2006 IPCC Guidelines: Waste Sector

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Outline

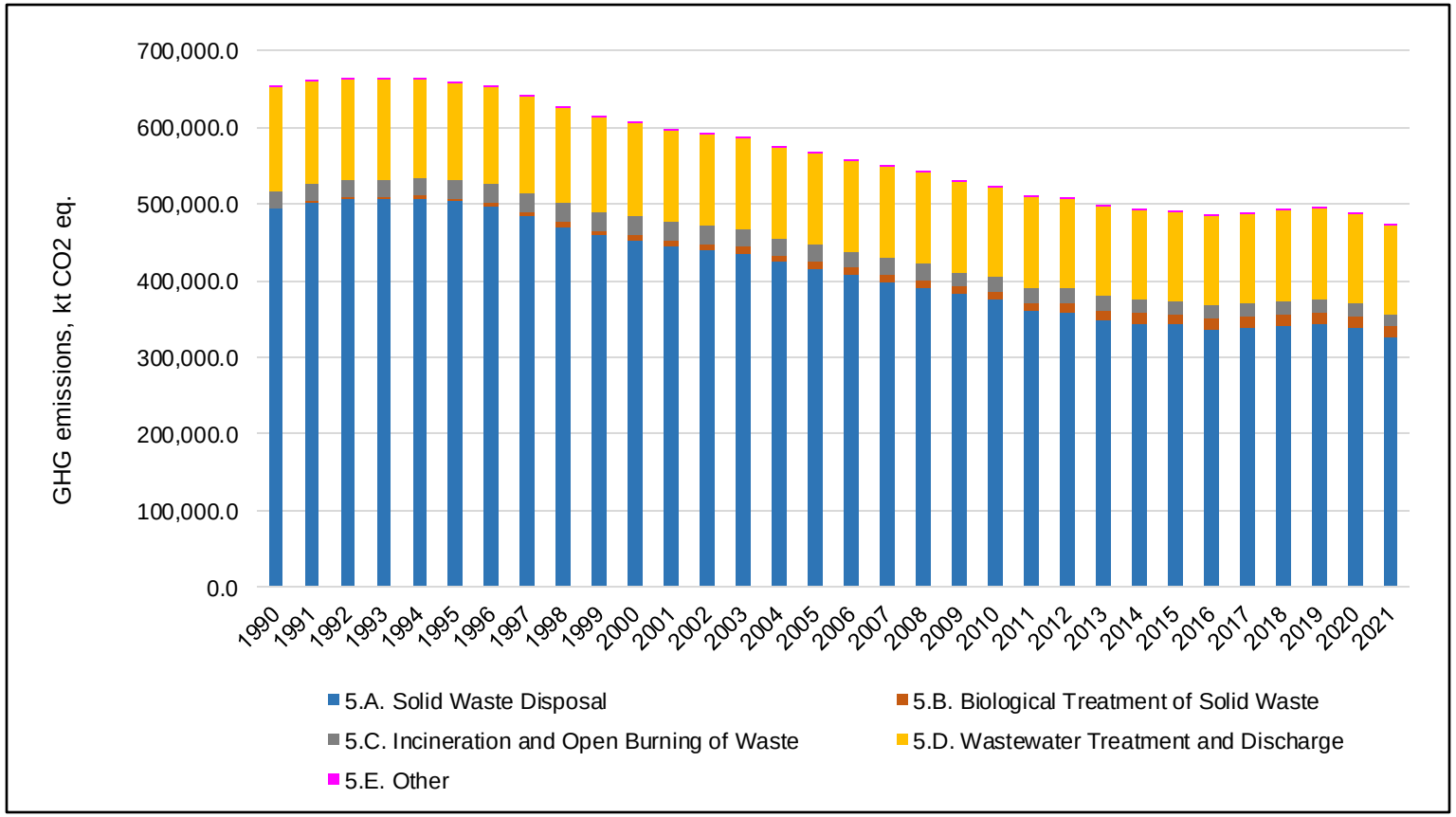
- Introduction
- Methods for Estimation of Greenhouse Gas Emissions from Waste Sector
  - Solid waste disposal
  - Biological treatment of solid waste
  - Incineration and open burning of waste
  - Wastewater treatment and discharge
- Waste Data

Introduction

- Volume 5 (Waste) provides methodological guidance for estimation of CO_2, CH_4 and N_2O emissions from following categories:
  - Solid waste disposal
  - Biological treatment of solid waste
  - Incineration and open burning of waste
  - Wastewater treatment and discharge
- Typically, CH_4 emissions from solid waste disposal sites (SWDS) are the largest source in Waste sector.
- Biogenic CO_2 emissions are not included in Waste sector
  - Any net changes in carbon stock of biogenic origin is covered under AFOLU sector
- All greenhouse gas (GHG) emissions from waste-to-energy should be estimated and reported under Energy sector.

Introduction

GHG emissions from Waste sector (Annex I Parties)



The emissions from Solid Waste Disposal account for 69-77% of Waste sector emissions followed by emissions from Wastewater Treatment and Discharge (19-24%)

Source: https://di.unfccc.int/ghg_profile_annex1

Solid Waste Disposal

- Disposal of **municipal, industrial** and **other solid waste** produces significant amounts of CH_4.
  - Decomposition of organic components in waste under anaerobic environment
- Waste disposal practices vary in placement of waste and management of the site, etc.
  - Methane correction factor (**MCF**) accounts for the fact that unmanaged SWDS produce less CH_4 from a given amount of waste than anaerobic managed SWDS.
- Methodology for estimating CH_4 emissions from SWDS is based on First Order Decay (**FOD**) method
  - Degradable organic component in waste at landfills decays slowly throughout a few decades during which significant amount of CH_4 and CO_2 are formed (some N_2O, NMVOCs, NOx and CO)
  - A simple **spreadsheet model** (IPCC Waste Model) is provided to assist countries in using the FOD method.

Solid Waste Disposal: CH_4 Emissions

- CH_4 emissions in year T from SWDS (Gg)

$$CH_4\ Emissions = \left[\sum_x CH_4 generated_{x,T} - R_T\right] \bullet \left(1 - OX_T\right)$$

T : inventory year

X : waste category or type/material

R_T: recovered CH_4 in year T, Gg

OX_T : oxidation factor in year T, fraction

- CH_4 generated is estimated on the basis of the amount of Decomposable Degradable Organic Carbon (DDOCm) which is the part of the organic carbon that will degrade under the anaerobic conditions in SWDS.

Solid Waste Disposal: Choice of Methods, AD and EFs

- Methodological tiers for estimation of CH_4 emissions
  - Tier 1: Based on IPCC FOD method using mainly default activity data (AD) and default parameters
  - Tier 2: Use IPCC FOD method and some default parameters, but require good quality country-specific AD on current and historical waste disposal at SWDS
  - Tier 3: Based on the use of good quality country-specific AD and the use of either the FOD method with (1) nationally developed key parameters, or (2) measurement derived country-specific parameters.
- Key parameters include **half-life**, and either methane generation potential (**Lo**) or degradable organic carbon (**DOC**) content in waste and the fraction of DOC which decomposes (DOC_f).
- The FOD method requires data for historical disposal of solid waste
  - The *2006 IPCC Guidelines* provide guidance on estimation of historical waste disposal data
- Default values for AD and emission parameters are given in Chapters 2 and 3.

2019 Refinement

Updated and **new** default values e.g., MCF, DOC_f

Biological Treatment of Solid Waste

- Composting and anaerobic digestion of organic waste (food waste, garden and park waste etc.)
  - reduced volume in the waste material
  - stabilisation of waste
  - production of biogas for energy use
  - end product can be recycled as a fertilizer or soil amendment
- Composting
  - large fraction of DOC in waste is converted to CO_2
  - CH_4 and N_2O can both be formed during composting
- Anaerobic digestion
  - Biogas (CH_4 and CO_2)
  - N_2O is assumed to be negligible

Biological Treatment of Solid Waste: CH_4 Emissions

- Default method for estimation of CH_4 emissions:

$$CH_4\ Emissions = \sum_i \left(M_i \bullet EF_i\right) \bullet 10^{-3} - R$$

CH_4 Emissions : total CH_4 emissions in inventory year, Gg CH_4

M_i : mass of organic waste treated by biological treatment type *i*, Gg

EF_i : emission factor for treatment *i*, g CH_4/kg waste treated

i : composting or anaerobic digestion

R : total amount of CH_4 recovered in inventory year, Gg CH_4. If the recovered gas is flared, the emissions should be reported in Waste Sector.

Biological Treatment of Solid Waste: N_2O Emissions

- Default method for estimation of N_2O emissions:

$$N_2O\ Emissions = \sum_i (M_i \bullet EF_i) \bullet 10^{-3}$$

N_2O Emissions : total N_2O emissions in inventory year, Gg N_2O

M_i : mass of organic waste treated by biological treatment type *i*, Gg

EF_i : emission factor for treatment *i*, g N_2O/kg waste treated

i : composting or anaerobic digestion

Biological Treatment of Solid Waste: Choice of Methods, AD and EFs

- Methodological tiers for estimation of CH_4 and N_2O emissions
  - Tier 1: Uses IPCC default EFs
  - Tier 2: Country-specific EFs based on representative measurements are used
  - Tier 3: Based on facility or site-specific measurements data (on-line or periodic)
- Regional default values for AD and EFs are given in Chapters 2 and 4
- It is *good practice* that countries use national, annually or periodically collected data, where available
  - National statistics
  - Data from municipal or regional authorities responsible for waste management, or from waste management companies.

Incineration and Open Burning of Waste

- Waste incineration: combustion of solid and liquid waste in controlled incineration facilities.
- Open burning of waste: combustion of solid waste in open-air or in open dumps. It also can include uncontrolled incineration devices.
- Incineration and open burning of waste are sources of GHG emissions including CO_2, CH_4 and N_2O
  - Emissions from waste incineration without energy recovery are reported in Waste Sector
  - Emissions from incineration with energy recovery are reported in Energy Sector

2019 Refinement

New thermal technologies (pyrolysis, gasification and plasma) and default EFs

Incineration and Open Burning of Waste: CO_2 Emissions

- Based on the total amount of waste combusted:

$$CO_2\ Emissions = \sum_i (SW_i \bullet dm_i \bullet CF_i \bullet FCF_i \bullet OF_i) \bullet 44/12$$

CO_2 Emissions : CO_2 emissions in inventory year, Gg/yr

SW_i : total amount of solid waste of type *i* (wet weight) incinerated or open-burned, Gg/yr

dm_i : dry matter content in the waste (wet weight) incinerated or open-burned, (fraction)

CF_i : fraction of carbon in the dry matter (total carbon content), (fraction)

FCF_i : fraction of fossil carbon in the total carbon, (fraction)

OF_i : oxidation factor, (fraction)

44/12 : conversion factor from C to CO_2

i : type of waste incinerated/open-burned such as municipal solid waste (MSW), industrial solid waste (ISW), sewage sludge, hazardous waste, clinical waste, etc.

Estimation of the amount of fossil carbon is the most important factor determining the CO_2 emissions as only CO_2 emissions of fossil origin (e.g., plastics, certain textiles, rubber, liquid solvents, and waste oil) should be included.

Incineration and Open Burning of Waste: CO_2 Emissions

- Emissions from MSW:

$$CO_2\ Emissions = MSW \bullet \sum_j (WF_j \bullet dm_j \bullet CF_j \bullet FCF_j \bullet OF_j) \bullet 44/12$$

CO_2 Emissions : CO_2 emissions in inventory year, Gg/yr

MSW : total amount of municipal solid waste as wet weight incinerated or open-burned, Gg/yr

WF_j : fraction of waste type/material of component *j* in the MSW (as wet weight incinerated or open-burned)

dm_j : dry matter content in the component *j* of the MSW incinerated or open-burned, (fraction)

CF_j : fraction of carbon in the dry matter (i.e., carbon content) of component *j*

FCF_j : fraction of fossil carbon in the total carbon of component *j*

OF_j : oxidation factor, (fraction)

44/12 : conversion factor from C to CO_2

j : component of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste

2019 Refinement

Updated oxidation factor for MSW open burning etc.

Incineration and Open Burning of Waste: CH_4 Emissions

- CH_4 emissions result from incomplete combustion of waste and can be affected by temperature, residence time, and air to waste ratio

$$CH_4\ Emissions = \sum_i (IW_i \bullet EF_i) \bullet 10^{-6}$$

CH_4 Emissions : CH_4 emissions in inventory year, Gg/yr

IW_i : amount of solid waste of type *i* incinerated or open-burned, Gg/yr

EF_i : aggregate CH_4 emission factor, kg CH_4/Gg of waste

10^{-6} : conversion factor from kilogram to gigagram

i : category or type of waste incinerated/open-burned (MSW, ISW, hazardous waste, clinical waste, sewage sludge, etc.)

The amount and composition of waste should be consistent with AD used for estimating CO_2 and N_2O emissions from incineration/open burning.

Incineration and Open Burning of Waste: N_2O Emissions

- The N_2O emissions are mainly determined by technology, combustion temperature (emitted at relatively low combustion temperatures 500-950°C) and waste composition.

$$N_2O\ Emissions = \sum_i (IW_i \bullet EF_i) \bullet 10^{-6}$$

N_2O Emissions : N_2O emissions in inventory year, Gg/yr

IW_i : amount of incinerated/open-burned waste of type *i* , Gg/yr

EF_i : N_2O emission factor (kg N_2O/Gg of waste) for waste of type *i*

10^{-6} : conversion from kilogram to gigagram

i : category or type of waste incinerated/open-burned (MSW, ISW, hazardous waste, clinical waste, sewage sludge, etc.)

Amount of Waste Open-burned

- Statistics may not be available. Where the data on waste amount are not available, total amount of MSW open-burned can be estimated

$$MSW_B = P \bullet P_{frac} \bullet MSW_P \bullet B_{frac} \bullet 365 \bullet 10^{-6}$$

MSW_B : Total amount of municipal solid waste open-burned, Gg/yr

P : population (capita)

P_{frac} : fraction of population burning waste, (fraction)

MSW_P : per capita waste generation, kg waste/capita/day

B_{frac} : fraction of the waste amount that is burned relative to the total amount of waste treated

365 : number of days by year

10^{-6} : conversion factor from kilogram to gigagram

Incineration of Fossil Liquid Waste: CO_2 Emissions

- Fossil liquid waste - industrial and municipal residues, based on mineral oil, natural gas or other fossil fuels. It includes waste formerly used as solvents and lubricants.
- If, fossil liquid waste is not included in other types of waste (e.g., industrial waste, hazardous waste), the emissions need to be calculated separately

$$CO_2\ Emissions = \sum_i \left(AL_i \bullet CL_i \bullet OF_i \right) \bullet 44/12$$

CO_2 Emissions : CO_2 emissions from incineration of fossil liquid waste, Gg

AL_i : amount of incinerated fossil liquid waste type *i*, Gg

CL_i : carbon content of fossil liquid waste type *i,* (fraction)

OF_i : oxidation factor for fossil liquid waste type *i*, (fraction)

44/12 : conversion factor from C to CO_2

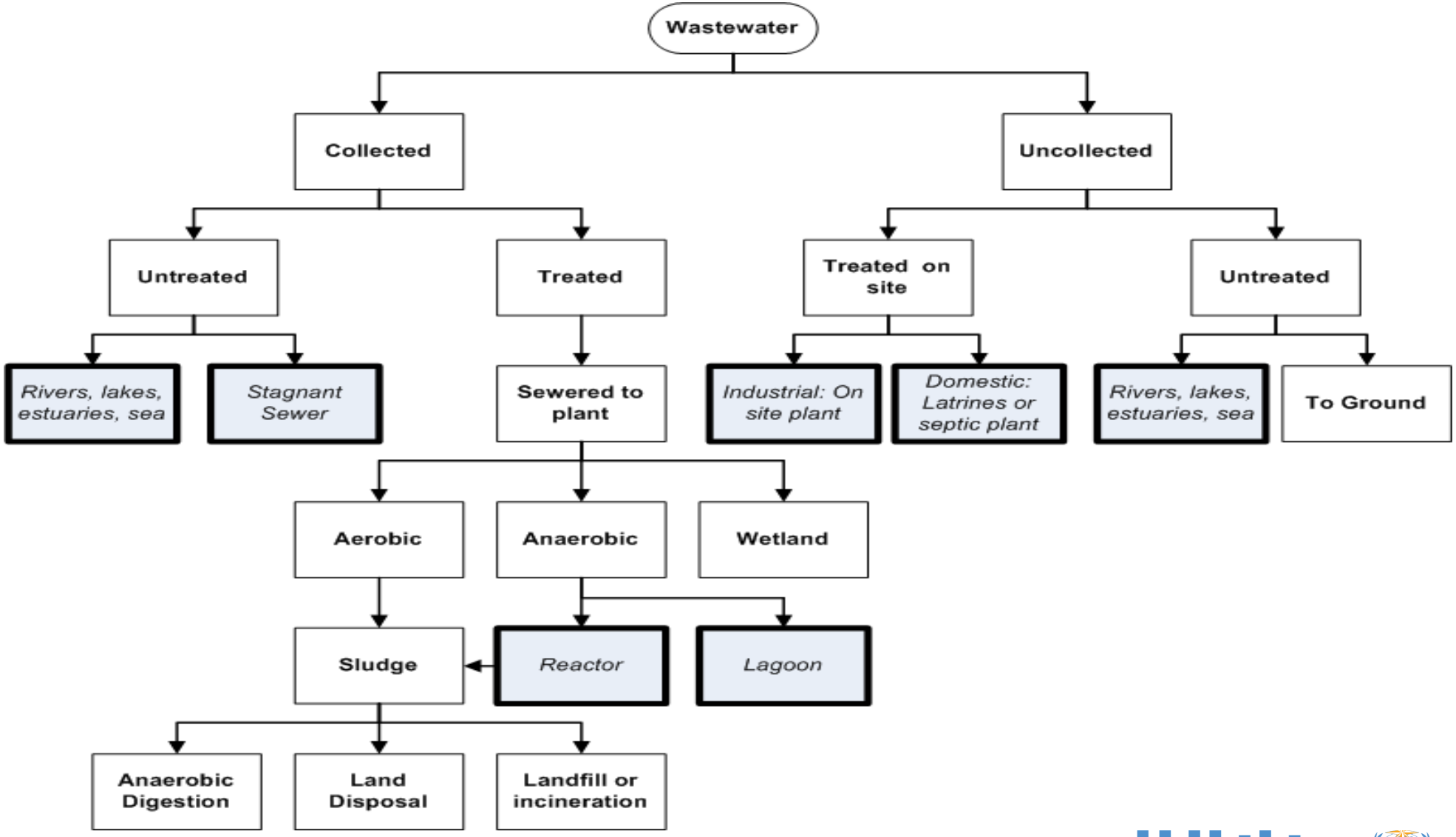
Incineration and Open Burning of Waste: Choice of Methods, AD and EFs

- Methodological tiers for estimation of CO_2 emissions:
  - Tier 1: Default AD and parameters
  - Tier 2: Country-specific AD, default and some country-specific parameters
  - Tier 3: Plant-/management-specific data
- Methodological tiers for estimation of CH_4 and N_2O emissions:
  - Tier 1: Default AD and EFs
  - Tier 2: Country-specific AD and EFs by waste type, technology or management practice
  - Tier 3: Plant-/management-specific data (e.g., flue gas concentrations for N_2O emissions)
- Default values are provided in Chapters 2 and 5.

Wastewater Treatment and Discharge

- Wastewater (domestic and industrial) may be treated on site (uncollected), sewered to a centralized plant (collected) or disposed untreated.
  - Treatment and discharge systems can differ between countries and can also differ for rural and urban users
- Treatment and disposal of wastewater produce GHGs such as CO_2, CH_4 and N_2O
  - CO_2 is of biogenic origin and not included
- Sludge produced in wastewater treatment is treated further. GHG emissions from sludge sent to landfills, incinerated or used in agriculture are not included in this category.

Wastewater Treatment Systems and Discharge Pathways



Wastewater Treatment and Discharge: CH_4 Emissions

- CH_4 production depends primarily on the amount of degradable organic material in wastewater, temperature and type of treatment system.
- Common parameters used to measure the organic component of the wastewater :
  - Biochemical Oxygen Demand (BOD): amount of carbon that is aerobically biodegradable
  - Chemical Oxygen Demand (COD): total organic material available for chemical oxidation
- Methodological tiers for estimation of CH_4 emissions:
  - Tier 1 method applies default values for EFs (Bo, MCF, etc.) and AD
  - Tier 2 method allows for incorporation of a country-specific EF and AD
  - Tier 3 method is a country-specific method with measurements or other bottom-up data
- CH_4 generated can be recovered and combusted in a flare or energy device
  - The flared or recovered for energy use should be subtracted from total emissions
  - CH_4 recovery for energy generation should be reported in the Energy Sector

Domestic Wastewater: CH_4 Emissions

- Total CH_4 emissions from domestic wastewater:

$$CH_4\ Emissions = \left[\sum_{i,j}\left(U_i \bullet T_{i,j} \bullet EF_j\right)\right](TOW - S) - R$$

CH_4 Emissions: CH_4 emissions in inventory year, kg CH_4/yr

TOW : total organics in wastewater in inventory year, kg BOD/yr

S : organic component removed as sludge in inventory year, kg BOD/yr

U_i : fraction of population in income group i in inventory year

$T_{i,j}$: degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction i in inventory year

i : income group: rural, urban high income and urban low income

j : each treatment/discharge pathway or system

EF_j : emission factor, kg CH_4/kg BOD

R : amount of CH_4 recovered in inventory year, kg CH_4/yr

2019 Refinement

Updated guidance on CH_4 emissions from domestic wastewater

Domestic Wastewater: CH_4 Emissions

- AD is the total amount of organically degradable material in the wastewater (TOW).

$$TOW = P \bullet BOD \bullet 0.001 \bullet I \bullet 365$$

TOW : total organics in wastewater in inventory year, kg BOD/yr

P : country population in inventory year, (person)

BOD : country-specific per capita BOD in inventory year, g/person/day

0.001 : conversion from grams BOD to kg BOD

I : correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00)

Domestic Wastewater: CH_4 Emissions

- EF for each domestic wastewater treatment/discharge pathway or system:

$$EF_j = B_o \bullet MCF_j$$

EF_j : emission factor, kg CH_4/kg BOD

j : each treatment/discharge pathway or system

B_o : maximum CH_4 producing capacity, kg CH_4/kg BOD

MCF_j : CH_4 correction factor (fraction) and indicates the degree to which the system is anaerobic

Industrial Wastewater: CH_4 Emissions

- Industrial wastewater may be treated on-site or released into domestic sewer systems.
- The CH_4 emissions from industrial wastewater treatment (on-site):

$$CH_4\ Emissions = \sum_i \left[(TOW_i - S_i) \bullet EF_i - R_i \right]$$

CH_4 Emissions : CH_4 emissions in inventory year, kg CH_4/yr

TOW_i : total organically degradable material in wastewater from industry *i* in inventory year, kg COD/yr

i : industrial sector

S_i : organic component removed as sludge in inventory year, kg COD/yr

EF_i : emission factor for industry *i*, kg CH_4/kg COD for treatment/discharge pathway or systems. If more than one treatment practice is used in an industry this factor would need to be a weighted average.

R_i : amount of CH_4 recovered in inventory year, kg CH_4/yr

2019 Refinement

Updated guidance on CH_4 emissions from industrial wastewater

Industrial Wastewater: CH_4 Emissions

- AD is the amount of organically degradable material in the wastewater (TOW):

$$TOW_i = P_i \bullet W_i \bullet COD_i$$

TOW_i : total organically degradable material in wastewater for industry *i*, kg COD/yr

i : industrial sector

P_i : total industrial product for industrial sector *i*, t/yr

W_i : wastewater generated, m^3/t product

COD_i : chemical oxygen demand (industrial degradable organic component in wastewater), kg COD/m^3

Industrial Wastewater: CH_4 Emissions

- EF for each treatment/discharge pathway/systems:

$$EF_j = B_o \bullet MCF_j$$

EF_j : emission factor, kg CH_4/kg COD

j : each treatment/discharge pathway or system

B_o : maximum CH_4 producing capacity, kg CH_4/kg COD

MCF_j : CH_4 correction factor (fraction)

Wastewater Treatment and Discharge: N_2O Emissions

- The N_2O emissions are associated with the degradation of nitrogen components in the wastewater (e.g., urea, nitrate and protein).
- N_2O emissions can occur as direct emissions from treatment plants or indirect emissions from wastewater after disposal of effluent into waterways, lakes or the sea.
- N_2O may be generated during
  - Nitrification: aerobic process converting ammonia and other nitrogen compounds into nitrate (NO_3^-)
  - Denitrification: biological conversion of NO_3^- into nitrogen gas (N_2) under anoxic environment.
- The emissions from industrial sources are believed to be insignificant compared to emissions from domestic wastewater.

2019 Refinement

New guidance on N_2O emissions from industrial wastewater

Domestic Wastewater: N_2O Emissions

- Indirect N_2O emissions from wastewater effluent discharged into aquatic environments

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF_{EFFLUENT} \bullet 44/28$$

N_2O Emissions : N_2O emissions in inventory year, kg N_2O/yr

$N_{EFFLUENT}$: nitrogen in the effluent discharged to aquatic environments, kg N/yr

$EF_{EFFLUENT}$: emission factor for N_2O emissions from discharged wastewater, kg N_2O-N/kg N

44/28 : conversion of kg N_2O-N into kg N_2O.

2019 Refinement

Updated guidance on N_2O emissions from domestic wastewater

Domestic Wastewater: N_2O Emissions

- Total N in the effluent

$$N_{EFFLUENT} = \left(P \bullet PROTEIN \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM}\right) - N_{SLUDGE}$$

$N_{EFFLUENT}$: total annual amount of nitrogen in the wastewater effluent, kg N/yr

P : human population

Protein : annual per capita protein consumption, kg/person/yr

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

$F_{NON-CON}$: factor for non-consumed protein added to the wastewater

$F_{IND-COM}$: factor for industrial and commercial co-discharged protein into the sewer system

N_{SLUDGE} : nitrogen removed with sludge (default = zero), kg N/yr

Domestic Wastewater: N_2O Emissions

- Emissions from advanced centralised wastewater treatment plants

$$N_2O_{PLANTS} = P \bullet T_{PLANT} \bullet F_{IND-COM} \bullet EF_{PLANT}$$

N_2O_{PLANTS} : total N_2O emissions from plants in inventory year, kg N_2O/yr

P : human population

T_{PLANT} : degree of utilization of modern, centralized WWT plants, %

$F_{IND-COMM}$: fraction of industrial and commercial co-discharged protein (default = 1.25)

EF_{PLANT} : emission factor, 3.2 g N_2O/person/year

To include N_2O emissions from plants, the amount of nitrogen associated with these emissions (N_{WWT}) must be subtracted from the $N_{EFFLUENT}$.

Waste Data

- Collection of data is a fundamental part of inventory compilation
  - Starting point of estimation of GHG emissions/removals
  - Chapter 2 of Volume 1 gives general guidance on data collection
- It is preferable to use national data
- If the data is not available, IPCC default values and data from other sources can be used. However, need to assess the applicability of the data to national circumstances.
  - Chapter 2 of Volume 5 provides default data on waste generation, composition and management
  - IPCC Emission Factor Database (EFDB https://www.ipcc-nggip.iges.or.jp/EFDB/main.php) contains data from various sources with background technical information.

2019 Refinement

Updated and **new data** on waste generation, composition and treatment

Thank you

https://www.ipcc-nggip.iges.or.jp/index.html
https://www.ipcc-nggip.iges.or.jp/software/index.html