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International Non-CO2 Greenhouse Gas Marginal Abatement Report

Draft Methane and Nitrous from Non-Agricultural Sources
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Chapter 4

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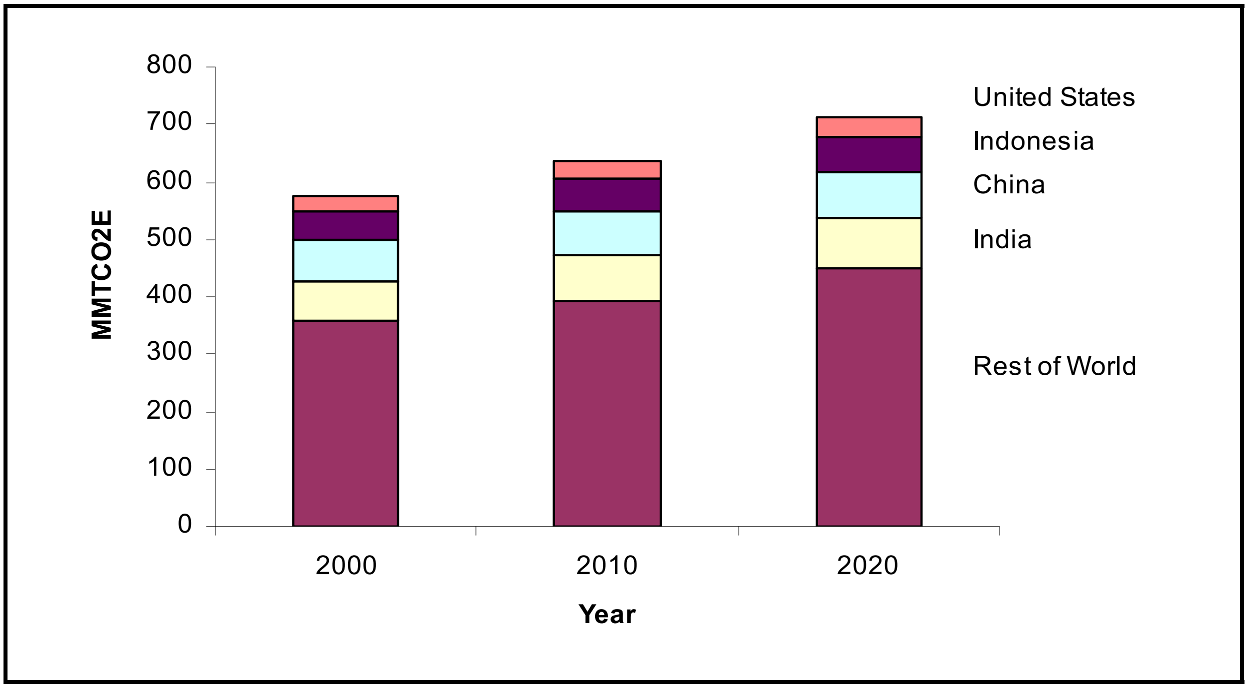
4. Wastewater Sector

Worldwide methane from wastewater accounts for over 575 million metric tonnes of carbon dioxide equivalent in 2000. Wastewater is the fifth largest source of anthropogenic methane emissions, contributing approximately 10 percent of total global methane emissions in 2000. India, China, Indonesia, and the United States combined account for 38 percent of the world's methane emissions from wastewater (see Exhibit 4-1). Global methane emissions from wastewater are expected to grow by approximately 20 percent between 2005 and 2020.

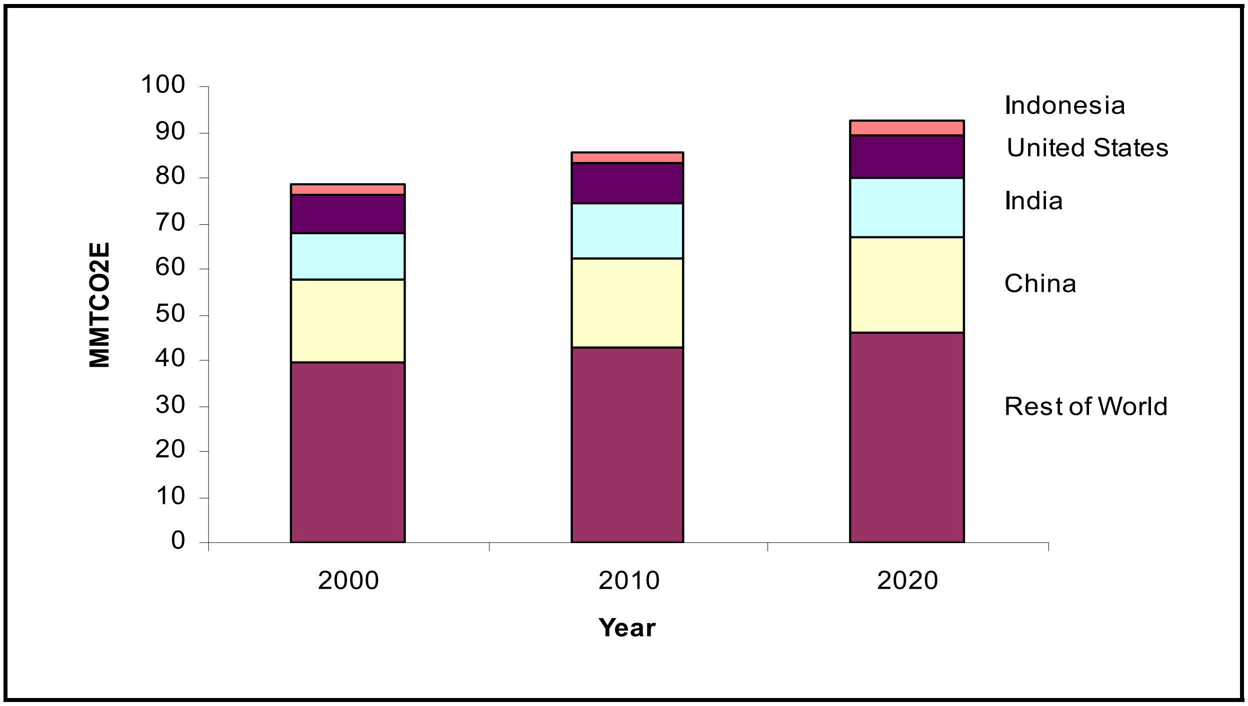
Exhibit 4-1. Wastewater Methane Emissions and Projected Emissions by Country



Source: EPA, 2005.

Wastewater is also a significant source of nitrous oxide (N_2O). Worldwide, N_2O emissions from wastewater accounted for approximately 78 million metric tonnes of carbon dioxide equivalent in 2000 (see explanatory note 1). Wastewater as a source is the sixth largest contributor to N_2O emissions, accounting for approximately 2 percent of N_2O emissions from all sources. Indonesia, the United States, India, and China accounted for approximately 50 percent of total N_2O emissions from domestic wastewater in 2000 (see Exhibit 4-2). Global N_2O emissions from wastewater are expected to grow by approximately 13 percent between 2005 and 2020.

Exhibit 4-2. Wastewater N_2O Emissions and Projected Emissions by Country



Source: EPA, 2005.

4.1 Introduction

Wastewater from domestic (sewage) and industrial sources is typically moved through a wastewater sewer system to a centralized wastewater management treatment center. At the treatment center, soluble organic material, suspended solids, pathogenic organisms, and chemical contaminants are removed from water using biological processes in which microorganisms consume the organic waste. This results in the production of biomass sludge. The microorganisms can perform this biodegradation process in aerobic and anaerobic environments, the former producing carbon dioxide (CO_2) and latter producing methane.

Wastewater treatment plants (WWTP) may be located on-site or off-site. In the case of domestic wastewater, septic tanks are an example of an on-site treatment plant for domestic wastewater, while a centralized municipal WWTP is an example of an off-site facility. EPA estimates that 25 percent of domestic wastewater is treated through on-site facilities such as septic tanks (EPA, 2004). Centralized WWTP requires that the wastewater be transported to the facility through a municipal sewer system.

Emissions from Wastewater Systems

Methane is produced by decay of organic material in wastewater as it decomposes in anaerobic environments. Methane emissions from wastewater are determined by the amount of organic material produced and the extent to which this material is allowed to decompose under anaerobic conditions. The organic content of wastewater is typically expressed in terms of either biochemical oxygen demand (BOD) or chemical oxygen demand (COD) (IPCC, 1996a). Most developed countries use centralized aerobic wastewater treatment facilities with closed anaerobic sludge digester systems to process municipal and industrial wastewater. Employment of these practices increases methane generation but ultimately reduces baseline emissions.

N_2O is produced during both the nitrification and denitrification of urea, ammonia, and proteins. These waste materials are converted to nitrate (NO_3) via nitrification, an aerobic process converting ammonia-nitrogen to nitrate. Denitrification occurs under anoxic conditions (without free oxygen) and involves the biological conversion of nitrate into dinitrogen gas (N_2). N_2O can be an intermediate product of both processes but is more often associated with denitrification (Sheehle and Doorn, 2001).

An overview of treatment methods, wastewater composition, and sources of methane emissions for domestic and industrial wastewater systems is provided below, followed by a discussion of N_2O emissions.

Domestic Wastewater

The process of treating domestic wastewater (sewage) involves three major phases. First, the wastewater collected at a centralized WWTP goes through a primary treatment phase. During this phase, large solids are removed through a filtration process where grit is removed and oxygen is added. Next, the wastewater enters a primary clarifier that removes almost 95 percent of settleable solids. This process takes approximately 30 minutes to an hour, and the initial biodegradation by microorganisms begins. Primary sludge is separated from the effluent at this stage. During this process, wastewater is generally aerated ensuring that the decomposition of the organic matter occurs in an aerobic environment.

Following the primary treatment, it is common to subject the remaining effluent to a secondary treatment. During this phase, the effluent undergoes bio-oxidation through an aerobic process in which aerobic microorganisms break down any remaining organic solids. In the secondary treatment, the effluent is passed through a trickling filter or aeration basin for approximately 4 to 6 hours. Next, the remaining effluent moves into a final clarifier where further biodegradation can occur. This secondary treatment produces additional secondary sludge (biomass). Following the secondary treatment, the effluent is released to a receiving stream.

The sludge (biomass) produced during the primary and secondary phases of treatment is then combined and moved into an encapsulated silo-like digester where it undergoes an anaerobic decomposition process using microorganisms that continue to break down the organics. The digester comprises a holding tank, a gas capture system, and a heating element. Over a period of time (weeks), microorganisms break down the large organic molecules in the feed sludge. Still smaller organisms convert this organic material into methane and CO_2. On average, 40 to 45 percent of feed sludge is converted to methane and CO_2 during the process. The methane produced is closely monitored for safety concerns and then combusted either in the form of a flare or used to generate heat required during this process. The remaining sludge is sent to landfills.

Industrial Wastewater

Industries producing large volumes of wastewater and industries with high organic COD wastewater load are likely to have significant methane emissions. In the United States, the meat and poultry, pulp and paper, and produce (i.e., fruits and vegetable) industries are the largest sources of industrial wastewater and contain high organic COD. These industries are also considered methane-emitting industries because they employ either shallow lagoons or settling ponds in their treatment of wastewater, which promotes anaerobic degradation.

The meat and poultry industry in the United States has been identified as a major source of methane emissions because of its extensive use of anaerobic lagoons in sequence to screening, fat traps, and dissolved air flotation. It is estimated that 77 percent of all wastewater from the meat and poultry industry degrades anaerobically (EPA, 1997a).

Treatment of industrial wastewater from the pulp and paper industry is similar to the treatment of municipal wastewater. Treatment in this industry generally includes neutralization, screening, sedimentation, and flotation/hydrocycloning to remove solids. Anaerobic conditions are most likely to occur during lagooning for storage, settling, and biological treatment (secondary treatment). During the primary treatment phase, lagoons are aerated to reduce anaerobic activity. However, the size of these lagoons makes it possible for zones of anaerobic degradation to take place. Approximately half of the initial COD remains following the primary treatment. This remaining COD is passed into a secondary treatment phase where anaerobic degradation is more likely to take place. EPA estimates that 25 percent of COD in secondary treatment lagoons degrades anaerobically (EPA, 1997b).

The fruit, vegetable, and juice-processing industries generate large amounts of wastewater. The treatment of wastewater from these industries generally includes screening, coagulation/settling, and biological treatment (lagooning), while effluent is typically discharged into municipal sewer system. Anaerobic degradation can occur within the lagoons during biological treatment. In the United States it is assumed that these lagoons are intended for aerobic operation, but during peak seasonal usage anaerobic conditions may occur. EPA estimates that approximately 5 percent of wastewater organics degrade anaerobically (Sheehle and Doorn, 2001).

N_2O from Wastewater

The two most significant sources of N_2O identified in the United States are emissions from wastewater treatment processes and emissions from effluent discharge into aquatic environments. The Intergovernmental Panel on Climate Change (IPCC) assumes that nitrogen disposal associated with land disposal, subsurface disposal, and domestic wastewater treatment are negligible as sources of N_2O emissions. Generally countries use the IPCC methodology (IPCC, 2000) for estimating national emissions from wastewater. However, current methodologies do not allow for a complete estimate of N_2O emissions. As a result, N_2O baselines reported in this chapter represent the human sewage component only; no methodology exists to estimate N_2O emissions from industrial wastewater.

The remainder of this chapter discusses the activity data and emission factors used to develop baseline emissions and methane marginal abatement curves (MACs) for wastewater systems. The chapter concludes with a discussion of uncertainties and limitations.

4.2 Baseline Emission Estimates

Methane generation occurs as organic matter undergoes decomposition in anaerobic conditions. However, methane generation varies widely depending on waste management techniques. Specifically engineered environments can increase the methane generation rates.

The quantity of methane generated can be expressed in terms of several key activity and emission factors:

Domestic Wastewater

$$CH_4 \text{ Generation} = (POP) * (BOD) * (PAD) * (CH_4P) \qquad (4.1)$$

where

POP = total population,

BOD = production of BOD per capita per year,

PAD = percentage of BOD anaerobically digested per year, and

CH_4P = methane generation potential per kg of BOD.[1]

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[1] IPCC emission factor of 0.6 kg CH_4/kg of BOD, cited in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2002*.

Industrial Wastewater

$$CH_4 \text{ Generation} = (IP) * (COD) * (PAD) * (CH_4P) \quad (4.2)$$

where

IP = industry production,

COD = production of COD per unit of output,

PAD = percentage of COD anaerobically digested per year, and

CH_4P = methane generation potential per kg of COD.[1]

4.2.1 Activity Factors

Activity factors determine the quantity of wastewater produced and the intensity in organic content (see explanatory note 2). Domestic wastewater production is related to the population size. The population size, in conjunction with the level of organic waste present in the wastewater (BOD), determines a country's methane generation potential. The per capita production of BOD may vary over time or by country depending on a population's consumption preferences.

Industrial wastewater generation is based largely on the annual product output from major wastewater-producing industries, including meat and poultry packing; pulp and paper manufacturing; and vegetable, fruits, and juices processing. Differences in production processes and recycling practices can influence the COB per unit of production in these industries.

N_2O production is typically estimated using an activity factor of annual per capita protein consumption (kg/yr). However, it has been suggested that this factor alone underestimates the actual amount of protein entering wastewater treatment systems. Food (waste) that is not consumed is often washed down the drain using garbage disposals. In addition, laundry water can contribute to nitrogen loadings. For these reasons, multipliers are commonly applied to the annual per capita protein consumption activity factor to account for these other sources of nitrogen loading.

Historic Activity Data

Wastewater production is directly related to a country's domestic population and industrial production of select industries. Population growth rates are traditionally higher in developing countries, while more

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[1] IPCC emission factor of 0.6 kg CH_4/kg of BOD, cited in EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2002*.

industrialized countries have recently tended to experience smaller increases in population over time. Along with population growth, production of BOD per capita has also been growing, which means that more organic material is present in wastewater. Increases in BOD per capita can result from various economic improvements, which could lead to a change in the availability of food types and consumption preferences.

Industrial growth rates and treatment practices differ by country. Whereas most developed and developing countries have thriving meat and poultry and produce industries, differences exist in the local regulation and treatment practices. Developing countries are more likely to employ lagoons or settling ponds in their treatment of industrial waste, which promotes anaerobic degradation.

Projected Activity Data

Both domestic and industrial wastewater production are expected to increase in the future as populations continue to grow and key industries continue to expand.

4.2.2 Emission Factors and Related Assumptions

The primary determinants of wastewater emission factors are

- methane generation potential per unit of BOD or COD and
- the percentage of BOD or COD that degrades in anaerobic conditions.

Methane generation potential per unit of BOD or COD is likely to remain constant because this is a measure of chemical potential, not the result of varying preferences. However, wastewater management practices vary across cities and countries, affecting the percentage of BOD or COD that degrades under anaerobic conditions. Even for managed systems, differences in operations and maintenance can result in unintended anaerobic conditions that lead to additional methane emissions.

Historical Emission Factors

A methane generation factor of 0.6 kg CH_4/kg BOD is provided in the IPCC *Good Practice Guidance* (IPCC, 2000) for domestic wastewater. This generation factor is also applied to the pulp and paper and meat and poultry industries. A methane generation factor of 0.4 kg CH_4/kg BOD is applied to the fruit, vegetable, and juice-processing industries. This generation factor represents the potential methane generation from a given unit of BOD, assuming that a unit of BOD degrades under anaerobic conditions.

Most developed countries have adopted municipal wastewater treatment practices that prevent the formation of anaerobic conditions in managing and treating wastewater. Developing countries have traditionally employed wastewater management practices that foster controlled anaerobic environments where the methane is captured for flaring or direct use. Settling ponds that are open to the atmosphere are typically aerated to promote the production or CO_2 as opposed to methane. However, in developing countries, industries, such as the pulp and paper or meat and poultry, are less likely to have adopted practices to prevent anaerobic degradation of COD in wastewater.

Projected Emission Factors

Projected emission factors from wastewater are expected to follow historic trends. The methane generation potential per unit of BOD will remain constant over time. Improvements to wastewater management practices are projected to occur with increased gross domestic product (GDP). These improvements may result in decreased baseline emissions for developing countries. As developing countries adopt better management practices, their baseline emissions will approach the baselines of developed countries with established wastewater infrastructure already in place. Overall, reductions in methane emission factors from wastewater will occur because of improvements in wastewater management and treatment.

4.2.3 Emission Estimates and Related Assumptions

This section discusses the historical and projected baseline emissions from wastewater. As shown in Equations (4.1) and (4.2), the amount of methane generated each year from wastewater is determined by a country's population, the per capita production of BOD or COD (in the industry), and the percentage of BOD that degrades under anaerobic conditions.

Historical Emission Estimates

Exhibits 4-3 and 4-4 provide emissions by country for methane and N_2O. Historically, China and India have the largest baseline methane and N_2O emissions from wastewater. China and India are the two most populous countries in the world with 1.3 and 1.1 billion people, respectively, in 2002 (World Bank, 2005). Their large populations in highly concentrated urban areas, combined with limited infrastructure for handling wastewater, result in substantial emissions. Similar conditions exist in Cambodia and Indonesia where densely populated areas produce significant methane emissions.

Exhibit 4-3. Methane Emissions from Wastewater by Country: 1990–2000 (MMTCO2E)

Country	1990	1995	2000
China	64.9	68.8	72.0
India	56.9	62.4	67.9
Cambodia	56.8	60.0	62.8
Indonesia	40.7	44.5	48.3
United States	24.1	26.7	28.4
Brazil	18.0	19.3	20.7
Mexico	10.0	11.0	14.6
Iran	12.0	13.1	14.1
Bangladesh	10.4	11.7	13.0
Russian Federation	9.4	9.4	9.3
Nigeria	6.8	7.9	9.0
Pakistan	6.9	7.8	8.9
Viet Nam	6.7	7.4	8.0
Turkey	5.7	6.3	6.8
Jordan	6.2	6.3	6.5

Source: EPA, 2005.

Exhibit 4-4. N_2O Emissions from Wastewater by Country: 1990–2000 (MMTCO2E)

Country	1990	1995	2000
China	16.7	17.6	18.4
India	8.5	9.4	10.2
US	6.7	7.4	8.1
Indonesia	2.0	2.2	2.4
Brazil	2.0	2.2	2.4
Russian Federation	2.2	2.2	2.2
Japan	2.0	2.0	2.0
Pakistan	1.2	1.3	1.5
Mexico	1.3	1.4	1.5
Germany	1.3	1.4	1.4
Nigeria	0.9	1.1	1.2
France	1.1	1.2	1.2
Bangladesh	0.9	1.0	1.1
Turkey	0.9	1.0	1.1
Italy	1.1	1.1	1.1

Source: EPA, 2005.

Projected Emissions Estimates

Worldwide methane emissions from wastewater are expected to increase in both developed and developing countries because of expanding populations and increases in GDP. Exhibits 4-5 and 4-6 list projected baseline emissions by country for methane and nitrous oxide. India is projected to replace China as the world's leading emitter of wastewater methane. The World Bank projects India's average

Exhibit 4-5. Projected Baseline Methane Emissions from Wastewater by Country: 2005–2020 (MMTCO2E)

Country	2005	2010	2015	2020
India	73.3	78.3	82.8	86.8
China	74.6	77.1	79.6	81.7
Cambodia	65.2	67.5	69.7	71.6
Indonesia	51.8	55.2	58.3	61.2
United States	29.6	30.9	32.2	33.5
Brazil	22.0	23.2	24.4	25.5
Bangladesh	14.5	15.9	17.4	18.8
Iran	15.0	15.9	16.8	17.7
Nigeria	10.3	11.6	13.1	14.6
Pakistan	10.1	11.4	12.9	14.3
Mexico	10.3	10.9	11.5	12.1
Viet Nam	8.5	9.0	9.6	10.2
Turkey	7.3	7.7	8.1	8.5
Russian Federation	9.0	8.7	8.5	8.3
Ethiopia	5.8	6.5	7.3	8.2

Source: EPA, 2005.

Exhibit 4-6. Projected Baseline N_2O Emissions from Wastewater by Country: 2005–2020 (MMTCO2E)

Country	2005	2010	2015	2020
China	19.0	19.7	20.3	20.8
India	11.0	11.8	12.4	13.0
US	8.5	8.9	9.2	9.5
Indonesia	2.5	2.6	2.8	2.9
Brazil	2.5	2.6	2.8	2.9
Russian Federation	2.1	2.0	2.0	1.9
Japan	2.0	2.0	2.0	2.0
Pakistan	1.7	2.0	2.2	2.5
Mexico	1.6	1.7	1.8	1.9
Germany	1.4	1.4	1.3	1.3
Nigeria	1.4	1.6	1.8	2.0
France	1.2	1.2	1.2	1.3
Bangladesh	1.3	1.4	1.5	1.6
Turkey	1.2	1.3	1.3	1.4
Italy	1.1	1.1	1.1	1.1

Source: EPA, 2005.

annual growth rate in population of 1.2 percent over the next 10 years, while China's is projected to be 0.6 percent over the same time period (World Bank, 2005). Although both countries' GDP is projected to increase over time, the most influential factor in determining each country's baseline will be the extent to which these countries improve their wastewater management practices.

4.3 Emissions Reductions from Wastewater

Components of abatement options for the wastewater sector include the incremental addition of methane mitigation equipment not already included in the initial construction of a municipal wastewater treatment plant. This section discusses opportunities for emissions reductions beyond existing baseline practices.

4.3.1 Abatement Option Opportunities

We describe two approaches to reducing methane emissions from wastewater following the implementation of municipal infrastructure:

- improved wastewater treatment practices (domestic and industrial) and
- anaerobic digester with collection and flaring or cogeneration.

Improved wastewater treatment practices include reducing the amount of organic waste anaerobically digested. This reduction can be achieved through improved aeration and/or the scaling back of the use of stagnant settling lagoons. Costs for improving treatment practices vary widely based on the technology applied and specific characteristics of the wastewater. Improvements to existing wastewater treatment practices assume that infrastructure is already in place and that the cost of any improvements would represent the incremental addition of technology as a capital improvement or increases in operation and maintenance (O&M) costs.

Anaerobic digesters can be flared or the methane used for cogeneration to reduce methane emissions from biomass or liquid effluents with high organic content. The IPCC estimates construction costs for anaerobic digesters to be $0.1 to $3 million (IPCC, 1996b). This estimate includes the construction of a collection system and either a flare or a utilization system. IPCC estimates annual O&M costs for this type of system at between $10,000 and $100,000, assuming wastewater flows of 0.1 to 100 million gallons (400 to 0.4×10^6 m^3) per day (IPCC, 1996b).

4.4.1 Uncertainties and Limitations

Uncertainty and limitations persist despite attempts to incorporate all publicly available information on international wastewater sectors. Limited information on the wastewater systems of developing countries increases this uncertainty. Additional information would improve the accuracy of baseline emission projections.

- BOD Production Rates: Improved information on specific population diets and consumption habits would greatly improve the analyst's ability to calculate baseline emissions.

- Country-Specific Waste Management Practices: Improved documentation of wastewater management practices would allow deviations from the normal assumption, allowing country-by-country estimates of percentage of BOD undergoing anaerobic degradation.
- Improved Cost Data: Improved documentation of wastewater methane abatement options and their costs components would improve the analyst's ability to estimate baseline reductions given some estimate of market penetration.

4.5 Summary

The data discussed in this chapter demonstrate that wastewater is a significant source of greenhouse gas emissions. However, policy approaches directly targeted at mitigating methane emissions from wastewater are limited, and no specific abatement options are presented as part of the analysis in this chapter. Several factors contribute to difficulties in developing MACs for wastewater abatement options.

The primary factor for determining emissions from the wastewater sector (in terms of methane emissions per BOD) is the type of treatment system employed to manage the waste. Centralized, managed treatment facilities can control anaerobic environments and have a greater potential to capture and use methane. Because most centralized systems automatically either flare or capture and use methane for safety reasons, "add-on" abatement options do not exist. As a result, potential emission reductions depend on large-scale structural changes in waste management practices. In contrast, smaller decentralized systems have less control over the share of aerobic versus anaerobic decomposition and have few feasible options for capturing methane.

At issue is that overriding economic and social factors influence wastewater treatment practices throughout the world. The benefits of installing a wastewater system in a developing country for the purpose of disease reduction greatly outweigh potential benefits associated with methane mitigation. This is not to say that methane mitigation is not one of many factors to be potentially considered in the selection of wastewater treatment systems. However, because of the scope of the costs and benefits of the investment decision, it would be misleading to imply that potential carbon prices (reflected in MACs) would be the driving force behind investment decisions that influence methane emissions from wastewater.

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Explanatory Notes

1. Assuming a global warming potential (GWP) value of 296.

2. The wastewater treatment practices that determine the share of BOD that degrades under anaerobic conditions are included in the emission factor discussion.