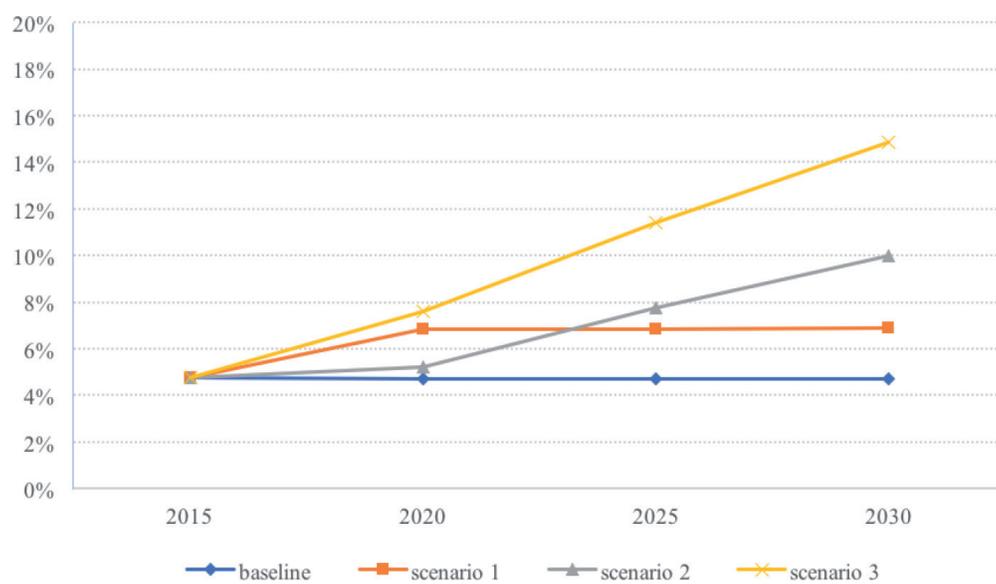


Figure 5. Relation between the supply of biogas and electricity demand for agricultural sector, for each scenario, % (2015, 2010, 2025 and 2030). Source: Prepared by the authors.

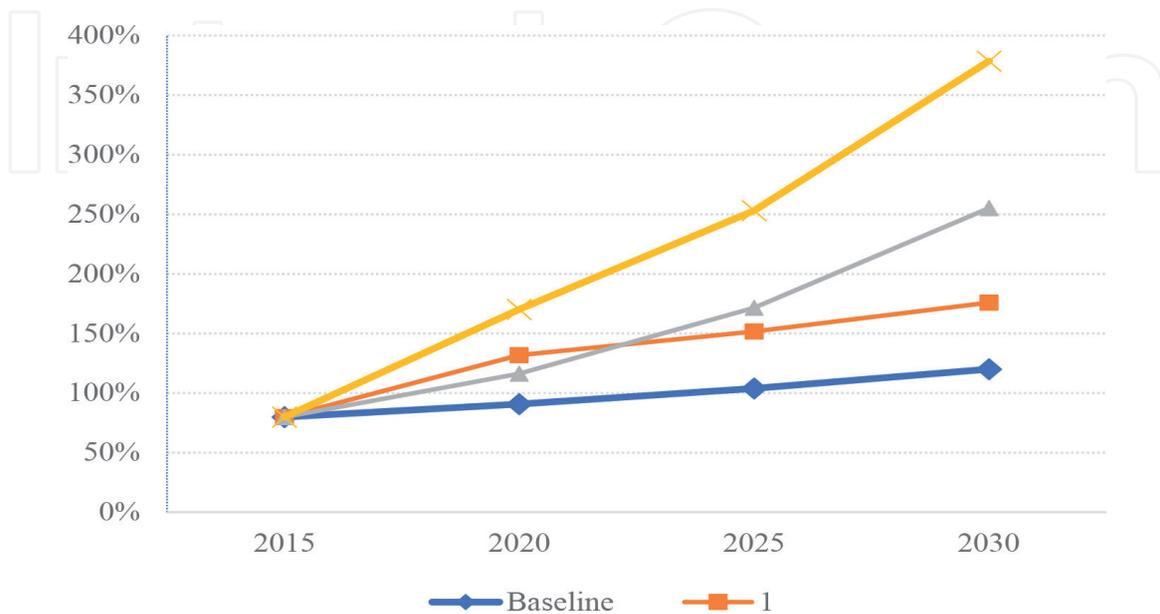


Figure 6. Relation between the supply of biogas and the electricity demand for slaughterhouses, % (2015, 2020, 2025 and 2030). Source: Prepared by the authors.

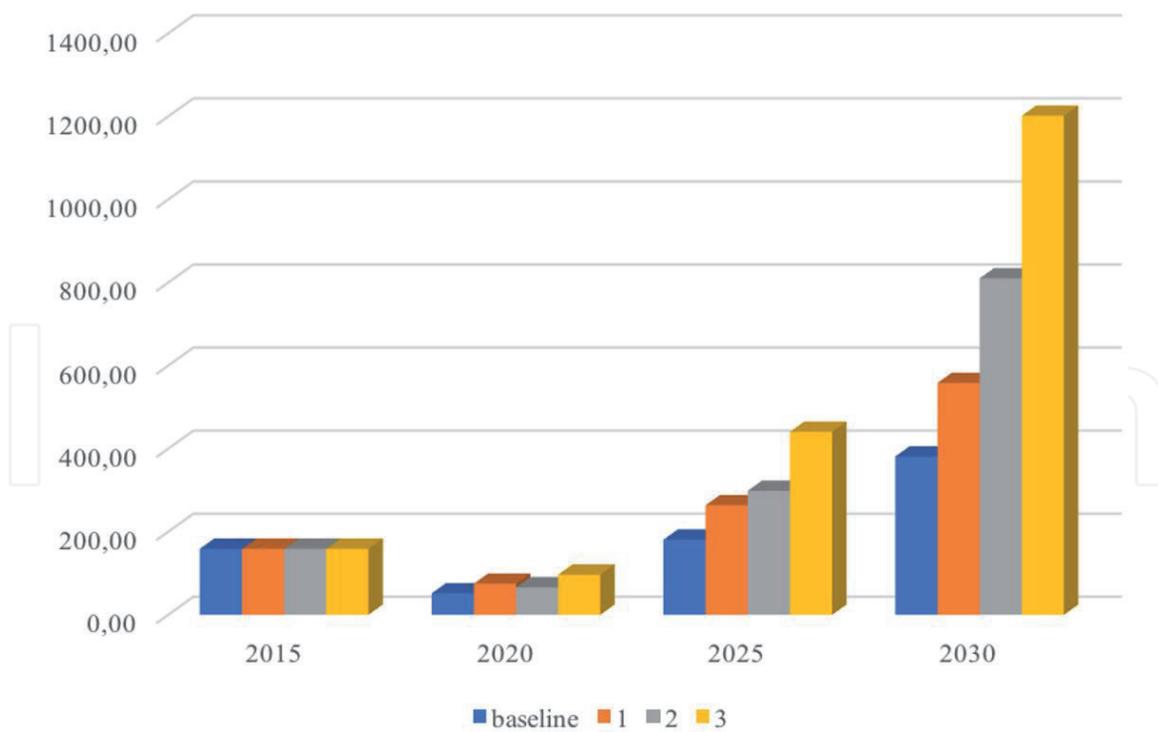


Figure 7. Emission reduction with biogas use, for each scenario, in GgCO₂e (2015, 2020, 2025 and 2030). Source: Prepared by the authors.

in the confinement rate and, above all, that the sum of the different intensification policies results in a significant increase. Thus, this result shows the strategic importance of biogas in Brazil as an energy source capable not only of meeting the demand of slaughterhouses and abattoirs, but also part of the energy demands of the agricultural sector.

An additional positive effect of the use of biogas, in addition to the expansion of energy demands, is on the reduction of GHG emissions. Despite having a low grid emission factor due to the high share of hydroelectricity in the Brazilian energetic matrix, the insertion of a renewable source with the low GHG emissions helps keep the emissions of the Brazilian electricity sector low. In the scenario with the implementation of all intensification policies in the agricultural sector (Scenario 3), it is possible to reduce in the long term (2030) a little more than 1201.56 GgCO₂e. Without any policy, this reduction will reach 381.12 GgCO₂e, as **Figure 7** shows.

6. Conclusion

Despite being one of the largest beef producers in the world, Brazil still has low productivity indices in the livestock sector, in which the predominance of extensive system means that the country has a stocking rate of between 1 and 2 heads of cattle per hectare. Given this fact, the country has great potential to intensify the sector with the possibility of the reduction of the demand for electricity in abattoirs and slaughterhouses using biogas and even the agricultural sector as a whole and to reduce somewhat greenhouse gas emissions generated by the sector through the introduction of a new renewable and cleaner energy source.

In the scenarios analyzed, it was perceived that the use of biogas in beef cattle confinement is an interesting complementary energy policy, which fits into the need to diversify renewable energy sources to reduce potential problems in electricity supply, in relation to an energy matrix that is dependent on hydroelectricity to

meet the growing demand of the agricultural sector for electricity. In scenario 3, it can be observed that the application of policies to intensify the livestock sector allows a considerable reduction in GHG emissions and to meet the needs of both the agricultural sector and the totality of the energy demand of slaughterhouses and abattoirs, which are close to the herd, facilitating the use of biogas to supply them.

More profound studies, assessing the economic question, such as the costs of expanded confinement and if, from the economic point of view, intensification is attractive, need to carry out to confirm whether, from the technical point of view, increasing beef confinement is an interesting energy policy to increase the offer of electricity and to reinforce the energy security of Brazil. The scenarios show the need to modernize livestock raising through the better use of the waste and the effluents created during the slaughter process and to propose as a short and mid-term energy policy.

Therefore, the conclusion is reached that the use of biogas is important to reduce greenhouse gas emissions, contribute to cleaner energy generation and reduce the energy dependence of the agricultural sector in Brazil. In the face of climate change, this energy resource can help the country to help meet the goals proposed under the Paris Agreement and attract foreign investment in view of the enormous potential to generate energy and reduce emissions.

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