An Assessment of the Use of Inventories in Determining Global Anthropogenic Methane and Nitrous Oxide Emissions

E. A. Scheehle, W.N. Irving, & D. Kruger
U.S. Environmental Protection Agency, Washington, DC, USA

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ABSTRACT: According to the IPCC's Special Report on Emission Scenarios (SRES), methane and nitrous oxide are estimated to represent 26% of global greenhouse gas emissions. This estimate was determined using top down models from six scientific groups and standardizing the results. Global estimates may also be determined using bottom-up methods, including the compilation of country specific inventories. This paper compares the global estimates from different sources and explores possible reasons for the differences.

1 INTRODUCTION

Detailed estimates of global anthropogenic non-CO_2 emissions by source and country are scarce. Yet understanding these non-CO_2 emissions is important because each gas is more effective, molecule-for-molecule, at trapping heat than CO_2 (IPCC 2001). As a result, their emissions contribute significantly to climate change. Additionally, including non-CO_2 greenhouse gases in an abatement strategy can be less expensive and more effective in mitigating climate change than focusing on only CO_2 (Reilly et al. 1999, Hansen et al. 2000).

Two basic methods, top down and bottom up, are available for estimating global anthropogenic methane and nitrous oxide emissions. The two methods are not exclusive, as the bottom up estimates may be used as inputs to top-down models. Ideally, these two approaches can be used together to refine global methane emissions. The top-down approach for estimating both methane and nitrous oxide is based on atmospheric measurements. A series of assumptions and/or inputs is necessary to estimate the natural sinks and distinguish between anthropogenic and natural sources. Using this method, the IPCC Special Report on Emission Scenarios (SRES) reports an estimate of 310 Tg of CH_4 and 6.7 Tg N in 1990 from anthropogenic sources. Another approach is to sum bottom-up, country-level estimates of individual anthropogenic sources. These estimates are usually based on national activity data and emission factors. A new database of bottom-up estimates compiled by USEPA reveals a total of 273 Tg CH_4, 12% smaller than the IPCC estimate and 6.5 Tg N_2O, 3% smaller than the IPCC estimate. This paper provides a detailed comparison of the estimates, and recommends specific areas of improvement that could reduce uncertainties.

2 Top-Down Estimates of Global Anthropogenic Methane & Nitrous Oxide Emissions

Using top-down models, the IPCC TAR estimates global emissions in 1990 to be 598 Tg CH_4 and an implied N_2O emission estimate of 16.4 Tg N. On the basis of carbon isotope measurements, the IPCC estimates that in 1990, 310 Tg (standardized from a range of 298-337 Tg) or 52% (50-56%) of global methane emissions are anthropogenic in origin. This estimate is lower than the IPCC's 1995 assessment, which estimated anthropogenic methane emissions to be 375 Tg and 70% of total methane emissions. Isotope analysis is also used for constraining the N_2O budget but has not yet resulted in better data than any other approaches (IPCC 2001). Approximately 40% of N2O is estimated as anthropogenic.

The first step in determining anthropogenic emissions is to estimate the annual change in the atmospheric concentration of each gas. This can be done with low uncertainty (+/- 5%) because atmospheric measurements are very accurate, and both gases are evenly distributed throughout the atmosphere. Using the change in concentration, it is straightforward to calculate the net annual emissions based on the following simple equation if the methane sink is known:

Annual Emissions = Annual Change in Atmospheric Concentration + Sink

This step introduces more uncertainty since the sinks can be difficult to quantify.

There is significantly larger uncertainty associated with separating the anthropogenic and natural components of aggregate annual emissions. The magnitudes of individual sources are typically estimated through aggregate calculations of major anthropogenic and natural sources. Some models use detailed bottom-up estimates but the majority of such estimates are generalized, as will be discussed below. Isotope analysis provides information on fossil sources, which are overwhelmingly anthropogenic in origin. Using these methods, the IPCC Special Report on Emission Scenarios (SRES) reports a figure for methane of 347 Tg/yr for the year 2000 and 310 Tg for 1990 and 7.0 TgN for 2000 and 6.7 TgN for 1990 for N_2O.

Thus, the weak link in the calculation is clearly the breakdown of total emissions into anthropogenic and natural constituents. The further division into specific sources and regions is even more approximate. Despite the low uncertainty of atmospheric measurements, estimates of anthropogenic emissions derived using this approach should be heavily qualified. Additionally, as discussed below, improvements in bottom up estimates could lead to more accurate estimates in both source strength and spatial distribution.

3 Bottom Up Approaches for Emission Estimation

Previous efforts to determine global methane and nitrous oxide emissions by country relied on IPCC default methodologies, international datasets and default emission factors. Recent studies have estimated global anthropogenic CH_4 emissions at 302 Tg for 1990 (EDGAR 2001) and 342 Tg for 1995 (OIES 1999) and global anthropogenic N_2O emissions at 8.1 Tg N for 1994 (Mosier et al 1998 and Kroeze et al. 1999) and 7.2 Tg N for 1990 (EDGAR 2001). The EDGAR estimates are more recent and include both CH_4 and N_2O, and therefore the focus will be on this dataset. Although the analysis focuses on EDGAR, the results are applicable for other bottom up models since they will encounter similar methodological challenges.

While these default approaches are useful for arriving at a global total quickly with relatively little data collection, they lack the accuracy and national specificity necessary for improving our understanding of how bottom-up methane estimates compare with global top-down estimates. First, the IPCC default methodologies used in these compilations are frequently not the preferable approach for estimating emissions from key sources.[1] The IPCC thus encourages countries to use state-of-the-art Tier 2 or Tier 3 methodologies, which take into consideration complicated emission processes and disaggregated data, for major emission sources. Secondly, default emission factors do not account for variations across countries or regions, and may lead to significant bias (e.g., default emission factors typically come from a small number of developed countries). Finally, country level statistics may be more accurate than statistics gathered by international organizations. In most cases, the best that can be hoped for international datasets are that they match national statistics.

To illustrate how the use of IPCC default methodologies can add considerable uncertainty, presented below are three examples of discrepancies between IPCC default estimates used in EDGAR model and more accurate higher tier country-specific estimates:

1. Coal Mining (USA): A Tier One estimate of methane emissions from coal mining relies on aggregate production data and default emission factors. The U.S. national inventory, submitted to the UNFCCC, uses a detailed Tier 3 methodology for underground mines, the source of the majority of emissions from coal mining (EPA 2001). Actual methane measurements at each underground mine serve as the basis of the estimate. The other sources, post- and surface-mining, reflect country-specific circumstances by using Tier 2 emission factors based on field measurements. These more detailed methods indicate that approximately 4 Tg of methane was emitted in 1990, which is two-thirds lower than the 11.9 Tg estimated by EDGAR. This discrepancy is significant, because EDGAR concludes that the US is responsible for almost one third of coal mining emissions.

2. Chemical Industries (Canada): The Canadian Inventory presents an estimate that was developed using plant specific data, where applicable, and information on abatement. The IPCC default estimate of 34.5 Tg for 1990 in EDGAR is over 3 Tg less than the Canadian estimate of 38 Tg (UNFCCC 2001). This difference will increase in future estimates, since Canadian plants are implementing abatement strategies that would not be captured by a default methodology.

3. Enteric Fermentation (Australia & New Zealand): For Australia and New Zealand, which account for over 98% of the Oceania region's emissions, agriculture is the dominant sector for methane emissions. For enteric fermentation, EDGAR estimates emissions for Oceania at 3.6 Tg, yet Australia and New Zealand both use higher tier methods with detailed animal data and estimate a combined 4.4 Tg in 1990 (Environment Australia 1997, New Zealand 1997, and UNFCCC 2001). In this case, the activity data used by EDGAR may be biased since it represents a point estimate in the winter and activity levels increase dramatically over the next months. The in country inventory preparers have more detailed and accurate data than available in international data sets.

These differences may seem minor compared to the overall global budgets. When summed into total source (e.g. global landfill emissions), country (e.g. total New Zealand emissions), or even global emissions,

[1] "A key source category is one that is prioritized within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both" (IPCC, 2001).

however, the discrepancies can be significant. For example, using EDGAR estimates to determine the source strength and spatial distribution for methane emissions from coal mining would lead to inaccurate results. Additionally, there is no reason to assume that these discrepancies ‘even out’ when summed to arrive at a global total. As noted above, there are biases in addition to random uncertainties associated with IPCC default estimates.

4 Comparison of Results

National greenhouse gas inventories have improved significantly over the last few years in both quality and quantity. Earlier studies have compared emission estimates (Van Amstel et al., 1999). However, many countries that previously prepared only Tier 1 estimates are now using more advanced methodologies. Additionally, through the efforts of national experts and with assistance from multilateral and bilateral donors, developing countries are making great strides at collecting new data and improving their inventories. EPA has relied upon this global improvement in inventories in order to compile state-of-the-art methane estimates in a single database. The goal of the database is to improve data inputs to economic and atmospheric modeling, but it has also enabled a better comparison of top-down and bottom-up estimates.

EPA’s analysis includes emission estimates for 84 individual countries and the rest of world by region. Primary data sources are National Communications submitted by Parties to the UNFCCC, or other country-prepared publications. The country-prepared estimates provide significant coverage. For example, they currently account for over 95% of both rice production and coal production. For any major source where an estimate was not available, EPA developed an estimate using country-specific data and IPCC Tier One methods. Additionally, EPA used the recent IPCC Good Practice Guidance, which included several updated emission factors.

EPA estimates methane emissions at 273 Tg in 1990: 126Tg for developed countries and 147 Tg for developing countries. Table 2 compares results from the EPA analysis, EDGAR, and IPCC TAR. The EPA total is 29 Tg (10%) less than the EDGAR total and 37 Tg (12%) less than the IPCC estimate. Fugitive emissions from fossil fuels and rice cultivation are the key areas in which aggregated national estimates are significantly different.

Table One. Comparison of 1990 Global Methane Estimates from EPA, EDGAR, and IPCC (in Tg)

	EPA	EDGAR	IPCC
World (developed/developing)	**273 (126/147)**	**302 (130/171)**	**310 (120/190)**
Fossil Fuel (combustion and fugitives)	74	96	68 – 94
Biofuel	10	13	27 – 46
Biomass Burning (ag residue, savannah, LUCF)	*13*	13	
Rice Cultivation	31	39	29 – 61
Enteric Fermentation	76	80	80 – 97
Manure Management	10	9	
Landfills	36	22	51 – 62
Wastewater	23	30	

The largest differences are in fossil fuel emissions from developed countries, particularly from coal and oil and gas systems in the US (10 Tg) and Russia (4 Tg). As noted above, the US estimate for coal mining relies on direct measurements and can be considered reliable. EPA has worked with Russian coalbed methane experts to derive similar estimates for Russia (EPA 1999). A pioneering study of the natural gas industry in the US (EPA/GRI 1995) determined detailed equipment-specific activity counts and emission factors from direct measurements, and greatly improved the estimate for methane emissions. Similar studies are available for Canada, the UK and other countries. The large natural gas industry in Russia is a major source of uncertainty in both EPA and EDGAR, and should be considered one of the highest priorities for further work. The most recent estimate of 16 Tg comes from Russia's Second National Communication, which uses a very general top-down approach (RFSHEM 1997).

Rice cultivation, another major methane source, is also an area of uncertainty. The TAR presents revised estimates for rice cultivation of around 40 Tg, with a range of 29 to 61 Tg. EPA's bottom-up estimate is 31 Tg, based on published estimates from over 30 countries, accounting for over 95% of rice production. Although significant uncertainty remains, many of these countries, including the major rice producers India, China, Philippines, and Japan, have improved their estimates to incorporate recent experimental results and country-specific measurements (UNDP 1998a, b, c). Continued inventory improvements in rice estimates for these countries will add more confidence to global bottom-up estimates.

Biomass burning is a known limitation of EPA's analysis and requires more research. EPA currently uses the EDGAR estimates since many countries do not estimate methane and nitrous oxide from this source. Improvements in statistics on savannah and forest areas burned, along with research into emissions factors, would be useful to better understand the nature of this source.

As shown in Tables 2 and 3, the areas of strongest agreement across the three analyses are for enteric fermentation and manure management. Despite this apparent agreement in source strength estimates, regional estimates for Asia and the OECD are not consistent. Enteric fermentation is the largest source of methane emissions in many developing countries, and countries should continue to devote resources to improve the accuracy of their estimates.

For the waste sector as a whole, the estimates are relatively consistent but EPA attributes most of the emissions with landfills whereas EDGAR attributes more to wastewater. Both analyses are based on the same report (Doorn 1999) and EPA's lower wastewater estimates are due to use of a new emission factor published in IPCC Good Practice Guidance. The higher landfill numbers in EPA's analysis results from the use of country estimates; for developing countries, over 7 Tg of the estimated 12 Tg came from country reports. The priorities for improvement in this sector are the utilization of time-lag models for landfills by more countries, and better characterization of wastewater treatment in developing countries.

Table 3 – **Comparison of 1990 Nitrous Oxide Emissions** (Tg N-N_2O)

	EPA	EDGAR	IPCC
World (developed/developing)	**6.5**	**7.2**	**6.7**
Agricultural Soils	4.7 (1.3/3.4)	5.6 (2.0/3.6)	4.1-4.8
Manure	0.4 (.2/.2)	0.4 (.2/.2)	
Industry & Fossil Fuel	0.9 (.7/.2)	0.8 (.6/.2)	0.9-1.2
Biomass Burning	*0.34*	.34	.4 - 1.32
Human Sewage	0.2 (>0.1,0.2)	0	
Wastewater	NE	.14	

The largest difference in estimates is from agricultural soils. The estimate, when combined with manure, is above the upper bound of the IPCC range, however, it is lower than the EDGAR estimate. The majority of the difference (70%) is in developed countries, where EPA uses country prepared estimates.

Manure, Industry, and Fossil fuel related emissions are more consistent. EPA and EDGAR estimates are close and, for industry and fossil fuel, both sources present estimates within the IPCC range.

As with methane, for the waste sector as a whole, the estimates are relatively consistent but EPA attributes all its emissions to human sewage whereas EDGAR contributes all emissions to wastewater. EPA did not estimate emissions from wastewater as they were considered insignificant compared to other sources. In the future EPA may include this source in it's estimation process based on the data from Doorn (1999).

For nitrous oxide as a whole, the EPA estimates are well within the range provided by the IPCC. Given the magnitude in comparison to other anthropogenic sources, future attention should continue to be focused on agricultural soils. As more countries complete rigourous inventories, the global total for this source will improve.

Although EPA uses higher tier methods, uncertainties still exist. Currently, a major uncertainty is that this analysis uses EDGAR estimates for agricultural biomass burning. Another area of uncertainty is the varied quality of country data and expertise. Some countries have more advanced primary data collection capabilities and more trained inventory experts than others. Additionally, not all national inventories are reviewed, nor do they all provide enough documentation to verify calculations. Despite these uncertainties, there is a clear trend towards inventory improvement, particularly in developing countries, such that an update to this study in a few years will provide a more accurate global total.

5 Conclusion

The spatial and source distribution of the methane and nitrous oxide budgets remain uncertain. However, opportunities exist to improve the current estimate. Although the use of atmospheric isotope analysis constrains methane emissions from various sources, atmospheric measurements can not fully describe the distribution of methane. Another approach to further improve source strength and spatial distribution estimates of emissions, is to use aggregated national inventories. These inventories have improved significantly over the last few years and are more accurate than estimates derived from simple default methodologies. EPA's analysis, which compiles the national inventories, results in an estimate that is within 10-15% of other global estimates yet countries have only been preparing greenhouse gas inventories for under a decade. As more emphasis is placed on inventories, these estimates will improve even more. Attention should be paid to a few key areas. First, the Russian emissions from natural gas are a major source of uncertainty. Secondly, rice estimates in Asia have improved significantly, but given the large source strength and continuing uncertainty, continued focus on methane emissions from rice is warranted. Thirdly, for the waste sector, useful improvements would be in the utilization of time-lag models for landfills and better characterization of wastewater treatment in developing countries. Fourth, additional inventory work on agricultural soils will help constrain the nitrous oxide budget. Finally, biomass burning emissions in Africa and South America needs more research on both emission factors and statistics. With these improvements, the methane budget could be significantly improved.

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