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Wastewater management in the state of Alagoas, Brazil: greenhouse gas emissions and organic load removal efficiency of wastewater treatment plants

Crislâny Canuto dos Santos[1*], Elane Pereira Gomes[2], Carolina Ferreira Simon Maia[2], Stoécio Malta Ferreira Maia[2]

1 Programa de Pós graduação em Agronomia, Universidade Federal de Alagoas, Campus de Engenharias e Ciências Agrárias, BR-104, Km 85, s/n, Rio Largo - AL, 57100-000.
2 Mestrado em Tecnologias Ambientais, Instituto Federal de Alagoas, Campus Marechal Deodoro. Rua Odilon Vasconcelos, 103, Maceió - AL, 57035-660.
*Corresponding author: crislanycanuto@outlook.com.

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Abstract - Domestic and industrial wastewater treatment plants are categorized as anthropogenic sources of direct greenhouse gases (GHG) emissions. In this study, greenhouse gases emissions from the wastewater sector in the state of Alagoas – Brazil were estimated, and the efficiency of sewage treatment plants was evaluated, based on biochemical oxygen demand (BOD) removal. In addition, possible GHG emission scenarios for direct emission sources were evaluated. To evaluate these emissions, calculation tool developed by the GHG Protocol (scopes 1 and 2) and the Intergovernmental Panel on Climate Changes (IPCC) Guidelines were used. As a result, in 2018, a total of 66.524.76 tCO_2e was emitted, of which 52.677.53 tCO_2e were due to sewage treatment. Electricity consumption was responsible for emitting 13.023.77 tCO_2e. Among wastewater treatment systems, the most efficient for BOD removal was septic tank with stabilization ponds, with 80% removal efficiency. Through scenario evaluations, this study suggests that the replacement of current treatments by well-operated aerobic systems is the most effective strategy in reducing total GHG emissions from sewage wastewater treatment plants. The results obtained constitute a management tool, helping the company in the strategic planning to achieve sustainability.

Keywords: Climate change. Biochemical oxygen demand. Corporate GHG emissions.

Gestão de águas residuais em Alagoas – Brasil: emissões de gases de efeito estufa e eficiência de remoção de carga orgânica das estações de tratamentos

Resumo - As estações de tratamento de águas residuais domésticas e industriais são categorizadas como fontes antropogênicas de emissão direta de gases do efeito estufa (GEE). Neste estudo, foram estimadas as emissões de gases de efeito estufa do setor de águas residuais no estado de Alagoas – Brasil e avaliada a eficiência das estações de tratamento de esgoto, com base na remoção da demanda bioquímica de oxigênio (DBO). Além disso, possíveis cenários de emissões de GEE para as fontes de emissão direta foram avaliados. Para contabilização dessas emissões foram utilizadas a ferramenta de cálculo elaborada pelo *GHG Protocol* (escopos 1 e 2) e as Guias do Painel Intergovernamental sobre Mudanças Climáticas (IPCC). Como resultados, foram emitidos em 2018, o total de 66.524,76 tCO_2e, destes, 52.677,53 tCO_2e foram decorrentes do tratamento de esgoto. O consumo de energia elétrica foi responsável por emitir 13.023,77 tCO_2e. Dentre os sistemas de tratamentos de efluente, o mais eficiente para a remoção da DBO foi o de tanque séptico com lagoas de estabilização, com uma eficiência de remoção de 80%. Por meio das avaliações dos cenários, este estudo sugere que a substituição dos tratamentos atuais por sistemas aeróbicos bem operados é a estratégia mais eficaz na redução das emissões totais de GEE das estações de tratamento de esgoto. Os resultados obtidos constituem uma ferramenta de gestão, ajudando a empresa no planejamento estratégico para alcançar a sustentabilidade.

Palavras-chave: Mudanças climáticas. Demanda bioquímica de oxigênio. Emissões de GEE corporativas.

Gestión de aguas residuales en Alagoas – Brasil: emisiones de gases de efecto invernadero y eficiencia en la remoción de carga orgánica de las plantas de tratamiento

Resumen - Las plantas de tratamiento de aguas residuales domésticas e industriales se clasifican como fuentes antropogénicas de emisiones directas de gases de efecto invernadero (GEI). En este estudio, se estimaron las emisiones de gases de efecto invernadero del sector de aguas residuales en el estado de Alagoas – Brasil y se evaluó la eficiencia de las plantas de tratamiento de aguas residuales, con base en la eliminación de la demanda bioquímica de oxígeno (DBO). Además, se evaluaron posibles escenarios de emisión de GEI para fuentes de emisión directa. Para dar cuenta de estas emisiones se utilizaron herramienta de cálculo desarrollada por GHG Protocol (alcances 1 y 2) y el Directrices de Panel Intergubernamental sobre Cambio Climático (IPCC). A consecuencia, en 2018 se emitieron un total de 66.524,76 tCO_2e, de las cuales 52.677,53 tCO_2e provinieron del tratamiento de aguas residuales. El consumo de energía eléctrica fue responsable de la emisión de 13.023,77 tCO_2e. Entre los sistemas de tratamiento de efluentes, el más eficiente para la remoción de DBO fue el tanque séptico con lagunas de estabilización, con una eficiencia de remoción del 80%. A través de evaluaciones de escenarios, este estudio sugiere que reemplazar los tratamientos actuales con sistemas aeróbicos bien operados es la estrategia más efectiva para reducir las emisiones totales de GEI de las plantas de tratamiento de aguas residuales. Los resultados obtenidos constituyen una herramienta de gestión, ayudando a la empresa en la planificación estratégica para lograr la sostenibilidad.

Palabras clave: Cambio climático. Demanda de oxigeno bioquímico. Emisiones corporativas de GEI.

Introducion

The increase in the average global temperature, as a result of anthropic activities, is a reality according to the Intergovernmental Panel on Climate Change (IPCC 2021). In its sixth evaluation report, IPCC presented scenarios with increases between 1.4 and 4.4 °C by the end of the century if actions are not adopted to reduce GHG emissions (IPCC 2021).

Wastewater treatment results in the direct carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (N_2O) emissions. The direct CO_2 emission in biological treatment processes is of natural origin (biogenic), and, therefore, is not considered a contributor to the greenhouse effect since it does not alter the GHG balance in the atmosphere (Lima and Salvador 2014). However, future improvements to the IPCC Guidelines should include a method for estimating these non-biogenic emissions associated with wastewater treatment operations and wastewater discharges (IPCC 2019). The indirect CO_2 emission can be evaluated based on the energy consumption in the sewage treatment process (Nayeb et al. 2020). N_2O emissions come from the transformations of nitrogenous substance (Huang et al. 2020).

CH_4 emission comes from anaerobic treatment processes, in which organic matter is degraded. Sewages with high organic matter content have high potential for CH_4 emissions. The organic matter present in these sewages is expressed in terms of Biochemical Oxygen Demand (BOD), which is the main determining factor of the CH_4 generation potential and represents the amount of oxygen consumed by microorganisms in the biochemical organic matter oxidation (Lima and Salvador 2014).

In Brazil, the Waste sector is responsible for only 4.5% of national GHG emissions; however, it showed increase of 152% between 1990 and 2016, becoming the sector with the highest increase in the country (MCTIC 2020). This increase is directly related to population growth, along with increased urbanization, which has led to ever-increasing demands for potable water with subsequent increases in wastewater (Asadi and McPhedran 2021). Furthermore, increases in waste treatment capacity contribute to higher GHG emissions, which become a concern for the sustainable development of this sector (Kumar et al. 2021).

In this context, the search for environmental quality and social responsibility has been growing in sanitation companies (Speranza and Resende 2015). Thus, the implementation in policies of actions such as GHG inventories is necessary since they help subsidize appropriate mitigation initiatives (Asadi and McPhedran 2021).

Several studies on GHG estimates from the wastewater management sector have been carried out in other countries. Li et al. (2017) compiled GHG emissions in Beijing and observed that the domestic sewage sector emitted 591 kt of CO_2 equivalent ($ktCO_2e$). In Greece, emission of 892.454 $ktCO_2e$ per year was verified in 2016, referring to the emission of 220 wastewater treatment plants in the country (Koutsou et al. 2018). In Iran, Nayeb et al. (2019) found that 3.498.74 $ktCO_2e$ were emitted per year by wastewater treatment plants.

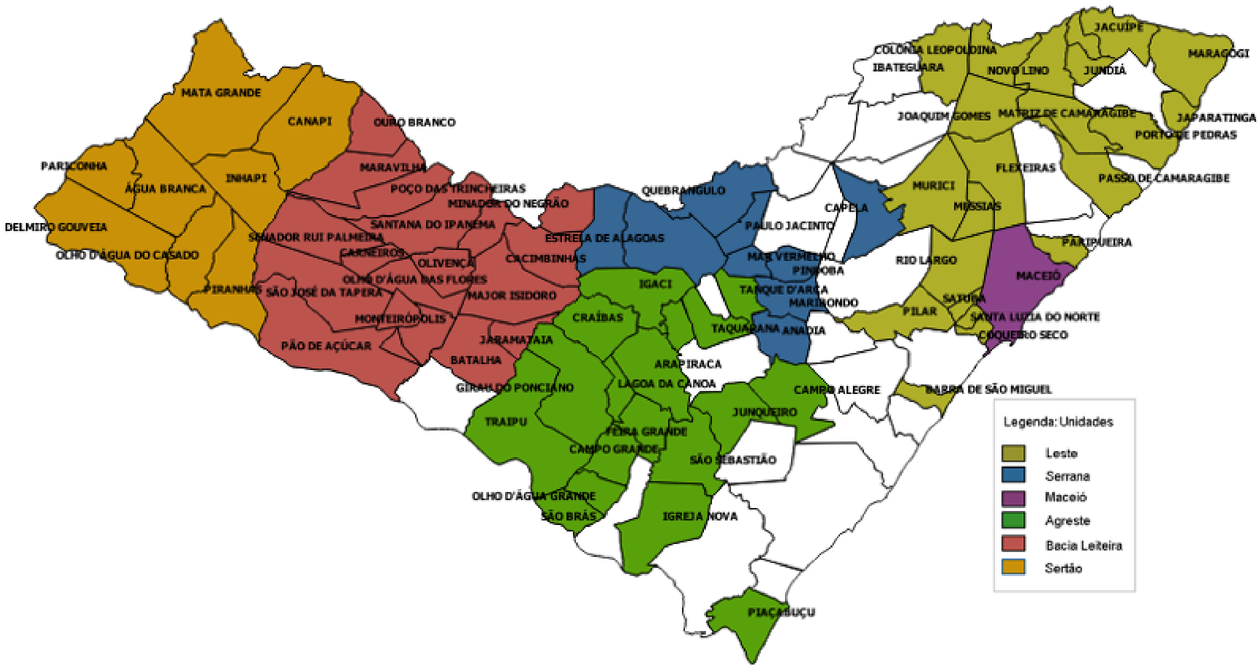
In Brazil, although this practice is not yet widespread among all companies in the sanitation sector, large companies such as: Sanitation Company of the State of São Paulo - SABESP; Sanitation Company of the state of Minas Gerais - COPASA and Sanitation Company of the state of Paraná - SANEPAR, already account for and publish their emissions regularly (COPASA 2018; SABESP 2018; SANEPAR 2019). The Sanitation Company of the state of Alagoas (CASAL) is one of the largest state-owned companies of Alagoas, operating 44 water supply systems and 50 sewage systems, playing an important role in the social development of the state. In this way, its activity must always be carried out with a view to economic-financial, social and environmental sustainability. However, CASAL still does not carry out the accounting of its GHG emissions.

In view of this demand, the aim of this work is to estimate GHG emissions generated by the main activities of the Sanitation Company of the state of Alagoas, for the year 2018, based on the efficiency of wastewater treatment plants (WWTP), to provide data and information that contribute to the planning and elaboration of public and business policies aimed at reducing GHG emissions. Additionally, it aimed to evaluate GHG emission scenarios for direct emission sources, considering changing the type of sewage treatment and improving the efficiency of WWTP systems.

Material and methods

This research was carried out at the Sanitation Company of the state of Alagoas (CASAL), a mixed economy company, created by Law No. 2.491 of 1962, for the provision of water supply and sewage treatment services. The company has administrative headquarters in the city of Maceió, three Business Units in the state capital (Benedito Bentes, Farol and Jaraguá) and five Business Units in the countryside (Leste, Serrana, Agreste, Bacia Leiteira and Sertão) (CASAL 2019), as shown in figure 1.

Figure 1. Distribution of Business Units and Municipalities served by CASAL, in Alagoas State, Northeast of Brazil.



Greenhouse gas emission were estimated based on the GHG protocol (WRI/WBCSD 2004) and on IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) on direct emissions from wastewater treatment.

GHG emission estimates

The GHG Protocol establishes three scopes for carrying out corporate GHG emission estimates. Scope 1 refers to direct emissions from the company's processes; scope 2 includes indirect emissions resulting from energy consumption and scope 3 refers to emissions that do not belong and/or are not controlled by the company, that is, it considers all indirect emissions not categorized in the other scopes (WRI/WBCSD 2004). Table 1 presents the sources of emissions, while the methods used for each source are detailed below. Estimates were made for the year 2018.

Table 1. Emission types and sources considered in the inventory.

Category	Emission sources	Emission type	Scope	Gases emitted
Wastewater	Wastewater treatment	Direct	1	CH_4
Mobile combustion	Vehicles	Direct	1	CO_2, CH_4 and N_2O
Stationary combustion	Generators, motors	Direct	1	CO_2, CH_4 and N_2O
Electricity	Capture, treatment and water distribution; collection, treatment and sewage disposal and administrative activities	Indirect	2	CO_2

Scope 1 - Direct emissions from wastewater treatment

Treatment plants were identified and classified according to their treatment processes. For the calculation of GHG emissions, collected and treated sewage and collected and untreated sewage were considered. Only CH_4 emissions were accounted for, as GHG emissions from the waste sector are predominantly CH_4 (95.8%) (MCTIC 2021). However, N_2O emissions can occur directly in the nitrification (aerobic) and denitrification (anoxic) process in treatment plants, or indirectly, in wastewater discharged into water bodies (Huang et al. 2020). The steps for calculating CH_4 emissions are described below (IPCC 2006):

1) Total organic load estimation

This parameter is a function of human population and BOD generation (biochemical oxygen demand) per person, being expressed in terms of kg BOD year^{-1} and calculated using the following equation 1 (IPCC 2006):

$$TOW = P \times BOD \times 0.001 \times I \times 365 \quad (1)$$

Where:

TOW = total organic load of wastewater in the year of the inventory, kg BOD year^{-1}.

P = population in the year of the inventory.

BOD (degradable organic component) = BOD per capita in the year of the inventory, g person day^{-1} (the standard amount for Brazil according to the IPCC-2006 Guide is 50 (g person day^{-1}).

0.001 = conversion factor (g to kg).

I = corrective factor for industrial BOD disposal in the collection network (standard values: 1.25 for collected and 1 for uncollected).

2) Population cover estimation (P)

The population covered (P) with sewage collection and treatment in the year of the inventory was estimated by the number of households served multiplied by the average of household occupation in each municipality (IBGE 2010).

3) Biological Oxygen Demand (BOD)

To calculate *per capita* BOD, data from the BOD removal efficiency monitoring in nine treatment plants were used, which was carried out by the CASAL Sewage Analysis Laboratory. For WWTP with no data availability, the average BOD entry and exit of the remaining WWTP was used. BOD removal was calculated using equation 2 (IPCC 2006):

$$BODr=(BOD\ entry-BOD\ exit)\ \ x\ Q\ treated \quad (2)$$

Where:
BODr = BOD removed (g day^{-1})
BOD entry = BOD in the influent of wastewater treatment plants (g L^{-1}).
BOD exit = BOD in the effluent of wastewater treatment plants (g L^{-1}).
Q treated = flow treated in each plant (L day^{-1}).

Table 2 shows the treatment systems and volumes of treated sewage used to calculate BOD.

Table 2. Volumes of sewage treated and untreated by treatment system for BOD calculation.

Type of treatment	Sewage volume (m^3 $year^{-1}$)
Oceanic disposal system	36.792.000.00
Anaerobic reactors	3.786.311.54
Septic systems	4.172.928.78
Stabilization ponds	5.951.357.12
Compact activated sludge	463.760.24
Collected and untreated	1.826.041.27

4) Emission factors for domestic sewage (EF) treatment and discharge.

The emission factor was established based on the maximum CH_4 production potential of each type of treatment and the corrective factor, according to equation 3 (IPCC 2006):

$$EF=Bo*MCF \quad (3)$$

Where:
EF = Emission factor (kg CH_4 kg BOD^{-1})

Bo = Maximum CH_4 production capacity (the value of 0.6 kg of CH_4 kg of BOD^{-1} was used (IPCC 2006)
MCF = Methane corrective factor, which indicates the degree to which the system is anaerobic.

After applying equation 3, the emission factor for each treatment system was found. This factor was then multiplied by removed BOD. The result is found in $kgCH_4$ and then converted into tCO_2e. Thus, for the conversion of CH_4 emissions into equivalent CO_2, GWP of 21 was adopted (Forster et al. 2007). In this work, types of treatment were grouped into categories and MCF values shown in table 3 were adopted.

Table 3. Types of treatment and respective methane correction factors.

Types of treatment	MCF
Oceanic disposal system	0.1
Activated sludge	0.3
Stabilization ponds	0.2
Septic systems	0.5
Anaerobic reactors	0.8

Source: IPCC (2006); Vieira et al. (2015).

For cases in which there was combination of anaerobic and aerobic treatment processes, the MCF of the most anaerobic treatment was selected, as CH_4 emissions occur during the organic matter anaerobic digestion.

Scope 1 - Mobile combustion

In the mobile combustion category, emissions caused by 335 vehicles used to carry out activities in the administrative and operational sectors were considered. Data were provided by the CASAL transport sector, responsible for controlling vehicles and fuel consumption. GHG emission was estimated using equation 4 (IPCC 2006):

Direct combustion = fuel consumption x emission factor (4)

Where:
Fuel consumption = amount of fuel consumed throughout the year (L).
Emission factor = as shown in table 4 (Kg L^{-1}).

Table 4. Fuel consumption and emission factors by fuel type for mobile combustion.

Fuel	Fuel consumption	Emission factors					
		Fossil fuel			Biofuel		
	(L)	(kg CO_2 L^{-1})	(kg CH_4 L^{-1})	(kg N_2O L^{-1})	(kg CO_2 L^{-1})	(kg CH_4 L^{-1})	(kg N_2O L^{-1})
Gasoline	360.520.28	2.212	0.0008	0.00026	1.526	0.0002	0.00001
Diesel	84.947.85	2.603	0.0001	0.00014	2.431	0.0003	0.00002
Ethanol	36.07	--	--	--	1.457	0.0004	0.00001

Source: CASAL and GHG PROTOCOL (2019).

Scope 1 - Stationary combustion

Sources referring to the generation of equipment and mowers used in the operational sector were considered. Data were provided by the CASAL transport sector, responsible for controlling fuel consumption. Table 5 presents the emission factors by type of fuel for stationary combustion, according to the previously mentioned calculation tool.

Table 5. Fuel consumption and emission factors by type of fuel for stationary combustion.

Fuel	Fuel consumption	CO_2	CH_4	N_2O
	(L)		(Kg L^{-1})	
Gasoline	3.520.05	2.24	0.00032	0.00002
Diesel	2.002.14	2.63	0.00036	0.00002

Source: CASAL and GHG PROTOCOL (2019).

Scope 2 - Electricity consumption

Data referring to electricity consumption of the administrative and operational water supply (surface and underground collections, pumping stations, treatment stations) and sewage management (pumping stations, treatment stations) of the 77 operating municipalities were provided by the CASAL Energetic Efficiency Sector.

Indirect GHG emissions generated using electricity were accounted for according to equation 5 (IPCC 2006):

$$\textit{Electricity emission} = \textit{monthly consumption X monthly emission factor} \quad (5)$$

Where:

Monthly consumption = monthly amount of electricity consumed in megawatt hours (MWh) (Table 6).

Monthly emission factor provided by MCTIC for Brazil in 2018 (tCO_2 MWh^{-1}) (Table 6).

Table 6. Monthly consumption (MWh) and average monthly emission factors (tCO_2 MWh^{-1}) for the months of 2018.

Month	Monthly consumption	Emission factor	Month	Monthly consumption	Emission factor
January	15.433.952	0.0640	July	14.725.215	0.1076
February	15.057.237	0.0608	August	14.854.409	0.1181
March	13.545.102	0.0635	September	14.764.869	0.1182
April	14.043.264	0.0523	October	14.933.256	0.0802
May	14.255.056	0.0607	November	15.456.092	0.0366
June	14.352.631	0.0915	December	14.580.428	0.0343

Source: CASAL and MCTIC (2018).

Scenarios of changing the type of sewage treatment and improving the efficiency of WWTP systems

Considering international and national initiatives aimed at adopting strategies to reduce GHG emissions, different CH_4 emission scenarios were evaluated, considering the change in the type of sewage treatment and the increase in the efficiency of WWTP systems (Table 7).

Table 7. Description of CH_4 emission scenarios for sewage treatment.

Scenario	Description
Current	Current Sewage Treatment Plants.
Scenario 1	Replacement of current treatment plants by well-operated conventional activated sludge systems.
Scenario 2	Replacement of current treatment plants by systems with anaerobic reactors.
Scenario 3	Implementation of the new WWTP with Moving Bed Biofilm Reactor (MBBR) System, advanced treatment technology for activated sludge and biofilters in the city of Maceió, replacing stabilization ponds and septic tank/anaerobic filter and compact activated sludge tank systems. Maintenance of other systems.
Scenario 4	Situation in which all WWTP work at optimal BOD removal efficiency.
Scenario 5	WWTP systems under current conditions, but with coverage of 100.0% of the population of the 77 municipalities in which it operates with the installation of anaerobic treatment systems.

Results and Discussion

GHG Emission

The total CO_2 equivalent emission for the year 2018 was 66.524.76 tCO_2e, as shown in Table 8. Emission referring to scope 1 sources (sewage treatment, mobile and stationary combustion) was 53.500.98 tCO_2e, while emission referring to scope 2 (electricity), the value was 13.023.77 tCO_2e. Emissions related to sewage treatment reached total of 52.677.53 tCO_2e, constituting the most significant source (about 79%) of GHG emissions among those analyzed.

Table 8. Total GHG emissions by emission sources of the Sanitation Company of the State of Alagoas for the year 2018.

Emission sources	Scope	Emission (tCO_2e.)	Contribution (%)
Wastewater treatment	1	52.677.53	79.2
Mobile combustion	1	811.83	1.2
Stationary combustion	1	11.62	0.0
Electricity	2	13.023.77	19.6
Total		66.524.76	100.0

Such GHG emission standard is also found in other Brazilian sanitation companies such as Sabesp, Copasa and Sanepar. However, in these companies, wastewater treatment contributions reach around 90.0%, which is mainly due to the higher level of population coverage with sewage collection and treatment systems and the inclusion of other emission substances and sources for accounting purposes. In Minas Gerais and São Paulo, the population percentage covered by the sewage system corresponded to 38% and 83% of the estimated total population, respectively (COPASA 2018; SABESP 2018). In the case of CASAL, the population covered with sewage treatment, according to this study, was 488.223 inhabitants, which corresponds to 14.7% of the state population.

Regarding emissions by type of sewage treatment (table 9), it was found that the oceanic disposal systems and anaerobic reactors presented the highest contributions of GHG emissions, with 32% and 29%, respectively. In contrast, treatment with activated sludge had the lowest emission (857.43 tCO_2e). GHG emission of collected and untreated sewage corresponds to 1.9% of the total. Despite the ocean disposal system having the highest percentage of emissions, the *per capita* emission was 0.07 tCO_2e. On the other hand, anaerobic systems presented per *capita* emission of 0.40 tCO_2e (Table 9). This is due to the low MCF presented by the oceanic disposal system (around 0.1), reducing the CO_2eq emission estimate (IPCC 2006). Therefore, the MCF of treatment systems is related to their *per capita* emissions.

Table 9. Annual tCO_2e emission by type of sewage treatment of the Sanitation Company of the State of Alagoas for the year 2018.

Type of treatment	Emission ($tCO_2e.$)	*Per capita* emission ($tCO_2e.hab^{-1}$)	Contribution (%)
Oceanic disposal system	16.909.05	0.07	32.1
Anaerobic reactors	15.379.52	0.40	29.2
Systems septic	10.978.93	0.15	20.8
Stabilization ponds	7.564.02	0.10	14.4
Collected and untreated	988.58	0.03	1.9
Compact activated sludge	857.43	0.05	1.6
Total	52.677.53		100.0

According to Lima and Salvador (2014), in a study performed with treatment plants in Brazil, anaerobic and open systems, such as septic ponds and tanks, are responsible for the highest GHG emissions, corroborating our results, when the *per capita* emissions found for these types of treatment were analyzed. One of the main characteristics of anaerobic reactors is the generation of biogas, which can play a negative role if it is directly sent to the atmosphere, or a positive role, if it is recovered (Lopes et al. 2020). In the city of Depok, Indonesia, septic tank treatment systems were the largest contributors to the total GHG emission (Pratana et al. 2021). Bahi et al. (2020) showed that anaerobic ponds were the main source of GHG emissions in the AinTaoujdate region – Morocco.

Of the total 811.83 tonnes of CO_2e emitted by mobile combustion sources, gasoline was responsible for emitting 608.61 tCO_2e, corresponding to 75.0% of the total GHG emissions related to mobile combustion, followed by diesel with 203.22 tCO_2e (25.0%) (Table 10). Alcohol, which was little consumed, presented negligible GHG emissions, as most of its emission corresponded to renewable biogenic CO_2. Stationary combustion produced a total of 11.62 tCO_2e, resulting from the burning of fossil fuels. The burning of diesel is responsible for the emission of 8.12 tCO_2e.

GHG emissions from mobile and stationary combustion accounted for only 1.2% of the total. Although small in relation to the treatment of sewages and energy, these emissions could be reduced by replacing the use of gasoline with ethanol in vehicles used by the company.

Table 10. Annual consumption and GHG emissions (tCO_2e) by combustion of the Sanitation Company of the State of Alagoas for the year 2018.

Fuel	Mobile combustion		Stationary combustion	
	Consumption (L)	Total emissions (tCO_2e)	Consumption (L)	Total emissions (tCO_2e)
Diesel	84.947.85	203.22	3.393.44	8.12
Gasoline	360.484.31	608.61	2.128.75	3.51
Ethanol	36.07	0.00	-	-
Total	445.468.23	811.83	5.522.19	11.62

Total GHG emissions resulting from electricity consumption were 13.023.77 tCO_2e/year. Of this total, 97.47% refer to water supply, 1.99% to wastewater and 0.55% to administrative activities. Santos (2015) found results similar to those identified in CASAL, with water supply being responsible for the highest consumption.

According to Zhang et al. (2017), in a study carried out in China between 2006 and 2012 with sanitation companies, it was observed that electricity consumption was responsible for 58.0% of the total GHG emitted by companies, since in addition to carrying out sewage treatment, they are responsible for treating water for human consumption and, in this sense, GHG is indirectly emitted during the operation of the water supply service.

Efficiency of treatment systems

Sewage monitoring data allowed observing the efficiency of treatment systems in promoting BOD removal, which is the main determinant of the potential for methane generation (Table 11). It was found that only 45.0% of entry BOD was removed during treatment, leaving 55.0%, which have been dumped into waterbodies.

Table 11. BOD removal by the sewage treatment.

Category	BOD (kg $year^{-1}$)	Contribution (%)
BOD Removed	7.412.457.53	45.0
BOD not removed	9.244.193.71	55.0
Total	16.656.651.24	100.0

These results reflect the deficiency of sewage treatment systems in the state of Alagoas - Brazil. In general, overall mean exit BOD of 192 ± 103 mg L^{-1} was obtained. The Resolution of the National Council for the Environment (CONAMA) No. 430/2011, which provides for sewage discharge standards, establishes maximum BOD of 120 mg L^{-1} as discharge standard for sewage treatment, which limit can be exceeded in the case of minimum BOD removal efficiency of 60.0% or through a receiving waterbody self-depuration study (BRASIL 2011).

According to the BOD removal efficiency in treatment systems and the average BOD values in the treated sewage for each system (Table 12), it appears that the most efficient treatment for BOD removal was the use of stabilization ponds, with BOD removal efficiency of 80.0%, with sewage BOD of 69.6 mg L^{-1}, followed by septic tank systems, with stabilization ponds and anaerobic reactors with stabilization ponds, with79.7 % and 79.5% of BOD removal efficiency, showing, respectively, sewage BOD of 58.1 and 52.0 mg L^{-1}. Stabilization pond systems are affected by cesspool and septic tank waste overloads. Strauss et al. (1997) reported that the process of co-treatment of waste from cesspools, septic tanks and sanitary sewage, in stabilization pond systems, can generate organic overload in the system and sludge accumulation at rates faster than expected, due to the high concentration of solids in septic tanks. In addition, fresh sludge also contains high ammonia concentration, which can harm and even prevent the development of algae, promoting a deficit in photosynthesis, consequently leading to low levels of dissolved oxygen in the liquid mass. The activated sludge system had the lowest BOD removal percentage (27.7%). Activated sludge is a very efficient technology; however, its operation is complex and to obtain maximum efficiency, it is necessary to control the aeration of the system, among other aspects. At CASAL, this operation did not occur in practice, which justifies the low efficiency achieved by the activated sludge. For the other treatments, BOD concentrations ranged from 132.0 to 282.2 mg L^{-1}, that is, above the limit concentration of 120 mg L^{-1} imposed by CONAMA resolution, and far higher than those found by Fonseca and Tibiriça (2018) and USEPA (2002). This result suggests that most of CASAL's WWTPs are operating below the ideal BOD removal efficiency. It is important to highlight that in the case of the oceanic disposal system, the low removal percentage is justified, given that such system corresponds to a preliminary treatment, whose principle is based on self-depuration carried out by the sea; therefore, its function is just the removal of coarse solids.

Table 12. BOD removal percentage in treatment systems.

Type of treatment	**Entry BOD** (kg $year^{-1}$)	**Removed BOD** (kg $year^{-1}$)	**Mean exit BOD** (mg L^{-1})	**Removal** (%)	**Ideal removal*** (%)
Stabilization ponds	2.440.758.27	1.951.763.97	69.6	80.0%	80.0%
Septic tank / filter / Stabilization ponds	269.011.54	214.384.67	58.1	79.7%	97.0%
Anaerobic reactors / ponds	205.476.11	163.353.33	52.0	79.5%	93.5%
UASB	66.414.82	47.474.29	140.0	71.5%	67.5%
Anaerobic reactors / aerobic reactors	1.162.664.49	807.343.45	132.0	69.4%	88.0%
Septic tank / filter	1.432.927.70	748.325.38	222.7	52.2%	82.5%
Anaerobic reactors / filter	145.479.59	62.048.65	211.8	42.7%	81.0%
Oceanic disposal system	10.735.905.60	3.293.409.60	202.3	30.7%	--
Compact activated sludge	226.834.04	62.840.70	282.2	27.7%	89.0%

Source: the author and *Von Sperling (2018)

Changes in CH_4 production or generation are related to the BOD removal process. If sewage treatment plants operate at their optimal removal potential, the treated sewage would meet discharge standards; however, there may be an increase in GHG emissions resulting from the treatment process, if CH_4 is not used (Huang et al. 2020). If there is low treatment efficiency, less GHG will be emitted, but the sewage treatment will not meet discharge standards (Bahi et al. 2020). In this sense, SUEZ, the company that operates the wastewater treatment plant in Strasbourg – France, has developed a project that consists of injecting biomethane produced from wastewater into the natural gas network. Currently, the company produces 1.6 million Nm3/year of purified methane, which is equivalent to the consumption of 5.000 low-consumption housing units. This new source of renewable energy has launched the transition to a new model of local and sustainable carbon energy in Strasbourg (SUEZ 2022).

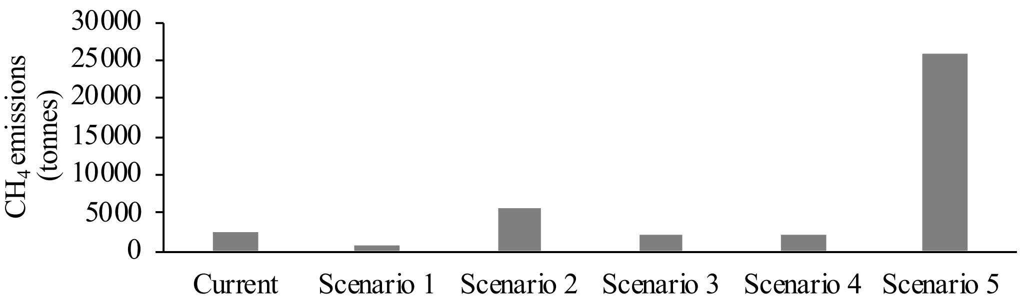
Evaluated scenarios

In 2016, Brazil emitted 1.467 Tg CO_2e with the waste treatment sector, being responsible for 4.5% of the country's total emissions (MCTIC 2021). Despite the low contribution of the sector, GHG emissions increased by 29% between 2010 and 2016, demonstrating the importance of adopting strategic actions to reduce such emissions.

In this perspective and considering that the largest emission contributions in the wastewater treatment and discharge sector are due to sewage treatment, IPCC (2006) proposes three options to reduce GHG emissions, namely: i) replacement of the anaerobic treatment process by aerobic process, which has low direct GHG emission if properly operated, as biogenic CO_2 emission does not alter the GHG balance in the atmosphere; ii) introduction of methane burners in anaerobic treatment systems, transforming it into CO_2 in a complete combustion; and iii) introduction of biogas recovery technologies for energy use. In this context, scenarios 1 and 3 were prepared according to option 1, suggested by IPCC.

In this study, CH_4 emission scenarios for the wastewater sector were proposed based on the results obtained (Figure 2). In scenario 1, with the replacement of current treatments by well-operated aerobic processes, there was a 62.9% reduction in methane emissions. However, it is noteworthy that when using aerobic systems, there is an increase in electricity consumption, as these systems need aerators, which consequently increases indirect emissions of equivalent CO_2. If current systems were replaced by anaerobic systems of anaerobic reactors, with MCF of 0.8 (scenario 2), there would be a 130.2% increase in CH_4 emissions. In scenario 3, which proposes the replacement of stabilization ponds by WWTP with MBBR aerobic system, there would be a 16.9% reduction in CH_4 emissions in relation to the current system. If current treatment plants operate at their maximum efficiency potential (scenario 4), there would be a 18.7% reduction in CH_4 emissions.

Figure 2. CH_4 emissions (tonnes) in different water treatment scenarios.



Scenario 5 demonstrates a reality in which there would be coverage with sanitary sewage for the entire population of the 77 municipalities served by CASAL with anaerobic treatments. In this scenario, there would be a 934.4% increase in CH_4 emissions, since increasing sewage collection and anaerobic treatment rates without CH_4 recovery tends to increase GHG emissions (Vieira et al. 2015). However, CH_4 emissions in scenario 5, despite being high when compared to the current scenario, have other environmental and public health benefits. Furthermore, the use of anaerobic systems, despite presenting higher CH_4 emissions, has the potential for use biogas to generate electricity, according to studies carried out by Lima and Salvador (2014); Nguyen et al. (2020); Ramtel et al. (2021).

For the year 2016, methane burning contributed to a 16% decrease in total emissions by the sewage treatment sector (MCTIC 2020). Thus, investment in technologies for the use of gas for energy generation or burning through flares, already adopted in Brazil, is an alternative to reduce GHG emissions (Lima and Salvador 2014).

According to Moreira et al. (2018), Brazilian WWTPs have significant potential for biogas production. However, according to the study on the potential of energy generation from sanitation waste by the United Nations Development Program – UNDP (PNUD BRAZIL 2010), although there is potential for use arising from the sewage volume generated in metropolises, there are few projects for the use of biogas in Brazil. In other countries, such as France, Denmark and Germany, (Macintosh et al. 2019; State of Green 2020; Suez 2022), there are projects for the use of biogas.

In addition to CH_4 emission scenarios referring to the type of sewage treatment, mobile combustion data were used for alternatives to reduce emissions arising from this category. As a result, when considering only the replacement of gasoline by ethanol, taking into account the amount of gasoline consumed by vehicles, there would be a 99.2% reduction in total CO_2 equivalent emissions. Thus, given the scenario presented for the use of fuel, the company is responsible for evaluating the benefits of using ethanol, aiming not only at the economic aspect, but mainly at the GHG aspect, in view of its responsibility with regard to social and environmental issues.

Knowing the profile of GHG emissions allows the establishment of strategies and targets for their reduction and/or compensation that, when carried out periodically, become a tool for managing such emissions (Pratana et al. 2021). CASAL, as one of the largest state-owned companies in Alagoas, operating 44 water supply systems and 51 sewage treatment systems, plays an important role in the social development of the state. Therefore, its activity must always be carried out with a view to economic, social and environmental sustainability.

Initially, for the establishment of a management tool, the involvement of senior management is of utmost importance in order to introduce the theme in the company, causing the engagement of all employees regarding the responsibility for managing the company's GHG emissions. The second step is the incorporation of practices for identifying GHG sources and methods for measuring GHG emissions within the organization through inventories, which enable the implementation of targets aimed at reducing such emissions. Additionally, these practices can be converted into a gain in the institutional image, as it demonstrates the company's responsibility and commitment to finding solutions or minimizing social and environmental impacts, also becoming a competitive advantage. (GHG PROTOCOL 2015).

Given the ever-increasing relevance of global warming and climate change, and public policies aimed at mitigating GHG emissions, it is essential that companies seek to know the profile of their emissions. Even so, despite the various initiatives and investments in this theme, carrying out GHG emission inventories and projects aimed at reducing these emissions still needs greater attention in the sanitation sector, since the practice of quantifying such emissions is not yet widespread in companies of the sector (Araujo et al. 2022). It is important to highlight that the present work analyzed the emissions form scope 1 and 2. However, the latest IPCC reports emphasized the urgency of incorporating the emissions form the scope 3, which include activities for which the company is not directly responsible for GHG emissions. Thus, the impacts of companies on the environment can be better evaluated and more effectively reduced. In recent times, the term ESG has gained great visibility due to the growing concern in the financial market about sustainability. Environmental, social and governance issues are now considered essential in risk analysis and investment decisions, putting strong pressure on the business sector, making ESG essential information for investor decision-making. ESG criteria are fully related to the 17 Sustainable Development Goals (SDGs). Thus, the rational and sustainable wastewater and water supply management for the population is directly related to SDGs 3 (Health and Welfare), 6 (Drinking Water and Sanitation), and 13 (Action Against Global Climate Change). One way to achieve the SDGs objectives is through actions known as nature-based solutions (NBS), which according to the European Commission (2015), are "actions inspired and supported by nature, which are cost-effective and simultaneously provide social, economic and environmental benefits and help build resilience". Several technologies have been recognized as NBS for energy recovery and reduction of GHG emissions by WWTPs (Pahunang et al. 2021). For example, algae-based wastewater treatment technologies are promising NBSs with economic and environmental benefits, mainly due to their efficiency, lower energy consumption and biomass production (Santos et al. 2021; Valchev et al. 2022; Viswanaathan et al. al. 2022). According to Santos et al. (2021), algae-based technology can generate reduction in energy operating costs between 0.05–0.41 EUR/m3 and 15.4–180.8 EUR/inhabitant compared to activated sludge and also reduce the carbon footprint by saving about 45 kg of CO_2eq/inhabitant per year. In view of these positive results, the Sanitation Company of the state of Alagoas must seek alternatives for effluent treatment that are increasingly ecological and less polluting than the current technologies adopted.

Conclusions

In this study, greenhouse gases emissions from the water supply and wastewater sector in Alagoas were estimated for scope I and scope II, which covers a population of 488.233 inhabitants, corresponding to 14.7% of the state population. Emissions from wastewater treatment were 66.524.76 tCO_2e for the year 2018. Of this total, 52.677.53 tCO_2e refer to sewage treatment, 13.023.77 tCO_2e

to electricity consumption and 823.45 tCO_2e to mobile and stationary combustion. Among types of sewage treatment, oceanic disposal systems and anaerobic reactors presented the highest GHG emission percentages, with 32% and 29% of GHG emissions, respectively. The system with the lowest GHG emission percentages was activated sludge, with only 2% contribution, but this system showed the lowest BOD removal percentage, with 27.7% removal. The most efficient sewage treatment for BOD removal was septic tank with stabilization ponds, with removal efficiency of 80.0%.

According to the different scenarios proposed, with the replacement of current treatments by well-operated aerobic systems, there will be reductions GHG generation.

The elaboration of GHG inventories is essential so that companies are aware of how much they emit and the sources of these emissions, so that they can use data obtained in a management tool, establishing mitigation strategies in their operations in order to achieve sustainability. The results may also help companies attract investors, due to the growing concern of the financial market about sustainability.

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References

Araujo MC, Medeiros DL, Cohim E. 2022. Desempenho energético e pegada de carbono de um sistema de esgotamento sanitário centralizado no nordeste brasileiro. Eng Sanit Ambient 27:(1):205-221. Doi: https://doi.org/10.1590/S1413-415220200325.

Asadi M, Mcphedran K. 2021. Estimation of greenhouse gas and odour emissions from a cold region municipal biological nutrient removal wastewater treatment plant. Journal of Environmental Management 281. Doi: https://doi.org/10.1016/j.jenvman.2020.111864.

Bahi Y, Akhssas A, Khamar M, Bahi L, Souidi H. 2020. Estimation of greenhouse gas (GHG) emissions from natural lagoon wastewater treatment plant: Case of AinTaoujdate Morocco. Web of Conferences 150. Doi: https://doi.org/10.1051/e3sconf/202015001012.

BRASIL. Ministério do Meio Ambiente. Resolução CONAMA nº 430, de 13 de maio de 2011. Dispõe sobre as condições e padrões de lançamento de efluentes, complementa e altera a Resolução no 357, de 17 de março de 2005, do Conselho Nacional do Meio Ambiente-CONAMA. [http://www2.mma.gov.br/port/conama/legiabre.cfm?codlegi=64].

Companhia de Saneamento de Alagoas (CASAL). 2019. Áreas de atuação. [https://www.casal.al.gov.br/areas-de-atuacao/]. Access 27th june 2019.

Companhia de Saneamento Básico do Estado de São Paulo (SABESP). 2018. Relatório de Sustentabilidade 2018, p.97

European Commission. 2015. Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities: Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'; Publications Office of the European Union: Luxembourg, p.3–70. ISBN 9789279460517. [https://data.europa.eu/doi/10.2777/479582]. Acess 12th February 2023.

Companhia de Saneamento de Minas Gerais (COPASA). 2018. Relatório de Sustentabilidade 2018, 176 p.

Companhia de Saneamento do Paraná (SANEPAR). 2019. Inventário de emissões de gases de efeito estufa 2018, p.37.

Fonseca WC, Tibiriça CEJA. 2021. Avaliação da influência da estação de tratamento de efluente de Catanduva (SP) na qualidade da água do rio São Domingos. Eng Sanit Ambient 26:(1):181-191. Doi: https://doi.org/10.1590/S1413-415220180157.

Forster P, Ramaswamy V, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC, Myhre G, Nganga J, Prinn R, Raga G, Schulz M, Van Dorland R. 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

GHG PROTOCOL. 2015. Por que fazer o inventário corporativo de emissões. 2015. [http://www.ghgprotocolbrasil.com.br/por-que-fazer-o-inventario-corporativo&gt]. Acess 02th december 2018.

GHG PROTOCOL. 2019. Ferramenta de cálculo. 2019. [http://www.ghgprotocolbrasil.com.br/ferramenta-de-calculo]. Acess 20th july 2020.

Instituto Brasileiro de Geografia e Estatísticas (IBGE). 2010. Domicílios particulares permanentes, Moradores em domicílios particulares permanentes e Média de moradores em domicílios particulares permanentes, por situação do domicílio. [https://sidra.ibge.gov.br/tabela/3451]. Acess 10th december 2019.

Intergovernmental Panel on Climate Change (IPCC). 2006: Guidelines for National Greenhouse Gas Inventories. Chapter 6. Wastewater treatment and discharge.

Intergovernmental Panel on Climate Change (IPCC). 2019. Chapter 6: Wastewater Treatment and Discharge. IN: Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Intergovernmental Panel on Climate Change (IPCC). 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Huang F, Shen W, Zhang X, Seferlis P. 2020. Impacts of dissolved oxygen control on different greenhouse gas emission sources in wastewater treatment process. Journal of Cleaner Production 274, Doi: https://doi.org/10.1016/j.jclepro.2020.123233.

Koutsou OP, Gatidou G, Stasinakis AS. 2018. Domestic wastewater management in Greece: Greenhouse gas emissions estimation at country scale. Journal of Cleaner Production 188:851-859. Doi: https://doi.org/10.1016/j.jclepro.2018.04.039.

Kumar A, Thanki A, Padhiyar H, Singh NK, Pandey S, Yadav M, Yu ZG. 2021. Greenhouse gases emission control in WWTS via potential operational strategies: A critical review. Chemosphere 273. Doi: https://doi.org/10.1016/j.chemosphere.2021.129694.

Li Y, Du W, Huisingh D. 2017. Challenges in developing an inventory of greenhouse gas emissions of Chinese cities: A case study of Beijing. Journal of Cleaner Production 161:1051-1063. Doi: https://doi.org/10.1016/j.jclepro.2017.06.072.

Lima AP, Salvador NNB. 2014. Geração de metano e de créditos de carbono no tratamento de esgotos sanitários. Revista DAE (195). Doi: http://dx.doi.org/10.4322/dae.2014.121.

Lopes TAS, Queiroza LM, Torres EA, Kiperstok A. 2020. Low complexity wastewater treatment process in developing countries: A LCA approach to evaluate environmental gains. Science of The Total Environment 720:137593. Doi: https://doi.org/10.1016/j.scitotenv.2020.137593.

Macintosh C, Astals S, Sembera C, Ertl A, Drewes JE, Jensen PD, Koch K. 2019. Successful strategies for increasing energy self-sufficiency at Grüneck wastewater treatment plant in Germany by food waste co-digestion and improved aeration Appl. Energy 242:797-808. Doi: https://doi.org/10.1016/j.apenergy.2019.03.126.

Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTIC). Fator médio – Inventários corporativos. 2018. [http://www.mctic.gov.br/mctic/opencms/ciencia/SEPED/clima/textogeral/emissao_corporativos.html]. Acess 16th july 2018.

Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTIC). 2020. Estimativas anuais de emissões de gases de efeito estufa no Brasil / Coordenação-Geral do Clima. 5. ed. Brasília: Ministério da Ciência, Tecnologia, Inovações e Comunicações.

Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTIC). 2021. Quarta Comunicação Nacional do Brasil à Convenção Quadro das Nações Unidas sobre Mudança do Clima / Secretaria de Pesquisa e Formação Científica. -- Brasília: Ministério da Ciência, Tecnologia e Inovações, 620 p.

Moreira HC, Possetti GRC, Souza RC, Knopki RH, Zawadzki RAFO. 2018. Diretrizes de capacitação para o uso de biogás de esgoto no Brasil. Revista DAE 66(209):134-150. Doi: http://dx.doi.org/10.4322/dae.2017.021.

Nayeb H, Maryam M, Motiee H, Alighardashi A, Khoshgard A. 2019. Estimating greenhouse gas emissions from Iran's domestic wastewater sector and modeling the emission scenarios by 2030. Journal of Cleaner Production, v. 236. Doi: https://doi.org/10.1016/j.jclepro.2019.117673.

Nayeb H, Maryam M.; Motiee H, Alighardashi A, Khoshgard A. 2020. A study on estimation of greenhouse gas emissions from industrial wastewater sector in Iran. J. App. Res. Wat. Wast. 7:64-69. Doi: https://doi.org/10.22126/arww.2020.4301.1129.

Nguyen LN, Kumar J, Vu MT, Mohammed JAH, Pathak N, Commault AS, Sutherland D, Zdarta J, Tyagi VK, Nghiem LD. 2020. Biomethane production from anaerobic co-digestion at wastewater treatment plants: a critical review on development and innovations in biogas upgrading techniques. Science of The Total Environment 765. Doi: https://doi.org/10.1016/j.scitotenv.2020.142753.

Pratana MA, Amrina U, Kristanto GA. 2021. Estimation of greenhouse gases from sewage from on-site sewage management system. IOP Conf. Ser.: Earth Environ. Sci. 724. Doi: https://doi.org/10.1088/1755-1315/724/1/012031.

Pahunang RR, Buonerba A, Senatore V, Oliva G, Ouda M, Zarra T, Muñoz R, Puig S, Ballesteros FC, Li CW, H SW, Belgiorno V, Naddeo V. 2021. Advances in technological control of greenhouse gas emissions from wastewater in the context of circular economy. The Science of the total environment 792:148479-148479. Doi: https://doi.org/10.1016/j.scitotenv.2021.148479.

Programa das Nações Unidas para o Desenvolvimento (PNUD BRAZIL). 2010. Produto 6 – resumo executivo. Estudo sobre o potencial de geração de energia a partir de resíduos de saneamento (lixo, esgoto), visando incrementar o uso de biogás como fonte alternativa de energia renovável. São Paulo: MMA.

Ramtel P, Tamang T, Pokhrel N, Mainali B, Paudel SR. 2021. Wastewater and biogas production in Kathmandu Valley, Nepal: Challenges and opportunities. Environmental Engineering and Management Journal 20(2):257-266.

Santos JO, Andrade JCS, Marinho MMO, Noyola A, Güereca LP. 2015. Greenhouse gas inventory of a state water and wastewater utility in Northeast Brazil. Journal of Cleaner Production 104:168-176. Doi: https://doi.org/10.1016/j.jclepro.2015.03.085.

Santos E, Albuquerque A, Lisboa I, Murray P, Ermis H. 2022. Economic Assessment of Energy Consumption in Wastewater Treatment Plants: Applicability of Alternative Nature-Based Technologies in Portugal. Water 14(13):2042. Doi: https://doi.org/10.3390/w14132042.

Strauss M, Larmie SA, Heinss U. 1997. Treatment of Sludges from On-Site Sanitation: Low-Cost Options. Water Science and Technology 35(6):129-136. Doi: https://doi.org/10.2166/wst.1997.0251.

Speranza J, Resende F. 2015. Adaptação às mudanças climáticas no Brasil: subsídios para o debate e a construção de políticas públicas. [http://forumempresarialpeloclima.org.br/wp-content/uploads/2015/04/Artigo-Adaptacao-Forum-Clima-20151.pdf]. Acess 27th june 2018.

State of green. 2020. From wastewater plant to power plant. [https://stateofgreen.com/en/partners/aarhus-vand/solutions/marselisborg-wwtp-energy-neutral-water-management/]. Acess 28th june 2021.

Suez. 2022. Harnessing the energy out of water and waste. [https://www.suez.com/en/who-we-are/innovating-for-the-future/exploit-the-energy-of-water-and-waste]. Acess 28th January 2023.

United States Environmental Protection Agency (USEPA). 2002. Wastewater Technology Fact Sheet: Aerated, Partial Mix Lagoons. EPA 832-F-02-008. Washington, D.C.: USEPA.

Valchev D, Ribarova I. 2022. A Review on the Reliability and the Readiness Level of Microalgae-Based Nutrient Recovery Technologies for Secondary Treated Effluent in Municipal Wastewater Treatment Plants. Processes 10(2):399. Doi: https://doi.org/10.3390/pr10020399.

Von Sperling M. 2018. Introdução à Qualidade das Águas e ao Tratamento de Esgotos. v.1. 4nd ed., Belo Horizonte, MG: UFMG, 470 p.

Vieira SMM, Alves JWS, Gonzalez MP. 2015. Terceiro inventário brasileiro de emissões e remoções antrópicas de gases de efeito estufa. Relatórios de Referência. Setor de tratamento de resíduos. Ministério da Ciência, Tecnologia e Inovação.

Viswanaathan S, Perumal PK, Sundaram S. 2022. Integrated Approach for Carbon Sequestration and Wastewater Treatment Using Algal–Bacterial Consortia: Opportunities and Challenges. Sustainability 14(3):1075. Doi: https://doi.org/10.3390/su14031075.

World Resources Institute and World Business Council for Sustainable Development (WRI/WBCSD). 2004. The Greenhouse Gas Protocol: a Corporate Accounting and Reporting Standard (Revised Edition). The Greenhouse Gas Protocol Initiative, USA and Switzerland.

Zhang Q, Nakatani J, Wang T. Chai C, Moriguchi Y. 2017. Hidden greenhouse gas emissions for water utilities in China's cities. Journal of Cleaner Production 162:665-677. Doi: https://doi.org/10.1016/j.jclepro.2017.06.042.