

# Estimation of greenhouse gas (GHG) emissions from natural lagoon wastewater treatment plant: Case of AinTaoujdate-Morocco

Yassine BAHI<sup>a</sup>, Ahmed AKHSSAS<sup>a</sup>, Mohamed KHAMAR<sup>b</sup>, Lahcen BAHI<sup>a</sup>, Hanane SOUIDI<sup>a</sup>

<sup>a</sup>Laboratory of Applied Geophysics, Geotechnics, Engineering Geology and Environment (L3GIE); Mohammadia School of Engineering; Mohammed V University of Rabat

<sup>b</sup>Civil Engineering and Environment Laboratory (LGCE); Materials, Water and Environment Team  
Higher School of Technology of Salé; Mohammed V University of Rabat

**Abstract.** The process of removing organic components from wastewater as BOD<sub>5</sub> through wastewater treatment plants has been proven to be a significant source of greenhouse gas emissions, mainly methane CH<sub>4</sub>, carbon dioxide CO<sub>2</sub> and nitrous oxide N<sub>2</sub>O. The reduction of these emissions has attracted more interest given their major contribution to global warming. This study was able to identify and estimate the amount of methane and CO<sub>2</sub> emissions on a monthly basis by a simple modeling approach and an empirical method (IPCC) for N<sub>2</sub>O emissions, in the case of Ain-Taoujdate wastewater treatment plant, throughout the years 2013, 2018 and 2019. The results showed that anaerobic ponds were the main source of on-site emissions with 66% of total contribution and 33% for facultative ponds, followed by the energy consumption of the pumping station as off-site GHG emissions.

Keywords: Greenhouse gases, Wastewater treatment plant, methane, On-site emissions, Off-site emissions

## 1. Introduction

Greenhouse gas emissions from anthropogenic sources such as use and production of fossil fuel, industrial and agricultural activities,[1] have been scientifically proven worldwide to be the main cause of global warming. The accumulation of GHGs in the atmosphere has increased rapidly in recent decades and threatens not only humans but also the entire planet's ecosystem. [2]

Wastewater treatment plants (WWTP) have been recognized as a major source of greenhouse gases due to their on-site and off-site production of three main gases: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), with a global warming potential (GWP) of 1, 28 and 265 respectively (IPCC 2014). [3] [4]

On-site emissions are source of different wastewater treatment procedures such as biological processes (CO<sub>2</sub> emissions from aerobic microbiological respiration, N<sub>2</sub>O source of nitrification and denitrification, CH<sub>4</sub> from anaerobic digestion). Methane from wastewater was found to contribute 5% of the global methane emissions. [1]

Off-site GhG emissions are from the energy consumption by different units of the station, in this case the power consumption of the WWTP and the pumping station.

Since the launch of the National Program of Sanitation and Wastewater treatment in 2006, Morocco has seen the creation of 140 wastewater treatment plants, which natural lagoon process is the most widely used at the national level, accounting for more than 82% of the WWTP carried out and 56% of the volume of treated wastewater. Aerated lagoon accounts for 2% of WWTP, activated sludge

12%, bacterial beds 2% and the algal channel about 2% of WWTP.

The city of AinTaoujdate has a natural lagoon-type wastewater treatment plant, consisting of pre-treatment facilities (screen, sand trap), four anaerobic basins and two Facultative basins, drying beds and an operating building.

Lagoon treatment process was used in our study to better estimate and quantify the sources of On-site emissions (Methane) based on the total BDO<sub>5</sub> removed ( $\Delta$ DBO) and Off-site (CO<sub>2</sub>) emissions from energy consumption [5] for the different scenarios 2013,2018 and 2019, and given the lack of data on analyses of total nitrogen removal ( $\Delta$ TN),nitrous oxide will be estimated annually by an empirical method based on assumptions provided by the 2019 IPCC guidelines.

## 2. Physical data on the study area:

### 2.1 Location of the wastewater treatment plant

The study area is located 5 km north of the city of Ain-Taoujdate (Fig1.B),and it's located 20 km from the city of Fès and 40 km from the city of Meknès (Fig 1.2d).

The city of AinTaoujdate is characterized by a warm and temperate climate, the temperature varies between a maximum of 35°C in August and a minimum of 4°C in January. The rainfall regime is characterized by heavy rains in autumn and winter and almost no rain in summer. Indeed, the rainfall year is composed of two seasons: a wet season from October to May with a maximum of 295.56mm in March and another dry season from June to September (Fig. 4).

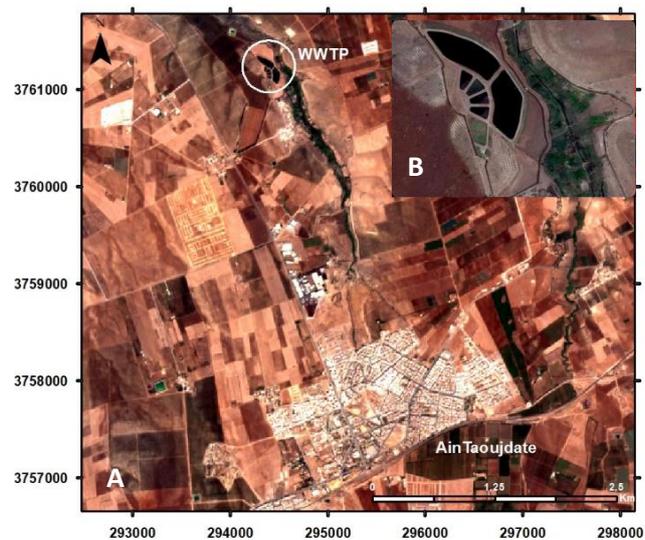
Temperature and precipitation regime are two factors that govern the purification performance of the anaerobic basins, the reduction of BOD<sub>5</sub> by the station is more efficient in a hot climate, since sunlight and adequate temperature play a very important role with a rate of 70% in the photosynthesis process.

On the other hand, under a winter season, the ambient temperature of the water becomes inadequate for the living microorganisms, the photosynthesis cycle breaks down, therefore less oxygen, the reduction becomes less effective with a rate of 40%.

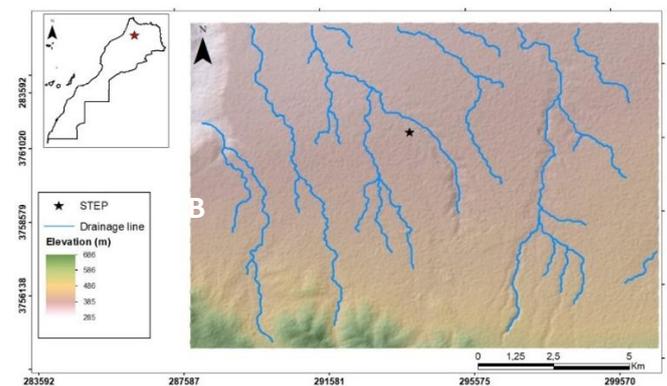
Afterward, temperatures also influence the transport and dispersion of GHG; they affect chemical

reactions between the constituents of the atmosphere. Precipitation, on the other hand, is involved in the formation, transport and deposition of aerosols. They also define the decomposition process (methane emission) and affect the growth of vegetation that absorbs some GHG and produces allergens (pollens, spores). [6]

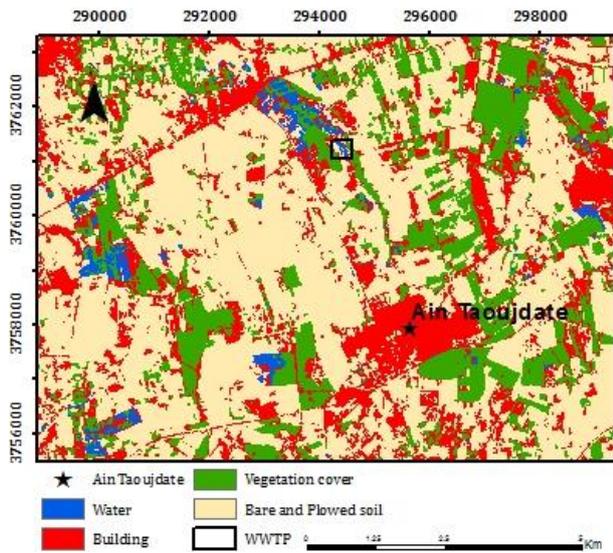
The current situation of the WWTP shows that it is located far from the city (5 km) and is surrounded in the center by areas of very dense vegetation and agricultural land that are governed by the changing seasons during the year (Fig. 3).



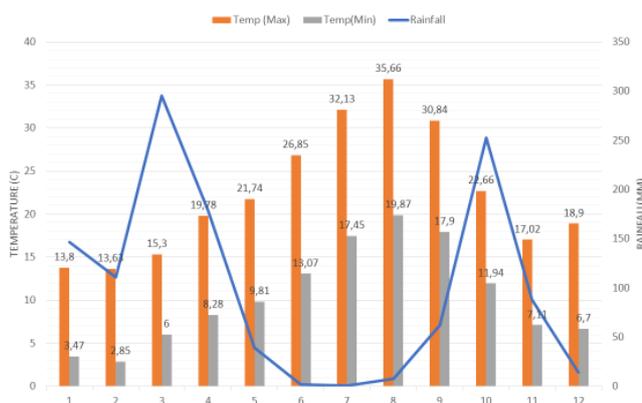
**Fig. 1. A) aerial view of the wastewater treatment plant. B) location of the treatment plant.**



**Fig.2: Digital Terrain Model of the AinTaoujdate region**



**Fig. 2.** Land use of Ain Taoujdate region



**Fig.3.** Temperature and precipitation variations Ain Taoujdate city in 2018 [7]

### 3. Methodology and methodology

The methodology of this study is based on the "Green House gas protocol" which was launched by the WBCSD (World Business Council for Sustainable Development) and the WRI (World Resources Institute), and serves as a knowledge and quantification tool for GHG emissions.

The calculation of emissions will be done in three steps:

#### Step 1: Setting organizational boundaries

the organizational boundary for this study includes the pumping station, the WWTP and the grid from which the energy is being imported. (Fig.6)

Sludge drying beds were not included in the scope due to the lack of reliable data on the quantity of sludge extracted.

#### Step 2: Setting operational boundaries

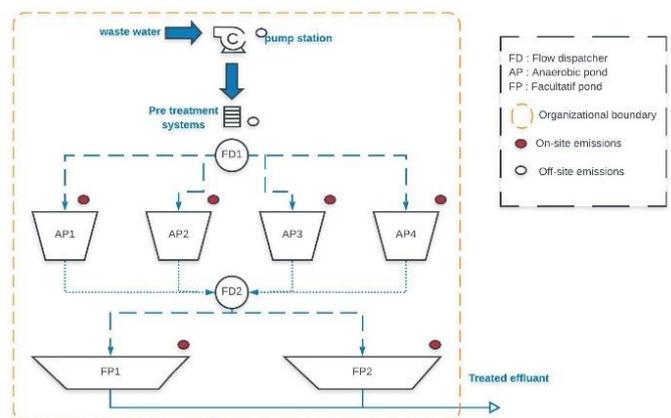
**Scope 1:** On-site emissions: Three gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O) will be considered and calculated. CO<sub>2</sub> emissions from the plant are not considered in the IPCC guidelines because Carbon dioxide, produced during biochemical treatment processes, is considered to be of "biogenic" origin, Therefore, its quantification should not be included in the estimation of national emissions. The IPCC suggests that biogenic CO<sub>2</sub> emissions should not be included, but some protocols encourage their quantification and inclusion in calculations [8].

A simplified modeling approach was chosen for estimating the direct emissions of each unit of the wastewater treatment plant for the BOD<sub>5</sub> [5] removal process, which includes the four aerobic and two facultative basins. (Fig.6)

Nitrous oxide emissions from the natural lagoon process are insignificant compared to methane emissions,[9] and will therefore be calculated using the empirical method proposed by the IPCC guidelines.

**Scope 2:** Off-site emissions: Indirect GHG emissions from imported electricity consumption. (Fig.6)

**Step 3:** Calculate and quantify monthly GHG emissions of the wastewater treatment plant for the years 2013,2018 and 2019. The year 2013 will be taken as a reference year since the station had a good performance in terms of its purification efficiency.



**Fig. 4** Organizational boundary of the WWTP

The organizational boundary shown in Figure 6 includes the direct and indirect emissions of the wastewater treatment plant:

**Pumping station:** 3 pumps including one backup pump with a nominal power of 15 Kw, and a total flow rate of 59l/s;

*Pre-treatment operations*, including a stilling basin, a decanting channel equipped with an inclined screen, an electromagnetic flow meter, and a venturi channel;

*Two flow distributors* (FD1&FD2), circular in shape (Diameter = 4m), one for anaerobic basins and one for facultative basins; (not included in the inventory, works as gravitational flow)

*Four anaerobic Ponds* (AP1, AP2, AP3, AP4) with a useful volume of 2,300 m<sup>3</sup> and a useful height of 3m;

*Two facultative ponds* (FP1&FP2) with a volume of 16,500 m<sup>3</sup> and a useful height of 1.5 m;

The station is also equipped with a sludge drying bed of Four units with a total surface area of 960 m<sup>2</sup>, but has been excluded from the boundary due to insufficient data and will therefore not be included.

### 3.1 Scope1: Method of calculation of On-site GhG emissions from the WWTP:

#### 3.1.1 Methane (CH<sub>4</sub>): estimated from anaerobic degradation of organic matter [10]

**Step.1:** Calculation of mass of BOD removed in unit process, i (Kg/BOD)  $M_{BOD,i}$  :

$$M_{BOD,i} = (\Delta BOD_i \times Q_{flow}) \times 10^{-3} \quad (1)$$

**Where:**

$\Delta BOD_i$  = removed BOD in unit process, i (mg/l)

$Q_{flow}$  = inflow wastewater (m<sup>3</sup>/d)

**Step.2:** Calculation of emission factor  $EF_{BOD,i}$  :

$$EF_{BOD,i} = B_0 \times MCF \quad (2)$$

**Where:**

$EF_{BOD,i}$  = emission factor, kg CH<sub>4</sub>/kg BOD

$i$  = each treatment/discharge pathway or system

$B_0$  = maximum CH<sub>4</sub> producing capacity, kg CH<sub>4</sub>/kg BOD

$MCF$  = methane correction factor (fraction)

The default methane correction coefficient (MCF) used will be 0.8 (according to IPCC 2019 guidelines).

The default maximum production capacity ( $B_0$ ) of CH<sub>4</sub> for domestic wastewater is 0.6 Kg CH<sub>4</sub>/Kg BOD.

Emission factor of CH<sub>4</sub> will be:

$$EF_{BOD,i} = 0.8 \times 0.6 = 0.48 \text{ kg CH}_4/\text{kg BOD}$$

**Step.3:** Estimation of CH<sub>4</sub> emissions from unit process, i (Kg CH<sub>4</sub>/d) :

$$CH_4 \text{ Unit process} = M_{BOD,i} \times EF_{BOD,i} \quad (3)$$

#### 3.1.2 Nitrous oxide (N<sub>2</sub>O): estimated from reactions associated with anoxic or anaerobic biological processes through nitrification and denitrification. [11]

**Step.1:** Calculation of total annual amount of nitrogen in wastewater  $TN_{DOM}$  :

$$TN_{DOM} = (P_{treatment} \times Protein \times F_{NPR} \times N_{HH} \times F_{non-com} \times F_{IND-COM}) \quad (4)$$

**Where:**

$TN_{DOM,j}$  = total annual amount of nitrogen in domestic wastewater for treatment pathway j, kg N/yr

$P_{treatment,j}$  = human population who are served by the treatment pathway j, person/yr

$Protein$  = annual per capita protein consumption, kg protein/person/yr

$F_{NPR}$  = fraction of nitrogen in protein, default = 0.16 kg N/kg protein

$F_{NON-CON}$  = factor for nitrogen in non-consumed protein disposed in sewer system, kg N/kg N.

$F_{IND-COM}$  = factor for industrial and commercial co-discharged protein into the sewer system, kg N/kg N

$N_{HH}$  = additional nitrogen from household products added to the wastewater, default is 1.1

The annual protein consumption per capita in Morocco is **0.9** Kg/person/year.

The factor for non-consumed protein disposed in wastewater ( $F_{NON-COM}$ ) will be **1.06**.

The factor for industrial and commercial co-discharged protein into the sewer system ( $F_{IND-COM}$ ) will be **1.25** kg N/kg N (source: IPCC 2019 guidelines).

**Step.2:** Calculation of the emission factor for nitrous oxide **EF**

The default value that has been taken for the EF is 0.001 kg  $N_2O$ -N/kg N (according to IPCC 2019 guidelines)

**Step.3:** Calculate  $N_2O$  emissions

$$N_2O \text{ Plants}_{DOM} = [\sum(U \times T \times EF)] \times TN_{DOM} \times \frac{44}{28} \quad (5)$$

**Where:**

$N_2O \text{ Plants}_{DOM}$  =  $N_2O$  emissions from domestic wastewater treatment plants in inventory year, kg  $N_2O$  /yr

$TN_{DOM}$ =total nitrogen in domestic wastewater in inventory year, kg N/yr.

**U**= fraction of population in income group *i* in inventory year.

**T**=degree of utilization treatment/discharge pathway or system

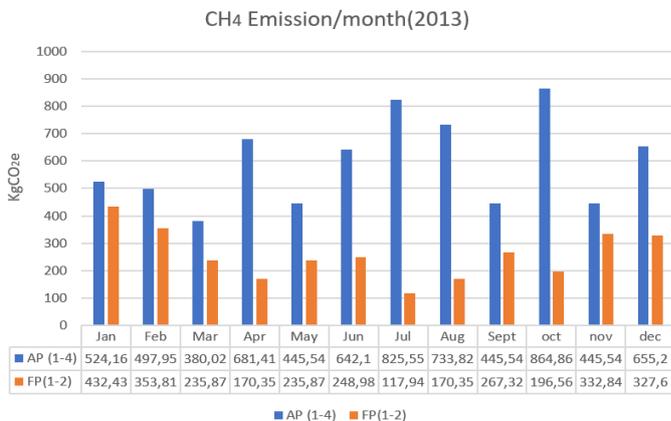
**EF**=emission factor for treatment/discharge pathway or system *j*, kg  $N_2O$  -N/kg N

### 3.2 Scope 2: Off-site GhG emissions from the WWTP:

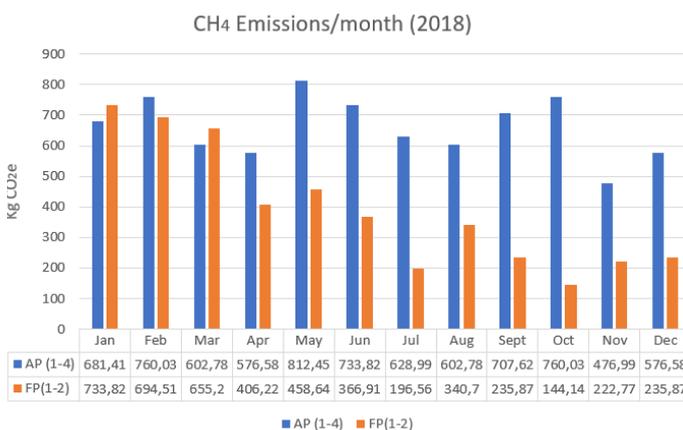
Indirect GHG emissions have been included as the electrical grid from which energy is being imported to supply the WWTP (Sand trap, Screening bar and the Electromagnetic flow meter), and the pumping station.

## 4. Results and discussions

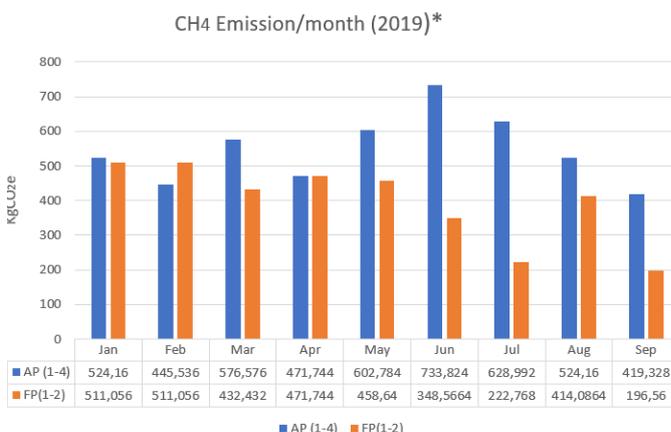
### 4.1. On-site emissions from the wastewater treatment plant



**Fig.5.** Estimation of methane emissions in 2013



**Fig.6.** Estimation of methane emissions in 2018



**Fig.9.** Estimation of methane emission in 2019\*

\*The data received on the BOD<sub>5</sub> analyses cover only the period of January and September

	2013	2018	2019*
Total GhG from anaerobic ponds (KgCO <sub>2</sub> e)	7141,68	7920,0576	4927,104
Total GhG from facultative ponds (KgCO <sub>2</sub> e)	3089,923	4691,23	3566,9
Total GhG from the WWTP (KgCO <sub>2</sub> e)	10231,60	12611,28	8494

**Table.10. The amounts of on-site GHG emissions generated from each unit-process**

To be able to analyze the variations over the years 2013, 2018, and 2019, the on-site emissions of methane generated from reactions of organic matter degradation and the off-site emissions of CO<sub>2</sub> from energy consumption were converted to KgCO<sub>2</sub>e (Fig. 7.8.9)

Off-site emissions from the wwtp will not be included in the analysis of variations since the consumption is the same for all years.

The results show that anaerobic basins are the major source of methane with a total of 7141,68KgCO<sub>2</sub>e/year, 7920,05 KgCO<sub>2</sub>e/year, 4927,104 KgCO<sub>2</sub>e/year, for the years of 2013, 2018, 2019 respectively against 3089,923 KgCO<sub>2</sub>e/year, 4691.23KgCO<sub>2</sub>e/year, 3566,9 KgCO<sub>2</sub>e/year for the facultative basins (Tab.10).

It should be noted that the total emissions in 2019 are provisional and therefore lower than the previous years since the last months (October, November, December) are not included in the study.

2018 is considered to be the year with the highest methane emissions with a total of 7920 KgCO<sub>2</sub>e with an average of 781,74 KgCO<sub>2</sub>e compared to 851,76 KgCO<sub>2</sub>e in 2013, and 840 KgCO<sub>2</sub>e in 2019. Should be noticed that the anaerobic basins were the major source of methane than facultative ones, except January and March with a total of 733,83 and 655,2 KgCO<sub>2</sub>e higher than anaerobic basins. It can be explained by the purification process, which means that during these two months, the wwtp faced some issues such as high organic load flow or aerobic and anaerobic conditions in both basins were not adequate.

Variations in methane emissions vary from year to year depending on the climate, volume load and water flow to be treated, emissions are high during June, July, August, and low during the rainy season

The current year recorded a maximum temperature of 32C, 35 C in June and July (Fig. 4) with a maximum methane emission of 733,82 and 629 KgCO<sub>2</sub>e, this increase in emissions can be explained by the increase in drinking water consumption, due to the arrival of mass of people during summer holidays, therefore a high production of waste water.

The facultative basins were the minor source of methane emissions with an average of 396,52 KgCO<sub>2</sub>e, meaning that at the exit of the WWTP the treated water becomes a small source of methane compared to the raw water.

The variation in methane emissions is related to the BOD<sub>5</sub> removal process, if we have a good efficiency from the plant, there will be more gas emissions and therefore treated water that meets discharge standards, but if we have a low efficiency from the plant, fewer gas emissions will be emitted and therefore non-compliant treated water.

Nitrous oxide (N<sub>2</sub>O) emissions, estimates were calculated annually by methods provided by the IPCC during the same periods (Tab.11), as analyses for total nitrogen removed (TN) were not performed, knowing that natural lagoon process is considered a minor source of nitrous oxide. [12]

The results showed an increase in N<sub>2</sub>O emissions in wastewater with a total of 1417,83 KgCO<sub>2</sub>e, 1662,36 KgCO<sub>2</sub>e and 1697,8 KgCO<sub>2</sub>e for the periods 2013,2018,2019 respectively, with a change rate of 2.11% for the period 2018-2019.

	2013	2018	2019
Population*	27589	30807	31465
U	0,6	0,63	0,63
T	0,98	0,98	0,98
EF (Kg N <sub>2</sub> O- N/Kg N)	0,001	0,001	0,001
TN <sub>DOM</sub> (Kg N/an)	5790,38	6465,77	6603,87
N <sub>2</sub> O Plants <sub>DOM</sub> (kgN <sub>2</sub> O/y)	5,35	6,27	6,40
CO <sub>2</sub> e/y	1417,83	1662,36	1697,87

**Table.11. Estimation of Nitrous Oxide emissions from domestic wastewater**

\* Source: [13]

#### 4.1 Off-site emissions from the wastewater treatment plant:

The annual energy consumption, total of indirect emissions generated by the wastewater treatment plant and pumping station and their percentage contributions are presented in the table (Tab.12) below:

	Annual consumption of electricity (Kwh)	Emission Factor* (Kg CO <sub>2</sub> /Kwh)	Scope 2 Emissions of CO <sub>2</sub> (KgCO <sub>2</sub> e)	Percentage (%)
Pump station	3996	0,717	2865,13	57,7
WWTP	2920	0,717	2093,64	42,2
Total	6910	0,717	4958,77	100

**Table.12. Total Electricity consumption and off-site emissions of the plant and the pump station**

\*Source: [14]

Estimation of off-site emissions from the pumping station show that the pumping station is the major source (2865,13 KgCO<sub>2</sub>e) contributing to 57.7% of total emissions (4958,77 KgCO<sub>2</sub>e) followed by the wastewater treatment plant with a contribution of 42.2% or 2093.64 KgCO<sub>2</sub>e.

By comparing the electricity consumption of our case natural lagoon-type station with the other types of stations, we can see that the electricity consumption for the bacterial bed-type process is estimated at 2,300 kWh/year for a capacity of 400 IE(inhabitant equivalent) and at 6,400 kWh/year for a capacity of 1000 IE, followed by aerated lagoon, where aeration is the largest energy consuming Unit with a specific energy consumption of about 1.1 to 2 kW/kg BOD<sub>5</sub> eliminated and from 100 to 370 Wh/m<sup>3</sup>. [15]

Eventually we find the activated sludge process which has been adopted for steps of more than 100,000 inhabitants and which is the most widely used in Morocco with an estimate of 280 to 780 Wh/m<sup>3</sup> when moving from a high to a low activated sludge load. Therefore, the electricity consumption at the level of natural lagoon process is estimated at 10% of the wwtp consumption per activated sludge. [16]

## 5. Conclusion and recommendations

The simple modelling approach for direct and indirect estimation has demonstrated accurate results on each unit of the treatment plant, better than the methods proposed by the IPCC guidelines.

These results showed that anaerobic basins accounted for the majority of on-site emissions followed by facultative basins, and the third source was the pumping station.

According to these estimation, the station is experiencing an exponential evolution of GhG emissions during the 2013-2019 period, and this evolution can be explained for several reasons: the increase of population connected to drinking water over the years, thus an increased production of wastewater, the increase of organic load received by the station, the long sludge cleaning period that takes place every 5-10 years, since the sludge retained at the bottom of the basins contribute as an important source of methane and CO<sub>2</sub>.

To be able to reduce the GHG emissions emitted by the WWTP, it is possible to opt for an aerated lagoon process using clean energies (e.g. Solar panels) which should increase the purification efficiency of the plant with less sludge production and a short cleaning period.

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