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Circular economy applied to wastewater treatment plants: an analysis of the energy generation potential at the Passos/MG WWTP

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ABSTRACT
The aim of this study was to analyze the pruojects carried out by company Sabesp in the state of São Paulo, especially in the municipality of Franca/SP, developed in partnership with the Fraunhofer Institute, which consists of reusing the sludge generated at its plants, transforming it into fuel (biogas) and fertilizer for agricultural recycling. In addition, the WWTP of the city of Passos/MG will also be analyzed, so that the main points and differences can be listed and analyzed, seeking to replicate the fundamental processes of Sabesp's projects at the WWTP in the municipality of Minas Gerais. The methodology used was the case study, where quantitative and qualitative data were collected from plants, which were compared and supported by a bibliographic review in order to list replicable processes. In this sense, it is expected that the work will contribute to the dissemination of Circular Economy concepts and assist in the sustainable development of the region, serving as a reference for the replication of good sanitation practices.
KEYWORDS: Sanitation. Solid waste. Sustainability. Development.

1 INTRODUCTION

The Circular Economy has emerged as a response to the need to review the current linear production system established since the Industrial Revolution. The discussion gained prominence in the 1980s, with the Brundtland Report, focusing on the importance of meeting present needs without compromising future generations. This sustainable paradigm proposes a change in the life cycle of products, replacing the linear model with a process that seeks to restore and regenerate, keeping products, components and materials in a constant production cycle.

The Basic Sanitation sector, driven by population growth and the consequent expansion of Wastewater Treatment Plants (WWTPs), faces significant challenges related to the management of the sludge generated. The urgency of this issue led to the implementation of the National Solid Waste Policy (PNRS) in 2010, aiming to mitigate the generation and promote the reuse of waste. At the global level, the UN Sustainable Development Goals establish strategic goals for sustainable development, aligned with the preservation of natural resources. In Brazil, the recent Law No. 14,026 of 2020, known as the Basic Sanitation Legal Framework, represents a deep transformation in the sector. Highlights include facilitating the entry of private companies through concession contracts, the organization of municipalities into blocks to support smaller cities, and the creation of the Interministerial Committee on Basic Sanitation to improve coordination between federal agencies operating in the sector.

Given the urgency of developing sustainable initiatives in the wastewater sector, this study aims to address the following question: How can the principles of the circular economy be implemented at the Wastewater Treatment Plant (WWTP) of Passos/MG? The study consisted of benchmarking the practices adopted by Sabesp and analyzing the feasibility of applying these processes at the Passos/MG WWTP. The research is guided by the following problem: How can circular economy concepts be effectively integrated into the Passos/MG WWTP?

The general objective was to analyze the applicability of the circular economy with the reuse of sludge generated at the Passos-MG WWTP. The specific objectives are to analyze the circular economy initiatives implemented by Sabesp – Franca, especially the transformation of biogas into electrical energy and fuel; to establish the energy potential of Passos WWTP in relation to the estimated biogas generation.

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2 METHODOLOGY

The methodology used in the study was the case study, using qualitative data from real events to explore contemporary phenomena. The research protocol was developed based on benchmarking, identifying essential requirements for data collection. Wastewater treatment plants (SAAE and SABESP) were contacted to obtain primary and secondary data, integrating the results as input for the analysis model.

2.1 Benchmarking – Franca WWTP (Sabesp)

The work included product and generic benchmarking, focusing on Sabesp's initiatives in Franca, especially its products such as biogas and fertilizers. The aim is to implement this methodology at the Passos wastewater treatment plant, which belongs to the SAAE autarchy. Sabesp's Franca Wastewater Treatment Plant was chosen as a model for benchmarking due to the congruence of its principles and objectives with those proposed by the project, as well as its similarity with the Passos Municipal Sanitation Plan, established by Law No. 3.511 of December 2019. It is worth mentioning that the Passos Municipal Sanitation Plan is aligned with the premises of Sabesp's Corporate Program for Sustainable WWTPs, which aims to transform byproducts generated by WWTPs (biogas, sludge and effluent) into sustainable resources with market value, considering their energy use (SABESP, 2019, p.65).

2.2 Study for application in energy generation

The study related to Biogas generation was based on the project carried out by Sabesp in Franca discussed by Miki (2019). Since there is no survey on the amount of biogas generated by the Passos WWTP, the number was an estimate, calculated using the Probio software, developed by the Sustainable WWTP initiative and UFMG. Data were used to analyze the WWTP potential for generating energy from biogas.

2.2.1 Probio – Mathematical Model

According to Posseti and Chenicharo (2015, p.22)

> The input data required for calculations are: contributing population; *per capita* sewage contribution (QPC); average affluent sewage flow (Qméd); total affluent chemical oxygen demand (COD) concentration ($CDQO_{totafl}$); COD removal efficiency (EDQO); sulfate concentration in the affluent (CSO_4); sulfate reduction efficiency (ESO_4); solids production coefficient (Y); STV to COD conversion factor ($K_{sólidos}$); CH_4 supersaturation factor in the liquid phase (Fs); CH_4 loss in the gas phase with the residual gas (pw); other CH_4 losses in the gas phase (po); reactor operating temperature (T).

Also according to the authors:

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> Once input data have been defined, the COD portions removed from the system, converted to sludge and consumed in the sulfate reduction, are first estimated. Using these portions, the maximum COD converted into CH_4 and the consequent maximum volumetric production are calculated. In order to calculate the CH_4 volume actually available for energy use, the model considers losses of CH_4 dissolved in the effluent and in the gas phase with the residual gas, in addition to other possible losses in the gas phase. Finally, after discounting these losses, the available energy potential is calculated. The equations used to calculate all parcels of the COD mass balance and the energy recovery potential are presented below (POSSETTI, CHERNICHARO, 2015, p.22).

To calculate the COD removed in the system, equations 1 and 2 are presented.

$$\mathrm{COD_{remov}} = \mathrm{Pop\ x\ QPC\ x\ C}_{COD_{\mathrm{totafl}}}\ \mathrm{x\ E_{COD}} \qquad (1)$$

$$\mathrm{COD_{remov}} = \mathrm{Q_{méd}\ x\ C_{COD_{totafl}}\ x\ E_{COD}} \qquad (2)$$

Where:

COD_{remov}=daily COD mass removed in the system (kgCOD_remov d^{-1});

Pop=contributing population (inhab);

QPC=per capita COD contribution ($m^3.inhab^{-1}.d^{-1}$);

$Q_{méd}$=Average flow of affluent sewage to the reactor ($m^3.d^{-1}$);

$C_{CODtotafl}$=total affluent COD concentration ($kgCOD.m^{-3}$);

E_{COD}=COD removal efficiency (%).

The sludge production in UASB reactors (COD converted into sludge) is estimated according to equations 3 and 4.

$$COD_{\mathrm{sludge}} = \mathrm{Y_{obs}}\ \mathrm{x}\ COD_{\mathrm{remov}} \qquad (3)$$

Where:

COD_{sludge}=daily COD mass converted into sludge ($kgCOD_{sludge}\ d^{-1}$);

COD*remov*=daily COD mass removed in the system ($kgCOD_{remov}.d^{-1}$);

Y_{obs}=solids production coefficient in the system ($kgCOD_{sludge}.kgCOD_{remov}^{-1}$);

Y_{obs}= Y x K_{solids} (4)

Where:

Y=solids production coefficient ($kgSVT^{-1}).kgCOD_{remov}^{-1}$);

K_{solids}=conversion factor of STV into COD (1.42 $kgCOD_{sludge}\ kgSVT^{-1}$)

It was observed that the COD converted into sludge, calculated by equation 5, can be divided into two parts: (1) COD converted into sludge and retained in the system and (2) COD converted into sludge and lost along with the effluent.

To calculate COD used by the BRS in the sulfate reduction, equations 5 and 6 are used, which correspond to the estimated sulfate load reduced to sulfide and the COD load used in the sulfate reduction, respectively.

$$\mathrm{CO_{SO_4\,converted}} = \mathrm{Q_{méd}\ x\ C_{SO_4}\ x\ E_{SO_4}} \qquad (5)$$

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Where:
$CO_{SO_4\,converted}$ = SO_4 load converted into sulfide ($kgSO_4.d^{-1}$);
$Q_{méd}$=Average flow of affluent sewage to the reactor ($m^3.d^{-1}$)
C_{SO4} = average SO_4 concentration in the affluent ($kgSO_4.m^{-3}$);
E_{SO4} = SO_4reduction efficiency (%)

$$COD_{SO_4} = C_{SO_4\,converted}\ x\ K_{COD-SO_4} \qquad (6)$$

Where:
COD_{SO4} = COD used by BRS in sulfate reduction ($kg_{CODSO4}\ d^{-1}$);
K_{COD-SO_4} = COD consumed in sulfate reduction (0.667 $kgDQO/kgSO_{4\,converted}$).

To determine COD converted into CH_4 and present in the biogas, the maximum theoretical methane production per gram of COD removed is first calculated, as shown in equation 7.

$$Q_{CH_4} = \frac{COD_{CH_4}\ x\ R\ x\ (273+T)}{P\ x\ K_{COD}\ x\ 1000} \qquad (7)$$

Where:
Q_{CH_4} = maximum volumetric methane production ($m^3.d^{-1}$);
$CODCH_4$ = daily COD mass removed in the reactor and converted into methane ($kgCOD_{CH4}.d^{-1}$);
P = atmospheric pressure (1atm);
K_{COD} = COD corresponding to one mole of CH_4 (0.064 kgCOD.mol^{-1});
R = gas constant (0.08206 $atm.L.mol^{-1}.K^{-1}$);
T = reactor operating temperature (K)

The daily COD mass converted into CH_4 is determined using equation 8.

$$COD_{CH_4} = COD_{rem} - COD_{lodo} - COD_{SO_4^{2-}} \qquad (8)$$

From the volumetric CH_4 production, the total biogas production can be estimated, based on the expected content in it, according to Equation 9.

$$Q_{biogas} = \frac{Q_{CH_4}}{C_{CH_4}} \qquad (9)$$

Where:
Q_{biogas} = volumetric biogas production ($m^3.d^{-1}$);
C_{CH4} = methane concentration in the biogas (% v/v).

To obtain CH_4 concentrations in the biogas as a function of the COD concentration, the following equations are used, in which for COD between 100mg.L^{-1} and 400mg.L^{-1}, equation 14 is used, and for COD between 500mg L^{-1} and 1,000mg L^{-1}, equation 10 is used.

C_{CH4} = 2x10-7COD3 – 0.0004 COD 2 + 0.2333 COD + 18 (10)

C_{CH4} = 0.0059 COD + 66.219 (11)

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To define COD converted into CH^4 and lost dissolved in the effluent and residual gas, it is important to note that equation 12 refers to the maximum volumetric methane production, not taking into account losses of CH_4 dissolved in the effluent or residual gas, as well as other losses, such as leaks, condensate purges, etc. (POSSETTI, CHERNICHARO, 2015). According to the authors, "when the purpose of the COD mass balance is to estimate the methane volume effectively collected inside the three-phase separator and available for energy recovery, it is important to consider these losses in order to obtain more realistic values". To calculate these methane losses in the residual gas and other losses, equations 12 and 13 are used, respectively.

$$Q_{W-CH_4} = Q_{CH_4} x\, p_W \quad (12)$$
$$Q_{O-CH_4} = Q_{CH_4} x\, p_O \quad (13)$$

Where:
Q_{W-CH4} = methane loss in the gas phase, with the residual gas $(m^3.d^{-1})$;
Pw = methane loss percentage in the gas phase, with the residual gas (%);
Q_{O-CH4} = other methane losses in the gas phase $(m^3.d^{-1})$;
PO = percentage of other methane losses in the gas phase (%).

In the program's mathematical model, the methane loss percentage values are shown in Table 1.

Table 1 - Methane loss values and percentages.

Type of methane loss	**Unit**	**Scenario**		
		Optimistic	Typical	Conservative
Loss with residual gas (PW)	%	2.5	5	7.5
Other losses (PO)	%	2.5	5	7.5

Source: Adapted from Lobato, 2011

Equation 14 is used to define losses of dissolved methane in the effluent.

$$Q_{L-CH_4} = Q_{méd} x\, p_L\, x\, f_{CH_4}\, x \left(\frac{R\, x\, (273+T)}{P\, x\, K_{COD}}\right) \quad (14)$$

Where:
Q_{L-CH4} = methane loss in the liquid phase, dissolved in the effluent $(m^3.d^{-1})$;
Qméd= average sewage flow $(m^3.d^{-1})$
PL = methane loss in the liquid phase, dissolved in the effluent $(kg.m^{-3})$;
fCH_4 = conversion factor of methane mass into COD mass (stoichiometric coefficient 4.0 $kgCOD.kgCH_4^{-1}$).

The variable PL is calculated using equation 15.

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$$p_L = \frac{c_{CH_4}}{100} \; x \; K_h \; x \; F_s \qquad (15)$$

Where:

PL = concentration of dissolved methane in the effluent ($\mathrm{mg.L^{-1}}$);

Kh = Henry's constant ($\mathrm{mg.L^{-1}.atm^{-1}}$);

Fs = CH_4 supersaturation factor in the liquid phase;

The supersaturation factor is predetermined and is shown in Table 2, varying according to the scenario.

Table 2 – Saturation factor (Fs)

Scenario	Fs
Optimistic	1
Typical	1.35
Conservative	1.7

Source: Posseti and Chenicharo, 2015

After determining the theoretical methane production and the parts related to losses, the methane volume effectively collected inside the three-phase separator and available for energy recovery must be estimated. Equation 16 corresponds to the estimate of the actual CH_4 production.

$$\mathrm{Q_{ACTUAL-CH_4} = Q_{CH_4} x\; Q_{W-CH_4} \; x \; Q_{O-CH_4} \; x \; Q_{L-CH_4}} \qquad (16)$$

Where:

Q_{ACTUAL}-CH_4 = actual methane production available for energy recovery ($m^3.d^{-1}$)

Finally, it is possible to calculate the energy potential available in the biogas effectively collected by the three-phase separator through equation 17:

$$\mathrm{PE_{ACTUAL-CH_4} = Q_{N-ACTUAL-CH_4} \; x \; E_{CH_4}} \qquad (17)$$

In which:

$PE_{ACTUAL-CH4}$ = Available energy potential ($\mathrm{MJ.d^{-1}}$);

QN- $_{ACTUAL-CH4}$= Normalized actual methane production ($\mathrm{Nm^3.d^{-1}}$);

E_{CH4} = calorific value resulting from methane combustion ($35.9 MJ.Nm^3$)

2.3 Characterization of the study sites

2.3.1 Sabesp

Sabesp is a mixed-economy corporation that holds the concession for basic sanitation public services in the State of São Paulo. The shareholding structure includes 50.3% of shares of the Treasury Department of the state of São Paulo, 25.9% on the New York Stock Exchange and 23.8% on the B3 New Market of São Paulo.

With headquartered in São Paulo (SP), the company serves 375 municipalities in the state, providing sanitation services. In the cities of São Caetano do Sul (SP) and Mogi das Cruzes

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(SP), in the Metropolitan Region of São Paulo, Sabesp supplies treated water and sewage treatment, while these cities are responsible for water distribution and sewage collection.

As a signatory to the UN Global Pact, Sabesp promotes corporate social responsibility and sustainable development policies. The company is recognized for its commitment to research and development, highlighting the allocation of approximately R$20.5 million to Research, Technological Development and Innovation projects in 2020.
According to the company

> In addition to the circular economy, our fronts are organized into different project lines to meet internal demands, namely: improvement of construction and operation processes of water and sewage systems; water and sewage treatment solutions; asset control and management; clean and renewable energy generation processes; energy efficiency; technologies for customer relations; and loss reduction (SABESP, 2020, p.77).

In the municipality of Franca, Sabesp began its services in March 1977. The city is supplied by the Water Treatment Plant and the sewage is processed in nine systems: Franca, Luiza, Paulistano I, Paulistano II, City Petrópolis, Aeroporto, Palestina, São Francisco and Morada do Verde.

2.3.2 Wastewater Treatment Plant of Franca/SP

The Franca/SP WWTP, in operation since 1998, covers a total area of 200,000 m², has installed capacity of 3.5 kW and currently serves the municipality of Franca, with estimated population of 355,901 inhabitants according to IBGE. With sanitary flow rate of 450 l/s, its total capacity can reach approximately 750 l/s, and the effluent is treated using aerobic and anaerobic methods.
The plant is organized into sectors:

Screening/Sand Boxes/E.E.E.B. (Raw Sewage Pumping Station): Performs preliminary treatment, removing solid materials such as stones and plastics. It uses screens and sand boxes for removal.

Primary Decanters: In this phase, settleable solids are removed, being sent for sludge treatment (Sector 5).

Aeration Tanks: After primary treatment, the effluent passes through aeration tanks, where the organic matter is degraded.

Secondary Decanters and E.E.R.L. (Sludge Recirculation Pumping Station): Designed to clarify the final effluent and treat the flocculated sludge, composed of bacteria and organic matter. The sludge is recirculated to the aeration tank.

Mixing Tank and Sludge Thickeners: Prepares a homogeneous mixture of primary and secondary sludge. The sludge is pumped to the biodigester.

Biodigesters: Here, the sludge undergoes anaerobic digestion, converting the organic matter into gases such as methane and carbon dioxide. The gas is collected and used, while the sludge is sent for dehydration.

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Conveyor Filter Press: Dehydrates the sludge, resulting in biosolids composed of organic matter, nitrogen, phosphorus and potassium, which can be used in agriculture. The percentage of dry solids reaches 20%.

2.3.3 SAAE

SAAE is a municipal autarchy with public legal personality and administrative and financial autonomy. It was established by Law No. 439, on November 25, 1960, with the purpose of operating, maintaining, protecting and exploring public drinking water and sewage services in the city of Passos. Its revenue is derived from water and sewage tariffs (SAAE, 2020).

2.3.4 Passos/MG Wastewater Treatment Plant

The Passos/MG WWTP, inaugurated in 2008, operates with treatment capacity of approximately 82% of the city's sewage production. The plant, which occupies an area of approximately 4 hectares, uses upflow anaerobic reactors (UASB) for its operation (SILVA, 2019; SAAE, 2020).

Sewage treatment at the Passos WWTP occurs in six stages:

Preliminary Treatment: Includes devices for removing sand and other materials, with three distinct parts, starting with screening with different spacing. The first screen is 25 mm, the second, which works automatically, is 15 mm, and then the effluent is directed to desanders.

Screening: Involves the removal of coarse solids by means of retention and removal devices, which can be mechanized or manual.

Desanders: Final stage of preliminary treatment, retaining sand and other particulates that may pose risks to subsequent wastewater treatment.

Flow Meter: After preliminary treatment, the effluent passes through a flow meter to indicate the amount of wastewater that will enter the reactors. This stage is essential for collecting data on flow rates, peak flows and wastewater quantification, in addition to allowing the evaluation of the process efficiency in relation to BOD and COD.

Sewage Distribution Box: Located after the flow meter and before Upflow Anaerobic Reactors, the distribution box has the function of distributing the sewage evenly in reactors, avoiding load or overload differences between them.

Upflow Anaerobic Reactors: Used as biological sewage treatment, these reactors are intended to remove organic matter and solid materials from the effluent. The station has two modules, each composed of three Upflow Anaerobic Reactors, totaling six reactors.

According to Silva (2019, p.11)

> Biological treatment occurs through an anaerobic process, that is, without oxygen. Basically, organic matter decomposition is performed by microorganisms present in a sludge layer, the sewage leaves the bottom of the reactor and passes through the sludge layer that acts as a filter. To better explain, in the reactor, the biomass grows dispersed in the environment forming small granules. The concentration of bacteria is high, forming a sludge layer. The effluent enters below the reactor and has an upward flow. At the top of the reactor, there is a conical structure, which

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allows the separation of gases resulting from the anaerobic process (carbon dioxide and methane) of the biomass, which settles in the cone and is returned to the reactor, and from the effluent, the area of this system is quite reduced due to the high concentration of bacteria. Sludge production is low and is already stabilized.

3 RESULTS

3.1 Results for Biogas Production at the Passos/MG WWTP

Due to the absence of some parameters for the exact calculation of biogas production at the Passos WWTP, standard numbers were used, divided into three scenarios for analysis: conservative, typical and optimistic. The variation of these input parameters is shown in Table 3.

Table 3 – Calculation parameters for estimating biogas production, according to the scenario.

Parameter	Unit	Conservative Scenario	Typical Scenario	Optimistic Scenario
SO_4 concentration in the affluent (CSO_4)	mg. L^{-1}	20	15	10
COD removal efficiency (ECOD)	%	60	65	70
SO_4 reduction efficiency (ESO_4)	%	80	75	70
Sludge production coefficient (Y)	$kgSV/kgCOD_{rem}$	0,15	0,15	0,15
COD-sludge production coefficient (Ksólidos)	$kgCOD\text{-}sludge/kgCOD_{rem}$	0,213	0,213	0,213
Reactor operating temperature (T)	°C	25	25	25
CH_4 supersaturation factor in the liquid phase (Fs)	-	1,7	1,35	1
CH_4 loss in the gas phase with the residual gas (pw)	%	7,5	5	2,5
CH_4 loss in the gas phase with the residual gas (pw)	%	7,5	5	2,5

Source: Prepared by the author.

It can be observed that the COD removal efficiency (COD), for example, was considered at 60% in a conservative scenario, 65% in a typical scenario and 70% in an optimistic scenario. In general, the biogas production and energy generation viability was analyzed in the three scenarios.

Regarding input data, the population considered was 115,970 inhabitants, which corresponds to the 2021 IBGE survey, and the sewage contribution per inhabitant and the affluent chemical demand (COD affluent) were provided by SAAE and correspond respectively to 180 L/inhab.day and 500mg/L.

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Therefore, the calculations of the balance of organic loads in the three possible scenarios are shown in Table 4.

Table 4 – Result of the balance of organic loads in the three possible scenarios.

Parameter	Unit	Conservative Scenario	Typical Scenario	Optimistic Scenario
Affluent COD load	KgCOD/day	10437,3	10437,3	10437,3
Affluent SO_4 load	$KgSO_4$/day	417.5	313.1	208.7
Effluent COD load	KgCOD/day	4174,9	3653,1	3131,2
Removed COD load	KgCOD/day	6262,4	6784,2	7306,1
COD load used in SO_4 reduction	KgCOD/day	222.8	156.6	97.5
COD load converted into sludge	KgCODsludge/day	1333,9	1445,0	1556,2
COD load converted into CH_4	KgCOD- CH_4/day	4705,7	5182,6	5652,4
COD converted into biomass	%	21.3	21.3	23.1
COD used to reduce SO_4	%	3.6	2.3	1.3
COD converted into CH_4	%	75.1	76.4	77.4

Source: Prepared by the author.

A more considerable variation is observed in some parameters, such as the SO_4 load in the affluent, which varied practically a little more than double from the conservative to the optimistic scenario, and in the COD used to reduce SO_4, which is almost triple between opposite scenarios.

With regard to methane and biogas production, and the energy generation potential in the three scenarios, the results are exemplified in tables 5 and 6 respectively.

Table 5 – Results of methane and biogas production in the three possible scenarios.

Parameter	Unit	Conservative Scenario	Typical Scenario	Optimistic Scenario
CH_4 in the biogas	%	69.2	69.2	69.2
Loss of dissolved CH_4 in the effluent	mg/L	25.2	20.0	14.8
COD load converted into CH_4	kgCOD-CH_4/day	4705,7	5182,6	5652,4
Temperature correction factor	kgCOD/m³	2.6	2.6	2.6
Volumetric CH_4 loss with the effluent	m³/day	803.5	638.1	472.7
Volumetric CH_4 loss with the residual gas	m³/day	74.6	67.1	42.2
Other volumetric CH_4 losses	m³/day	74.6	67.1	42.2
Actual CH_4 production in biogas	m³/day	845.3	1207,9	1602,7
Actual biogas production	m³/day	1222,1	1746,3	2317,1

Source: Prepared by the author

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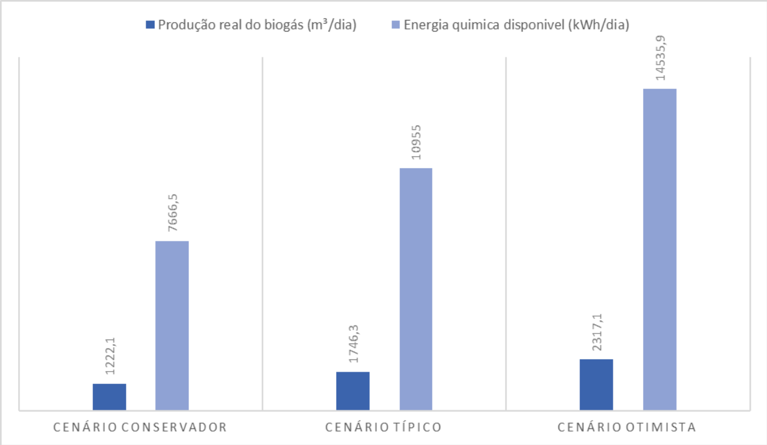
Table 6 – Energy generation potential in the three possible scenarios.

Parameter	Unit	Conservative Scenario	Typical Scenario	Optimistic Scenario
Standardized CH_4 production	Nm³/day	774.4	1106,6	1468,3
CH_4 emission rate	Ton/year	5087,8	7270,1	9646,6
Standardized biogas production	Nm³/day	1119,6	1599,8	2122,7
Available chemical energy	kWh/day	7666,5	10955,0	14535,9

Source: Prepared by the author

Graph 1 illustrates the comparison of the actual biogas production and the available chemical energy between the 3 scenarios.

Graph 1 – Actual biogas production and available chemical energy in the 3 scenarios.



Source: Prepared by the author

When analyzing energy generation, it is important to observe that the available chemical energy does not represent an absolute value, since when it is converted into electrical energy, part of this energy is dissipated. Therefore, to obtain the actual energy availability value, it is necessary to take into account the efficiency of the equipment chosen for the conversion. Currently, internal combustion engines, which convert this energy, have efficiency varying between 30% and 44%, therefore, for the calculation, the average value of 37% was considered. Therefore, the electrical energy generation values are 2,836.6 kWh/day, 4,053.35 kWh/day and 5,378.36 kWh/day in the conservative, typical and optimistic scenarios, respectively.

Considering that the average electricity consumption in Brazilian homes is 150 KWh/month, the estimated number of homes that could be supplied with the use of biogas from the Passos WWTP is shown in Chart 6.

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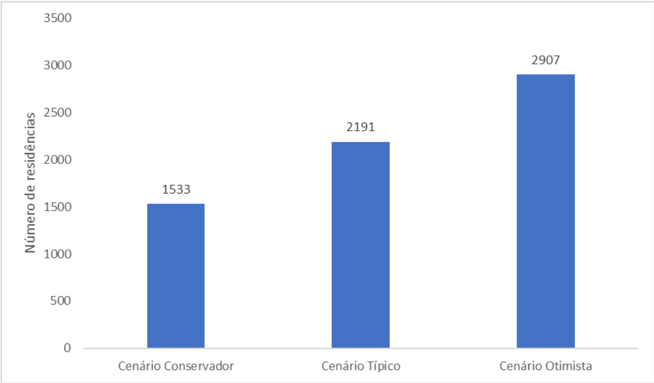
Chart 2 – Number of homes that could be supplied with electricity generated by the use of biogas – Passos WWTP/MG.

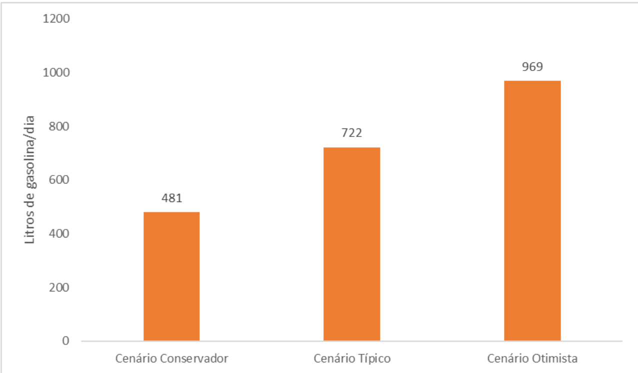


Source: Prepared by the author

Regarding the use of biogas generated as fuel, it is important to point out that the Passos WWTP has a treatment capacity and, consequently, smaller biogas generation compared to the Franca WWTP, but the results are still promising.

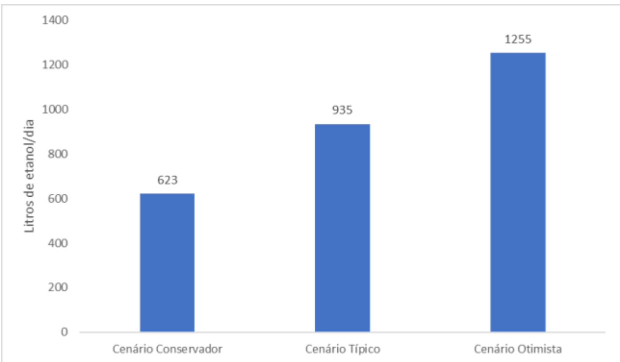
Charts 7, 8, 9 and 10 show comparisons of the estimated biogas volume generated at the Passos WWTP in relation to the equivalence with other fuels. As previously observed, the three scenarios were considered.

Chart 3 – Liters of gasoline equivalent to the biogas generated at the Passos/MG WWTP, in L/day.



Source: Prepared by the author

Chart 4 – Liters of ethanol equivalent to the biogas generated at the Passos/MG WWTP, in L/day.



Source: Prepared by the author

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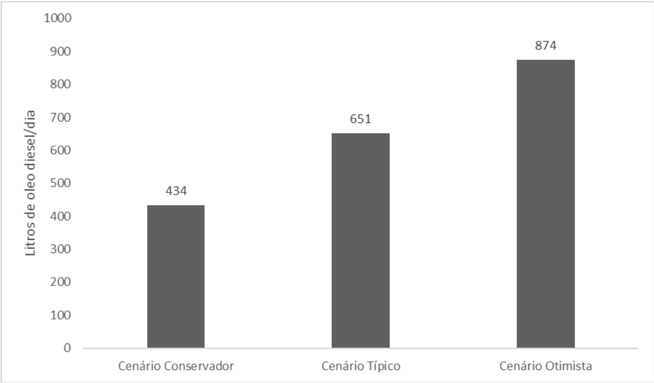
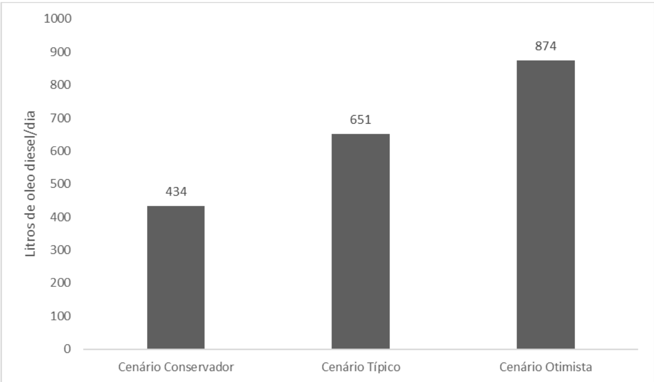
Chart 5 – Liters of diesel oil equivalent to the biogas generated at the Passos/MG WWTP, in L/day.



Source: Prepared by the author

Chart 6 – m³ of natural gas equivalent to the biogas generated at the Passos/MG WWTP, in L/day.



Source: Prepared by the author

With the results obtained, the energy potential of the Passos WWTP in relation to the estimated biogas generation is clear.

Even with the most conservative estimates, a biogas reuse project is necessary, whether for electricity generation or for fuel generation. Another important point is that there is currently a project to expand the Passos WWTP, where the treatment capacity will increase, and consequently, sludge and biogas production. This could represent a considerable increase in the existing potential for energy reuse.

Every year, 150 to 200 tons of sludge are generated by the Passos WWTP, which is a major problem for SAAE, which spends around R$ 400,00 per ton on the disposal of this waste.

The study is expected to help promote the application of the Circular Economy at the Passos/MG wastewater treatment plant. In the near future, an action plan can be developed to elaborate initiatives similar to those of Sabesp. In addition, the concepts can be replicated for other plants in the region, and for water treatment plants (WTPs).

Given the urgency of the topic, it is also expected that this study can contribute to literature, serving as a reference for future studies that seek to improve the processes described, or even replicate them.

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4 CONCLUSION

The results highlight the high energy potential of the Passos WWTP in generating biogas, suggesting the need for a project for the reuse of this resource, whether for electricity or fuel. With an expansion project underway, the WWTP capacity will be expanded, increasing sludge and biogas production. Managing the 150 to 200 tons of sludge per year, which costs R$ 400,00 per ton to SAAE, represents a financial challenge. This study seeks to promote the Circular Economy at the Passos WWTP, aiming to develop an action plan similar to that of Sabesp, with potential replication in other plants in the region, including water treatment plants. The urgency of the topic makes the study a reference for future studies that aim to improve or replicate these processes.

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