

COMPARAÇÃO DOS CUSTOS DE DIFERENTES CONFIGURAÇÕES DE CONSTRUÇÃO DE BIODIGESTORES MODELO INDIANO

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RESUMO: o biodigestor é eficaz no tratamento de resíduos orgânicos e representa bom investimento para qualquer produtor, com benefícios ambientais e econômicos que superam os custos de implantação. Para auxiliar na decisão, este trabalho teve como objetivo comparar os custos de diferentes configurações de construção de biodigestores modelo indiano, considerando os custos dos materiais na construção do tanque digestor e na confecção do gasômetro. O custo dos biodigestores foi estimado e os valores encontrados podem ser adaptados e utilizados em qualquer localidade. A análise financeira das diferentes configurações foi realizada pela capacidade da conversão dos dejetos de suínos em biogás comparada ao gás liquefeito de petróleo (GLP) e gás natural veicular (GNV). O tempo médio de retorno do investimento foi calculado usando os métodos *Payback* simples e *Payback* descontado. Os resultados apontaram custo maior para o biodigestor em alvenaria com gasômetro em chapa de aço e custo menor para o biodigestor em ferrocimento com gasômetro em fibra de vidro. O gasômetro construído em chapa de aço contribuiu para o aumento do valor do investimento e a sua substituição pela fibra de vidro demonstrou ser uma boa alternativa. A viabilidade financeira quanto ao retorno do capital investido foi demonstrada em todas as configurações de construção dos biodigestores. Além do biogás, avaliado neste trabalho, há ainda que considerar a produção do biofertilizante e os ganhos relevantes quanto ao bem-estar social e ambiental, vantagens que podem ser observadas em qualquer localidade onde o biodigestor for construído.

Palavras-chave: bioresíduos, sustentabilidade rural, biogás.

COMPARISON OF THE COSTS OF DIFFERENT CONFIGURATIONS OF CONSTRUCTION OF INDIAN MODEL BIODIGESTORS

ABSTRACT: The biodigester is effective in the treatment of organic waste and represents a good investment for any producer, with environmental and economic benefits that outweigh the implementation costs. To assist in the decision, this work aimed to compare the costs of different configurations of construction of Indian model biodigestors, considering the costs of materials in the construction of the digester tank and in the manufacture of the gasometer. The cost of biodigestors was estimated and the values found can be adapted and used in any location. The financial analysis of the different configurations was performed by the capacity of converting swine manure into biogas compared to liquefied petroleum gas (LPG) and vehicular natural gas (CNG). The average payback time was calculated using the Simple Payback and Discounted Payback methods. The results showed higher cost for the biodigester in masonry with gasometer in steel plate and lower cost for the biodigester in ferrocement with gasometer in fiberglass. The gasometer built in steel plate contributed to the increase in the value of the investment and its replacement by fiberglass proved to be a good alternative. The financial viability regarding the return on invested capital was demonstrated in all

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biodigesters construction configurations. In addition to the biogas evaluated in this work, it is also necessary to consider the production of biofertilizer and the relevant gains in terms of social and environmental well-being, advantages that can be observed in any location where the biodigester is built.

Keywords: biowaste, rural sustainability, biogas

1 INTRODUCTION

In pig and cattle farming, important activities in the agricultural sector, waste composed of feces, urine, and leftover feed becomes highly polluting and can contaminate the soil, water sources, and groundwater if disposed of without proper treatment. The use of a biodigester can be considered very useful in rural areas, since treating waste properly via anaerobic digestion allows it to be reused, thus increasing the producer's income through its transformation into biogas and biofertilizer, resulting in social and environmental benefits (BARBOSA; LANGER, 2011).

The anaerobic digestion (AD) process is entirely biological; organic matter is stabilized in the absence of oxygen, producing methane (CH₄) and carbon dioxide (CO₂). This process allows the conversion of organic nitrogen into ammonium and the retention of nutrients, producing fertilizers that are considered excellent sources of nutrients available for plant absorption (COSTA *et al.*, 2016).

The efficiency of DA can be affected by several factors intrinsic to the process, such as oxygen availability, temperature, pH, alkalinity, acidity, nutrients and chemical composition (KUNZ; HIGARASHI; OLIVEIRA, 2014).

The entire DA process takes place inside a piece of equipment consisting of a closed fermentation chamber, called a biodigester or bioreactor, where anaerobic digestion occurs by anaerobic bacteria. This structure is considered an efficient measure to combat environmental pollution because of its proven effectiveness in treating waste, as well as producing biogas and biofertilizer, also allowing for a reduction in energy and fertilization costs (SANTOS *et al.*, 2017).

Biodigesters follow the priority order of the National Solid Waste Policy (BRAZIL, 2010) because they prevent the final disposal of

waste that can be treated and reused, in addition to generating income.

Biodigesters can be classified according to different factors, such as the solids content, feeding method, number of stages, and volume of waste treated. The feeding methods can be classified as batch, continuous, or mixed (FRIGO *et al.*, 2015). Batch loading involves slowly decomposing organic loads all at once, remaining contained until complete biodigestion, then being emptied to receive a new load; continuous use involves daily or periodic organic loads; and mixed feeding involves loads of both slowly decomposing and organic compounds, requiring short pauses between loads (ANDRADE *et al.*, 2002).

According to Otenio *et al.* (2015), by opting for proper management of animal waste, rural producers can become self-sufficient in electricity and recover the capital invested in the installation of biodigesters.

Silva *et al.* (2018) reported that biodigesters constitute a group of 61 technologies that offer various benefits because of their multiple uses and that have been replicated in the semiarid region of Brazil since 2014.

Calza *et al.* (2015) noted that "the literature presents the Chinese, Indian and Canadian models as the main biodigester models, with the Canadian biodigester model being different from the others because it is horizontal and has a loading box lined with plastic sheeting."

According to the same authors, a preliminary analysis of biodigester construction projects is necessary to reduce costs for facilities and guarantee a quick return on investment. *et al.* (2015).

The Indian model biodigester can be described as a vertical cylinder constructed of bricks and internally lined with waterproof cement, with a longitudinal wall that divides it into two chambers. The biomass inlet pipe is

connected to one of these chambers, and the outlet pipe is connected to the other. This biodigester is characterized by a floating bell-shaped gasometer made of sheet steel (NISHIMURA *et al.*, 2009).

In the Brazilian semiarid region, the Indian model is the most widely used model because of the possibility of adaptations regarding construction materials, allowing for the selection of low-cost materials that are more readily available locally. In this model, adaptation is possible both in the digester tank and in the construction of the gasometer; however, the use of skilled labor must be considered to ensure the proper functioning and durability of the equipment (SILVA; ARAÚJO, 2016).

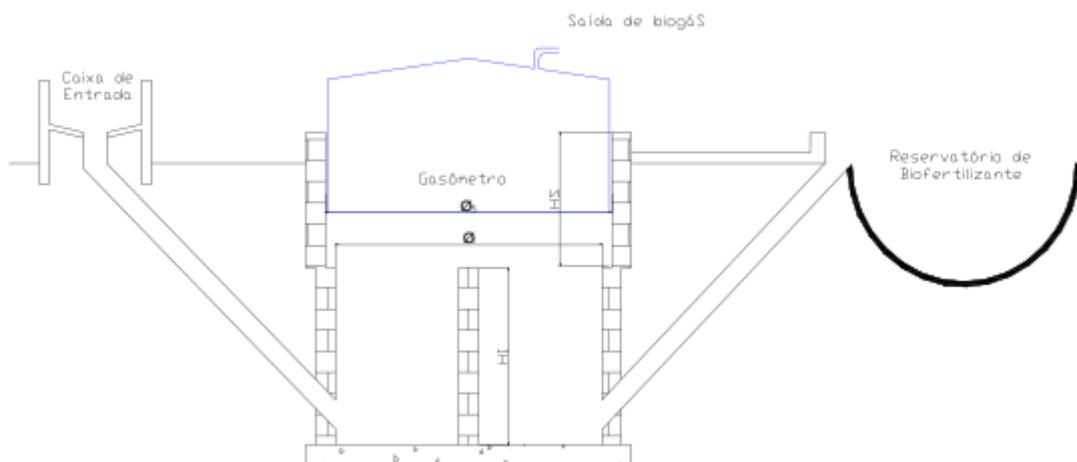
With the aim of presenting different options for constructing an Indian model biodigester in terms of investment between

different configurations, which can be adapted to any location, the objective of this work was to compare the estimated final cost of biodigesters using different construction materials, namely, a) masonry with a steel sheet gasometer (B1); b) masonry with a fiberglass gasometer (B2); c) cement boards with a fiberglass gasometer (B3); and d) ferrocement with a fiberglass gasometer (B4).

2 MATERIALS AND METHODS

The Indian biodigester, used as a model for this study, is located at the Institute of Agricultural Sciences of the Federal University of Minas Gerais, Montes Claros *Campus*, MG. It is a continuous flow biodigester constructed of masonry with a steel sheet gasometer, as shown in Figure 1.

Figure 1. Longitudinal section of the Indian model biodigester built at the ICA/UFMG.



Source: Dias *et al.* (2013)

All the constructive models of biodigesters presented in this study involve digestion tanks with the same characteristics and dimensions as the biodigester model

presented by Dias *et al.* (2013), as shown in Table 1, which considers construction in masonry, cement boards or ferrocement.

Table 1. Characteristics of the digestion tanks of the Indian model biodigesters analyzed in this study.

Characteristics of the biodigester	Measures
Useful volume (m ³)	17.43
Upper diameter (m)	2.90
Bottom diameter (m)	2.70
Upper height (m)	1.32
Partition wall height (m)	1.68

Source: DIAS *et al.* (2013)

The gasometers evaluated in this study were made of steel sheets or fibreglasses, with the characteristics presented in Table 2.

Table 2. Characteristics of the gasometers evaluated in the study.

Characteristics of gasometers	Made of steel sheet	Made of fiberglass
Gasometer volume (m ³)	8.42	8.00
Gasometer diameter (m)	2.85	Higher (2.84) lower (2.30)
Gasometer height (m)	1.32	1.76

Source: DIAS *et al.* (2013) (Adapted)

An investigation of the materials used to construct each biodigester configuration studied was carried out while considering the same capacity (17.43 m³) and adapting to the list of materials used by Dias *et al.* (2013). Research on the manufacturing costs of biodigesters was carried out on the commercial market of the city of Montes Claros, northern Minas Gerais.

For the configuration of the Indian model biodigester built in masonry with a fiberglass gasometer (B2), the change involved replacing the steel sheet gasometer with a fiberglass box of equivalent capacity to allow

the operation of a bell-shaped structure suitable for the volume of the digester tank.

For the Indian model biodigester constructed with cement boards with a fiberglass gasometer (B3), the biodigester constructed by Diaconia (2017), with the characteristics presented in Table 3, was used as a model. As this biodigester has a useful capacity of 7.2 m³, the bill of materials was adjusted to a capacity of 17.43 m³ via proportion rules, and the prices of materials, as well as labor, were updated according to the local market.

Table 3. Characteristics of the Indian model biodigester constructed of cement slabs with a fiberglass gasometer and a capacity of 7.2 m³.

Characteristics of the biodigester	Measures
Useful volume (m ³)	7.2
Upper diameter (m)	2.14
Bottom diameter (m)	2.14
Upper height (m)	2.00
Gasometer characteristics	
Gasometer volume (m ³)	3.00
Gasometer diameter (m)	Higher (2.06) lower (1.52)
Gasometer height (m)	1.32

Source: Diaconia Actaliança (2017)

The calculation of the estimated value of the Indian model biodigester constructed of ferrocement with a fiberglass gasometer (B4) was based on the materials used for the construction of the 35 m³ capacity ferrocement tank developed by Candioto, Grisa and Schimitz (2015). The values were adjusted for the construction of a 17.43 m³ capacity ferrocement tank, as proposed in this work, via proportional rules, and the values of an 8.0 m³ fiberglass gasometer, waterproofing and other complementary materials, as well as labor, were added.

The investment values for each of the four types of biodigesters studied and their respective volumetric capacities were used to calculate the value per cubic meter (m³) by dividing the total value of each biodigester by its volume capacity.

The financial analysis of the different models was carried out on the basis of the capacity to convert swine manure into biogas and then into liquefied petroleum gas (LPG) and compressed natural gas (CNG), and the biofertilizer production capacity was not considered in this study.

$$\text{Payback simples} = \frac{\text{investimento inicial}}{\text{investimento no período}} \quad (1)$$

$$\text{Payback descontado} = \frac{\text{investimento inicial}}{\text{ganho no período (VPL)}} \quad (2)$$

3 RESULTS AND DISCUSSION

The estimated cost of the Indian model biodigester built in masonry with a gasometer

Biogas production was considered at a minimum energy equivalence of 1.0 m³ of biogas corresponding to 0.45 kg of LPG (approximate energy equivalence of 2:1) and 1.0 kg of CNG (energy equivalence of 1:1).

Operating regularly, this biodigester has an estimated average daily production capacity of 38.33 m³ of biogas (DIAS *et al.*, 2013), which, by equivalence, will represent 17.25 kg of LPG and 38.33 kg of CNG. As an LPG cylinder weighs 13 kg, biogas production was estimated at 1.33 cylinders per day and 39.8 cylinders per month.

Biogas production was compared with the estimated monthly income, considering energy equivalence with LPG and CNG, and the estimated return on investment for each biodigester was subsequently calculated via the *payback method*.

This method represents the period required to recover the value of an investment through cash inflows, with very simple rules, which can be used by small or sophisticated companies to find the payback period of the investment and can be used as... *Simple Payback* - Equation 1 and *Discounted Payback* - Equation 2 (FORTES, 2014).

in sheet steel (B1), implemented at the ICA/UFGM, according to the materials used and the updated prices (Apr/2023), is described in Table 4.

Table 4. Estimated cost of the Indian model biodigester built in masonry with a steel sheet gasometer (B1), with a useful volume of 17.43 m³, implemented at the ICA/UFMG.

Material	Unit	Qty .	Cost per unit	
			(R\$)	Total (R\$)
Adapters	unit	8.0	4.10	32.80
Medium washed sand	m ³	5.0	140.00	700.00
Brita No. 1	m ³	2.5	150.00	375.00
Brita No. 2	m ³	1.0	150.00	150.00
1" drill bit	unit	10.0	5.25	52.50
Cement - CP II	bag	65.0	35.00	2,275.00
PVC glue (75 g)	unit	2.0	7.80	15.60
90° 50 mm PVCA Bend	unit	6.0	9.87	59.22
7.22 3/8 " rebar	bar	10.0	71.37	713.70
Thread seal tape (20 m)	unit	3.0	4.60	13.80
Gasometer made of steel sheet.	unit	1.0	12,863.36	12,863.36
Vedacit waterproofing (18 kg)	can	2.0	117.80	235.60
50 mm PVCA glove	unit	5.0	7.07	35.35
Transparent level hose 3/4"	m	8.0	2.94	23.52
50 mm PVC valve	unit	3.0	15.72	47.16
Solid brick	thousand	5.8	1,170.00	6,786.00
150 mm PVC pipe (6 m)	bar	6.0	265.94	1,595.64
50 mm PVC pipe (6 m)	bar	12.0	110.87	1,330.44
Total material				27,304.69
Excavation machine	time	5.0	230.00	1,150.00
Labor (bricklayer)	daily	20.0	180.00	3,600.00
Labor (helper)	daily	25.0	80.00	2,000.00
Total labor				6,750.00
Total				34,054.69

Source: Adapted from Dias *et al.* (2013) (Updated in Apr/2023).

The estimated cost for constructing the Indian model masonry biodigester with a

fiberglass gasometer (B2) and a useful volume of 17.43 m³ is presented in Table 5.

Table 5. Estimated cost of constructing an Indian model biodigester built in masonry with a fiberglass gasometer (B2), with a useful volume of 17.43 m³.

Material	Unit	Qty .	Cost per unit (R\$)	Total (R\$)
Adapters	unit	8.0	4.10	32.80
Medium washed sand	m ³	5.0	140.00	700.00
Brita N 1	m ³	2.5	150.00	375.00
Brita N 2	m ³	1.0	150.00	150.00
1" drill bit	unit	10.0	5.25	52.50
Fiberglass tank (8,000 L)	unit	1.0	4,675.00	4,675.00
Cement - CP II	bag	65.0	35.00	2,275.00
PVC glue (75 g)	unit	2.0	7.80	15.60
90° PVCA Bends, 50 mm	unit	6.0	9.87	59.22
7.22 3/8 " rebar	kg	10.0	71.37	713.70
Thread seal tape (20 m)	unit	3.0	4.60	13.80
Vedacit waterproofing agent (18 kg)	can	2.0	117.80	235.60
PVC gloves 50 mm	unit	5.0	7.07	35.35
Transparent level hose 3/4"	m	8.0	2.94	23.52
50 mm PVC ball valve	unit	3.0	15.72	47.16
Solid brick	thousand	5.8	1,170.00	6,786.00
150 mm PVC pipe (6 m)	bar	6.0	265.94	1,595.64
50 mm PVC pipe (6 m)	bar	12.0	110.87	1,330.44
Total material				19,116.33
Excavation machine	time	5.0	230.00	1,150.00
Labor (bricklayer)	daily	20.0	180.00	3,600.00
Labor (helper)	daily	25.0	80.00	2,000.00
Total labor				6,750.00
Grand total				25,866.33

Source: Adapted from Dias *et al.* (2013) (Updated in Apr/2023).

The estimated investments for the Indian model biodigester, constructed of cement slabs and with a fiberglass gasometer

(B3), with a capacity of 17.43 m³, are presented in Table 6.

Table 6. Estimated cost of the Indian model biodigester constructed with cement slabs with a fiberglass gasometer (B3) and a capacity of 17.43 m³.

Material	Unit	Qty .	Cost/unit (R\$)	Total (R\$)
CA-50 6.3 mm x 6 m Rebar	bar	5.0	23.64	118.20
Galvanized wire #12	kg	12.5	20.37	254.63
Brita N 1 (18 L)	can	15.0	7.00	105.00
Fiberglass tank (3,000 L)	unit	3.0	2,276.00	6,828.00
Zinc sheet 40 cm	kg	20.0	22.10	442.00
Nylon screen (1.50 x 0.80 m)	subway	3.8	8.40	31.50
eight-hole ceramic block	hundred	2.5	115.83	289.58
100 mm PVC pipe	unit	2.5	104.95	262.38
50 mm PVC pipe	unit	8.8	107.75	942.81
mm galvanized steel pipe	subway	8.8	48.75	426.56
3/8" French Screw (29 cm long)	subway	2.5	0.95	2.38
French screw 3/8" x 10 (10 cm full thread)	box	2.5	12.30	30.75
Wooden beam 7 x 7 with 3 m	unit	7.5	42.20	316.50
75 mm PVC pipe	subway	3.8	10.40	39.00
x 60 mm PVC Flange Adapter	unit	2.5	26.76	66.90
Board 15 cm x 4 cm x 2 m	unit	2.5	46.00	115.00
75 mm PVCE Plug Cap	unit	2.5	9.50	23.75
20 mm rigid PVC tee	unit	2.5	0.80	2.00
20 mm PVC pipe	unit	10.0	20.00	200.00
20 mm rigid PVC 90° elbow	unit	20.0	0.55	11.00
20 mm flange	unit	7.5	14.20	106.50
20 mm plastic hose (braided)	subway	12.5	6.95	86.88
20 mm PVC ball valve	unit	5.0	8.96	44.80
Worm gear clamp 1/2" 20 mm INC	unit	10.0	2.28	22.80
Acrylic water bottle (20 L)	unit	2.5	25.00	62.50
20 mm water -weldable union	unit	2.5	7.17	17.93
PVC glue (75 g)	unit	2.5	7.80	19.50
Cement - CP II	bag	22.5	35.00	787.50
Fine washed sand	subway	5.0	150.00	750.00
Twisted annealed wire #18	kg	1.3	14.80	18.50
Total material				12,424.83
Mason	daily	7.5	180.00	1,350.00
Servant	daily	15.0	80.00	1,200.00
Total labor				2,550.00
Grand total (17.43 m3)				14,974.83

Source: Adapted from Dias *et al.* (2013) (Updated in Apr/2023).

For the Indian model biodigester built in ferrocement, the estimate was based on the construction of a tank with a useful volume

capacity of 35 m³ and adjusted to a tank with a capacity of 17.43 m³ (TABLE 7).

Table 7. Estimated material cost for a ferrocement tank with a volume of 17.43 m³

Material	Unit	Qty .	Cost per unit (R\$)	Total (R\$)
Wire form BWG 12 2.77 mm thin	kg	4.0	20.00	80.00
Medium washed sand	m ³	2.5	135.00	337.50
Brita N 0	m ³	1.5	150.00	225.00
Cement - CP II	bag	17.5	35.00	612.50
Q92 mesh 15x15 2.45x6 m 4.2"	unit	39.0	22.00	858.00
65% Shade Cloth	m ²	10.0	28.00	280.00
1/2" metal screen	m ²	30.0	8.05	241.50
1/2" plastic screen	m ²	20.0	9.20	184.00
Total material 17.43 m³				2,818.50

Source: Adapted from Candiotto, Grisa and Schimitz (2015) (updated in Apr/2023).

For the construction of the Indian model biodigester in ferrocement with a fiberglass

gasometer (B4) and a capacity of 17.43 m³, the estimated total cost is presented in Table 8.

Table 8. Estimated construction cost of the Indian ferrocement biodigester with a fiberglass gasometer (B4) and a capacity of 17.43 m³

Materials	Unit	Qty .	Cost per unit (R\$)	Total (R\$)
Ferrocement tank 17.43 m ³	unit	1.0	2,818.50	2,818.50
Adapters	unit	8.0	4.10	32.80
1" drill bit	unit	10.0	5.25	52.50
Fiberglass tank (8,000 L)	part	1.0	4,675.00	4,675.00
PVC glue (75 g)	unit	2.0	7.80	15.60
90° PVC Bends 50 mm	unit	6.0	9.87	59.22
7.22 3/8 " rebar	bar	10.0	61.00	610.00
Thread seal tape (20 m)	unit	3.0	4.60	13.80
Waterproofing agent (concrete/mortar)	kg	4.0	64.50	258.00
50 mm PVC gloves	unit	5.0	7.07	35.35
Transparent level hose 3/4"	m	8.0	2.94	23.52
50 mm PVC ball valve	unit	3.0	15.72	47.16
150 mm PVC pipe (6 m)	unit	6.0	265.94	1,595.64
PVC pipe (6 m)	bar	12.0	110.87	1,330.44
TOTAL MATERIAL				11,567.53
Labor (bricklayer)	day	6.0	180.00	1,080.00
Labor (helper)	day	6.0	80.00	480.00
TOTAL LABOR				1,560.00
GRAND TOTAL				13,127.53

Source: Adapted from Dias *et al.* 2013. (Updated in Apr/2023).

In summary, the estimates of the construction cost and average price per m³ for each type of biodigester analyzed, with a

capacity of 17.43 m³ in April of 2023 are presented in Table 9.

Table 9. Estimates of construction cost and average price per m³, considering a volumetric capacity of 17.43 m³ for the four types of biodigesters analyzed.

Biodigesters	Investment (R\$)	Price (R\$) per m ³
B1	34,054.69	17.43
B2	25,866.33	17.43
B3	14,974.83	17.43
B4	13,127.53	17.43

B1. Masonry biodigester with a steel sheet gasometer; B2. Masonry biodigester with a fiberglass gasometer; B3. Cement slab biodigester with a fiberglass gasometer; B4. Ferrocement biodigester with a fiberglass gasometer.

Source: The authors (2023)

Data analysis allows the identification of the best biodigester configuration on the basis of construction and implementation costs. However, when choosing the most suitable option, it is necessary to consider the availability of materials, the need for periodic maintenance, and the capabilities of the existing workforce to ensure optimal performance and durability.

On the basis of the estimated construction costs for each biodigester evaluated, the Indian model built of masonry with a steel sheet gasometer (B1) had the highest cost, and the factor contributing to this increase was the use of a steel sheet gasometer. This material, in addition to its high price, can also suffer corrosion due to the oxidation process of steel and requires periodic painting for maintenance.

The cost of the B2 biodigester was reduced because of the type of material used in its bell-shaped structure, fiberglass, which costs 36% less than a steel sheet. The advantage of this type of bell-shaped structure is that the fiberglass box, in addition to being less expensive, is a lightweight, resistant, and rust-resistant material, facilitating work and eliminating the need for painting for maintenance.

Silva and Pires Sobrinho (2016) consider that the main advantage of masonry construction is its strength and ease of construction; however, they emphasize that if preventive elements against possible damage are not applied, cracks commonly occur between the masonry and the concrete in this type of construction, making its restoration costly.

Biodigesters constructed of cement slabs and ferrocement, both with fiberglass

gasometers (B3), presented lower costs than those constructed of masonry, owing to the reduction in the use of bricks, cement, and labor, and presented very similar construction costs. Ferrocement construction (B4) was the model that presented the lowest cost, with a reduction of 61.4% compared with the most expensive (B1).

Rural biodigesters using cement slabs follow the same construction procedure as slab cisterns do, with their main success factors being their characteristics: low cost, easy maintenance, and the use of materials readily available in local building supply stores (MATTOS; FARIAS JÚNIOR, 2011).

Silva and Araújo (2016) focused on the widespread use of cement board construction technology in the Agreste and Sertão regions of northeastern Brazil, where it is widely used, mainly because of the economy of the materials used, its simplicity, and its efficiency. However, the authors warn that this efficiency may vary depending on the context in which the construction is carried out. According to Oliveira (2009), the efficiency of anaerobic digestion can be strongly affected by factors related to the substrate, the characteristics of the digester, or the operating and environmental conditions, such as the type of biomass, the biodigester model, the quantity/volume of biomass, management, the microorganism profile, acidity, and temperature.

Viana and Magalhães (2013) consider that the configuration using ferrocement technology can be considered entirely artisanal, and characteristics such as impermeability and low cost guarantee greater social reach. They also require less material consumption and guarantee high resistance (BRASIL, 2010).

The financial analysis of the biodigesters was performed on the basis of biogas production capacity, considering an estimated average daily production capacity of

38.3 m³ of biogas. Using this production method and the *simple payback method*, the return on investment time from biogas revenue is presented in Table 10.

Table 10. Monthly payback period (PRP) considering biogas revenue compared with LPG and CNG revenue via the *simple payback method*.

Biodigester	Initial investment (R\$)	Monthly LPG revenue (R\$)	TRC LPG (month)	Monthly CNG revenue (R\$)	TRC CNG (month)
B1	34,054.69	5,174.55	6.58	5,002.07	6.81
B2	25,866.33	5,174.55	5.00	5,002.07	5.17
B3	14,974.83	5,174.55	2.89	5,002.07	2.99
B4	13,127.53	5,174.55	2.54	5,002.07	2.62

Source: The authors (2023).

Payback uses a discounted rate, which considers the time value of money and a minimum acceptable rate of return (MARR) of

10% per year; the payback period for the investment, which is based on biogas revenue, is shown in Table 11.

Table 11. Compared with LPG and CNG, the monthly payback period (TRC) when biogas revenue is considered when the *discounted payback method* is used.

Biodigester	Initial investment (R\$)	Adjusted monthly revenue for LPG (R\$)	TRC LPG (month)	Adjusted monthly revenue for CNG (R\$)	TRC CNG (month)
B1	34,054.69	4,704.14	7.24	4,547.33	7.49
B2	25,866.33	4,704.14	5.50	4,547.33	5.69
B3	14,974.83	4,704.14	3.18	4,547.33	3.29
B4	13,127.53	4,704.14	2.79	4,547.33	2.89

Source: The authors (2023)

Using both *simple payback* and *discounted payback*, the return on investment was estimated to be less than a year, approximately six months. The ferrocement biodigester with a fiberglass gasometer (B4) deserves special mention, as it presented the lowest investment and the shortest payback time, less than three months. This brief return shows... It can be built on different rural properties, regardless of size, so that the owner can benefit from its implementation. Furthermore, the advantages of biodigesters, such as energy and biofertilizer production, the treatment and reuse of these residues, the lack of environmental pollution, and the significant gains in social and environmental well-being, make their application viable.

FADE (2014) also suggested that the investment, operation and maintenance costs of biodigesters can be offset by the revenue from these units, which is obtained from the sale of biogas energy and the resulting organic compost.

The energy generated by biodigesters can also be calculated via mathematical models and the definitions of the technical parameters of each model; in this case, the potential for biogas and methane production depends mainly on the composition of the effluent and the residence time of the material in the reactor. In accordance with Obregon *et al.* (2020), mathematical modeling of biodigesters is used to predict the quantity and characteristics of biogas produced, as well as the relationships between these characteristics and the amount of

mechanical energy, mechanical work, and electrical energy generated.

4 CONCLUSIONS

A comparison of the materials used in the construction of the four configurations evaluated revealed that ferrocement construction presented the lowest investment value and shortest payback time, followed by cement boards and solid brick masonry, with a fiberglass gasometer. The gasometer constructed of steel sheets contributed to a significant increase in the investment value, indicating that replacing steel sheets with fiberglass is a good alternative.

Considering biogas production, the return on investment was estimated for a period of less than one year. In addition to biogas, the production of biofertilizer, which was not evaluated in this study, must also be considered, as well as the significant gains in sanitation related to social and environmental well-being.

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