Emissions and Projections of Non-CO_2 Greenhouse Gases from Developing Countries: 1990-2020

DRAFT

June 2002

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1. Introduction

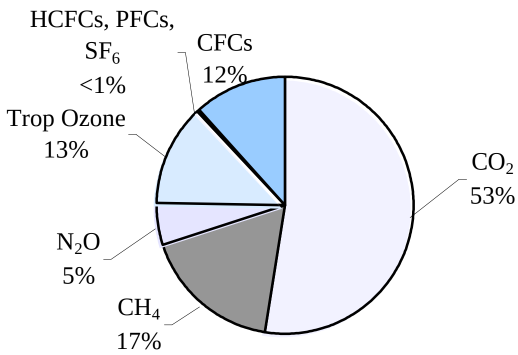
While projections of carbon dioxide (CO_2) emissions from energy consumption are widely available, projections have been less available for the other (non-CO_2) greenhouse gases (GHGs). This report is the second of two reports that can be used together to assess global emissions of non-CO_2 gases by source. The aim of these reports is to fill this gap by presenting emissions and baseline projections of the non-CO_2 gases from major anthropogenic sources. This report provides a consistent and comprehensive estimate of non-CO_2 greenhouse gases that can be used to understand national contributions to climate change, as well as mitigation opportunities and costs. In combination with data on developed countries (EPA, 2001), global contributions to climate change can be analyzed.

The gases included in this report are the direct greenhouse gases reported by parties to the UNFCCC: methane (CH_4), and nitrous oxide (N_2O). The high global warming potential (High GWP) gases will be included in the final draft. Historical estimates are reported for 1990, 1995, and 2000, and projections of emissions in the absence of climate measures ("Business As Usual") are provided for 2005 through 2020. Historical and future trends are shown by region and by gas. The emission estimates presented in this report are derived from publicly available country-submitted estimates, when they are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997). In specific cases, the U.S. Environmental Protection Agency (EPA) has revised the national estimates to be consistent with the IPCC Guidelines and/or a Business As Usual scenario. Any revisions are intended to ensure overall consistency in approach, because in some cases the available estimates could not be compared to other data in their original form. These revisions and recalculations do not suggest that the country level data are inaccurate. All changes and modifications to national data have been documented. When estimates are unavailable from country-submitted reports, emissions have been calculated using a Tier One IPCC methodology.

1.1 Overview of Non-CO_2 Greenhouse Gas Emissions

Each non-CO_2 greenhouse gas is more effective at trapping heat than CO_2. As a result, emissions of these gases contribute significantly to climate change. As shown in Exhibit 1-1, global emissions of methane, nitrous oxide, and all of the high GWP gases (including Montreal Protocol Gases such as CFCs and HCFCs, which are not addressed by the UNFCCC) account for approximately 30 percent of the enhanced greenhouse effect since pre-industrial times.

Exhibit 1-1: Contribution of Anthropogenic Emissions of All Greenhouse Gases to the Enhanced Greenhouse Effect Since Industrial Times (measured in Watts/m^2)



Source: IPCC, 2001

A comprehensive multi-gas mitigation strategy can be less expensive and more effective in mitigating climate change than focusing on only CO_2. In 1999, researchers with the Massachusetts Institute of Technology demonstrated that the "inclusion of sinks and abatement opportunities from gases other than CO_2 could reduce the [global] cost of meeting the Kyoto Protocol by 60 percent" (Reilly et al, 1999a). Additionally, a recent National Academy of Sciences article by NASA scientists concludes that the climate forcing of direct and indirect non-CO_2 greenhouse gases equals that of CO_2 and, at this current forcing level, has contributed to at least 0.5 degrees of future temperature increase (PNAS, 2000). The anticipated future temperature increase is sensitive to atmospheric lifetimes of these gases. For example, methane remains in the atmosphere for approximately 10 years compared to 100 years for carbon dioxide (IPCC, 2001). If methane emissions were significantly reduced today, the effect on atmospheric concentrations could be seen within a decade or two, much more quickly than similar reductions in CO_2 emissions. Conversely, the longer lived non-CO_2 gases such as SF_6 are also important since any emissions of these gases will continue to affect the atmosphere for at least several hundred years.

1.2 Emission Sources

This report focuses exclusively on anthropogenic sources of non-CO_2 direct greenhouse gases not covered by the Montreal Protocol. The emissions are converted to a CO_2 equivalent basis using the global warming potentials shown in Exhibit 1-2, as published by the IPCC and recognized by the UN Framework Convention on Climate Change. Exhibit 1-3 lists the source categories discussed in this report. All anthropogenic sources of methane are included, with the major sources considered individually. The major sources of nitrous oxide emissions are presented: agricultural soils, industrial processes, combustion, and manure management. The high GWP sources include substitutes for ozone depleting substances (ODS) and industrial sources of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). More detailed information on each gas and source can be found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 through 1999* (EPA, 2001) and *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997).

Exhibit 1-2: Global Warming Potentials

Gas	GWP
Carbon dioxide (CO_2)	1
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
HFC-23	11,700
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-4310mee	1,300
CF_4	6,500
C_2F_6	9,200
C_4F_{10}	7,000
C_6F_{14}	7,400
SF_6	23,900

Source: IPCC, 1996

Exhibit 1-3: Sources Included

Methane	Nitrous Oxide	High GWP Gases*
Biomass Combustion	Fossil Fuel Combustion	Substitutes for Ozone- Depleting Substances:
Coal Mining	Adipic & Nitric Acid Production	• HFCs, PFCs
Fossil Fuel Combustion	Agricultural Soils	HCFC-22 Production:
Natural Gas & Oil Systems	Livestock Manure Management	• HFC-23
Agricultural Biomass Burning:	Human Sewage	Aluminum Production:
• Agricultural Residue Burning		• PFCs
• Prescribed Burning of Savanna		Magnesium Production:
Livestock Manure Management		• SF_6
Livestock Enteric Fermentation		Electrical Equipment:
Rice Cultivation		• SF_6
Landfills		Semiconductor Manufacturing:
Wastewater Treatment		• PFCs, SF_6

*Note: High GWP sources will be included at a later date

1.3 Approach

The analysis provides estimates for 48 developing countries and seven regions for 1990 through 2020, in five year increments. In addition to the individual country data, EPA presents overall trends by region and by gas. The regional groupings include Africa, China/Centrally Planned Asia, Eastern Europe, South and East Asia, Latin America, Middle East, and Former Soviet Union. These regional country groupings are further defined in Exhibit 1-4 and Appendix A.

Exhibit 1-4: Definition of Regional Country Groupings

Africa	China/CPA	Eastern Europe	Former Soviet Union	Latin America	Middle East	South And East Asia	OECD90
Algeria	China	Moldova	Armenia	Argentina	Iran	Bangladesh	Turkey
Congo (Kinshasa)	Mongolia	Rest of Eastern Europe	Azerbaijan	Bolivia	Iraq	India	Rest of OECD90
Egypt	North Korea (DPRK)		Belarus	Brazil	Israel	Indonesia	
Ethiopia			Georgia	Chile	Jordan	Myanmar	
Nigeria	Vietnam		Kazakhstan	Colombia	Kuwait	Nepal	
Senegal	Rest of CPA		Turkmenistan	Ecuador	Saudi Arabia	Pakistan	
South Africa			Uzbekistan	Mexico	United Arab Emirates	Philippines	
Uganda			Rest of FSU	Peru	Rest of Middle East	Singapore	
Rest of Africa				Uruguay		Thailand	
				Venezuela		South Korea (ROK)	
				Rest of Latin America		Rest of SE Asia	

Note: Many countries were covered in EPA (2001). For a full list of countries in the 'Rest of' World regions and those covered in EPA (2001), see Appendix A.

This report is in the preliminary stage and although some gaps exist, estimates for all years and countries/regions are included for the majority of sources.

The emission estimates for methane, nitrous oxide, and the high GWP gases are described in Chapters 2 through 5. In general, estimates were developed as follows:

- For all sources, the primary sources of data on historical and projected emissions are National Communications, Country Studies, inventories submitted to the UNFCCC, or other country prepared publications.

- For N_2O from agricultural soils, EPA adjusted the estimates for many countries because many reports did not use the *Revised 1996 IPCC Guidelines*. The use of these new methods for agricultural nitrous emissions is important because the methods have improved significantly. For 1990 and 1995 historical inventories, EPA used recent annual inventories submitted to the UNFCCC, if consistent with the IPCC guidelines. The projections for 2000 to 2020 are based upon internationally recognized data sets to compute projections consistent with the *Revised 1996 IPCC Guidelines*.

- For any major source where an estimate was not available, EPA developed an estimate using country specific data and IPCC Tier One methods.

- Most countries did not include detailed estimates for high GWP emissions and projections. Where estimates are available from national sources, they have been used. Otherwise, this analysis developed emission estimates for the high-GWP source categories not covered by the Montreal Protocol.

The projections in this report provide a consistent baseline to compare opportunities and costs of mitigation options across countries. Actual emissions over time are likely to be lower than these business as usual forecasts because many businesses and governments plan to implement additional actions to reduce emissions.

1.4 Limitations

This report is in preliminary stages and not all sources and years are fully covered. This draft is primarily for expert comment on the current methodology and proposed changes. The report will be updated after this review period.

This draft covers all major methane and most nitrous oxide sources and regions for 1990. For some minor sources, preliminary country-level emissions are estimated but the global totals are not complete (e.g. Stationary Sources). In these cases, estimates have been prepared for the countries likely to emit the majority of developing country emissions.

While the latest available information is reflected in these estimates, the projections are sensitive to changes in key assumptions. For example, the emissions rates of new equipment using the ODS substitutes are likely to be much lower than the leakage rates of the older equipment. This newer equipment is only now being phased in, and the long-term emissions characteristics are not yet well known.

Additionally, in some cases the “business as usual” (BAU) baseline includes incidental greenhouse gas reductions originating from climate-related actions or government polices. For consistency, EPA removed the effects of planned mitigation efforts. Alternative definitions of “business as usual” activities could lead to different estimates for some sources.

Finally, data gaps existed in emissions data for several countries. To fill the gaps, EPA used methods ranging from interpolation to growth patterns based on analogous countries. The appendices detail all adjustments for each country and source.

1.5 Organization of this Report

The remainder of this report expands upon these results in four main sections. Emission inventories and projections by country and region are presented in Chapter 2 for Energy, Chapter 3 for Industrial Processes, and Chapter 4 for Agriculture, and Chapter 5 for Waste. Within each of these chapters, the discussion covers all key sources that contribute to emissions. Documentation of individual data points is provided in the appendices.

Note: Chapter 3 (Industrial Processes) is currently incomplete. Emissions and projections of high GWP gases are still being developed.

2. Energy

2.1 Methane Emissions from Biomass Combustion in Developing Countries

Introduction

Methane is produced as a result of incomplete fuel combustion. Fuel wood, charcoal, agricultural residues, agricultural waste and municipal waste combustion are the major contributors to CH_4 emissions within this category. The agricultural sectors will be discussed separately in the agricultural biomass burning chapter.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Several developing countries report estimates of methane and nitrous oxide emissions from biomass combustion in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections, using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). The basic equation to estimate emissions from biomass combustion is as follows:

$$\textit{Methane Emissions} = \textit{Emission Factor} * \textit{Activity}$$

Where:

- The emission factor is specific to each fuel type (wood, charcoal, other) and sector (energy industries, manufacturing, and other);
- and the activity is the energy input in TJ.

Historical Emissions

If Reported Emissions Are Available for One or More Years

- EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.

If No Emissions Data Were Available

- Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region.

- For 1990, biomass consumption data was obtained from the International Energy Agency's Energy Statistics of Non-OECD Countries 1960-1999 (IEA 2001). The fuel consumption data was then be multiplied by the IPCC default emissions factors to estimate emissions of methane.

Results

Exhibit 2-1 presents the results of the EPA analysis. Estimates that are taken directly from country reports are bolded.

Exhibit 2-1: Methane Emissions from Biomass Combustion for Key Developing Countries and Regions: 1990 (Gg)

Country/Region	1990 Emissions (Gg)
China	**2,971**
India	**1,574**
Indonesia	**534**
Thailand	**451**
Nigeria	**387**
Brazil	277
Philippines	**215**
Bangladesh	**162**
Viet Nam	**162**
Pakistan	**133**
Myanmar	**111**
South Africa	80
Nepal	71
Colombia	60
Egypt	**47**
Peru	41
Chile	25
Ecuador	**18**
Senegal	13
Bolivia	**7**
Argentina	4
Congo (Kinshasa)	4
Uruguay	4
Moldova	**3**
Venezuela	3
Belarus	1
Georgia	1
Iran	1
North Korea (DPRK)	1
Singapore	0
Turkmenistan	0
Algeria	+
Armenia	+

Exhibit 2-1: Methane Emissions from Biomass Combustion for Key Developing Countries and Regions: 1990 (Gg)

Country/Region	1990 Emissions (Gg)
Azerbijian	+
Ethiopia	+
Iraq	+
Israel	+
Jordan	+
Kazakhstan	+
Saudi Arabia	+
Uzbekistan	+
Rest of CPA	1
Rest of S&E Asia	17
Rest of FSU	+
Rest of Eastern Europe	5
Rest of Latin America	130
Rest of Africa	1,452
Rest of Middle East	1
Total Developing Countries	9,100
Total Developed Countries*	800
Global Total	10,000

Note: The 'Rest of' regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

There are significant uncertainties in the estimation of methane emissions from biomass combustion. The default emission factor is one of the greatest uncertainties since it is very dependent on the efficiency of combustion. Also, accurate statistics on biomass combustion are difficult to obtain. Statistics will have significant use of biomass combustion for a country in one year and none in the previous.

2.2 Methane Emissions from Coal Mining in Developing Countries

Overview

Methane is produced during the process of coalification, where vegetation is converted by geological and biological forces into coal. Methane is stored within the coal seams and the surrounding rock strata and is liberated when the pressure above or surrounding the coal bed is reduced as a result of natural erosions, faulting, or mining (EPA 1993, 1999).

The quantity of gas emitted from mining operations is a function of two primary factors: coal rank and coal depth. Coal rank is a measure of the carbon content of the coal, with higher coal ranks corresponding to higher carbon contents and generally higher methane contents. Coals such as anthracite and semianthracite have the highest coal ranks, while peat and lignite have the lowest. Pressure increases with depth and prevents methane from migrating to the surface. Thus, underground mining operations typically emit more methane than surface mining (EPA 1993).

Methane emissions from the coal mining sector come from four main sources:

- **Underground Mines.** Underground mines account for the majority of global methane emissions from coal mining. Geologic pressure traps larger volumes of methane in deeper coal seams and the surrounding rock strata. Because methane is explosive at concentrations of between five and fifteen percent, methane is removed from underground mines by ventilation or degasification as a safety precaution (EPA 1993, 1999).

- **Surface Mines.** As the coal seam is exposed during surface mining, methane is liberated directly to the atmosphere. Surface mines generally emit considerably less methane than underground mines because coal ranks are typically lower and there is less pressure to trap methane in the coal.

- **Post-Mining Operations.** Post-mining operations refer to the processing, storage, and transportation of the mined coal. Coal can continue tom emit methane for months after mining, depending on the characteristics of the coal and the handling procedures. The highest releases occur when coal is crushed, sized, and dried for industrial and utility uses (EPA 1999).

- **Abandoned Mines**. Methane emissions from coal mines can continue after operations have ceased. The key factors are surrounding strata permeability and emissions while active.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of fugitive methane emissions from coal mining in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions and/or projections, using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the Good Practice Guidelines (IPCC 2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions from underground, surface, and post-mining operations is as follows:

Fugitive Methane Emissions = Annual Coal Production x Emissions Factor

Assuming that the emission factors do not change, the driver for determining fugitive methane emissions from coal mining is coal production. Because very little is known about fugitive emissions from abandoned mines, this source was not considered further.

Historical Emissions

If Reported Emissions Are Available for One or More Years

- EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.
  - If emission information was not available for all historical years, emissions were extrapolated based on changes in coal production. Coal production data from EIA (2001) for 1993 through 1999 was linearly extrapolated out to 2000.
  - Projections for each five-year interval out to 2020 were then estimated using the methodology described below.

If No Emissions Data Were Available:

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region. Unless otherwise noted, EPA assumed that hard coal produced in underground coal mines and soft coal was produced in surface mines. However, this assumption does not have a major impact on the estimates because most countries that do not report fugitive methane emissions from coal mining have relatively insignificant levels of coal production. The following steps outline the general methodology:

- Coal Production:
  - Obtained historic coal production data from 1980 through 1999 (EIA 2000);
  - Linearly extrapolated production data from 1993 through 1999 out to 2000;
- Emissions:
  - Multiplied Hard Coal Production for 1990, 1995, and 2000 by IPCC (1997) default factors for underground and associated post mining activities.
  - Multiplied Soft Coal Production for 1990, 1995, and 2000 by IPCC (1997) default factors for surface and associated post mining activities.

Projected Emissions

Where projections were not available, EPA used the following methodology to project emission estimates:

- Activity Data:

- Extrapolated production data from 2005 to 2020, with each five-year interval based on changes in coal production from 1995 to 2000;

- For regions where production was projected to fall below zero, assume a zero production level.

- Projections:

    - Projected emissions out to 2020 based on estimates of future coal production, using average emission factors based on the high and low default values provided by IPCC (1997).

Adjustments to General Approach

For a few countries, adjustments were made to the above methodology, as outlined below:

China: China was one of two countries for which methane emission estimates through 2020 were available (UNDP 1998a). However, the situation in China has changed significantly since the report was published; by 1999 coal production fell below 1990 levels. The decrease is a result of government policy supporting cleaner energy sources, as well as overproduction of coal in recent years. In order to account for the unexpected reduction in coal production, EPA adjusted the estimates from 2000-2020 as follows:

- The emission factor was assumed to remain the same as in the previous analysis. UNDP (1998a) provided projections of coal production for each five year increment, including the year 2000. The implied emission factor was determined by dividing the emissions by the production.

- The updated production estimate for 2000 was multiplied by the implied emission factor to produce an adjusted emission estimate for 2000.

- For 2005 through 2020, emissions were estimated by applying the growth rates from UNDP (1998a) to the adjusted 2000 emission estimate.

India: UNDP (1998b) provided methane emission estimates for 1990. WEC (2000) reports production estimates for 2000 to 2020. The projected production was in line with reports that India's coal production will potentially double by 2010 (Mining India 2000).

- The 1990 estimate was extrapolated to 2020 based on changes in coal production, assuming the average emission factor will remain constant.

Kazakhstan and Uzbekistan: In the early 1990s, the countries of the Former Soviet Union began a transition to market economies. This transformation led to an economic downturn in many sectors, including coal mining. As these countries recover, coal production is expected to stop decreasing as quickly. Therefore, projecting emissions based on recent coal production trends would likely underestimate future emissions. To account for the unique situation of these countries, emission estimates after 2000 were assumed to follow the trend predicted for Russian (EPA, 2001).

North Korea: Using the general methodology, coal production and thus emissions are projected to decline drastically from 2000 to 2020. This trend seems unlikely as coal is expected to remain the key energy source in North Korea. North Korea does not export and imports only small amounts of coal. Therefore, coal consumption was used as a proxy for production, assuming this trade situation remains the same.

- For 2000-2020, coal production is assumed to grow at the same rate as coal consumption in developing Asia (EIA 2001).

- The projected coal production is multiplied by the default emission factors to determine projected methane emissions out to 2020.

South Korea: In the 1990s, South Korea's government began supporting programs to decrease coal production and consumption for local environmental reasons. The recent coal production decline is not likely to continue, however, and seems to have been leveling off in the last few years. As a result, coal production is assumed constant at 2000 levels through 2020.

Indonesia: Coal production projections for surface and underground mining were available for Indonesia (American Embassy 1995). The 1990 estimate for Indonesia, available from the ALGAS study, was projected based on the coal production growth rates. Surface mining was assumed to remain at 90% of all mining activities (Suyartono and Ginting 1995).

Results

Exhibit 2-2 presents the results of our analysis. Estimates that are bolded are provided by country reports are bolded. As indicated, China has the largest emissions from coal mining activities.

Exhibit 2-2: Fugitive Methane Emissions from Coal Mining for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country/Region	1990	1995	2000	2005	2010	2015	2020
China	**8,775**	10,373	8,180	9,438	10,696	11,955	13,213
North Korea	1,203	1,297	1,036	1,133	1,239	1,354	1,481
Kazakhstan	**752**	**474**	331	318	304	290	277
Uzbekistan	**469**	**225**	211	202	194	185	176
India	**330**	421	464	680	896	1,314	1,732
South Africa	**320**	**317**	**337**	**353**	**344**	**338**	**354**
South Korea	**230**	76	56	56	56	56	56
Colombia	**105**	132	168	225	287	365	466
Turkey	78	74	84	102	125	153	187
Mexico	70	84	90	103	119	136	156
Brazil	**59**	50	52	53	54	55	55
Indonesia	33	82	163	199	230	268	305
Chile	30	14	7	2	1	0.4	0.2
Vietnam	29	**52**	67	87	112	145	188
Iran	15	15	13	11	10	8.2	7
Georgia	**13**	**1**	**1**	**3**	**8**	9	10
Thailand	**10**	15	15	17	18	20	22

Exhibit 2-2: Fugitive Methane Emissions from Coal Mining for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country/Region	1990	1995	2000	2005	2010	2015	2020
Mongolia	**9**	6	7	6	6	6	6
Argentina	9	**5**	12	11	10	9	9
Philippines	**7**	8	7	7	6	5	5
Moldova	4	0.4	0.4	0.3	0.3	0.2	0.2
Pakistan	**3**	3	4	4	4	5	5
Venezuela	**3**	6	10	16	24	38	58
Peru	**2**	3	0.4	1	1	1	2
Congo (Kinshasa)	1	1	1	1	1	1	1
Nigeria	1	1	0.4	0.4	0.4	0.4	0.4
Myanmar	**0.4**	0.4	0.4	0.4	0.4	0.4	0.4
Algeria	0.1	0.3	0.3	0.3	0.3	0.4	0.4
Rest of SE Asia	3	2	4	7	11	18	30
Rest of Eastern Europe	2	0.1	0.04	0.02	0.01	0	0
Rest of Latin America	0	0	0	0	0	0	0
Rest of Africa	96	96	83	83	84	84.	85
Rest of Middle East	0	0	0	0	0	0	0
Rest of FSU	23	3	4	3	3	3	2
Total – Developing Countries	12,683	13,835	11,406	13,119	14,842	16,822	18,887
Total Developed Countries (EPA, 2001)	14,445	10,896	10,309	10,329	10,297	N/A	N/A
Global Total	27,129	24,731	21,715	23,449	25,139	N/A	N/A

Bolded Numbers are taken directly from country-prepared publications.

Note: The regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

The greatest uncertainties are due to the use of default emission factors, and difficulties in projecting coal production through the year 2020 for rapidly changing global economies, such as those in developing Asia. Where emissions are not reported, the assumption that hard coal production comes from underground mines and soft coal comes from surface mines could result in inaccurate estimates because default underground mining emission factors are ten times greater than surface mining emission factors. As mentioned previously, however, this uncertainty does not have a major impact on the estimates because the countries that report emissions account for over 95 percent of annual global coal production and over 90 percent of estimated global emissions.

2.3 Methane Emissions from Oil and Gas Systems in Developing Countries

Overview

Methane is the principal component (95 percent) of natural gas and is emitted from natural gas production, transmission and distribution, and processing operations. Natural gas is often found in conjunction with oil, thus oil production and processing can also emit methane in significant quantities. In both oil and gas systems, methane is emitted by leaking equipment, system upsets, and deliberate venting throughout the systems, including in production fields, processing facilities, transmission lines, storage facilities, and gas distribution lines**.**

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of fugitive methane emissions from oil and gas systems in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections, using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions is as follows:

Fugitive Methane Emissions = (Annual Oil Production x Emissions Factor + Annual Oil Consumption x Emissions Factor) + (Annual Natural Gas Production x Emissions Factor + Annual Natural Gas Consumption x Emissions Factor) + [(Annual Gas Produciton + Annual Oil Production) Venting & Flaring Emission Factor]*

Assuming that the emission factors do not change, the driver for determining fugitive methane emissions from oil and natural gas is the respective production and consumption of these fuels.

Historical Emissions

If Reported Emissions Are Available for One or More Years

EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.

- If historical data combined oil and natural gas emissions into one estimate, separate emissions associated with each industry were developed. Some countries reported total emissions from oil and natural gas systems without providing a breakdown of data. In this case, EPA used the IPCC Tier 1 methodology to calculate separate emissions from oil and gas. EPA then determined the percent of emissions generated from each industry. EPA applied this percentage to the historical data to determine the approximate emissions associated with each industry.

- If emission information was not available for all historical years, emissions were extrapolated based on changes in oil and natural gas production and consumption from EIA (2000).
  - ➢ Linearly extrapolated production and consumption data from 1993 through 1999 out to 2000.

If No Emissions Data Were Available

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region:

- Activity Data
  - ➢ Obtained historic natural gas and oil production and consumption data from 1980 through 1999 (EIA 2001);
  - ➢ Data for 1999 was used as a proxy for 2000 data;
- Emissions
  - ➢ Multiplied Natural Gas Production for 1990, 1995, and 2000 by IPCC (1997) default factors.
  - ➢ Multiplied Natural Gas Consumption for 1990, 1995, and 2000 by IPCC (1997) default factors.
  - ➢ Multiplied Oil Production for 1990, 1995, and 2000 by IPCC (1997) default factors.
  - ➢ Multiplied Oil Consumption for 1990, 1995, and 2000 by IPCC (1997) default factors.
  - ➢ Added Oil and Natural Gas Production and multiplied by venting and flaring emission factor
  - ➢ Added together emissions from all four sectors.

If no reported emissions or EIA production data were available, EPA assumed zero emissions for this source.

Projected Emissions

- Activity Data
  - ➢ Projections of natural gas production and oil production and consumption were available from EIA (2001). EPA used growth rates as provided by EIA 'reference case'

projections for the periods 1999-2005, 2005-2010, 2010-2015 and 2015-2020. These are available by country or region.

- Projections

  - EPA applied the average annual consumption growth rate for the corresponding periods, to the emissions attributed to consumption of oil and the average annual production growth rate, for the corresponding periods, to the emissions attributed to production of oil. For natural gas, only a consumption rate is provided, consequently, EPA applied this rate to all reported natural gas emissions to project emissions to 2020.

Adjustments to General Approach

For a few countries, adjustments were made to the above methodology as outlined below:

Azerbijian, Kazakhstan, Turkmenistan and Uzbekistan: The countries of the Former Soviet Union are expected to be key producers in the future. Since EIA(2001) provides only natural gas consumption projections, country-specific production projections out to 2020 from OGJ (2001) were used.

For key countries, the validity of the assumption that production growth will equal consumption growth was checked using the historical ratio of consumption and production in a country. Although historical trends are not always indicative of the future, this analysis will be a starting point for improving projections.

- Bangladesh, China, India, Iran, Pakistan, Saudi Arabia, Thailand, Turkey, Venezuela, and Vietnam: Gas production growth has equaled roughly gas consumption from 1980-1998.

- China, India, Pakistan, Thailand, Venezuela, and Vietnam: Gas production has roughly equaled gas consumption for 1980-1998.

- Argentina, Algeria, Bolivia, Georgia, Kuwait, and Indonesia: Gas production and consumption growth have been significantly different from 1990-1999.

Results

Exhibit 2-3 presents the results of EPA's analysis. Estimates that are provided by country reports are displayed in bold. As indicated, Venezuela had the largest emissions from oil and natural gas activities in 1990.

Exhibit 2-3: Fugitive Methane Emissions from Oil and Gas Systems for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country/Region	1990	1995	2000	2005	2010	2015	2020
Venezuela	**1926**	2043	2502	2877	3252	3740	4228
Saudi Arabia	1374	1717	2039	2519	3028	3346	3597
Uzbekistan	**1298**	**1446**	1607	1829	2044	2086	2137
Iran	1056	1549	2351	2903	3491	3854	4116

Exhibit 2-3: Fugitive Methane Emissions from Oil and Gas Systems for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country/Region	1990	1995	2000	2005	2010	2015	2020
Mexico	**969**	1044	1193	1499	1633	1778	1861
United Arab Emirates	951	1266	1572	1936	2325	2571	2751
Turkmenistan	**929**	844	422	768	1178	1325	1465
India	**626**	981	1175	1905	2635	3510	4096
Algeria	**510**	333	404	483	543	664	745
Azerbaijan	**443**	285	215	261	297	428	539
Argentina	**387**	521	665	1046	1467	2037	2719
Belarus	290	257	342	366	398	456	502
Pakistan	282	377	454	638	803	968	1155
Kuwait	253	240	311	388	470	517	563
Indonesia	**178**	303	300	408	511	620	743
Iraq	178	170	215	262	312	343	381
Nigeria	**175**	208	254	304	342	418	469
Kazakhstan	**152**	81	95	146	210	282	357
Egypt	**148**	222	276	329	370	450	504
Thailand	139	245	416	596	765	947	1164
Colombia	96	103	117	188	262	361	476
China	**93**	111	159	261	370	509	667
Bolivia	**81**	84	63	82	102	130	163
Armenia	**80**	66	53	57	62	71	78
Brazil	56	88	127	407	688	857	1138
Moldova	51	85	127	175	259	354	423
Georgia	47	41	24	25	28	32	35
Chile	34	35	64	104	146	203	269
Turkey	33	65	115	144	201	259	345
South Korea (ROK)	28	83	147	221	296	417	538
Ecuador	**21**	26	53	89	157	228	370
South Africa	16	23	17	21	23	28	32
Peru	11	17	9	14	19	26	33
Myanmar	8	11	17	23	29	34	40
Bangladesh	**7**	11	14	20	25	29	34
Jordan	2	5	5	6	8	9	9
Viet Nam	1	12	17	25	31	36	42
Philippines	**1**	1	1	1	1	2	2
Singapore	1	1	1	1	2	2	2
Israel	**1**	1	1	1	1	1	1
Senegal	1	1	1	1	1	1	1
Congo (Kinshasa)	0	0	0	0	0	0	0
North Korea (DPRK)	0	0	0	0	0	0	0
Uruguay	0	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0	0
Mongolia	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	0	0
Nepal	0	0	0	0	0	0	0
Rest of S&E Asia	200	267	346	470	587	697	814
Rest of FSU	16	14	27	28	31	35	39
Rest of Eastern Europe	70	69	55	71	105	144	171

Exhibit 2-3: Fugitive Methane Emissions from Oil and Gas Systems for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country/Region	1990	1995	2000	2005	2010	2015	2020
Rest of Latin America	64	93	127	187	261	360	474
Rest of Africa	94	96	128	148	169	206	234
Rest of Middle East	223	308	428	511	614	679	723
Total – Developing Countries	13627	15588	18708	24281	29970	35363	40440
Total Developed Countries (EPA, 2001)	31571	30857	32286	32571	33143	N/A	N/A
Global Total	45198	46446	50994	56853	63113	N/A	N/A

Bolded Numbers are taken directly from country-prepared publications.

Note: The regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

The greatest uncertainties are due to the use of default emission factors, and difficulties in projecting oil and natural gas consumption and production through the year 2020 for rapidly changing global economies, such as those in the Former Soviet Union and developing Asia. In addition, methane emissions from oil and natural gas systems are not linearly related to throughput so the Tier 1 methodology and emission factors can lead to overestimates.

3. Industry

3.1 Nitrous Oxide Emissions from Industrial Sources in Developing Countries

Introduction

Adipic acid (hexane-1, 6-dioxic acid) is a white crystalline solid used as a feedstock in the manufacture of synthetic fibers, coatings, plastics, urethane foams, elastomers, and synthetic lubricants. Commercially, it is the most important of the aliphatic dicarboxylic acids, which are used to manufacture polyesters. In the US, for example, 90 percent of all adipic acid is used in the production of nylon 6,6 (SRI, 1998). Adipic acid is produced through a two-stage process with nitrous oxide generated in the second stage. By treating nitrogen oxides (NO_x) and other regulated pollutants in the waste gas stream, N_2O emissions can be reduced. Studies confirm that these abatement technologies can reduce N_2O emissions by up to 99 percent, depending on plant specifications (Riemer et al., 1999).

Nitric acid (HNO_3) is an inorganic compound used primarily to make synthetic commercial fertilizer. It is also a major component in the production of adipic acid and explosives. During the catalytic oxidation of ammonia, nitrous oxide is formed as a by-product and released from reactor vents into the atmosphere. While the waste gas stream may be cleaned of other pollutants such as nitrogen dioxide, there are currently no control measures aimed at eliminating nitrous oxide.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of fugitive methane emissions from coal mining in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections, using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions from nitric acid is as follows:

*Nitrous Oxide emissions = Nitric Acid Production * Emission Factor*

The basic equation to estimate emissions from adipic acid is as follows:

*Nitrous Oxide emissions = Adipic Acid Production * Emission Factor * [1 – (destruction factor * abatement utility factor)]*

Historical Emissions

If Reported Emissions Are Available for One or More Years

EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region.

If No Emissions Data Were Available

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region.

Adipic Acid Production

- Activity Data
    - Production data was estimated based on adipic acid plant capacity figures and estimated capacity utilization (Chemical week 1999a). Capacity utilization was assumed to be 75 percent for 1990, 80 percent for 1995, and 90 percent for 2000.
- Emission Factors
    - The IPCC default emission factor was used for all plants.
- Plant Specific Destruction and Utility Factors:
    - EPA assumed only one plant, in Singapore, had abatement technology. The destruction factor was assumed at 98 percent and abatement utility factor at 95% (Reimer, 1999a).

Nitric Acid Production

- Activity Data
    - Nitric acid production for China, Brazil, and Mexico was estimated based on production figures from various sources (Chemical and Engineering News; Chemical Week; and Brazil Chemical Industry). For other countries, production figures were estimated based on regional fertilizer plant capacities and estimated capacity utilization (Chemical Week, 1999b).
- Emission Factors
    - The emission factor for developing countries is assumed to be 10 kg N_2O per tonne nitric acid (IPCC, 2001).
    - Non-selective catalytic reduction is assumed to reduce emissions by 80 percent. It is estimated to be used in 1% of plants in Asia.

Projected Emissions

Where projections were not available, EPA used the following methodology to project emission estimates:

Adipic Acid

- Production is forecast to increase by two percent annually until 2010 and one percent per year from 2011 to 2020 based on various expert projections and a historical growth of 2 percent per year (CMR, 1998; SRI Consulting, 1999; Reimer, 1999a).

Nitric Acid

- Emissions from nitric acid production were projected based on increases in fertilizer production as estimated in the agricultural soils chapter.

Results

Exhibit 3-1 presents the results of our analysis. Estimates that are bolded are provided by country reports are bolded. As indicated, China has the largest emissions from industrial sources.

Exhibit 3-1: Methane Emissions from Industrial Sources for Key Developing Countries and Regions: 1990 – 2020

Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
China	63	89	97	103	110	114	119
Brazil	17	18	21	23	25	26	28
South Korea	16	17	20	22	24	25	26
Mexico	3	4	5	5	5	6	6
Singapore	0	2	2	2	3	3	3
Total - Developing Countries	99	130	145	155	167	175	183
Developed Countries	606	548	342	358	371	*N/A*	*N/A*
Global Total	705	678	487	513	538	*N/A*	*N/A*

Uncertainties

In general the nitric acid industry is not well characterized. Production data are uncertain due to the fact that nitric acid production is often part of larger production facilities, such as fertilizer or explosive manufacturing. As a result, only a small percentage of nitric acid is sold on the market, making production difficult to track. For all developing countries except China and Mexico, production was based on fertilizer plant capacities but the correlation is uncertain. Additionally, emission factors are difficult to determine because of the large number of plants using different technologies.

Nitrous oxide emissions from adipic acid production are relatively certain since there are only a few plans worldwide. However, production data is confidential and plant specific production must be estimated by allocating total adipic acid production using plant capacities.

4. Agriculture

4.1 Nitrous Oxide Emissions From Agricultural Soils Management

Overview

Nitrous oxide (N_2O) is produced naturally in soils through the microbial process of denitrification and nitrification. A number of anthropogenic activities add nitrogen to the soils, thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N_2O emitted. Anthropogenic activities may add nitrogen to the soils either directly or indirectly.

Direct additions occur from the following activities:

- Various cropping practices, including (1) application of fertilizers, (2) production of nitrogen-fixing crops (beans, pulses, and alfalfa), (3) incorporation of crop residues into the soil, and (4) cultivation of high organic content soils (histosols).

- Livestock waste management, including (1) spreading of livestock wastes on cropland and pasture; and (2) direct deposition of wastes by grazing livestock

Indirect additions occur through volatilization and subsequent atmospheric deposition of ammonia and oxides of nitrogen that originate from the application of fertilizers and the production of livestock wastes and from surface runoff and leaching of nitrogen from the same sources.

Methodology for Estimating N_2O Emissions

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of nitrous oxide emissions from agricultural soils in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions from agricultural soils is as follows:

Historical Emissions

<u>If Reported Emissions Are Available for One or More Years</u>

EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.

- If reported emissions are available for one or more historical years, estimated emissions for remaining years using fertilizer growth rates. For example, if 1990 and 1995 estimates are available, EPA estimated emissions for 2000 by using compounded country-specific historical fertilizer growth rates from 1995 to 1998, as described in detail in the next section.

- If no reported estimates are available for a country, estimates were developed using the IPCC default methodology for agricultural soils. In these cases, EPA developed country estimates based on the Tier 1a default methodologies as described in the IPCC 1996 Revised Guidelines (IPCC, 1996) and in the IPCC Good Practice Guidance (IPCC, 2000). The steps involved in applying the IPCC default methodology for each sub-category of agricultural soils are described in the following sections.

If No Emissions Data Were Available

Where no estimates were available, EPA estimated emissions for each sub-category, using the IPCC Tier 1 methodology outlined in the following sections.

Projected Emissions

If projections were unavailable or the projections were not available out to 2020, EPA used the methodologies outlined for each sub-category, as described in the following sections.

Direct N_2O Emissions from Commercial Synthetic Fertilizer Application

This section describes the activity data and methods that EPA used for estimating and projecting commercial synthetic fertilizer use from 1990 to 2020 for countries where emissions data were not available. Emissions calculation steps utilizing these data are detailed below.

Historical Emissions

Activity Data

- EPA obtained historical commercial synthetic fertilizer consumption data from the FAO database of agricultural statistics (FAOSTAT 2001). These data are available for most countries from 1990-1998. Specifically, EPA used the consumption of nitrogenous fertilizer data, reported in metric tons of nitrogen. EPA used several assumptions for countries without complete data:

    - **Ethiopia**. In 1993, the Former Ethiopia divided into Ethiopia and Eritrea. To estimate the fertilizer consumption of the current Ethiopia in 1990-1992, EPA determined the ratio of the fertilizer consumption of the current Ethiopia to the fertilizer consumption of the Former Ethiopia in 1993 (FAO reports consumption for both Former Ethiopia and Ethiopia in 1993). This ratio (96 percent for fertilizer consumption) was then applied to the fertilizer consumption of the Former Ethiopia for 1990-1992, to estimate the fertilizer consumption of the current Ethiopia for 1990-1992.

    - **FSU**. In 1992, the Soviet Union divided into separate countries. The distribution of fertilizer consumption among the FSU countries in 1992 was assumed to be the same for

1990 and 1991. Consequently, USSR consumption data in 1990 and 1991 were allocated among the FSU countries by the percentages they comprised in 1992.

<u>Growth Rates</u>

- EPA used the country-specific historical growth rate of fertilizer consumption to estimate consumption in 2000. This rate was developed by determining the compounded annual growth rate in consumption for each country between 1995 and 1998, the latest year for which data are available. The growth rate is expressed as:

$$i = ((1998\ consumption/1995\ consumption)^\wedge(1/3)) - 1$$

<u>Emissions</u>

- As recommended in the IPCC Revised Guidelines (IPCC, 1996) and Good Practice Guidelines (IPCC, 2000), EPA assumed that 1.25 percent of all N from fertilizer consumption, excluding the 10 percent of N in fertilizer that volatilizes as NO_x and $NH_{3,}$ is directly emitted as N_2O. Therefore, emissions were calculated as follows:

$$Gg\ N_2O = [F_{country} - (F_{country} * 0.10)] * 0.0125 * 44/28 * 1000$$

Where:

$F_{country}$	= fertilizer consumption for the specified year and country in metric tons of N.
0.10	= fraction of N volatilized
0.0125	= emissions factor in kg N_20-N/kg N
44/28	= N to N_2O conversion
1000	= conversion from metric tonnes to Gg.

Projected Emissions

To project emissions to 2005 through 2020, EPA used the Food and Agriculture Organization's published regional fertilizer consumption growth rate projections for 1995/97 to 2015 (FAO 2000).

Direct Emissions from Cultivation of Nitrogen-Fixing Crops

This section describes how emissions from the cultivation of nitrogen-fixing crops were calculated for countries where these emissions were not available in published reference sources.

Historical Emissions

<u>Activity Data</u>

- EPA obtained production statistics for soybeans and pulses from the FAOSTAT database. The availability of data and the assumptions for each category are discussed below:

- Soybeans**.** For 1990-2000, data on soybean production are available for all of the countries except Mongolia, Bangladesh, Singapore, Armenia, Turkmenistan, Uzbekistan, Chile, Algeria, Senegal, Israel, Jordan, and Saudi Arabia. EPA assumed that these countries did not produce soybeans. For 1990 no data were available for any FSU countries, Moldova, or Ethiopia, but the data were available for 1992 and after (for FSU) and 1993 and after (for Ethiopia). For Ethiopia and FSU countries, data were estimated from 1990-1992 (for FSU) and 1990-1993 (for Ethiopia) using the same methodology as the estimate of fertilizer consumption.

- Total pulses. Pulse production data were available for 1995 for all of the countries except Singapore, which EPA assumed did not produce pulses.

Emissions

- EPA used the crop production statistics to estimate N levels by multiplying the crops' residue-to-crop-mass ratios and dry matter fractions for residue (Strehler and Stutzle, 1987). These data are presented in Table 4.16 of the IPCC Good Practice Guidelines (IPCC, 2000).

- To convert to units of nitrogen, EPA assumed that 3 percent of the total crop dry mass for all crops was nitrogen (IPCC, 1996). An average of the residue-to-crop-mass ratios and dry matter fractions of peas, beans, and peanuts were used for the pulses factors.

- The crop production statistics account for only the mass of the crop rather than the entire aboveground plant. To convert to kg N and account for the aboveground biomass nitrogen, EPA used the following equation:

  *kg N = Production (mt) * (1+ residue-to-crop ratio) * dry matter fraction * N content * 1000*

  Units in kg N were then multiplied by the emissions factor of 0.0125 kg N_2O/kg N and converted from kg to Gg by 1/10^6 to get Gg N_2O

Projected Emissions

Activity Data

Estimated future production of soybeans and pulses, using the following methodologies:

- Soybeans. Neither projected soybean production data nor regional growth rates were available for any countries. Therefore, country-specific growth rates were determined by taking historical soybean production and deriving an average annual growth rate where *i* = ((2000 production/1990 production)^(1/10)) – 1. This rate was applied to the 1995 values to determine 2000 values (which were not available from FAO). The same growth rate was applied to 2000 onwards to obtain projected production to 2020.

- Total pulses. Projections of pulses were not available. Country-specific annual growth rates were determined through the same methodology as the soybeans.

Projections

EPA estimated future emissions to 2020 by applying the projected activity data to the methodology described under the historical emissions section above.

Direct N_2O Emissions from the Incorporation of Crop Residues

Incorporation of crop residues directly adds nitrogen to the soil, resulting in an increase in N_2O emissions. This section describes how emissions from crop residue incorporation were calculated for countries where these emissions were not available in published reference sources.

Historical Emissions

Activity Data

- Obtained production statistics for corn, wheat, beans, and pulses, residues of which are typically incorporated into soils. Bean and pulse production were estimated in the previous section. Historical production data for corn and wheat were available for products from 1990-2000 (FAO, 2001).

Emissions

- EPA assumed that 75 percent of all crop residues are returned to the soils in developing countries (IPCC, 1996). Crop residue biomass, in dry matter kg, was derived based on the following equation:

  *Crop residue biomass (kg N) = Production (mt) * (residue-to-crop ratio) * dry matter fraction * N content * 75% applied to fields * 1000 kg/metric tonne*

  The data for these calculations were obtained from Table 4.16 in the Good Practice Guidelines. IPCC estimates that 1.25 percent of all N from incorporated residues is directly emitted as N_2O. The estimate was converted from kg to Gg N_2O.

Projected Emissions

EPA assumed that N_2O emissions from incorporation of crop residue grow in proportion to production. Using historical average annual growth rates from 1990-2000 (derived through same methodology as soybean growth rates), the production of corn and wheat was estimated for 2005-2020. EPA calculated projected crop residue biomass using the projected production estimates in the above mentioned equation.

Direct Emissions from Manure (Pasture, Range, and Paddock, and All Applied Manure)

Direct nitrous oxide emissions result from livestock manure that is applied to soils either through daily spread operations (all applied manure) or direct deposition on pastures, range, and paddocks (PRP) by grazing livestock.

Historical Emissions

Activity Data

- EPA obtained animal population from FAOSTAT for most countries for 1990, 1995, and 2000 (FAO, 2001) except for the **FSU countries and Ethiopia**, which did not have data until 1995. As was done in estimating crop production for 1990 from these countries, the ratio of the current countries' animal populations to the former countries' animal populations in 1995 was established. The animal populations from the former countries in 1990 were multiplied by this ratio to obtain an estimate for the animal population of the current country in 1990.

Historical Emissions

- EPA calculated total livestock nitrogen excretion, calculated for each animal type (non-dairy cattle, dairy cattle, swine, sheep, poultry, and others) and divided it among animal waste management systems using IPCC default assumptions.

- EPA assumed that 20 percent of total annual excreted livestock N was volatilized (IPCC, 1996).

- Finally, EPA separated the value of the remainder of the excreted livestock N into manure applied to soils and PRP manure. Each was then multiplied by the emission factor specific to the animal manure management systems; 0.0125 kg N_2O-N/kg N excreted for manure applied to soils and 0.02 kg N_2O-N/ kg N excreted for manure in PRP.

  Emissions from manure applied to soils:

$$kg\ N_2O\text{-}N\ from\ manure\ applied\ to\ soils = kg\ N\ applied\ to\ soils * 0.8 * 0.0125$$

  Emissions from manure applied to PRP:

$$kg\ N_20\text{-}N\ from\ PRP\ manure = kg\ N\ applied\ to\ PRP * 0.02\ kg\ N_2O\text{-}N/kg\ N$$

Projected Emissions

EPA assumed that emissions would grow at the same rate as methane emissions from manure, as reported by five-year increments in the methane emissions from manure section of this report. This approach was taken because projections of animal populations are not available.

Indirect Emissions from Agricultural Soils

This component accounts for N_2O that is emitted indirectly from N applied as fertilizer and excreted by livestock. Nitrous oxide enters the atmosphere indirectly through atmospheric deposition of NO_x and NH_3 (originating from fertilizer use and livestock excretion of N), and through leaching and runoff of N from fertilizer applied to agricultural fields and from livestock excretion.

- **Emissions from fertilizer consumption**: EPA used nitrogen consumption data and forecasts, determined in the fertilizer application section. EPA assumed that 10 percent of the applied synthetic fertilizer nitrogen volatilizes to NH_3 and NO_x, and 1 percent of the total volatilized N was emitted as N_2O (IPCC, 1996). To estimate emissions from leaching and run-off, EPA assumed that 30 percent of the total N applied was lost to leaching and surface runoff, and 2.5 percent of this lost N was emitted as N_2O (IPCC, 1996).

- **Emissions from livestock excretion**: EPA assumed that 20 percent of N in livestock excretion volatilizes to NH_4 and NO_x, and that 1 percent of the total volatilized N was emitted as N_2O (IPCC, 1996). To estimate emissions from leaching and runoff, EPA assumed that 30 percent of the total N applied was lost to leaching and surface runoff, and 2.5 percent of this lost N was emitted as N_2O (IPCC 1996). Livestock excretion projections for 2005-2020 were not available. Therefore, the indirect emissions from animal waste were expected to grow at the same rate as direct emissions from animal waste, as determined in the methane emissions from livestock manure section.

Estimates for the "Rest-of-World"

Activity Data

To estimate "Rest-of-World" emissions from agricultural soils EPA obtained activity data from FAO for nitrogenous fertilizer use, production of soybeans, pulses, corn, and wheat, and animal populations for each country in the Rest-of-World regions for 1990 to 2000 (only available to 1998 for fertilizer). EPA combined these data into regional value (e.g., all the fertilizer consumption in Kyrgystan and Tajikistan were combined into one Rest of FSU fertilizer consumption value). The same methodology as described above was used to estimate emissions for the regions.

Growth Rates

For growth rates in crop production (all years), manure applied to soils (all years), and fertilizer consumption (to 2000), EPA used a rate which was determined by summing the activity data from all the countries in a given region for 1990 and the latest year available, and then determining the growth rate between those two values. For example, to obtain the Rest of Centrally Planned Asia region crop production growth rate, EPA summed the crop production of China, North Korea, Mongolia, and Vietnam in 2000 and in 1990. Then, from those summed numbers, EPA determined the growth rate over the time period just as was done for individual countries. These rates were applied to the latest activity data available to project activity data. For fertilizer consumption beyond 2000, EPA used the regional growth rates provided by FAO (2000).

Exhibit 4-1: Nitrous Oxide Emissions from Agricultural Soils (Gg N_2O)

Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
China	1,328	1,597	1,623	1,708	1,795	1,893	1,995
India	916	950	1,195	1,264	1,339	1,423	1,516
Brazil	429	483	491	557	633	721	824
Pakistan	196	236	256	259	263	268	273
Mexico	169	159	164	182	203	226	252
Argentina	**146**	**150**	172	201	236	281	339
Turkey	133	119	126	146	169	197	229
Ethiopia	117	122	134	158	186	220	260
Iran	117	127	146	166	190	217	252
Bangladesh	98	127	130	142	153	171	190
Nigeria	93	97	109	129	152	180	213
South Africa	70	68	73	77	81	86	92
Kazakhstan	58	39	18	19	19	20	20
Indonesia	**52**	65	82	86	91	95	100
Venezuela	40	45	46	52	58	64	72
Uzbekistan	**34**	**29**	53	56	59	62	66
Peru	33	36	38	43	48	54	61
Uruguay	32	32	30	34	38	42	47
Belarus	31	22	22	23	25	26	28
North Korea	27	7	9	10	10	11	12
Mongolia	26	30	38	41	44	47	51
Algeria	23	22	26	29	33	38	43
Saudi Arabia	22	21	25	28	32	36	41
Bolivia	21	24	27	33	42	59	95
Egypt	**21**	27	28	32	37	43	49
Iraq	19	18	20	23	26	30	34
Philippines	**18**	18	19	20	21	22	23
Uganda	18	16	22	26	31	37	45
Nepal	18	20	22	25	28	32	36
Chile	16	**16**	16	18	20	22	25
Ecuador	15	18	21	24	26	30	33
Senegal	14	17	18	18	18	18	18
Congo (Kinshasa) DPRC	12	12	11	13	15	18	21
Turkmenistan	11	10	10	11	11	12	13
Thailand	**9**	12	17	17	18	19	20
Myanmar	**7**	11	**15**	20	**24**	30	**36**
Colombia	**7**	5	7	8	9	10	12
Georgia	**3**	**1**	1	1	1	1	2
Jordan	3	4	4	4	5	6	6
Viet Nam	**3**	3	**3**	4	**4**	4	**5**
Moldova	**2**	**+**	+	+	+	+	+
Azerbaijan	**2**	1	+	+	+	+	+
Israel	2	**3**	4	4	5	6	6
South Korea	**1**	1	1	1	1	1	1
Singapore	+	+	+	+	+	+	+
Armenia	**+**	+	+	+	+	+	+

Exhibit 4-1: Nitrous Oxide Emissions from Agricultural Soils (Gg N_2O)

Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Rest of CPA	10	13	12	15	17	18	20
Rest of S&E Asia	46	48	62	67	75	83	94
Rest of FSU	21	22	13	12	13	13	14
Rest of Eastern Europe	29	23	22	21	23	25	27
Rest of Latin America	96	99	105	111	123	137	153
Rest of Africa	578	652	711	704	794	896	1,012
Rest of Middle East	72	70	72	77	87	98	110
Rest of OECD	1	1	1	2	2	2	3
Total – Developing Countries	5,268	5,748	6,271	6,718	7,335	8,056	8,892
Total Developed Countries (EPA, 2001)	2116	1981	2081	2177	2261	N/A	N/A
Global Total	7384	7728	8351	8895	9596	N/A	N/A

Bolded Numbers are taken directly from country-prepared publications.

Note: The regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

The greatest uncertainties exist in the completeness of the activity data used to derive the emissions estimates. Emissions from fertilizers were estimated from only synthetic fertilizer use. In reality, organic fertilizers (other than the estimated manure and crop residues) also contribute to N_2O emissions from soils, but this activity is not captured in these estimates. Only two nitrogen-fixing crops were used in these estimates; other crops besides soybeans and pulses fix nitrogen and therefore contribute to N_2O emissions. Similarly, other crop residues besides soybeans, pulses, corn, and wheat may be left on the field, thus resulting in N_2O emissions. The identity and quantity of these crops would vary among the different countries. The livestock excretion values, while based on detailed population statistics, do not take animal weight into account. These calculations are also based on assumptions that reduce the types of management systems used to simpler forms. And finally, emissions from histosols and from sewage sludge were not calculated or included in these estimates. Though small components of N_2O emissions, both of these sources do contribute to total emissions.

Uncertainty also exists in the projections. For many sub-categories, growth was based on historical trends. Additionally, when EPA used previously published projections, they were on a regional level, not a country-specific level.

4.2 Methane Emissions from Agricultural Biomass Burning in Developing Countries

Overview

Methane is produced from the open burning of biomass during agricultural activities and from land use change. The sources included in this section are savanna burning, agricultural residue burning, and open burning from forest clearing.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Several developing countries report estimates of methane emissions from agricultural biomass burning in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

In future versions of this report, EPA will estimate emissions from all countries and regions using IPCC methodologies. Additionally, EPA will develop a methodology for projecting these emissions to 2020.

Results

Exhibit 4-6 presents the results of the EPA analysis. Estimates that are provided by country reports are bolded.

Uncertainties

There are significant uncertainties in the estimation of methane emissions from other agricultural sources. Country level activity data on savanna burning and forest clearing are difficult to obtain.

Exhibit 4-6: Methane Emissions from Agricultural Biomass Burning for Key Developing Countries and Regions: 1990 (Gg CH4)

Country	1990
Indonesia	**570**
South Africa	**271**
Mexico	**241**
Peru	**214**
Nigeria	**126**
Brazil	**121**
India	**116**
Chile	**113**
Vietnam	**99**
Thailand	**82**
Ecuador	**64**
Bolivia	**57**
Colombia	**48**
Philippines	**38**
Argentina	**34**
Venezuela	**33**
Georgia	**17**
Egypt	**7**
Bangladesh	**5**
Moldova	**3**
Pakistan	**3**
Senegal	**2**
Jordan	**2**
Uruguay	**1**
Kazakhstan	**1**
Armenia	+
Rest of CPA	**30**
Africa	**414**
Latin America	**9**
SE Asia	**6**
Total – Developing Countries	2,800
Total – Developed Countries	1,400
Global Total	4,200

Note: The ‘Rest of’ regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

4.3 Methane Emissions from Enteric Fermentation in Developing Countries

Overview

Normal digestive processes in animals result in methane (CH_4) emissions. Enteric fermentation refers to a fermentation process whereby microbes present in animals' digestive systems ferment food. Methane is produced as a by-product and can be exhaled by the animal.

Domesticated ruminants such as cattle, buffalo, sheep, goats and camels account for the major CH_4 emissions in this sector. Other domesticated non-ruminants such as swine and horses also produce CH_4 as a by-product of enteric fermentation but emissions per animal are significantly.

The quantity, quality, and type of feed are also significant determinants of methane emissions. Feed intake varies by animal type and age for individual animal types. The following sections discuss the methodology as well as uncertainties associated with methane emissions estimates from enteric fermentation.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of methane emissions from enteric fermentation in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions from enteric fermentation is as follows:

$$\textit{Emissions factor (kg/head/yr) x animal population (head) } /10^6 \textit{ kg/Gg = emissions (Gg/yr)}$$

Assuming that the emission factors do not change over time, the driver for determining methane emissions is animal population.

Historical Emissions

<u>If Reported Emissions Are Available for One or More Years</u>

EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.

If emission information was not available for all historical years, EPA determined the growth rate of animal populations over the required intervals. For example, for countries with emissions data for 1990 and 1995, EPA extrapolated emissions to 2000 based on the expected growth rate in animal population. This estimated growth rate was determined as the difference in Tier 1 estimates for 1995 and 2000, using FAO (2001) data on animal populations. This growth rate was applied to reported 1995 estimates.

If both aggregate and disaggregate estimates are reported, EPA used the available disaggregated estimates to develop a disaggregated time series. For example, if a country published separate manure management and enteric fermentation emissions estimates for one year and aggregated emissions from these two sources for subsequent years, EPA calculated the ratio of enteric fermentation emissions to total emissions from manure management and enteric fermentation in the disaggregated estimate. This ratio was subsequently applied to all aggregate emissions from livestock to obtain enteric fermentation emissions estimates from 1990 to 2000.

If No Emissions Data Were Available

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region.

- **Activity Data**
  - EPA obtained 1990, 1995, and 2000 animal population data from the Food and Agriculture Organization (FAO).[1] Estimates for non-dairy cattle were obtained by subtracting FAO dairy cattle estimates from FAO total cattle estimates.
  - For 1990 estimates of **Former Soviet Union (FSU) countries and Ethiopia**, animal population data were only available for the Soviet Union and the Ethiopian People's Democratic Republic (Ethiopia and Eritrea) respectively. EPA divided the 1990 livestock populations in the FSU based upon each country's relative share in 1992. For Ethiopia, EPA used the data for year 1993. Applying this methodology, EPA obtained animal populations by animal type for the individual countries for 1990. Emissions for 1995 and 2000 were estimated as for other countries with no reported emissions data.
  - **Regions**: For each region, EPA summed the animal population for those countries that comprise the region and used the Tier 1 methodology to estimate emissions for the region.
- **Emission Factors**
  - Except for cattle, swine and buffalo, only two categories of emissions factors for each major animal category are given in the IPCC Guidelines: (1) developed countries; and (2) developing countries. The developing country emission factor is used for all countries in this analysis.
- **Emissions**: Multiplied activity data by emission factor for each country for 1990 - 2000.

[1] 1990 and 2000 data for Pakistan for all livestock categories except poultry were obtained from Pakistan's ALGAS Report. 1995 livestock population data were interpolated. 1990, 1995, and 2000 poultry data were obtained from FAO.

Projected Emissions

Where projections were not available, EPA used the following methodology to project emission estimates:

- EPA extrapolated to 2020 emissions estimates based on annual average regional meat and milk production growth rates (IFPRI 1999) weighted by individual country animal populations in 2000.[2]

- **For Thailand**, a growth rate was cited in the specific ALGAS Report; EPA used this growth rate rather than meat and milk production growth rates.

[2] These growth rates are generated by a model that incorporates supply and demand parameters. These parameters include the feed mix applied according to relative price movements, international trade, national income, population, and urban growth rates as well as anticipated changes in these rates over time. However, assumptions are needed regarding the application of these growth rates to animal population. EPA estimated an average of meat and milk growth rates weighted by the animal population for each individual country in 2000 and applied this estimate to emissions projections beyond 2000. Milk production growth rates were applied to dairy cow and buffalo populations while meat production growth rates were applied to all other animal types.

Exhibit 4-2 - Methane Emissions from Enteric Fermentation (Gg CH_4)

Country	1990	1995	2000	2005	2010	2015	2020
Brazil	7,941	8,674	8,866	9,883	11,018	12,283	13,693
India	7,563	7,930	8,297	8,700	9,102	9,544	9,985
China	4,548	6,952	9,355	10,105	10,855	11,138	11,420
Argentina	2,621	2,611	2,601	2,900	3,233	3,604	4,018
Pakistan	1,968	2,182	2,397	2,663	2,952	3,245	3,537
Mexico	1,701	1,621	1,624	1,810	2,018	2,250	2,508
Turkey	1,215	1,138	1,026	1,161	1,314	1,486	1,682
Colombia	1,124	1,185	1,211	1,350	1,504	1,676	1,868
Ethiopia	991	1,028	1,161	1,373	1,625	1,922	2,274
Indonesia	844	902	965	1,072	1,179	1,394	1,501
Kazakhstan	693	711	729	754	781	808	836
Venezuela	688	769	823	918	1,023	1,141	1,272
Iran	654	711	733	829	938	1,062	1,201
Nigeria	648	711	884	1,045	1,236	1,461	1,727
Uruguay	590	654	636	709	790	881	982
Thailand	530	664	831	1,041	1,303	1,632	2,043
Bangladesh	519	514	508	557	606	689	771
Peru	480	507	559	623	695	775	864
Belarus	461	365	297	307	318	329	340
South Africa	452	394	343	355	367	380	394
Myanmar	397	442	487	553	619	704	788
Nepal	369	401	423	483	550	628	716
Bolivia	333	357	398	443	494	551	614
Egypt	323	361	380	430	486	550	623
Vietnam	311	359	407	455	503	588	674
Uzbekistan	278	285	275	284	294	304	314
Chile	277	309	345	384	428	477	532
Philippines	249	254	273	294	320	350	386
Ecuador	243	277	287	320	357	398	443
Mongolia	235	258	283	308	332	359	387
Uganda	186	201	226	268	317	375	444
Azerbaijan	164	140	166	172	178	184	190
Algeria	159	154	175	198	224	253	286
South Korea	144	167	190	200	210	218	225
Senegal	138	153	149	176	208	246	290
Iraq	123	92	95	108	122	138	157
Moldova	83	70	39	40	41	43	44
Georgia	78	54	62	64	66	68	71
Turkmenistan	77	95	117	121	125	130	134
Congo (Kinshasa)	74	65	53	62	74	87	103
North Korea (DPRK)	57	48	42	47	53	60	68
Saudi Arabia	56	69	70	79	90	102	115
Armenia	44	37	35	36	37	39	40
Israel	30	32	34	35	37	38	39
Jordan	12	17	13	15	17	19	22
Singapore	0	0	0	0	0	0	0

Rest of CPA	239	287	277	322	375	437	509
Rest of S&E Asia	425	453	549	639	745	867	1,010

Exhibit 4-2 - Methane Emissions from Enteric Fermentation (Gg CH_4)

Country	1990	1995	2000	2005	2010	2015	2020
Rest of FSU	249	234	179	185	192	198	205
Rest of Eastern Europe	342	312	256	265	275	284	294
Rest of Latin America	1,485	1,553	1,554	1,733	1,931	2,153	2,400
Rest of Africa	5,652	6,252	6,797	8,040	9,510	11,249	13,305
Rest of Middle East	231	226	266	301	340	385	435
Rest of OECD-90	8	9	9	9	10	10	10
Total – Developing Countries	49,300	54,200	58,800	65,200	72,400	80,200	88,800
Total Developed Countries (EPA, 2001)	27,400	25000	25,100	26,000	26,300	N/A	N/A
Global Total	76,700	79,200	83,900	91,300	98,700	N/A	N/A

Bolded Numbers are taken directly from country-prepared publications.

Note: The regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

The greatest uncertainties are associated with the use of default emission factors due to the lack of information on country specific animal diets. Emission estimates for countries with significant diet variance could be inaccurate. For projected emissions, EPA assumed that meat production growth rates are applicable to all animal types except for dairy cows. Although some animal types are used for both dairy and meat products in certain countries (e.g. goats, sheep), EPA has insufficient data to differentiate the use for these animal types.

4.4 Methane and Nitrous Oxide Emissions from Manure Management in Developing Countries

Overview

Livestock manure management produces methane (CH_4) and nitrous oxide (N_2O). Methane is produced during the anaerobic decomposition of manure while nitrous oxide is produced by the nitrification and denitrification of the organic nitrogen content in livestock manure and urine.

The quantity of CH_4 emitted from manure management operations is a function of three primary factors: the type of treatment or storage facility, the ambient climate, and the composition of manure. When manure is stored or treated in anaerobic systems such as lagoons, ponds or pits, the decomposition process results in CH_4 emissions. Ambient temperature and moisture content also affect methane formation, with higher ambient temperature and moisture conditions favoring CH_4 production. The composition of manure is directly related to animal types and diets. Feeds with higher energy content and digestibility have a higher potential for CH_4 generation.

N_2O generation is also a function of the composition of the manure, as well as the type of bacteria involved in the decomposition process and the oxygen and liquid content of manure. N_2O emissions occur when the manure is first handled aerobically (nitrification) and then handled anaerobically (denitrification). N_2O generation is most likely to occur in dry manure handling systems that can also create pockets of anaerobic conditions. N_2O emissions from pastures, ranges, and paddocks are discussed under Agricultural Soil Management.

The following sections discuss the methodology as well as uncertainties associated with methane and nitrous oxide emissions estimates from manure management.

Methodology for Estimating Methane Emissions

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of methane emissions from manure management in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions from manure management is as follows:

Emissions factor (kg/head/yr) x animal population (head) /10^6 kg/Gg = emissions (Gg/yr)

Assuming that the emission factors do not change over time, the driver for determining methane emissions from manure is animal population.

Historical Emissions

<u>If Reported Emissions Are Available for One or More Years</u>

EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.

- If emission information was not available for all historical years, EPA determined the growth rate of animal populations over the required intervals**.** For example, for countries with emissions data for 1990 and 1995, EPA extrapolated emissions to 2000 based on the expected growth rate in animal population. This estimated growth rate was determined as the difference in Tier 1 estimates for 1995 and 2000, using FAO (2001) data on animal populations. This growth rate was applied to reported 1995 estimates.

- If both aggregate and disaggregate estimates are reported, EPA used the available disaggregated estimates to develop a disaggregated time series. For example, if a country published separate manure management and enteric fermentation emissions estimates for one year and aggregated emissions from these two sources for subsequent years, EPA calculated the ratio of manure management emissions to total emissions from manure management and enteric fermentation in the disaggregated estimate. This ratio was subsequently applied to all aggregate emissions from livestock to obtain manure management emissions estimates from 1990 to 2000.

If No Emissions Data Were Available

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region.

- Activity Data
  - ➢ EPA obtained 1990, 1995, and 2000 animal population data from the Food and Agriculture Organization (FAO).[3] Estimates for non-dairy cattle were obtained by subtracting FAO dairy cattle estimates from FAO total cattle estimates.
    - ✓ For 1990 estimates of **Former Soviet Union (FSU) countries and Ethiopia**, animal population data were only available for the Soviet Union and the Ethiopian People's Democratic Republic (Ethiopia and Eritrea) respectively. EPA divided the 1990 livestock populations in the FSU based upon each country's relative share in 1992. For Ethiopia, EPA used the data for year 1993. Applying this methodology, EPA obtained animal populations by animal type for the individual countries for 1990. Emissions for 1995 and 2000 were estimated as for other countries with no reported emissions data.
    - ✓ **Regions**: For each region, EPA summed the animal population for those countries that comprise the region and used the Tier 1 methodology to estimate emissions for the region.
- Emission Factors
  - ➢ Except for cattle, swine and buffalo, two categories of emissions factors for each major animal category are given in the IPCC Guidelines: 1) developed countries; and 2) developing countries. The developing country emission factor is used in this analysis.
  - ➢ The emissions factors also were based on climate type (i.e., cool, temperate, and warm). EPA estimated temperature data from the Global Historical Climatology Network data published by the National Climatic Data Center which has temperatures for the country's capital/major cities obtained from national data gathering centers. Given the lack of animal population data by areas within a country, EPA assumed that 100 percent of the animal population are located in a climate defined by the country's average temperature.
    - ✓ **For Bolivia, Chile, Colombia, Ecuador and Peru**: Geographic Information System (GIS) information on temperature ranges was used to determine the climate type applicable to livestock areas in these countries.

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[3] 1990 and 2000 data for Pakistan for all livestock categories except poultry were obtained from Pakistan's ALGAS Report. 1995 livestock population data were interpolated. 1990, 1995, and 2000 poultry data were obtained from FAO.

- ✓ **Regions**: China/CPA, Africa and Middle East regions were assumed to have warm climates while South/East Asia, Former Soviet Union (FSU), Eastern Europe, Latin America, and OECD-90 regions were assumed to have temperate climates.

- Historical Emissions: Multiplied activity data by emission factor for each country for 1990, 1995, and 2000.

Projected Emissions

Where projections were not available, EPA used the following methodology to project emission estimates:

- EPA extrapolated to 2020 emissions estimates based on annual average regional meat and milk production growth rates (IFPRI 1999) weighted by individual country animal populations in 2000. EPA used annual regional meat and milk production growth rates as defined in "Livestock to 2020" (IFPRI 1999, Table 18). EPA estimated an average of meat and milk growth rates weighted by the animal population for each individual country in 2000 and applied this estimate to emissions projections beyond 2000. Milk production growth rates were applied to dairy cow and buffalo populations while meat production growth rates were applied to all other animal types.

  - ➢ **For Thailand**, a growth rate was cited in the specific ALGAS Report; EPA used this growth rate rather than meat and milk production growth rates.

Methodology for Estimating Nitrous Oxide Emissions

Direct nitrous oxide (N_2O) emissions result from manure management systems, including anaerobic and liquid systems. Because no country reported nitrous oxide emissions, EPA developed estimates using the Tier One IPCC methodology:

Emissions factor (kg/head/yr) x animal population (head) /10^6 kg/Gg = emissions (Gg/yr)

Activity Data

EPA used data from FAO (2001) as described in the methane section of this chapter.

- **Historical emissions**. IPCC default emission factors for each manure management system were multiplied by the population for each animal type (non-dairy cattle, dairy cattle, swine, sheep, poultry, and others). Emissions for each manure management system (anaerobic lagoons, liquid systems, solid storage and drylot, other systems) were then summed to obtain an annual total estimate of N_2O emissions.

- **Projected Emissions**. EPA multiplied year 2000 nitrous oxide emissions estimates by country-specific growth rates developed for methane emissions from manure management as part of this report. These growth rates were applied to the 2000 nitrous oxide estimates to develop projections in 5-year increments (2000-2020).

Results

Exhibit 4-3: Nitrous Oxide Emissions from Manure Management (in Gg N_2O)

Country	1990	1995	2000	2005	2010	2015	2020
China	160	194	201	212	222	234	246
India	17	18	19	20	20	21	22
Brazil	13	14	12	13	15	16	18
Indonesia	10	12	12	13	15	17	19
Kazakhstan	9	7	4	4	5	5	5
Belarus	7	6	5	6	6	6	6
Turkey	6	7	6	7	8	9	10
Mexico	6	6	6	6	7	8	9
Viet Nam	6	7	9	10	11	13	15
Myanmar	6	6	7	9	11	14	17
Thailand	5	6	6	7	9	12	15
Uzbekistan	5	5	5	5	5	5	5
Philippines	4	4	5	5	6	7	7
South Korea	3	4	4	4	5	5	5
North Korea (DPRK)	2	1	1	1	2	2	2
Pakistan	2	3	3	3	4	4	5
Nigeria	2	3	3	3	4	5	6
Azerbaijan	2	2	2	2	2	3	3
Moldova	2	1	1	1	1	1	1
Mongolia	2	2	2	2	2	3	3
Bangladesh	2	2	2	2	2	3	3
Georgia	1	1	1	1	1	1	1
Turkmenistan	1	1	1	1	1	1	1
Argentina	1	1	2	2	2	2	3
Colombia	1	1	1	2	2	2	2
Venezuela	1	2	2	2	2	3	3
South Africa	1	1	1	1	1	1	1
Peru	1	1	1	1	1	2	2
Bolivia	1	1	1	1	1	2	2
Ecuador	1	1	1	1	2	2	2
Ethiopia	1	1	1	1	1	1	2
Nepal	1	1	1	1	1	1	1
Armenia	1	1	1	1	1	1	1
Congo (Kinshasa)	1	1	1	1	1	1	1
Chile	1	1	1	1	1	1	1
Uganda	1	1	1	1	1	1	1
Iran	1	1	1	1	1	1	1
Algeria	0	0	0	0	0	0	0
Egypt	0	0	0	0	0	0	0
Senegal	0	0	0	0	0	1	1
Iraq	0	0	0	0	0	0	0
Singapore	0	0	0	0	0	0	0
Uruguay	0	0	0	0	0	0	0
Israel	0	0	0	0	0	0	0
Saudi Arabia	0	0	0	0	0	0	0
Jordan	0	0	0	0	0	0	0

Exhibit 4-3: Nitrous Oxide Emissions from Manure Management (in Gg N_2O)

Country	1990	1995	2000	2005	2010	2015	2020
Rest of CPA	3	3	3	4	4	5	6
Rest of S&E Asia	4	4	5	5	5	6	8
Rest of FSU	5	2	2	2	2	2	3
Rest of Eastern Europe	6	6	5	5	5	6	6
Rest of Latin America	3	3	4	4	5	6	6
Rest of Africa	8	9	9	10	11	12	14
Rest of Middle East	0	0	0	0	0	0	1
Rest of OECD	0	0	0	0	0	0	0
Total – Developing Countries	311	351	361	387	415	452	488
Total – Developed Countries	303	268	277	294	303	N/A	N/A
Global Total	614	619	639	681	719	N/A	N/A

Exhibit 4-4: Methane Emissions from Manure Management (Gg CH_4)

Country	1990	1995	2000	2005	2010	2015	2020
India	**905**	941	**977**	1,007	**1,036**	1,068	**1,099**
China	**666**	902	**1,139**	1,197	**1,256**	1,324	**1,393**
Turkey	401	394	366	414	468	530	600
Brazil	**306**	**346**	345	385	429	478	533
South Africa	180	159	139	144	149	155	160
Pakistan	178	184	188	214	244	278	317
Thailand	**116**	145	182	228	285	357	447
Vietnam	104	128	153	171	189	221	253
Argentina	103	104	105	117	130	145	162
Kazakhstan	**82**	47	27	27	28	29	30
Iran	74	77	81	91	103	117	132
Bangladesh	**73**	72	72	78	85	97	109
Philippines	62	64	68	74	80	88	97
Belarus	55	43	36	37	38	40	41
Mexico	**49**	50	50	55	62	69	77
Indonesia	47	60	76	84	93	110	118
Myanmar	**43**	53	**62**	79	**97**	126	**155**
South Korea	**40**	50	**60**	65	**70**	75	**80**
Uzbekistan	**38**	38	35	37	38	39	41
Colombia	**37**	40	41	46	51	57	64
Nepal	33	36	39	45	51	58	66
Nigeria	33	37	44	52	61	72	86
Azerbaijan	**30**	24	29	30	31	32	33
Ethiopia	**30**	31	35	41	49	58	68
Egypt	**23**	29	30	34	39	44	50
Peru	19	19	22	24	27	30	34
Venezuela	19	22	25	28	31	34	38
Turkmenistan	15	18	21	22	23	24	25
Moldova	**15**	**10**	6	6	6	7	7
Georgia	**13**	**10**	11	12	12	13	13

Exhibit 4-4: Methane Emissions from Manure Management (Gg CH_4)							
Country	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Uruguay	13	15	14	15	17	19	21
Bolivia	11	12	14	15	17	19	21
Mongolia	**9**	10	11	11	12	13	14
Chile	9	11	13	15	16	18	20
Ecuador	9	10	12	13	15	17	18
Israel	9	10	11	11	12	12	12
North Korea DPRK	7	4	4	5	5	6	7
Algeria	7	7	9	10	11	12	14
Uganda	7	8	9	11	12	15	17
Iraq	7	4	4	5	6	6	7
Senegal	6	8	8	9	11	13	16
Congo (Kinshasa)	5	5	5	5	6	7	9
Saudi Arabia	5	7	7	8	9	10	12
Armenia	**3**	2	2	2	2	2	2
Singapore	2	1	1	2	2	2	3
Jordan	1	1	1	1	2	2	2
Rest of CPA	35	44	44	51	60	69	81
Rest of S&E Asia	57	68	74	87	101	117	137
Rest of FSU	47	38	35	36	37	38	40
Rest of Eastern Europe	107	95	83	86	89	92	95
Rest of Latin America	44	48	50	56	63	70	78
Rest of Africa	238	262	281	332	393	464	549
Rest of Middle East	13	13	16	18	20	23	26
Rest of OECD-90	6	7	8	8	8	9	9
Total – Developing Countries	4,446	4,823	5,178	5,657	6,187	6,830	7,535
Total -Developed Countries (EPA, 2001)	4,857	4,667	5,095	5,095	5,190	N/A	N/A
Global Total	9,303	9,489	10,273	10,752	11,378	N/A	N/A

Bolded Numbers are taken directly from country-prepared publications.

Note: The regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

The greatest uncertainties are associated with the use of default emission factors due to the lack of information on country specific animal diets and geographic concentration of animal populations. Emissions estimates for countries with significant diet variance could be inaccurate. For projected emissions, EPA assumed that meat production growth rates are applicable to all animal types except for dairy cows. Although some animal types are used for both dairy and meat products in certain countries (e.g. goats, sheep), EPA has insufficient data to differentiate the use for these animal types.

4.5 Methane Emissions from Rice Cultivation in Developing Countries

Methane is produced from the anaerobic decomposition of organic matter in flooded rice fields. When fields are flooded, aerobic decomposition of organic material gradually depletes the oxygen present in the soil and flood water, causing anaerobic conditions in the soil to develop. Once the environment becomes anaerobic, methane is produced. Several factors influence the amount of methane produced, including water management and the amount of organic material.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of fugitive methane emissions from rice cultivation in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions from rice cultivation is as follows:

$$\textit{Methane emissions} = S_i S_j S_k\ (\textit{Emission Factor}_{ijk} * \textit{Annual Area Harvested}_{ijk} * 10\wedge^{-12})$$

Where:

> i, j, and k represent different ecosystems, water management regimes, and other conditions under which CH4 emissions from rice may vary.

Assuming that the emission factors do not change, the drivers for determining fugitive methane emissions from rice cultivation are the type and amount of area harvested, which depends on rice demand, amount of available land, and typical yields.

Historical Emissions

<u>If Reported Emissions Are Available for One or More Years</u>

EPA took emissions directly from publicly available, country-prepared reports, wherever possible.

- If emission information was not available for all historical years, EPA estimated emissions using the Tier One methodology, as described below, for the time series and calculated a growth rate for each five year increment. The growth rate was applied to the available country prepared estimates to determine historical estimates.

- Projections for each five-year interval out to 2020 were then estimated using the methodology described below.

<u>If No Emissions Data Were Available</u>

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region.

- **Area Harvested**:
  - ➢ Obtained data on area harvested for rice cultivation from 1990 through 2000 (FAO 2001);
  - ➢ Obtained information on type of water management regime (upland, irrigated, rainfed, or other) from IRRI (2001). If information was not available from IRRI, data was obtained from IPCC (1997)
- **Emission Factor**:
  - ➢ Emission factors were available from IPCC (1997), based on water management regime. If a country was similar to a country with a IPCC published emissions factor, that emission factor was used:
    - ✓ Thailand's emission factors were applied to Laos, Malaysia, and Cambodia.
    - ✓ India's emission factors were applied to Bhutan and Nepal.
  - ➢ Irrigated Land: Due to limited information, EPA assumed that all irrigated land was continuously flooded, with no aeration. This assumption is conservative and could lead to overestimates in emissions.
  - ➢ Rainfed Land: Climate statistics were used to determine whether the lands were flood or drought prone.
- Emissions:
  - ➢ Multiplied area harvested for 1990, 1995, and 2000 by percentage in each water management type.
  - ➢ Multiplied area harvested for each year and in each water management type by appropriate emission factor (IPCC, 1997).
  - ➢ Summed methane emissions from each water management type.

If no reported emissions or FAO/IRRI production data were available, EPA assumed zero emissions from this source.

Projected Emissions

Where projections were not available, EPA used the following methodology to project emission estimates:

- **Activity Data**:

  - Due to the lack of projections on future rice area harvested, EPA used population as the driver for methane emissions from rice cultivation. Since this does not account for increases in yield or lack of available area, this methodology is likely to overestimate emissions in 2020.

  - Obtained population projections from UN. Determined growth rate for each country and region for each five year increment from 2000 to 2020.

- **Projections**:

  - EPA applied the population growth rates to the historical emissions attributed to rice cultivation, to develop projections at five-year intervals.

Results

Exhibit 4-5 presents the results of our analysis. Estimates that are bolded are provided by country reports are displayed in bold. As indicated, China has the largest emissions from rice cultivation in 1990. Country reported estimates accounted for over 90 percent of rice area harvested in 1990.

Exhibit 4-5: Methane Emissions from Rice Cultivation for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country	1990	1995	2000	2005	2010	2015	2020
China	**11,155**	11,302	**11,450**	11,725	**12,000**	12,225	**12,450**
India	**4,070**	4,315	**4,560**	4,695	**4.830**	4,975	**5,120**
Indonesia	**2,543**	2,751	2,771	2,946	3,110	3,271	3,427
Thailand	2,096	**2,110**	**2,157**	**2,177**	**2198**	**2,220**	**2,244**
Viet Nam	**1,755**	1,825	**1,894**	1,946	**1998**	2,055	**2,111**
Myanmar	**1,327**	1,607	1,598	1,691	1,784	1,876	1,961
Bangladesh	**767**	730	781	850	918	977	1,029
Philippines	**567**	**587**	**632**	**632**	**632**	**632**	**632**
Pakistan	**526**	538	573	649	731	815	894
South Korea	**414**	365	316	307	298	298	298
Nigeria	**385**	518	564	623	686	752	818
Brazil	**240**	263	213	225	237	249	260
Colombia	**199**	218	287	310	333	355	376
Egypt	190	185	180	194	208	220	233
Nepal	119	123	127	142	158	174	189
Ecuador	**105**	139	133	144	155	165	174
Iran	105	113	117	123	133	144	155
North Korea	81	72	67	70	73	76	79
Uruguay	**69**	101	123	127	131	135	139

Exhibit 4-5: Methane Emissions from Rice Cultivation for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country	1990	1995	2000	2005	2010	2015	2020
Venezuela	**67**	91	74	81	87	93	99
Peru	50	**55**	73	79	84	89	94
Mexico	**35**	23	28	29	31	33	34
Kazakhstan	**25**	**19**	**16**	16	16	17	17
Uganda	**24**	30	38	43	49	56	63
Argentina	**17**	30	30	32	33	35	36
Iraq	16	35	26	30	34	38	42
Uzbekistan	**12**	14	5	6	6	7	7
Senegal	9	9	11	12	13	15	16
Congo (Kinshasa)	7	8	6	7	8	9	10
Chile	6	**6**	5	5	5	6	6
Bolivia	5	**5**	6	7	7	8	9
Turkmenistan	4	**3**	5	5	5	6	6
Turkey	3	2	3	3	4	4	4
Azerbijian	**0**	0	1	1	1	1	1
South Africa	0	0	0	0	0	0	0
Algeria	0	0	0	0	0	0	0
Rest of S & E Asia	314	331	320	349	380	415	452
Rest of Eastern Europe	1	0	0	0	0	0	0
Rest of Latin America	82	88	98	106	115	124	134
Rest of Africa	489	580	298	329	364	403	445
Rest of Middle East	0	0	0	0	0	0	0
Rest of FSU	4	3	4	5	5	6	6
Rest of CPA	339	336	349	380	414	452	492
Total – Developing Countries	28,223	29,529	29,937	31,102	32,276	33,425	34,561
Total – Developed Countries (EPA, 2001)	2,249	2,356	2,083	2,134	2,233	N/A	N/A
Global Total	30,472	31,885	32,021	33,236	34,509	N/A	N/A

Note: The 'Rest of' regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

There are significant uncertainties in the estimation of methane emissions from rice cultivation. The default emission factors are one of the greatest uncertainties. The IPCC emission factor is country specific for only a handful of counties. Additionally, it is adjusted for water management, however, it is not adjusted for other parameters such as ratooning. Finally, information is not readily available on the amount of organic amendment, and flooding and aeration in irrigated areas. Another area of uncertainty is the best driver to use for projections. Future work will look at the historic relationship between demand, yield and area harvested.

5. Waste

5.1 Methane Emissions from Landfills in Developing Countries

Overview

Methane is produced and emitted from the anaerobic decomposition of organic material in landfills. The major drivers of emissions are the amount of organic material deposited in landfills, the extent of anaerobic decomposition, and the level of landfill methane collection and combustion (e.g., energy use or flaring). Because organic material deep within landfills takes many years to decompose completely, past landfill disposal practices greatly influence present day emissions.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of methane emissions from landfills in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections, using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). EPA used the 1996 IPCC Tier One methodology and available activity data to estimate emissions. The basic equation to estimate emissions from rice cultivation is as follows:

$$Methane\ emissions = MSW_T * MSW_F * MCF * DOC * DOC_F * F * 16/12-R)*(1-Ox)$$

Where:

MSW_T	=	total municipal solid waste(MSW) generated = Population * waste generation per person
MSW_F	=	Fraction of MSW disposed to solid waste disposal sites
MCF	=	methane correction factor
DOC	=	degradable organic carbon
DOC_F	=	fraction DOC dissimilated
F	=	fraction of methane in landfill gas
R	=	recovery
Ox	=	oxidation

Historical Emissions

<u>If Reported Emissions Were Available for One or More Years:</u>

EPA took emissions and projections directly from publicly available, country-prepared reports, wherever possible.

- If emission information was not available for all historical years, EPA estimated emissions using the Tier One methodology, as described below, for the time series and calculated a growth rate for each five-year increment. The growth rate was applied to the available country prepared estimates to determine historical estimates.

If No Emissions Data Were Available:

Where no estimates were available, EPA used the IPCC Tier 1 methodology for each country and/or region.

- Activity Data:
  - Urban population data were taken from the UN.
- Emission Factor:
  - The MSW_F and MCF were taken from IEA, 1990.
  - The waste generated per person, DOC, DOC_F, R, and Ox are IPCC default values (IPCC,1997).
  - Oxidation and recovery were assumed to equal zero.

Projected Emissions

Where projections were not available, EPA used the following methodology to project emission estimates:

- Activity Data:
  - Obtained population projections from UN. Determined growth rate for each country and region for each five-year increment from 2000 to 2020.
  - Obtained GDP projections by country from the World Bank.
- Emission Factors:
  - The MSW per capita generation rate is assumed to increase at the rate of projected GDP.
  - The proportion of wastes placed in landfills versus open dumps increases at the rate of per capita GDP growth.

Results

Exhibit 5-1 presents the results of our analysis. Estimates that are provided by country reports are displayed in bold. As indicated, China has the largest emissions from landfills.

Exhibit 5-1: Methane Emissions from Landfills for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country	1990	1995	2000	2005	2010	2015	2020
China	**2,430**	3,320	**4,210**	5,272	**6,333**	7,815	9,297
Mexico	**618**	664	715	771	830	894	963
Brazil	**618**	**677**	722	770	822	877	935
South Africa	**510**	577	653	739	837	947	1,072
Turkey	405	441	480	523	569	620	674
Jordan	371	**371**	429	497	575	665	769
Israel	370	**370**	393	418	444	472	501
India	**334**	382	436	498	569	650	743
Venezuela	323	351	381	414	449	488	530
Argentina	**315**	333	352	373	394	417	441
Indonesia	**288**	327	372	423	481	546	621
Peru	286	311	339	369	402	438	477
Egypt	**264**	296	333	373	419	470	528
Iran	237	270	308	352	402	458	523
Saudi Arabia	226	262	303	351	406	470	544
Pakistan	**201**	239	285	340	405	482	574
South Korea	**200**	209	217	227	236	246	257
Algeria	**196**	221	250	282	318	359	405
Nigeria	184	222	267	322	389	469	565
Philippines	**173**	194	217	243	272	304	340
North Korea	162	194	201	218	234	250	268
Colombia	**159**	172	187	202	219	238	258
Thailand	**146**	165	187	212	240	272	308
Uzbekistan	**139**	**145**	165	187	212	241	273
Myanmar	**124**	144	167	193	224	260	302
Belarus	123	124	125	126	128	129	130
Kazakhstan	**93**	109	**125**	133	141	150	160
Iraq	88	100	115	131	149	171	195
Senegal	**87**	103	122	144	170	201	238
Congo	77	66	57	50	43	37	32
Bolivia	74	**20**	23	26	29	33	38
Chile	74	**74**	78	83	88	93	99
Azerbijian	**64**	**67**	72	78	84	91	98
Singapore	53	55	57	58	61	63	65
Georgia	**51**	**50**	52	55	57	60	62
Viet Nam	**48**	55	64	74	85	98	113
Bangladesh	**44**	53	76	93	112	132	153
Ecuador	**40**	44	49	55	61	67	75
Moldova	**35**	**23**	**22**	23	25	26	28
Ethiopia	33	43	56	73	95	123	159
Uruguay	**31**	32	33	34	35	36	37
Armenia	**24**	25	26	27	28	30	31
Turkmenistan	10	**10**	12	13	15	17	19

Exhibit 5-1: Methane Emissions from Landfills for Key Developing Countries and Regions: 1990 – 2020 (Gg CH_4)

Country	1990	1995	2000	2005	2010	2015	2020
Uganda	9	12	16	20	26	34	44
Nepal	**9**	11	11	12	14	18	23
Mongolia	**3**	**3**	4	4	5	5	6
Rest of Eastern Europe	19	22	26	31	37	43	51
Rest ofCPA	10	11	13	15	17	20	24
Rest of Middle East	247	273	302	333	368	407	450
Rest of Africa	447	538	647	778	936	1,126	1,354
Rest of Latin America	672	749	834	929	1,034	1,152	1,283
Rest of SE Asia	105	123	147	176	210	252	301
Rest of FSU	52	60	68	77	87	99	113
Total –Developing Countries	11,848	13,654	15,722	17,995	20,578	23,793	27,256
Total – Developed Countries (EPA, 2001)	23,857	22,905	23,333	23,429	23,619	N/A	N/A
Global Total	35,705	36,559	39,055	41,424	44,197	N/A	N/A

Note: The 'Rest of' regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

There are uncertainties in the estimation of methane emissions from landfills. All of the parameters, including methane generation per person; percent to MSW; percent to managed landfills; oxidation; and recovery, are difficult to assess for each country. However, the majority of countries have estimates available. The drivers for projections are also uncertain. Population and GDP are drivers but the exact relationship is uncertain.

5.2 Methane Emissions from Wastewater in Developing Countries

Overview

Methane is emitted both incidentally and deliberately during the handling and treatment of municipal and industrial wastewater. The organic material in the wastewater produces methane when it decomposes anaerobically. The amount of organic material produced and the extent to which it is broken down anaerobically drive the emissions. Most developed countries rely on centralized aerobic wastewater treatment to handle their municipal wastewater, so that methane emissions are small and incidental. Industrial wastewater can also be treated anaerobically, with significant methane being emitted.

Methodology

The preferred approach for developing emissions and projections was to use country-prepared, publicly available reports wherever possible. Many developing countries report estimates of methane emissions from wastewater in their National Communications, Country Study Reports, or other documents such as the Asia Least-Cost Greenhouse Gas Abatement Strategy (ALGAS) reports.

When no emissions data were available or when the data were insufficient, EPA developed emissions estimates and/or projections, using the default methodology presented in the 1996 Revised IPCC Guidelines (1997) and the IPCC Good Practice Guidance (2001). The basic equation to estimate emissions from wastewater is as follows:

*Methane emissions = Emission Factor * Total Organic Waste*

Where:

> The Emission Factor is the maximum methane producing capacity * the methane conversion factor (MCF). The MCF is a weighted average of the amount of wastewater handled by different systems times the appropriate MCF.
>
> And the total organic waste is the human population * the degradable organic component

Assuming that the emission factors do not change, the driver for determining methane emissions from wastewater is population. The emission factor may change with time, though, with countries switching handling systems as their GDP increases.

Historical Emissions

Due to the significant changes from the 1996 Revised Guidelines and the 2001 Good Practice Guidance, EPA used the IPCC Tier 1 Methodology for each country and/or region. The methodology is described in detail in Doorn (1999a,b), with the exception of the emission factor. The maximum methane producing capacity, part of the emission factor, used in this analysis is 0.6 kg CH4/kg BOD.

Results

Exhibit 5-2 presents the results of the EPA analysis. Estimates that are provided by country reports are bolded. As indicated, China has the largest emissions from wastewater in 1990.

Exhibit 5-2: Methane Emissions from Wastewater for Key Developing Countries and Regions: 1990 -2000

Country	1990	1995	2000
China	4,544	4,710	4,877
India	3,987	4,330	4,673
Brazil	929	964	999
Indonesia	906	981	1057
Pakistan	531	599	668
Mexico	496	536	575
Bangladesh	493	538	584
Nigeria	344	404	465
Viet Nam	329	356	383
Philippines	314	354	394
Turkey	285	302	319
Thailand	277	287	298
Iran	274	296	319
South Korea	217	224	231
South Africa	205	198	191
Egypt	203	223	242
Myanmar	195	199	203
Colombia	193	211	229
Argentina	192	203	214
Ethiopia	173	211	249
Peru	131	144	156
Congo (Kinshasa)	123	163	202
Venezuela	116	126	136
Algeria	100	111	121
North Korea	97	101	105
Uzbekistan	97	108	120
Nepal	90	105	120
Chile	79	83	88
Kazakhstan	77	79	81
Iraq	76	93	110
Ecuador	60	67	75
Saudi Arabia	59	83	107
Uganda	54	72	91
Bolivia	40	43	47
Belarus	35	34	34
Azerbijian	34	36	38
Senegal	25	32	39
Georgia	25	25	24
Israel	25	27	28
Uruguay	18	19	19
Jordan	17	21	24
Turkmenistan	17	20	22
Moldova	14	14	15
Singapore	12	16	20
Armenia	11	11	11

Exhibit 5-2: Methane Emissions from Wastewater for Key Developing Countries and Regions: 1990 -2000

Country	1990	1995	2000
Mongolia	11	12	13
Rest of CPA	419	463	507
Rest of S&E Asia	65	66	67
Rest of FSU	364	402	440
Rest of Eastern Europe	1,171	1,338	1,505
Rest of Latin America	155	196	237
Rest of Africa	41	48	54
Rest of Middle East	65	77	88
Rest of OECD90	5	5	5
Total – Developing Countries	18,816	20,367	21,918
Total – Developed Countries	1,714	1,656	1,672
Global Total	20,531	22,023	23,590

Note: The 'Rest of' regional totals do not account for countries contained within EPA (2001). A list of countries included in each region can be found in Appendix A.

Uncertainties

There are significant uncertainties in the estimation of methane emissions from wastewater. The default emission factor is one of the greatest uncertainties. Another area of uncertainty is the best driver to use for projections. Population is one aspect but GDP may also influence the type of treatment system used.

Appendix A

Definitions of Country Groupings

Appendix A-1: Regional Definitions

* Countries have territories assumed to be included

OECD90

Turkey	Rest of OECD90

FSU

Azerbaijan	Kazakhstan
Armenia	Turkmenistan
Belarus	Uzbekistan
Georgia	Rest of FSU

Eastern Europe

Moldova	Rest of Eastern Europe

China/CPA

China*	Vietnam
North Korea	Rest of CPA
Mongolia	

Middle East

Iran	Jordan
Iraq	*Kuwait*
Israel	Saudi-Arabia

Africa

Algeria	Ethiopia	South Africa
Congo (Kinshasa)	Nigeria	Uganda
Egypt	Senegal	Rest of Africa

Latin America

Argentina	Columbia	Uruguay
Bolivia	Ecuador	Venezuela
Brazil	Mexico	Rest of Latin America
Chile	Peru	

S&E Asia

Bangladesh	Pakistan	Rest of S&E Asia
Myanmar	Philippines	
Indonesia	Singapore	
India	South Korea	
Nepal	Thailand	

Appendix A-2: Rest of World Definitions

Rest of OECD90

Cyprus	Malta	San-Marino

Rest of FSU

Kyrgyzstan	Tajikistan

Rest of Eastern Europe

Albania	Bosnia & Herzegovina	Macedonia	Yugoslavia

Rest of CPA

Cambodia	Laos

Rest of Middle East

(Italicized countries are estimated separately for the oil and gas systems sector)

Bahrain	*Kuwait*	Qatar	*United-Arab-Emirates*
Iran	Lebanon	Syria	Yemen
Iraq	Oman		

Rest of Africa

Angola	Djibouti	Liberia	Niger	Zaire
Benin	Equatorial-Guinea	Libya	Reunion	Zambia
Botswana	Gabon	Madagascar	Rwanda	Zimbabwe
Burundi	Gambia	Malawi	Sierra-Leone	
Burkina-Faso	Ghana	Mali	Somalia	
Cameroon	Guinea	Mauritania	Sudan	
Central-African-Republic	Guinea-Bissau	Mauritius	Swaziland	
Chad	Ivory-Coast	Morocco	Tanzania	
Comoros	Kenya	Mozambique	Togo	
Congo (Brazzaville)	Lesotho	Namibia	Tunisia	

Rest of Latin America

Antigua-and-Barbuda	Cuba	Guadeloupe	Martinique	St.-Martin
Bahamas	Dominica	Guatemala	Marshall-Islands	St.-Vincent
Barbados	Dominican-Republic	Guyana	Nicaragua	Suriname
Belize	El-Salvador	Haiti	Panama	Trinidad
Canary-Islands	French-Guiana	Honduras	Paraguay	
Costa-Rica	Grenada	Jamaica	St.-Lucia	

Rest of S&E Asia

Afghanistan	Kiribati	Papua-New-Guinea
Andorra	Maldives	Seychelles
Bhutan	Micronesia	Solomon-Islands Sri-Lanka
Brunei	Malaysia	Tonga
Fiji	Nauru	Tuvalu
India	Palau-Islands	Vanuatu

Appendix A-3: Countries Included in the Developed Country Report by Region

* Countries have territories assumed to be included

OECD90

Australia*	Greece	Netherlands*
Austria	Iceland	New Zealand*
Belgium	Ireland	Norway*
Canada	Italy	Portugal
Denmark*	Japan	Spain
Finland	Liechenstein	Sweden
France*	Luxembourg	Switzerland
Germany	Monaco	United-Kingdom*
		United States*

FSU

Belarus	Lithuania
Estonia	Russia
Latvia	Ukraine

Eastern Europe

Bulgaria	Poland
Croatia	Romania
Czech Republic	Slovakia
Hungary	Slovenia

Appendix B

Data Sources and Methodologies by Country

Exhibit B-1: Data Sources and Methodologies by Country for Enteric Fermentation

	Data Source		
Country	***Historical***	***Projected***	**Methodology**
Algeria	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Argentina	National Communication	IFPRI	Estimated 1990,1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Armenia	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Azerbaijan	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Bangladesh	ALGAS	ALGAS	Applied ratios of 1990 ALGAS manure and enteric emissions to ALGAS 2000, 2010, 2020 aggregate data and interpolated for 1995,2005,2015.
Belarus	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Bolivia	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Brazil	National Communication	IFPRI	1990 and 1995 data from National Communication. Used FAO data and Tier 1 methodology to estimate 1995 and 2000 estimates and applied growth rate from these estimates to given 1995 data in National Communication to obtain 2000 emissions. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Chile	National Communication	IFPRI	Estimated 1990, 1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
China	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Colombia	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Congo	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Ecuador	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emission and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.

Exhibit B-1: Data Sources and Methodologies by Country for Enteric Fermentation

	Data Source		
Country	***Historical***	***Projected***	**Methodology**
Egypt	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Ethiopia	Country Study	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995,2000 emissions and applied growth rate from these estimates to given 1990 data in Country Study. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Georgia	National Communication	IFPRI	1990 and 1995 data from National Communication. Used FAO data and Tier 1 methodology to estimate 1995 and 2000 emissions and applied growth rate from these estimates to given 1995 data in National Communication to obtain 2000 emissions. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
India	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Indonesia	National Communication	ALGAS	Estimated 1990, 1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Applied ALGAS 2005-2020 growth rate to estimated 2000 data.
Iran	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Iraq	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Israel	National Communication	IFPRI	Estimated 1990,1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1996 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Jordan	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Kazakhstan	National Communication	IFPRI	1990 emissions given. 1995, 2000 emissions through calculated growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Mexico	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Moldova	National Communication	IFPRI	1990 and 1995 data from National Communication. Used FAO data and Tier 1 methodology to estimate 1995 and 2000 estimates and applied growth rate from these estimates to given 1995 data in National Communication to obtain 2000 emissions. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Mongolia	ALGAS	ALGAS	Applied ratios of 1990 ALGAS manure and enteric emissions to ALGAS 1995 to 2020 aggregate data and interpolated for 2005, 2015.

Exhibit B-1: Data Sources and Methodologies by Country for Enteric Fermentation

	Data Source		
Country	***Historical***	***Projected***	**Methodology**
Myanmar	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Nepal	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Nigeria	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
North Korea	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Pakistan	ALGAS	ALGAS	Given data for all years except 1995. For 1995, interpolated midpoint from 1990 and 2000.
Peru	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Philippines	ALGAS	ALGAS	ALGAS states that enteric fermentation accounts for 80% of livestock emissions and manure management accounts for 20% of livestock emissions
Saudi Arabia	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Senegal	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Singapore	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
South Africa	National Communication	IFPRI	Estimated 1990,1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1993 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated for 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
South Korea	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Thailand	ALGAS	ALGAS	1990 data from ALGAS report. Subsequent years estimated at given 4.6% annual growth rate for livestock/agriculture.
Turkey	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Turkmenistan	National Communication	IFPRI	Estimated 1990, 1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated for 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Uganda	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Uruguay	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.

Exhibit B-1: Data Sources and Methodologies by Country for Enteric Fermentation

	Data Source		
Country	***Historical***	***Projected***	**Methodology**
Uzbekistan	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Venezuela	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Viet Nam	ALGAS	ALGAS	Applied 1993 ratios of manure and enteric emissions to ALGAS 2000 to 2020 aggregate data. 1990 emissions estimated by using FAO data and Tier 1 methodology to obtain growth rate. This growth rate was used for back-calculating 1990 emissions based on ALGAS 1993 emissions. 1995 emissions interpolated from 1990 and 2000 emissions.

Exhibit B-2: Data Sources and Methodologies by Country for Manure Management

Country	Data Source		Methodology
	Historical	*Projected*	
Algeria	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Argentina	National Communication	IFPRI	Estimated 1990,1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Armenia	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Azerbaijan	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Bangladesh	ALGAS	ALGAS	Applied ratios of 1990 ALGAS manure and enteric emissions to ALGAS 2000, 2010, 2020 aggregate data and interpolated for 1995,2005,2015.
Belarus	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Bolivia	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Brazil	National Communication	IFPRI	1990 and 1995 data from National Communication. Used FAO data and Tier 1 methodology to estimate 1995 and 2000 estimates and applied growth rate from these estimates to given 1995 data in National Communication to obtain 2000 emissions. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Chile	National Communication	IFPRI	Estimated 1990, 1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
China	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Colombia	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Congo	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Ecuador	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emission and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.

Exhibit B-2: Data Sources and Methodologies by Country for Manure Management

Country	Data Source		Methodology
	Historical	*Projected*	
Egypt	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Ethiopia	Country Study	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995,2000 emissions and applied growth rate from these estimates to given 1990 data in Country Study. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Georgia	National Communication	IFPRI	1990 and 1995 data from National Communication. Used FAO data and Tier 1 methodology to estimate 1995 and 2000 emissions and applied growth rate from these estimates to given 1995 data in National Communication to obtain 2000 emissions. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
India	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Indonesia	National Comm.	ALGAS	Estimated 1990, 1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Applied ALGAS 2005-2020 growth rate to estimated 2000 data.
Iran	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Iraq	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Israel	National Communication	IFPRI	Estimated 1990,1995 emissions by applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given NC 1996 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Jordan	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Kazakhstan	National Communication	IFPRI	1990 emissions given. 1995, 2000 emissions through calculated growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Mexico	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Moldova	National Communication	IFPRI	1990 and 1995 data from National Communication. Used FAO data and Tier 1 methodology to estimate 1995 and 2000 estimates and applied growth rate from these estimates to given 1995 data in National Communication to obtain 2000 emissions. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Mongolia	ALGAS	ALGAS	Applied ratios of 1990 ALGAS manure and enteric emissions to ALGAS 1995 to 2020 aggregate data and interpolated for 2005, 2015.

Exhibit B-2: Data Sources and Methodologies by Country for Manure Management

Country	Data Source		Methodology
	Historical	*Projected*	
Myanmar	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Nepal	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Nigeria	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
North Korea	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Pakistan	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated for 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Peru	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Philippines	ALGAS	ALGAS	ALGAS states that enteric fermentation accounts for 80% of livestock emissions and manure management accounts for 20% of livestock emissions.
Saudi Arabia	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Senegal	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Singapore	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
South Africa	National Communication	IFPRI	Estimated 1990,1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1993 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated for 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
South Korea	ALGAS	ALGAS	Interpolated midpoint from 2 base years (Given data in 10 year increments from 1990).
Thailand	ALGAS	ALGAS	1990 data from ALGAS report. Subsequent years estimated at given annual growth rate of 4.6 percent for livestock/agriculture.
Turkey	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Turkmenistan	National Communication	IFPRI	Estimated 1990, 1995 emissions through applying growth rate based on FAO data and Tier 1 methodology. Applied this growth rate to given National Communication 1994 estimates. Obtained 2000 estimate by applying this growth rate to 1995 estimate. Extrapolated for 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 1995.
Uganda	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Uruguay	FAO	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.

Exhibit B-2: Data Sources and Methodologies by Country for Manure Management

Country	Data Source		Methodology
	Historical	*Projected*	
Uzbekistan	National Communication	IFPRI	Used FAO data and Tier 1 methodology to estimate 1990, 1995, 2000 emissions and applied growth rate from these estimates to given 1990 data in National Communication. Extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Venezuela	FAO	IFPRI	Used FAO data and Tier 1 methodology for 1990, 1995, 2000 emissions and extrapolated from 2005-2020 based on IFPRI meat and milk production growth rates weighted by individual country animal populations in 2000.
Viet Nam	ALGAS	ALGAS	Applied 1993 ratios of manure and enteric emissions to ALGAS 2000 to 2020 aggregate data. 1990 emissions estimated by using FAO data and Tier 1 methodology to obtain growth rate. This growth rate was used for back-calculating 1990 emissions based on ALGAS 1993 emissions. 1995 emissions interpolated from 1990 and 2000 emissions.

Exhibit B-3: Data Sources and Methodologies by Country for Agricultural Soils Management

Country	Data Source		Methodology
	Historical	*Projected*	
Algeria	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Argentina	Argentina National Communication	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Projected 1995 reported estimate to 2000 based on IPCC Tier 1a modeling, then projected to 2005 to 2020 based on FAO regional fertilizer growth rates
Armenia	Armenia National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Applied country-specific fertilizer consumption growth rate until 2000, then applied FAO (2000) regional fertilizer consumption projections in 2015 to 2005-2020.
Azerbaijan	Azerbaijan National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Bangladesh	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Belarus	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Bolivia	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Brazil	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Chile	Chile National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1995 data and applied country-specific fertilizer consumption growth rate to estimate 1990 and 2000, then extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
China	FAO data	FAO historical fertilizer consumption and fertilizer consumption projections.	Used IPCC Tier 1a methodology
Colombia	Colombia GHG Inventory 1990	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Congo (Kinshasa) DPRC	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Ecuador	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Egypt	Egypt National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Ethiopia	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology

Exhibit B-3: Data Sources and Methodologies by Country for Agricultural Soils Management

Country	Data Source		Methodology
	Historical	*Projected*	
Georgia	Georgia National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Applied country-specific fertilizer consumption growth rate until 2000, then extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
India	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Indonesia	Indonesia National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Iran	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Iraq	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Israel	Israel National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1996 value and applied country-specific fertilizer consumption growth rate to estimate 1990 and 2000, then extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Jordan	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Kazakhstan	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Mexico	FAO data	FAO historical fertilizer consumption and fertilizer consumption projections.	Used IPCC Tier 1a methodology
Moldova	Moldova National Communication	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 and 1994 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and to 2020 based on FAO 1995/1997 to 2015 growth rate.
Mongolia	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Myanmar	ALGAS, Myanmar	ALGAS, Myanmar	Used ALGAS projections to 2020 and interpolated.
Nepal	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Nigeria	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
North Korea	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Pakistan	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Peru	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and	Used IPCC Tier 1a methodology

Exhibit B-3: Data Sources and Methodologies by Country for Agricultural Soils Management

Country	Data Source		Methodology
	Historical	*Projected*	
		historical methane from manure growth rates.	
Philippines	ALGAS, Philippines	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Saudi Arabia	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Senegal	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Singapore	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
South Africa	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
South Korea	ALGAS, South Korea	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Thailand	ALGAS, Thailand	FAO historical fertilizer consumption and fertilizer consumption projections.	Used reported 1990 data and extrapolated to 2000 based on country-specific fertilizer consumption growth rate, and extrapolated to 2020 based on FAO 1995/1997 to 2015 regional fertilizer consumption growth rate.
Turkey	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Turkmenistan	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Uganda	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Uruguay	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Uzbekistan	Uzbekistan National Communication.	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Projected 1995 reported estimate to 2000 based on IPCC Tier 1a modeling, then projected to 2005 to 2020 based on FAO regional fertilizer growth rates
Venezuela	FAO data	FAO fertilizer consumption projections, historical crop production growth rates, and historical methane from manure growth rates.	Used IPCC Tier 1a methodology
Viet Nam	ALGAS, Vietnam	ALGAS, Vietnam	Used ALGAS projections to 2020 and interpolated.