

BEYOND

SMART CITIES

URBAN GREENHOUSE GAS INVENTORY

SPECIALIST TRAINING COURSE

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GHG AND CLIMATE CHANGE SPECIALIST CURRICULUM

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FOR GHG & CLIMATE CHANGE PROFESSIONALS

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WHAT SHOULD YOU LEARN



Categorizing waste and wastewater emissions

Defining Solid Waste types and general calculation procedures

Calculating emissions from solid waste disposal

Calculating emissions from biological treatment of solid waste

Calculating emissions from waste incineration and open burning

Calculating emissions from wastewater treatment

INTRODUCTION

Cities produce solid waste and wastewater (together referred to collectively as "waste") that may be disposed of and/or treated at facilities inside the city boundary, or transported to other cities for treatment. Waste disposal and treatment produces GHG emissions through aerobic or anaerobic decomposition, or incineration.

✓Cities shall report all GHG emissions from disposal or treatment of waste generated within the city boundary, whether treated inside or outside the city boundary.

✓Emissions from waste imported from outside the city but treated inside the city shall be excluded from BASIC/BASIC+ totals. These emissions shall still be reported in total scope 1 emissions.

CATEGORIZING WASTE AND WASTEWATER EMISSIONS

Solid waste and wastewater may be generated and treated within the same city boundary, or in different cities. For accounting purposes, the following rules apply:

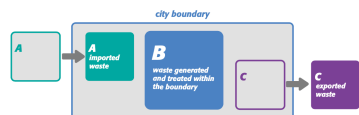
✓Scope 1: Emissions from waste treated inside the city

✓Scope 2: Not applicable

✓Scope 3: Emissions from waste generated by the city but treated outside the city

CATEGORIZING WASTE AND WASTEWATER EMISSIONS

Figure.1 illustrates boundary considerations for emission sources in the Waste sector. In this figure, the blue border represents the city's geographic boundary and:



✓A illustrates waste generated outside of the city boundary and treated within the boundary

✓B illustrates waste generated and treated within the city's boundary

✓C illustrates waste generated inside the boundary and treated outside of the boundary

DEFINING SOLID WASTE TYPES AND GENERAL CALCULATION PROCEDURES

Waste type categories and waste collection methods vary by country. Cities should identify city-specific waste composition and waste generation data where possible, to achieve more accurate calculation results.

✓ **Municipal solid waste (MSW)** : MSW is generally defined as waste collected by municipalities or other local authorities. MSW typically includes: food waste, garden and park waste, paper and cardboard, wood, textiles, disposable diapers, rubber and leather, plastics, metal, glass, and other materials (e.g., ash, dirt, dust, soil, electronic waste).

✓ **Sludge** : In some cities, domestic wastewater sludge is reported as MSW, and industrial wastewater treatment sludge in industrial waste. Other cities may consider all sludge as industrial waste. Cities should indicate this classification when reporting sludge emissions

DEFINING SOLID WASTE TYPES AND GENERAL CALCULATION PROCEDURES

✓ **Industrial Waste** : Industrial waste generation and composition vary depending on the type of industry and processes/ technologies used and how the waste is classified by country. For example, construction and demolition waste can be included in industrial waste, MSW, or defined as a separate category. In many countries industrial waste is managed as a specific stream and the waste amounts are not covered by general waste statistics.

✓ **Other waste** : Clinical waste, Hazardous waste



CALCULATING EMISSIONS FROM SOLID WASTE DISPOSAL

Solid waste may be disposed of at managed sites (e.g., sanitary landfill and managed dumps), and at unmanaged disposal sites (e.g., open dumps, including above-ground piles, holes in the ground, and dumping into natural features, such as ravines).

The CPC provides two commonly acceptable methods for estimating methane emissions from solid waste disposal: first order of decay and methane commitment.

✓ **First order of decay (FOD)** assigns landfill emissions based on emissions during that year. It counts GHGs actually emitted that year, regardless of when the waste was disposed. The FOD model assumes that the degradable organic component (DOC) in waste decays slowly over a few decades, during which CH₄ and CO₂ are released.

✓ **Methane commitment (MC)** assigns landfill emissions based on waste disposed in a given year. It takes a lifecycle and mass-balance approach and calculates landfill emissions based on the amount of waste disposed in a given year, regardless of when the emissions actually occur (a portion of emissions are released every year after the waste is disposed).

COMPARING METHANE COMMITMENT TO FIRST ORDER DECAY METHOD

User Consideration	Methane commitment (MC)	First Order of Decay (FOD)
Simplicity of implementation, data requirements	Advantage: Based on quantity of waste disposed during inventory year, requiring no knowledge of prior disposal. Disadvantage: Does not represent GHG emissions during inventory year. Rolls together current and future emissions and treats them as equal. Inconsistent with other emissions in the inventory.	Disadvantage: Based on quantity of waste disposed during inventory year as well as existing waste in landfill(s). Requires historic waste disposal information. Advantage: Represents GHG emissions during the inventory year, consistent with other emissions in the inventory.
Consistency with annualized emissions inventories		
Decision-making for future waste management practices	Disadvantage: May lead to overestimation of emission reduction potential.	Advantage: Spreads benefits of avoided landfill disposal over upcoming years.
Credit for source reduction/reycling	Advantage: Accounts for emissions affected by source reduction, reuse, and recycling.	Disadvantage: For materials with significant landfill impacts, FOD not as immediately sensitive to source reduction, reuse, and recycling efforts.
Credit for engineering controls, best/power generation	Disadvantage: Doesn't count current emissions from historic waste in landfills, thus overplaying opportunities to reduce those emissions via engineering controls.	Advantage: Suitable for approximating amount of landfill gas available for flaring, heat recovery or power generation projects.
Credit for avoided landfill disposal	Disadvantage: Overstates short-term benefits of avoided landfill disposal.	Advantage: Spreads benefits of avoided landfill disposal over upcoming years, minimizing overestimation of emission reduction potential.
Accuracy	Disadvantage: Requires predicting future gas collection efficiency and modeling parameters over the life of future emissions.	Advantage: More accurate reflects total emissions occurring in the inventory year.

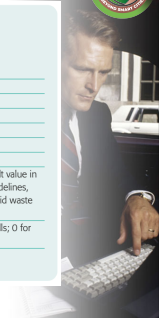


FIRST ORDER OF DECAY (FOD) MODEL ESTIMATE FOR SOLID WASTE SENT TO LANDFILL

$$\text{CH}_4 \text{ emissions} = \left[\sum_x \left[\text{MSW}_x \times L_0(x) \times \left((1 - e^{-k}) \times e^{+k \cdot (t-x)} \right) \right] - R(t) \right] \times (1 - \text{OX})$$

Description	Value
CH ₄ emissions	= Total CH ₄ emissions in tonnes Computed
x	= Landfill opening year or earliest year of historical data available User input
t	= Inventory year User input
MSW _x	= Total municipal solid waste disposed at SWDS in year x in tonnes User input
R	= Methane collected and removed (ton) in inventory year User input
L ₀	= Methane generation potential Consult equation 8.4
k	= Methane generation rate constant, which is related to the time taken for the DOC in waste to decay to half its initial mass (the "half-life") User input or consult default value in table 3.4 of 2006 IPCC guidelines, vol. 3: waste, chapter 3: solid waste disposal, p. 3.17
OX	= Oxidation factor 0.1 for well-managed landfills; 0 for unmanaged landfills

Source: IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2000)

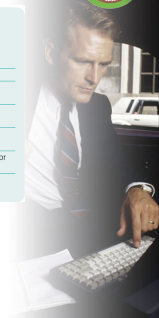


METHANE COMMITMENT ESTIMATE FOR SOLID WASTE SENT TO LANDFILL

$$\text{CH}_4 \text{ emissions} = \text{MSW}_x \times L_0 \times (1 - f_{\text{re}}) \times (1 - \text{OX})$$

Description	Value
CH ₄ emissions	= Total CH ₄ emissions in metric tonnes Computed
MSW _x	= Mass of solid waste sent to landfill in inventory year, measured in metric tonnes User input
L ₀	= Methane generation potential Equation 8.4 Methane generation potential
f _{re}	= Fraction of methane recovered at the landfill (flared or energy recovery) User input
OX	= Oxidation factor 0.1 for well-managed landfills; 0 for unmanaged landfills

Source: Adapted from Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories



Source: IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2000)

$$\text{N}_2\text{O Emissions} = (\sum_i (m_i \times \text{EF_N}_2\text{O}_i) \times 10^{-3})$$

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 4: Biological Treatment of Solid Waste

A photograph showing a large pile of waste being incinerated. Thick, dark smoke rises from the pile, filling the upper half of the frame. The sky is clear and blue. The foreground shows the ground covered in ash and debris.



NON-BIOGENIC CO2 EMISSIONS FROM THE INCINERATION OF WASTE

CO₂ Emissions =

$$m \times \sum (WF_i \times dm_i \times CF_i \times FCF_i \times OF_i) \times (44/12)$$

Description		Value
CO ₂ emissions	= Total CO ₂ emissions from incineration of solid waste in tonnes	Computed
m	= Mass of waste incinerated, in tonnes	User input
WF _i	= Fraction of waste consisting of type i matter	User input ¹⁴
dm _i	= Dry matter content in the type i matter	
CF _i	= Fraction of carbon in the dry matter of type i matter	
FCF _i	= Fraction of fossil carbon in the total carbon component of type i matter	User input (default values provided in Table 8.4 below)
OF _i	= Oxidation fraction or factor	
i	= Matter type of the Solid Waste incinerated such as paper/cardboard, textile, food waste, etc.	

Note: $\sum WF_i = 1$

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories

CH₄ EMISSIONS FROM THE INCINERATION OF WASTE

CH₄ Emissions =

$$\sum (IW_i \times EF_i) \times 10^{-6}$$

Description		Value
CH ₄ Emissions	= CH ₄ emissions in inventory year, tonnes	Computed
IW _i	= Amount of solid waste of type i incinerated or open-burned, tonnes	User Input
EF _i	= Aggregate CH ₄ emission factor, g CH ₄ /ton of waste type i	User Input (default values provided in Table 8.5 below)
10 ⁻⁶	= Converting factor from gCH ₄ to t CH ₄	
i	= Category or type of waste incinerated/open-burned, specified as follows: MSW municipal solid waste, ISW: industrial solid waste, HW: hazardous waste, CW: clinical waste, SS: sewage sludge, others (that must be specified)	User input

N₂O EMISSIONS FROM THE INCINERATION OF WASTE

N₂O Emissions =

$$\sum (IW_i \times EF_i) \times 10^{-4}$$

Description		Value
N ₂ O Emissions	= N ₂ O emissions in inventory year, in tonnes	Computed
IW _i	= Amount of solid waste of type i incinerated or open-burned, in tonnes	User Input
EF _i	= Aggregate N ₂ O emission factor, g CH ₄ /ton of waste type i	User Input (default values provided in Table 8.6 below)
i	= Category or type of waste incinerated/open-burned, specified as follows: MSW: municipal solid waste, ISW: industrial solid waste, HW: hazardous waste, CW: clinical waste, SS: sewage sludge, others (that must be specified)	User input

CALCULATING EMISSIONS FROM WASTE INCINERATION AND OPEN BURNING

Incineration is a controlled, industrial process, often with energy recovery where inputs and emissions can be measured and data is often available. By contrast, open burning is an uncontrolled, often illicit process with different emissions and can typically only be estimated based on collection rates. To calculate emissions from waste incineration, cities must identify:

- ✓ Quantity (mass) of total solid waste incinerated in the city, and the portion of waste generated by other communities and incinerated in the inventory analysis year (if calculating for in-boundary incineration facilities)
- ✓ Type of technology and conditions used in the incineration process
- ✓ "Energy transformation efficiency" (applies to incineration with energy recovery)



CALCULATING EMISSIONS FROM WASTEWATER TREATMENT

Municipal wastewater can be treated aerobically (in presence of oxygen) or anaerobically (in absence of oxygen). When wastewater is treated anaerobically, methane (CH₄) is produced. Both types of treatment also generate nitrous oxide (N₂O) through the nitrification and denitrification of sewage nitrogen. N₂O and CH₄ are potent GHGs that are accounted for during wastewater treatment, while most of CO₂ from wastewater treatment is considered to be of biogenic origin.

In order to quantify the methane emissions from both industrial and domestic wastewater treatment, cities will need to know:

- ✓ The quantity of wastewater generated.
- ✓ How wastewater and sewage are treated (see Box 8.3 for information on wastewater discharge directly into open bodies of water).
- ✓ The wastewater's source and its organic content. This can be estimated based on population of the cities served and the city's composition in the case of domestic wastewater, or the city's industrial sector in the case of industrial waste water.



CH₄ GENERATION FROM WASTEWATER TREATMENT

$$\text{CH}_4 \text{ emissions} = \sum_i [(TOW_i - S_i) EF_i - R_i] \times 10^{-3}$$

Description	Value
CH ₄ emissions	Total CH ₄ emissions in metric tonnes Computed
TOW _i	Organic content in the wastewater For domestic wastewater: total organics in wastewater in inventory year, kg BOD ₅ /yr ^{Note 1} For industrial wastewater: total organically degradable material in wastewater from industry i in inventory year, kg COD/yr ² Equation 8.10
EF _i	Emission factor kg CH ₄ per kg BOD or kg CH ₄ per kg COD ^{Note 2} Equation 8.10
S _i	Organic component removed as sludge in inventory year, kg COD/yr or kg BOD/yr User input
R _i	Amount of CH ₄ recovered in inventory year, kg CH ₄ /yr User input
i	Type of wastewater For domestic wastewater: income group for each wastewater treatment and handling system For industrial wastewater: total organically degradable material in wastewater from industry i in inventory year, kg COD/yr Equation 8.10

Note 1: Biochemical Oxygen Demand (BOD): The BOD concentration indicates only the amount of carbon that is aerobically biodegradable. The standard measurement for BOD is a 5-day test, denoted as BOD₅. The term "BOD" in this chapter refers to BOD₅.

Note 2: Chemical Oxygen Demand (COD): COD measures the total material available for chemical oxidation (both biodegradable and non-biodegradable).

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, chapter 6: Wastewater Treatment and Discharge



TOTAL CH₄ EMISSIONS FROM INDUSTRIAL WASTEWATER



$$\text{CH}_4 \text{ emissions} = \sum_i [(TOW_i - S_i) \times EF_i - R_i] \times 10^{-6}$$

Description		Value
CH ₄ emissions	= Total CH ₄ emissions in metric tonnes	Computed
TOW _i	= Total organically degradable material in wastewater from industry i in inventory year, kg COD/yr	User input
i	= industrial sector	User input
EF _i	= Emission factor for industry i, kg CH ₄ per kg COD	User input
S _i	= Organic component removed as sludge in inventory year, kg COD/yr or kg BOD/yr	User input
R _i	= Amount of CH ₄ recovered in inventory year, kg CH ₄ /yr	User input
10 ⁻⁶	= Conversion of kg to Gg	

Source: 2019 Refinement - IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, chapter 6: Wastewater Treatment and Discharge

ORGANIC CONTENT AND EMISSION FACTORS IN DOMESTIC WASTEWATER



$$TOW_i = P \times BOD \times i \times 365$$

$$BOD_i = B_o \times MCF_i \times U_i \times T_{c,i}$$

Description		Value
TOW _i	= For domestic wastewater: total organics in wastewater in inventory year, kg BOD/yr	Computed
P	= City's population in inventory year (person)	User input ¹⁵
BOD	= City-specific per capita BOD in inventory year, g/person/day	User input ¹⁷
i	= Correction factor for additional industrial BOD discharged into sewers	In the absence of expert judgment, a city may apply default value 1.25 for collected wastewater, and 1.00 for uncollected. ¹⁶
EF _i	= Emission factor for each treatment and handling system	Computed
B _o	= Maximum CH ₄ producing capacity	User input or default value: • 0.6 kg CH ₄ /kg BOD • 0.25 kg CH ₄ /kg COD
MCF _i	= Methane correction factor (fraction)	User input ¹⁸
U _i	= Fraction of population in income group i in inventory year	
T _{c,i}	= Degree of utilization (ratio) of treatment/discharge pathway or system, j, for each income group fraction i in inventory year	User input ¹⁹

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, chapter 6: Wastewater Treatment and Discharge

INDIRECT N₂O EMISSIONS FROM WASTEWATER EFFLUENT



$$\text{N}_2\text{O emissions} = [(P \times \text{Protein} \times F_{\text{PR}} \times F_{\text{NDCN}} \times F_{\text{INDCOM}}) - N_{\text{SLUDGE}}] \times EF_{\text{EFFLUENT}} \times 44/28 \times 10^3$$

Description		Value
N ₂ O emissions	= Total N ₂ O emissions in tonnes	Computed
P	= Total population served by the water treatment plant	User input
Protein	= Annual per capita protein consumption, kg/person/yr	User input
F _{NDCN}	= Factor to adjust for non-consumed protein	1.1 for countries with no garbage disposals, 1.4 for countries with garbage disposals
F _{PR}	= Fraction of nitrogen in protein	0.16, kg N/kg protein
F _{INDCOM}	= Factor for industrial and commercial co-discharged protein into the sewer system	1.25 Centralized systems 0 Decentralized systems
N _{SLUDGE}	= Nitrogen removed with sludge, kg N/yr	User input or default value: 0
EF _{EFFLUENT}	= Emission factor for N ₂ O emissions from discharged to wastewater in kg N ₂ O-N per kg N ₂ O	Refer to default EF values for domestic and industrial wastewater ²⁰
44/ 28	= The conversion of kg N ₂ O-N into kg N ₂ O	

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, chapter 6: Wastewater Treatment and Discharge