



# Greenhouse Gas Emissions from Wastewater Treatment Plants: A Case Study of Noida

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## ABSTRACT

Wastewater treatment plants (WWTPs) are based in natural processes and provide a high removal of BOD, COD, organic carbon, nutrients and pathogenic microorganisms from wastewater. Wastewater treatment generates significant amount of greenhouse gases mainly methane and nitrous oxide. Reducing these emissions from the treatment process and the contribution of the WWT processes to global warming is a major concern. On the other hand, WWTPs allow recovering energy, and nutrients, thus the reuse of treated wastewater in developing and developed countries can be appropriated. Hence, the understanding and estimation of the greenhouse gases emission pathways of the WW treatment plant is essential to tackle this challenge. This research has attempted to evaluate and quantify the greenhouse gases, mainly methane and nitrous oxide, emissions from the wastewater treatment system.

**Keywords:** Greenhouse gases; Global warming; Climate Change; Methane

## 1. INTRODUCTION

During the last 200 years the atmospheric concentrations of greenhouse gases (GHGs) have been increasing. Human activities such as agriculture, industry, waste disposal, deforestation, and especially fossil fuel have been producing increasing amounts of GHGs. For example, the concentrations of CO<sub>2</sub> increased from approximately 280 part per million by volume (ppmv) in pre-industrial age to 372.3 ppmv in 2001 and it will continue to increase at about 0.5% per year (IPCC, 2001) whereas current CH<sub>4</sub> atmospheric concentration is going up at a rate 0.02 ppmv per year. Furthermore, the annual sources of N<sub>2</sub>O have been increased from the surface of the Earth by about 40–50% over pre-industrial levels. As a result, variations in the radiative forcing of Earth's atmosphere could be being produced, so leading to large and rapid changes in the

earth's climate due to global warming produced by these gases.

The major greenhouse gases, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) can all be produced in wastewater treatment operations. Their greenhouse effect is typically weighted by their Global Warming Potentials (GWP) which is dependent on the timeframe of consideration, usually 100 years. The GWP factors for a 100 year horizon are given in Table 1. This means that over a period of 100 years one tonne of methane (CH<sub>4</sub>) will have a warming effect equivalent to 25 tonnes of CO<sub>2</sub>. In the calculations in this paper, only methane and nitrous oxide are considered since, carbon that is present in wastewater is biogenic (that is to say it was initially drawn down from the atmosphere in the production of food crops). As such, returning the carbon in this material to the atmosphere as CO<sub>2</sub> represents no net flux to the system (IPCC 2006).

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**Table 1** The GWP of GHGs produced in WWTPs

Gas	Chemical name	GWP
Carbon dioxide	CO <sub>2</sub>	1
Methane	CH <sub>4</sub>	25
Nitrous oxide	N <sub>2</sub> O	298

Source: IPCC Fourth Assessment Report, 2007

Beside the actual production of CO<sub>2</sub> and CH<sub>4</sub> in the treatment plant itself, the GHG production in the power generation process needs to be included in the calculations as well. While there are some major differences between various countries, a large number of them use fossil energy (coal, gas, oil) for power generation. These therefore contribute considerably to the overall GHG production. For the calculations in this paper, coal-based power generation has been assumed which is the most common form used in India.

Wastewater from the treatment plants can be a source of methane (CH<sub>4</sub>) when treated or disposed anaerobically. It can also be a source of nitrous oxide (N<sub>2</sub>O) and carbon dioxide (CO<sub>2</sub>).

### 1.1 Primary Greenhouse Gases of Concern from Wastewater Treatment Plants Are:

- a) CO<sub>2</sub>;
- b) CH<sub>4</sub>; and
- c) N<sub>2</sub>O

The greenhouse gas emitted from wastewater treatment plants depend upon the treatment technology employed therein. The paragraphs below detail the emissions sources of a particular GHG from a wastewater treatment plant.

#### 1.1.1 Carbon Dioxide (CO<sub>2</sub>)

CO<sub>2</sub> production is attributed to two main factors; treatment process and electricity consumption. During anaerobic process the BOD<sub>5</sub> of wastewater is either incorporated into biomass or it is converted to CO<sub>2</sub> and CH<sub>4</sub>. A fraction of biomass is further converted to CO<sub>2</sub> and CH<sub>4</sub> via endogenous respiration. Other emission sources of carbon dioxide are sludge digesters and from digester gas combustion.

In the aerobic process CO<sub>2</sub> is produced through the breakdown of organic matter in the activated sludge process and some through the primary clarifiers.

#### 1.1.2 Methane (CH<sub>4</sub>)

Wastewater as well as its sludge components can produce CH<sub>4</sub> if it degrades anaerobically. The extent of CH<sub>4</sub> production depends primarily on the quantity of degradable organic material in the wastewater, the temperature, and the type of treatment system. With increases in temperature, the rate of CH<sub>4</sub> production increases. This is especially important in uncontrolled systems and in warm climates.

#### 1.1.3 Nitrous Oxide (N<sub>2</sub>O)

N<sub>2</sub>O is associated with the degradation of nitrogen components in the wastewater, e.g., urea, nitrate and protein. Domestic wastewater includes human sewage mixed with other household wastewater, which can include effluent from shower drains, sink drains, washing machines, etc. Centralized wastewater

treatment systems may include a variety of processes, ranging from lagooning to advanced tertiary treatment technology for removing nitrogen compounds. After being processed, treated effluent is typically discharged to a receiving water environment (e.g., river, lake, estuary, etc.). Direct emissions of  $N_2O$  may be generated during both NDN of the nitrogen present. Both processes can occur in the plant and in the water body that is receiving the effluent. Nitrification is an aerobic process converting ammonia and other nitrogen compounds into nitrate ( $NO_3^-$ ), while denitrification occurs under anoxic conditions (without free oxygen), and involves the biological conversion of nitrate into nitrogen gas ( $N_2$ ).  $N_2O$  can be an intermediate product of both processes, but is more often associated with denitrification.

## 2. METHODOLOGY

The methodology of this paper is based on GHG protocol and IPCC Guidelines for National Greenhouse Gas Inventories (2006).

### 2.1 The Greenhouse Gas Protocol (GHG Protocol)

The GHG Protocol is an internationally accepted protocol for quantifying GHG emissions. It is a joint initiative by WBCSD and WRI and serves as the premier source of knowledge about corporate GHG accounting and reporting.

### 2.2 Steps Followed for Preparing A GHG Inventory Are as Follows:

#### Step 1: Setting organizational boundaries:

The organizational boundary for this study includes the WWTP and the grid from which the electricity is being imported.

#### Step 2: Setting operational boundaries:

This study identifies following emissions associated with operation and the treatment process at WWTP:

- **Scope 1: Direct GHG emissions** – In scope 1 three gases i.e.  $CO_2$ ,  $CH_4$  and  $N_2O$  are calculated for WWTP.  $CO_2$  emissions from WWTP are not considered in the IPCC Guidelines because these are of biogenic origin and should not be included in national total emissions. Biogenic origin means short cycle or natural sources of atmospheric  $CO_2$  which cycles from plants to animals to humans as part of the natural carbon cycle and food chain do not contribute to global warming. Photosynthesis produced short-cycle  $CO_2$ , removes an equal mass of  $CO_2$  from the atmosphere that returns during respiration or wastewater treatment.

- **Scope 2: Indirect GHG emissions:** Scope 2 emissions are from import of electricity, steam or gas; and

- **Scope 3: Other Indirect GHG emissions:** Scope 3 emissions have not been included because of insufficient data.

#### Step 3: Tracking emissions over time:

In this study GHG emissions are calculated for a period of one year from Jan. 2011 – Dec. 2011 (both months inclusive).

#### Step 4: Identifying and calculating GHG emissions:

We have followed IPCC Guidelines for National Greenhouse Gas Inventories, 2006 for calculating GHG emissions from WWTPs.

## 3. GHG EMISSIONS FROM WW TREATMENT AT GLOBAL LEVEL

Worldwide wastewater is the fifth largest source of anthropogenic CH<sub>4</sub> emissions, contributing approximately 9% of total global CH<sub>4</sub> emissions in 2000. India, China, United States, and Indonesia combined account for 49% of the world's CH<sub>4</sub> emissions from wastewater. Global CH<sub>4</sub> emissions from wastewater are expected to grow by approximately 20% between 2005 and 2020.

Also, worldwide wastewater as a source is the sixth largest contributor to N<sub>2</sub>O emissions, accounting for approximately 3 % of N<sub>2</sub>O emissions from all sources. Indonesia, the United States, India, and China accounted for approximately 50 % of total N<sub>2</sub>O emissions from domestic wastewater in 2000. Global N<sub>2</sub>O emissions from wastewater are expected to grow by approximately 13% between 2005 and 2020.

The highest regional percentages for CH<sub>4</sub> emissions from wastewater are from Asia (especially China, India) (US EPA, 2006). Other countries with high emissions in their respective regions include Turkey, Bulgaria, Iran, Brazil, Nigeria and Egypt. Total global emissions of CH<sub>4</sub> from wastewater handling are expected to rise by more than 45% from 1990 to 2020 with much of the increase from the developing countries of East and South Asia, the Middle East, the Caribbean, and Central and South America. The EU has projected lower emissions in 2020 relative to 1990 (US EPA, 2006).

#### 4. GHG EMISSIONS FOR WWTP AT NOIDA- CASE STUDY

##### 4.1 Description of system

The plant is situated in Uttar Pradesh, Noida Sector-54. The capacity of the plant is 33 MLD at present. This 33 MLD sewage treatment plant is based on Sequencing Batch Re-

actor (SBRs). Flow diagram of the WWTP is shown below in figure 1.

##### 4.2 Calculation of GHG emissions from the plant

The GHG emissions for the plant were estimated based on the technology used for treatment of WW and the anticipated energy used in the plant during operation.

###### • Scope 1: Direct GHG emissions

- a. CO<sub>2</sub> produced through breakdown of organic matter during the aerobic phases of the SBR process.
- b. CH<sub>4</sub> emissions from SBR are primary clarifiers and aeration basins in small quantities or if improperly managed.
- c. N<sub>2</sub>O emissions from the discharge of the effluent into the receiving environment.
- d. From the diesel generator used at the site. There is one DG set of 1250 KVA at the plant.

###### • Scope 2: Indirect GHG emissions

Indirect GHG emissions resulting from the off-site generation of electric power consumed at WWTP. The expected power use on site was calculated based on the electricity consumption from the following components:

- a. Raw sewage pump and pump house
- b. Primary units
  - Grit mechanism
  - Grit screw conveyor
- c. C-Tech basins
  - Return activated sludge pumps (RAS)
  - Surplus activated sludge pumps (SAS)
- d. Blower room for C-Tech
  - Blower for C-Tech
  - Service water pumps for after cooler
- e. Sludge sump, centrifuge platform and pump house
  - Blower for sludge sump

- Centrifuge feed pumps (roto pumps)
  - DWPE dosing pumps
  - DWPE agitators
- f. Chlorination room and pump house
- Booster pumps
  - Blower for caustic soda pump
  - Caustic solution pump
  - Service water pumps for DWPE

**I. Steps for calculating CH<sub>4</sub> emissions are as follows:**

- Step 1: Estimation of organically degradable material in domestic wastewater is shown in Table 2.
- Step 2: Estimation of methane emission factor for domestic wastewater is shown in Table 3.
- Step 3: Estimation of CH<sub>4</sub> emissions from domestic wastewater is summa-

rized in Table 4.

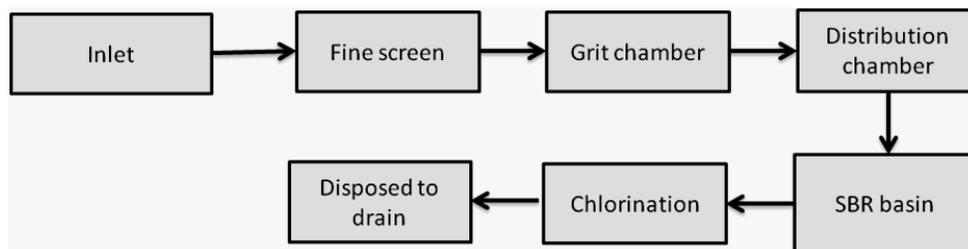
**II. Steps for calculating N<sub>2</sub>O emissions**

- Step 1: Estimation of nitrogen in effluent is shown in Table 5.
- Step 2: Estimation of emission factor and emissions of indirect N<sub>2</sub>O emissions from wastewater is shown in Table 6.

**III. Emissions from DG set used at site are depicted in Table 7.**

**IV. Indirect GHG emissions from the consumption of electricity at WWTP are summarized in Table 8.**

Calculations of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions are shown below in the following tables:



**Figure 1** Flow diagram of the WWTP

**Table 2** Estimation of organically degradable material in domestic wastewater

Sector	Waste			
Category	Domestic wastewater treatment and discharge			
Sheet	1 of 3 Estimation of organically degradable material in domestic wastewater			
<b>STEP 1</b>				
	A	B	C	D
<b>City (region)</b>	Population (P) cap	Degradable organic component (BOD) (kg BOD/cap/yr) <sup>1</sup>	Correction factor for industrial BOD discharged into sewers (I) <sup>2</sup>	Organically degradable material in wastewater (TOW) (kg BOD/yr)
<b>Uttar Pradesh (Noida)</b>				D= A x B x C
	610394	12.41	1.25	9468736.925

<sup>1</sup> g BOD/cap/day x .001x365 = kg BOD/cap/yr

<sup>2</sup> Correction factor for additional industrial BOD discharged into sewers, (for collected the default is 1.25, for uncollected the default is 1.00)

**Table 3** Estimation of methane emission factor for domestic wastewater

Sector	Waste		
Category	Domestic wastewater treatment and discharge		
Sheet	1 of 2 Estimation of CH <sub>4</sub> emission factor for domestic wastewater		
<b>STEP 2</b>			
	A	B	C
<b>Type of treatment or discharge</b>	Maximum methane producing capacity (Bo) (kg CH <sub>4</sub> / kg BOD)	Methane correction factor or each treatment system (MCF <sub>i</sub> )	Emission factor (EF <sub>i</sub> ) (kg CH <sub>4</sub> /kg BOD)
<b>Aerobic treatment</b>	0.6	0.05	C=AXB 0.03

**Table 4** Estimation of methane emissions from domestic wastewater

Sector	Waste					
Category	Domestic wastewater treatment and discharge					
Sheet	3 of 3 Estimation of CH <sub>4</sub> emissions from domestic wastewater					
<b>STEP 3</b>						
		A	B	C	D	E
<b>Income group</b>	Type of treatment or discharge	Fraction of Population income group (U <sub>i</sub> ) fraction	Degree of utilization (T <sub>ij</sub> ) fraction	Emission factor (EF <sub>j</sub> ) (kg CH <sub>4</sub> / kg BOD)	Organically degradable material in wastewater (TOW) (kg BOD/yr)	Sludge removed (S) (kg BOD/yr)
	Aerobic treatment			Step 2 of 3	Step 1 of 3	
<b>Rural</b>		0.71	0.1	0.03	9468736.92	0
<b>Urban high income</b>		0.06	0.07			
<b>Urban low income</b>		0.23	0.03			
<b>Total</b>		0.333	0.066			
		F	G	F	H	I
<b>Income group</b>	Type of treatment or discharge	Methane recovered and flared (R) (kg CH <sub>4</sub> /yr)	Net methane Emissions (CH <sub>4</sub> ) (kg CH <sub>4</sub> /yr)	GWP for CH <sub>4</sub> <sub>298</sub> (IPCC FAR, 2007)	Total CO <sub>2</sub> e kg CO <sub>2</sub> e/yr	Total CO <sub>2</sub> e t CO <sub>2</sub> e/yr
	Aerobic treatment		G=[(AxBxC) x (D-E)]-F	25		
<b>Rural</b>		0				
<b>Urban high income</b>						
<b>Urban low income</b>						
<b>Total</b>			6243		156077.75	156.07

**Table 5** Estimation of nitrogen in effluent

Sector		Waste					
Category		Domestic wastewater treatment and discharge					
Sheet		1 of 2 Estimation of nitrogen in effluent					
<b>STEP 1</b>							
	A	B	C	D	E	F	G
	Popula- tion (P)	Per capita protein consumption (Protein)	Fraction of nitro- gen in protein (F <sub>npr</sub> )	Fraction of non consump- tion protein (F <sub>non-con</sub> )	Fraction of industrial and commercial co-discharged protein (F <sub>ind- com</sub> )	Nitrogen removed with sludge (default is zero) (N <sub>sludge</sub> )	Total nitrogen in effluent (N <sub>effluent</sub> )
<b>Units</b>	people	kg/person/yr	kgN/ kg protein	-	-	kg	kg N/year
							G= (AXBXCX DXE) – F
	610394	0.056	0.16	1.4	1.25	0	9570.97

**Table 6** Estimation of emission factor and emissions of indirect N<sub>2</sub>O emissions from wastewater

Sector		Waste						
Category		Domestic wastewater treatment and discharge						
Sheet		2 of 2 Estimation of emission factor and emissions of indirect N <sub>2</sub> O emissions from wastewater						
<b>STEP 2</b>								
	A	B	C	D	E	F	G	H
	Nitrogen in effluent	Emission factor	Conversion factor of kg N <sub>2</sub> O-N into kg N <sub>2</sub> O	Emissions from waste- water plants (default as zero)	Total N <sub>2</sub> O emissions	GWP for N <sub>2</sub> O	Total CO <sub>2</sub> e	Total CO <sub>2</sub> e
<b>Units</b>	kg N/ year	(kg N <sub>2</sub> O- N/kg N)	44/28	kg N <sub>2</sub> O/ year	kg N <sub>2</sub> O/ year	298 (IPCC FAR, 2007)	kg CO <sub>2</sub> e/yr	t CO <sub>2</sub> e/yr
	9571	0.0005	1.57	0	7.52	298	2240.98	2.24

**Table 7** Emissions from diesel generator set

Total Diesel consumption (L/year)	Emission factor (t CO <sub>2</sub> e/ L) of diesel	Total CO <sub>2</sub> e (t CO <sub>2</sub> e/ year)
18200	0.00255	46.41

**Table 8** Electricity consumption of the plant

Area	Total MWH Used yearly	Emissions Factor 0.91 t CO <sub>2</sub> e	Total Scope 2 Emissions CO <sub>2</sub> e
Pump house	215.715	0.91 t CO <sub>2</sub> / Mwh	196 t CO <sub>2</sub> e
Primary units	39.420	0.91 t CO <sub>2</sub> / Mwh	36 t CO <sub>2</sub> e
C-Tech basins	3.394	0.91 t CO <sub>2</sub> / Mwh	3 t CO <sub>2</sub> e
Blower room	2842.642	0.91 t CO <sub>2</sub> / Mwh	2587 t CO <sub>2</sub> e
Sludge pump	45.260	0.91 t CO <sub>2</sub> / Mwh	41 t CO <sub>2</sub> e
Chlorination room	-	-	-
<b>Total</b>	<b>3146</b>	<b>0.91 t CO<sub>2</sub>/ Mwh</b>	<b>2863 t CO<sub>2</sub>e</b>

**Note:** Power used for chlorination room is not included because it was not found operational during visit.

**Table 9** Total emissions of the plant

Area	Source	CO <sub>2</sub> e Emissions
Scope 1	CH <sub>4</sub>	156 t CO <sub>2</sub> e
	N <sub>2</sub> O	2.24 t CO <sub>2</sub> e
	DG set	46.41 t CO <sub>2</sub> e
Scope 2	Electricity use	2863 t CO <sub>2</sub> e
Scope 3		Not Assessed
<b>Total</b>		<b>3027.84 t CO<sub>2</sub>e</b>

## 5. TOTAL EMISSIONS OF THE PLANT

Total emissions of the plant are shown in Table 9.

## CONCLUSIONS

The study is used for estimating energy use and GHG emissions from WWTPs. Under the proposed configuration, the plant's GHG is comprised mainly of scope 2 emissions related to the operation of the SBR process and associated equipment. CH<sub>4</sub> production is assessed as 157 t CO<sub>2</sub>e and N<sub>2</sub>O emissions to the receiving environment are also very less.

- CH<sub>4</sub> produced in the treatment process should be captured and used for generation of electricity or used as a fuel at site, if it is not captured it will discharged into the atmosphere and which will cause increased concentration of GHGs in the atmosphere.
- The CO<sub>2</sub> from the power generation can be eliminated if primarily anaerobic processes are used. Overall, a largely anaerobic degradation of the wastewater pollutants seems economically, and technically feasible and would have major environmental benefits in terms of greenhouse gas production.

**NOMENCLATURE**

GWP: Global warming potential  
 CH<sub>4</sub>: Methane  
 N<sub>2</sub>O: Nitrous oxide  
 CO<sub>2</sub>: Carbon dioxide  
 CO<sub>2</sub>e: Carbon dioxide equivalent  
 WWTP: Wastewater Treatment Plant  
 GHG: Greenhouse Gas

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