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Meeting Report

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Summary

In September 1996, the IPCC Plenary identified the quality of national greenhouse gas inventories as a priority. Governments noted that the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories *(Guidelines)* should result in emissions estimates that can be monitored and verified for compliance. They requested that the IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories convene an expert meeting on the quality of national greenhouse gas (GHG) inventories. At the invitation of the Dutch Government, an IPCC Expert Meeting on Methods for the Assessment of Inventory Quality was held in Bilthoven (5-7 November 1997). The primary objectives of the meeting were:

- to examine whether the *IPCC Methodology* produces emissions estimates of good quality which can be monitored and independently verified;
- to examine approaches for assessing and improving the quality of national GHG inventories and to identify the potential of these approaches;
- to identify sources of uncertainty in national GHG inventories and to suggest ways for reducing them;
- to recommend actions for improving the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*.

The meeting examined four approaches to assess the quality of GHG inventories. These were:

Inventory quality assurance - Evaluation of the underlying data and algorithms of inventories according to a range of criteria.

***Inventory comparisons* -** Comparisons among inventories, methodologies and input data to identify major discrepancies.

***Model comparisons* -** Comparisons of inventories with atmospheric budgets to assess the accuracy of the inventories.

***Direct emission measurements* -** Comparisons of inventories with atmospheric measurements to assess the accuracy of inventories.

Comparisons among the diverse approaches were difficult. The suitability of each approach depends on the gas, and source/sink sector under consideration. Participants nevertheless endorsed all approaches as appropriate techniques for assessing and improving inventory quality in different ways.

Both *inventory quality assurance* and *inventory comparisons* were recognised as effective tools that could be applied at a national level. The participants recommended further work in these areas.

Over the longer term, *model comparisons* were recognised as useful to test the scientific credibility of GHG inventories. At the continental level, models could be used to estimate carbon fluxes from land-use change and forestry. *Model comparisons* are valuable since this is an area with medium to high uncertainty in the reported global estimates. At the national level, *model comparisons* show greater potential for assessing inventories of CH_4 than for other GHGs. Participants recommended continued co-operation between the inventories community and modellers.

Direct emission measurements lend themselves to the evaluation of national inventories of CH_4 and N_2O. This approach is applicable to both diffuse sources and localised ‘hotspots’ of trace gases.
Further progress is needed to ensure that national GHG inventories can be monitored and verified for

compliance under the Kyoto Protocol. Several steps were recommended to advance current understanding of sources and removals of GHGs. The following steps are seen as critical to providing better inventory data. Over the long term, their implementation may lead to further revision of the *Guidelines* - the basis for legally binding commitments.

Firstly, participants suggested there is a need to develop a common terminology for inventory quality. Key criteria are *completeness, consistency, transparency,* and *comparability*. Other terms include: *accuracy, precision, error,* and *uncertainty*. Although their meanings are distinct, these terms are often not used rigorously. *Validation* and *verification* were considered as useful concepts to describe quality assessment. The Glossary of Terms prepared for the meeting could help develop consensus on their definitions (see Annex 2).

Secondly, participants identified and quantified sources of uncertainty in national emissions estimates, and recommended ways to minimise them. For biogenic and natural sources and sinks, however, there are limitations imposed by the natural variability of the system. More data and improved methods will help reduce uncertainties, but not eliminate them. For many gases and sectors, the barrier to better inventory quality is often the underlying data, not the IPCC Methodology, which is scientifically robust. But some methodologies are still evolving; such as land-use change and forestry, soil carbon, and the 'new gases' (e.g. HFCs, PFCs, and SF_6). For the 'new gases', the main issue is tracking changes in emission rates as a result of evolving technology.

Thirdly, participants developed likely ranges of uncertainty for GHG inventories by sector. They identified a framework for estimating and reporting degrees of uncertainty for national estimates as a high priority. Such a framework would improve the current IPCC classification scheme of *high, medium* and *low* confidence levels. Both *qualitative* and *quantitative* approaches were suggested, all requiring further technical development and discussion. Future meetings on uncertainties were recommended to address this issue.

Participants recommended that the IPCC develop *codes of good practice* to improve the availability of underlying data for inventories. These codes will help countries prepare national inventories, develop emission factors and conduct direct emissions measurements. They would be based on internationally accepted procedures. Moreover, they could be applied to obtain data in regions where none exist and to extend the existing global databases on activity data and emission factors. These data could eventually be incorporated into the *Guidelines*. An example is conducting forest surveys in order to establish growth rates, carbon densities, etc.

Participants felt that a clearer definition of the terms anthropogenic and natural was an important requirement for reducing the uncertainty of biogenic sources and removals of GHG. This clarification would help differentiate between anthropogenic and natural emissions in national GHG inventories - a principal objective of the *Guidelines.*

Finally, participants recommended the use of the IPCC Reference Approach from the Energy Sector of the *Guidelines* as a verification procedure for CO_2 emissions from the energy sector. They suggested that the IPCC develop reference approaches in other sectors, again for verification.

1. Background

In 1996, the IPCC Plenary in Mexico City identified inventory quality as an emerging issue. The Plenary noted that the '*Guidelines* should produce estimates that can be monitored and independently verified through consistency with independent sources of information and comparability between countries.

One year later, Annex-I Parties agreed to legally binding commitments under the Protocol (Kyoto, 1-12 December 1997). Clearly, the quality of national GHG inventories has implications for the effective monitoring and verification of commitments under the Protocol. The uncertainty of estimates may also significantly influence the design of a trading system. Neither of these technical issues has yet been resolved.

To address the IPCC request, an IPCC Expert Meeting on *Methods for the Assessment of Inventory Quality* was held in Bilthoven (5-7 November 1997). The meeting was hosted by the Dutch National Institute for Public Health and the Environment (RIVM) and co-sponsored by the CKO/CCB Centre on Climate Research Utrecht, and Wageningen Climate Change and Biosphere Programme.

The meeting brought together over 60 participants from 20 countries. Among these were atmospheric modellers, empirical scientists and inventory experts. The meeting examined a range of approaches for the validation and verification of national GHG inventories, as well as the estimation and reporting of uncertainties in national estimates. The meeting also considered the direction of future work. This report summarises discussions and presents recommendations from that meeting.

2. Objectives

The main objectives of the meeting were :

- to examine whether the *IPCC Methodology* produces national, regional and global emissions estimates of good quality which can be monitored and independently verified;
- to examine approaches for assessing and improving the quality of national GHG inventories and to identify the potential of these approaches;
- to identify sources of uncertainty in national GHG inventories and to suggest ways for reducing them;
- to recommend actions for improving the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.

In addressing these objectives, a clear direction for future work should be obtained. The technical options were examined while keeping in mind their relevance to policy.

3. Verifying the effectiveness of the IPCC methodology

Determining the effect of increased GHG emissions on the environment requires a methodology which will accurately estimate emissions at a global scale. The *Guidelines* is a methodology applied by most non-Annex I Parties. One of the meeting's objectives was to verify the methodology.

National GHG inventories were aggregated on a global scale and compared with IPCC global budgets (Table 3-1 to Table 3-3). For each gas, national communications submitted to the UNFCCC and country studies were used to obtain global inventory estimates. These data were augmented with emissions estimates from published scientific databases (Van Amstel et al., 1997).

For CO_2, the difference between the estimated global budget of fossil fuel and the sum of the available inventories is small (<10%). It must be noted, however, that the IPCC global budget (1996) was also obtained from a global database of emissions estimates. Because of this, the estimated global budget and the sum of inventory data are expected to be similar. This makes the comparison less meaningful.

Table 3-1: Global totals for carbon dioxide

Source	Number of countries	Total emissions (Tg/year.)	Global budget (Tg/year.) [b]
First national communications [a]	34	13 675	-
Country studies [c]	31	5 081	-
Global database [d]	124	6 666	-
Total	**189**	**25 422**	**28 233**[e]

a = UNFCCC (1997), b = IPCC (1996), c = Braatz et. al. (1996), d = TNO-RIVM (1996)
e = Global anthropogenic budget from IPCC, 1996, Second Assessment Report (7.7 GtC x 44/12)

For CH_4, there is a discrepancy between the global budget and the sum of the available inventories. In this case, the difference is within the expected 30% level of uncertainty. The global budget was obtained from observed atmospheric increases and is therefore independent of the inventory data. The agreement between the two budgets gives confidence in the inventory methods.

Table 3-2: Global totals for methane

Source	Number of countries	Total emissions (Tg/year.)	Global budget (Tg/year.) [b]
First national communications [a]	33	108	-
Country studies [c]	31	66	-
Global database [d]	125	121	-
Total	**189**	**295**	**375** [e]

a = UNFCCC (1997), b = IPCC (1996), c = Braatz et. al. (1996), d = TNO-RIVM (1996))
e = Global anthropogenic budget from IPCC, 1996, Second Assessment Report

For N_2O, the sum of available inventories falls within the range of the calculated global budget. The global budget was obtained from observed atmospheric increases and is therefore independent of the inventories.

Table 3-3: Global totals for nitrous oxide

Source	Number of countries	Total emissions (Tg N_2O/year.)	Global budget (Tg N_2O/year.) [b]
First national communications [a]	33	2.05	-
Country studies [c]	31	0.12	-
Global database [d]	125	2.8	-
Total	**189**	**4.9**	**5 to 13** [e]

a = UNFCCC (1997), b = IPCC (1996), c = Braatz et. al. (1996), d = TNO-RIVM (1996)
e = Global anthropogenic budget from IPCC, 1996, Second Assessment Report (3 to 8 Tg(N)/yr. multiplied by 44/28)

The values in Table 3-3 were obtained primarily by using the previous IPCC Methodology for N_2O (IPCC, 1995). Using the current *Guidelines* (IPCC, 1997) the global emission was estimated at 11 Tg N_2O/year. (Mosier et al., 1998). This is in the midrange of the global budget again giving confidence in the current *Guidelines* methodology at the global level.

4. Assessing the quality of national inventories

The meeting considered several approaches to assessing the quality of GHG inventories:

Approach 1: inventory quality assurance

Evaluation of the underlying data and algorithms of inventories according to a range of criteria.

Approach 2: inventory comparisons

Comparisons among national, regional and global inventories, including their estimation methodologies and input data.

Approach 3: model comparisons

Comparisons of national, regional and global inventories with atmospheric budgets derived from atmospheric concentrations and chemical transport models.

Approach 4: direct emission measurements

Comparisons of national or regional inventories with atmospheric measurements upwind or downwind from local, national or regional sources.

As a fifth approach, participants suggested the use of indicators of economic and other activities to verify emission trends in countries. One drawback of this method is that correlation between emissions and an independent variable does not necessarily imply cause and effect. At best, the use of indicators would be limited to flagging anomalies, rather than for assessing inventory quality. Examples are Schipper et al. (1997) for CO_2 indicators and Bosseboeuf et al. (1997) for energy indicators.

It should be noted that Approaches 1, 2 and 4 were examined in relation to each of the main GHG. For Approach 1 the details are provided in Table 5-1 to Table 5-3. Approach 3, *model comparisons*, was examined separately in greater detail.

4.1 Approach 1: inventory quality assurance

4.1.1 Background

This approach evaluates the sources of underlying data and the methods used to prepare inventories. Evaluation may include: tracing the original sources of *emission factors* and testing the sample set for appropriateness, reproducibility, statistical variance, etc.; assessing the robustness of the survey techniques used for collecting *activity data*; identifying and evaluating the reliability of national and international sources of *emission factors* and *activity data*, and comparing independent sources of these data; assessing the *algorithms* used to prepare emissions estimates. This approach can allow the uncertainties and systematic differences of data and emissions estimates to be quantified.

4.1.2 Assessment

Criteria for inventory quality commonly include: *accuracy, precision, uncertainty, error, reliability, completeness, comparability* and *transparency*. Participants had difficulty in ranking these criteria since their relative importance depends on the purpose of the inventory (scientific, policy, or otherwise). They recognised the need to clarify what is meant by accurate inventories, and suggested that a common terminology be developed by the IPCC. The Glossary of Terms prepared for this meeting was a useful starting point. Some participants suggested that the Glossary be expanded to include 'top-down' and 'bottom-up'.

Most participants agreed that key criteria (unranked) were: *completeness, consistency, transparency, comparability,* and *accuracy*. Others differentiated *comparability* from *consistency*. For *consistency*, there must be internal agreement on methods or data *within* a country whereas *comparability* means consistency of methods or data *between* countries.

The definitions of *validation* and *verification* were debated. Many participants thought these definitions were clear. *Validation* is a procedure which provides, by reference to independent sources, evidence that an inquiry is free from bias or otherwise conforms to its declared purpose. *Verification* is a procedure to test the internal agreement of data or procedures. Some argued that *validation* and *verification* were used interchangeably. Further clarification is needed.

National representatives believed inventories had two main purposes: analysing trends, and assessing the effects of policy and measures. The quality of GHG emissions estimates should be adequate for both purposes. Participants felt a need to develop standard operating procedures in National Communications and that certified ISO standards should be developed. Some participants recognised that the uncertainty of inventories was an issue for emissions trading and for monitoring compliance under the Protocol.

Atmospheric modellers felt that the quality of anthropogenic GHG inventories was adequate for their purposes. Uncertainties of anthropogenic emission estimates based on inventories are typically lower than, or comparable with, model uncertainties or those of natural fluxes.

Participants also recognised that data *generation* and *management* in inventories were problems. Some participants felt strongly that the barrier to improving inventory data was internal co-ordination in developing countries. Generating more data would not solve the problem. These countries should improve their capacity to manage information systematically. Many participants said that more investment should go to developing countries where energy and land-use change and forestry statistics were poorly known. Some suggested that satellite measurements and remote sensing could help resolve the data issue. Others suggested that this method of collecting data was too expensive to be practical.

4.2 Approach 2: inventory comparisons

4.2.1 Background

Inventory comparisons are often a two-step process. The first step is a comparison of national, regional or global emissions estimates at a sectoral level. This initial comparison identifies gross inconsistencies, but does not provide reasons for discrepancies. Only a second comparison of emission factors, activity data, or algorithms, provides clues as to why the emissions estimates differ. Providing there is sufficient transparency in the inventory documentation, these simple comparisons can prove useful.

Several researchers have made inventory comparisons. Moran and Salt (1996) compared the inventories prepared by the IPCC Methodology with those by CORINAIR. Marland and Rotty (1984) established uncertainty ranges of emissions estimates. Marland and Boden (1993) and Graedel et al. (1993) used comparisons of activity data and inventories for quality control. Inter-country comparisons of inventory data have also been performed in the development of the *IPCC Guidelines* (IPCC 1992a and b, 1994).

4.2.2 Assessment

Carbon dioxide

As a first step, GHG inventories from different sources (e.g. UNFCCC, United States Countries Studies Programme (USCSP) with the Emissions Database for Global Atmospheric Research (EDGAR)) were compared (Van Amstel et al., 1997 and Marland et al., 1997). Comparisons showed that differences between the inventories are generally less than 10% for fossil fuel emissions; differences are greater in the land-use change and forestry, agriculture, and for biofuel combustion (Van Amstel et al., 1997).

Participants discussed ways to improve the IPCC Methodology. For energy and industrial processes, no immediate action was considered necessary. This was not the case for land-use change and forestry. Here, problems originate from both the methods and data. Participants were more confident with flux estimates from forestry than for data from land-use change. They noted that clarification of the term anthropogenic was a high priority.

Of the approaches evaluated, participants identified *inventory comparisons* as the most useful for evaluating and improving CO_2 inventory quality. National CO_2 inventories in the energy sector should be compared with estimates from the IPCC Reference Approach. The International Energy Agency has already published these emissions estimates using the IEA energy balances as input data (IEA, 1997). Results show that differences between national and IEA emissions estimates are often within 5%. For several countries, these variations can be explained.

Methane

Methane inventories from National Communications and the EDGAR scientific database differ in all sectors by more than 10%. Discrepancies are highest in the land-use change and forestry, and agriculture sectors (Van Amstel et al., 1997).

Participants noted that comparisons between EDGAR and IPCC results had been useful in identifying where the gaps were in methane inventories. The general point was made that sometimes changes in annual flux were due to natural variability rather than changes in activities, e.g. variability in temperature can affect methane emissions from rice paddies. In this case, emission factors are not static over time.

In The Netherlands, a comparison between the revised method and earlier estimates for methane emissions from landfills confirmed that it was important to consider the time dynamic. First-order decay equations can be used for regions with no historical data for wastewater generation or landfilling. Information on the range of landfill sizes by area extent and volume would be useful. Also, estimating the proportion of total waste disposed in the size categories would improve the accuracy of the methodology.

Some verification exercises have been completed for biomass burning. Researchers at King's College, London estimated CH_4 emissions from biofuel for many countries. These results were found to differ from national inventories by as much as a thousand fold. Better emission factors are needed for developing countries for all categories of biomass burning.

For enteric fermentation, comparisons of emission factors would be more revealing than comparisons of the emissions themselves.

Nitrous oxide

The Revised IPCC Methodology for agricultural N_2O demonstrates that globally, emissions for this sector were significantly underestimated by about a factor of three, based on the 1995 *Guidelines*. Comparisons of inventories based on an outdated IPCC Methodology may therefore be of limited value.

Participants thought that national GHG inventories for all gases could be compared with:

- other national inventories;
- emission factors from independent databases;
- inventories prepared with the Revised IPCC default Methodology;
- scientific databases, e.g. GEIA and EDGAR inventories.

If independent national data are used to prepare inventories and these are compared, this is considered to be validation. However, if similar emission factors are used to construct inventories, the data are not independent. Comparison of these inventories is considered to be verification. Furthermore, if the activity data originate from similar data sources, this is also considered verification. Verification techniques can be used to check the completeness of inventories and to identify outliers. Two conditions for proper verification are well-defined sectoral reporting formats and sufficient detail in standard reporting tables.

Currently, the *IPCC Overview and Summary Tables* do not supply sufficient detail for comparisons. For complete verification of national inventories, more detailed information than is provided in the *IPCC Guidelines* is necessary. Detailed worksheets are required.

For more general conclusions about inventory and *model comparisons*, see Van Amstel et al. (1997).

4.2.3 Limitation of comparisons

Because definitions of sources/sinks of inventories often differ, it is difficult to make direct comparisons without first harmonising the sectors. Therefore, to carry out such comparisons, the structure of the emissions datasets must be aligned and be comparable.

4.3 Approach 3: model comparisons

4.3.1 Background

Comparisons of atmospheric modelling results with inventories are relatively novel. Such an approach might potentially be used as an independent source to validate GHG inventories. In this approach, inventories are compared with emissions estimates (or budgets) derived from observed atmospheric concentrations and chemical transport models, using techniques such as *inverse modelling*. Likewise, *estimated* and *observed* atmospheric concentrations can also be compared. In this case, models are applied in the *forward* mode to obtain estimated concentrations. Gridded emissions estimates are typically used as input data. A key feature of *model comparisons* is that the significance of the results depends on both the difference and the confidence limits of the two estimates.

4.3.2 Assessment

Carbon dioxide

At present, the uncertainty of the global CO_2 budget calculated by models is estimated to be about 25%. This is considerably higher than the uncertainty of national inventories (about 10%)(Van Amstel et al., 1997). The uncertainty of atmospheric models would need to be improved if their results were to serve as useful comparisons with GHG inventories.

Currently, these cannot be used to validate or verify CO_2 inventories at the national level. The use of models is more promising at the global scale (Table 4-1). Fluxes from the terrestrial biosphere are not as well known compared to fluxes from other reservoirs (e.g. fossil fuels, oceans). Consequently, models could be used to constrain terrestrial CO_2 fluxes. Currently, the spatial resolution of models is limited to the zonal and continental level. To obtain regional and national detail, more atmospheric measurements and progress in model development would be needed. With the possible exception of isotopic studies, few other options to validate terrestrial carbon fluxes exist.

Table 4-1: Uncertainty and potential for use of modelling for CO_2

Model scale	Model uncertainty at this scale	Potential for use of the model at this scale
Global	+/- 1 Gt C	Land use-change and forestry;* systematic bias can be determined.
Zonal	+/- 1 Gt C	Sources and sinks can be discriminated roughly in latitudinal bands.
Regional	Need for measurements over continental areas at stations and from aircraft.	In the coming years, regional budgets of the biosphere are possible.
National/Local	There is a need for feasibility studies.	--

*** Based on the assumption that fossil fuel emissions and sea-air exchange are reasonably well known.**

Methane.

Models estimate CH_4 budgets at the global and zonal scales with reasonable success. In Europe, where the sampling network is well developed, regional budgets are feasible. The uncertainties in inventories and atmospheric budgets are of a similar magnitude (25-30%)(Van Amstel et al., 1997). Such comparisons could be used to validate national inventories. Comparisons could potentially yield the sectoral detail needed for the refinement of the *Guidelines*, particularly if supplementary isotopic information is available.

Amongst the gases considered, CH_4 shows the highest potential for validation using models. This is due to two factors. First, the atmospheric distribution of CH_4 is relatively non-homogeneous; this facilitates the use of atmospheric transport models to map emissions estimates. Second, model uncertainties are comparable (20-40%) with uncertainties of national inventories (+/-30%) (Table 4-2). Uncertainties, here, are derived by expert judgement. Both factors greatly enhance the effectiveness of *model comparisons*. Moreover, participants noted that the potential of using models exists at all spatial scales. Widespread application of this approach is currently limited by the small number of monitoring sites and measurement data.

Table 4-2: Uncertainty and potential for use of modelling for CH_4

Model scale	Model uncertainty at this scale	Potential for use of the model at this scale
Global	+/- 20%	Global estimates "with improved accuracy".
Zonal	> 20%, depending on latitude.	Zonal estimates, Rough sector analysis.
Regional	20 - 40% Need for more measurements.	Country budgets, Rough sector analysis.
National/Local	20 - 40% Need for more measurements from stations, aircraft and satellites.	Country scale GHG budget validation. Rough sector disaggregation.

Nitrous oxide

Nitrous oxide budgets can be estimated at global and zonal scales. Based on a preliminary uncertainty analysis, the uncertainties in inventories (70-100%) are larger than global budgets (30-50%) (Van Amstel et al., 1997).

However, for N_2O, the potential for inventory validation was greater than anticipated. Modellers identified their potential use with enthusiasm. At all spatial scales, model uncertainties (+/- 40%) were high (derived by expert judgement). But these uncertainties were comparable to those of national N_2O inventories (Table 5-3). The similarity of the uncertainty ranges between models and inventories allows for *model comparisons* to be used for validation. At Mace Head (Ireland), regional scale experiments have been successful in constructing emission budgets of anthropogenic N_2O from European sources (Derwent et al., 1998). Further modelling efforts should focus on improving the understanding of the stratospheric sink.

Table 4-3: Uncertainty and potential for use of modelling for N_2O

Model scale	Model uncertainty at this scale	Potential for use of the model at this scale
Global	+/- 50%	Estimate stratospheric sink constrain anthropogenic source.
Zonal	4 zonal bands +/- 30%.	Estimate zonal budget.
Regional	Need measurements of GHGs over continents and satellite data.	Continental/country budget. Country budget validation.
National/Local	+/- 40% for some countries.	Country scale GHG budget validation.

Note : Inverse modelling requires a new focus on the design of the monitoring networks from background measuring stations to new stations allocated downflow from polluted areas (continental areas) (relevant for compliance)

4.3.3 Limitation of comparisons

Model comparisons are limited by several factors. The most important of these are the comparability of datasets and uncertainties surrounding inventories and models.

Comparability of the dataset

The structure of emissions estimates from atmospheric models and inventories varies. Inverse models generally provide estimates of net (anthropogenic and natural) concentrations, or budgets and source categories, of a gas at a particular location and time. By contrast, inventories prepared for the UNFCCC include only anthropogenic emissions/removals, they are averaged over one year, and are typically at the national scale and by sector. For comparisons to be meaningful, emissions estimates from both the inventories and models must relate to the same group of GHG source/sink sectors, and over the same time period.

Uncertainties in model comparisons

Both inventories and *model comparisons* are subject to sampling errors, systematic bias, and theoretical uncertainties. In national inventories, uncertainties are present in field measurements, upscaling of measurements, and the statistics of national (economic) activities. Uncertainties in global budgets come about from the changes in reservoirs, the magnitude of the reservoirs themselves, calibration of the models, interpolation of the field measurements, the inherent limitations of the models and uncertainty in processes. If a modelling technique has a wider range of error than an inventory methodology, it may not improve the accuracy or precision of an inventory. Any difference between the inventory and modelling estimates must also be tested for significance. Therefore, more extensive quantification of uncertainties in inventories and atmospheric models is required.

4.4 Approach 4: direct emission measurements

4.4.1 Background

With current observing techniques, it is possible to measure the flux of a gas upwind and downwind of major cities and even nations. These and similar techniques provide direct emission and uptake measurements on scales approaching national inventories which have been applied on the east coast of the United States and in the United Kingdom. They may offer an alternative method of validating national GHG emissions and removals.

4.4.2 Assessment

Carbon dioxide

It was not clear to participants at the meeting that direct flux measurements would lead to cost-effective improvements for estimating CO_2 from Energy and Industrial Processes. Forest tower flux measurements might help to estimate the net transfer of carbon from forests to the atmosphere.

Methane

Direct Emissions Measurements lend themselves to large-scale experiments and surveys of oil and gas leaks, landfills, enteric fermentation, biomass burning and agricultural CH_4. Atmospheric measurements need to be interpreted in conjunction with remote sensing and isotopic analysis.

Nitrous oxide

Typically, biogenic emissions of N_2O show high spatial and temporal variability. Measurements and emissions should therefore be integrated over sufficiently long sampling periods to smooth out signals and seasonal variations. Currently, about half of global fertiliser N is applied in Asia and this is expected to increase. Yet research on emissions has mostly been carried out in Western Europe and North America, where climates and agricultural practices differ.

Direct flux measurements of agricultural sources at representative sites can be used to improve or to validate emissions estimates. Presently, emissions estimates are based on a limited number of measurements. These do not always cover the ‘full cycle’ of crop production, agricultural, animal and waste management practices. The use of standard measurement techniques, developed in Western Europe and North America, for obtaining estimates is recommended for areas where emission factors are lacking.

In the case of biomass burning, measurements should be carried out over sufficiently long sampling periods to capture post-burn effects following deforestation.

5. Evaluating the uncertainties in national greenhouse gas inventories

There are five independent sources of uncertainty in emission inventories:

- measurements of fluxes;
- development of emission factors;
- activity data;
- calculation method;
- errors in upscaling from the process to the country level.

Developing quantitative knowledge about each of these sources is an essential step in improving the quality of inventories. Measurement uncertainty can be quantified and reduced only through a detailed understanding of the measurement procedures and sampling techniques. Uncertainties in the inventory method varies by source/sink and can be understood through detailed study of individual categories.

One step is to identify some of the main sources of uncertainty in the national communications and in the IPCC Methodology. Sources of uncertainty in inventories vary depending on the activity. For fossil fuel combustion, the emission factors are fairly well known compared to the fuel use. Conversely, for agricultural N_2O, fertiliser statistics are generally better than the emission factors.

The *IPCC Guidelines* contain a table on the sources of uncertainties in GHG estimates. Participants at the meeting considered how this table could be improved, e.g. emission factors and activity data.

The table was highly contentious. Participants considered such a table was very useful but it should be improved by:

Firstly, developing the table with greater sectoral breakdown, and making it consistent with other IPCC Reporting Tables. A rating system was proposed as a semi-quantitative approach to estimating uncertainties. This procedure would standardise uncertainty estimation, and be an immediate improvement over the current IPCC Methodology. Countries could assign an uncertainty rating to an emission coefficient, activity data or emissions estimate. To capture the uncertainty due to the algorithm used, an additional column should be added to the table.

Secondly, countries should be encouraged to report their inventory data as a range rather than an absolute number. This would illustrate the variability which can be expected, given the uncertainty of the estimate. The *Guidelines* should also help differentiate between random error and systematic bias, and to identify the main sources of error.

Finally, some participants suggested developing a hierarchy of uncertainties, as this might establish priorities to reduce them.

Participants then considered the:

- uncertainty of national GHG inventories on a sectoral basis;
- reduction of uncertainty in the *IPCC Guidelines*;
- quantification of uncertainty in national GHG inventories;
- potential uses of the approaches for reducing uncertainties.

Participants emphasised that they each applied different methods to *define, estimate* and *report* uncertainties.

5.1 Carbon dioxide

Three sectors were considered for CO_2: Energy, Industrial Processes and Land-use Change and Forestry. Land-use change was separated from forestry because of their differing uncertainties. Participants estimated the uncertainty in GHG inventories and discussed ways of quantifying and reducing uncertainties.

Uncertainty in GHG inventories

Participants felt reasonably confident with the quality of energy data; energy emissions were estimated with the lowest uncertainty (<10%). Emissions and removals from land-use change were highest (>50%), forestry was slightly lower (>25%) (Table 5-1). Uncertainties for emissions from industrial processes were estimated at 15%. This uncertainty might be reduced if combustion and process data could be separated.

Quantifying uncertainty

A priority is to develop a framework for estimating and reporting uncertainties. The IPCC/OECD/IEA Inventories Programme should study how countries estimate their uncertainties for national inventories and use these ideas to scope future work.

Several semi-quantitative techniques for estimation of uncertainties should be evaluated according to the attributes of the method and the quality of the underlying data. These ranking systems could be based on one of four proposed schemes:

- classification as quantified by percentage ranges of uncertainty (a nominal scale could be 'very high, high, medium, low and very low'),
- uncertainties of sectoral emissions expressed as a percentage of its contribution to total national emissions,
- upper and lower ranges for emissions estimates, and
- quality assurance ranking systems.

Reducing uncertainty

Participants felt that improved activity data are required for:

- energy data in *some* countries (e.g. former Soviet Union);
- land-use data for *all* countries;
- forest inventories, deforestation and reforestation rates;

They also felt that a clearer definition of anthropogenic and natural emissions in the land-use change and forestry sector was required.

Table 5-1: Uncertainty and proposed improvements for CO_2 emission estimates

Sector	Uncertainty	*Inventory quality assurance*	*Inventory comparisons*
Energy	<10%	The quality is good for fuel combustion where activity data exist.	Comparisons should be made based on 'IPCC Reference Approach'.
Industrial Processes	15%	Better focus is needed on the industrial process. Distinguish between combustion emissions and process.	--
Land-use Change	>50%	Better tropical deforestation data are needed. Better reforestation data are needed. Basic data on soil carbon processes. Better data on land-use statistics.	The IPCC should collaborate with and support Land-use Change and Forestry global databases.
Forestry	>25%	Better forest inventories. Anthropogenic definition.	--
Overarching	--	The problem is not the methodology. To reduce uncertainty we need better activity data. Need to develop a 'docket' approach for field testing reports and quality assurance trail.	Comparisons should be made between national communications and international databases.

5.2 Methane

Three sectors were considered for CH_4: Energy; Agriculture; and Waste. Further disaggregation of these sectors is shown in Table 5-2. The uncertainty in GHG inventories, quantifying uncertainty and reducing uncertainty were discussed.

Uncertainty in GHG inventories

Here uncertainties are provided for 'best' case scenarios. These values are thought to be achievable for most national, annual inventories. For most sectors, uncertainties fell in the range of +/-30%. The highest uncertainties are for biofuel combustion and biomass burning. Both sources are important for developing countries.

Quantifying uncertainty

This could be greatly improved by specific reporting of the emission factors, algorithm and activity data. Disaggregation would lead to better scientific understanding. Care should be taken to avoid a scientific preoccupation with detail.

Reducing uncertainty

In most sectors, the largest gains can be made by improving the activity data, rather than the methodology (Table 5-2).

Table 5-2: Uncertainty and proposed improvements for CH_4 emission estimates

Sector	Category	Uncertainty	*Inventory quality assurance*	*Inventory comparisons*	*Direct emission measurements*
Energy	Coal Mining	+/- 30%	Complete disaggregation from the country scale to coal mining region, to individual mine, coal handling practices, above and below ground operations, open-cast vs. deep mining.	--	--
	Oil and Gas production /distribution/ transmission	--	Quantify and refine country to country variations at production sites, transmission and distribution pipeline losses, leakage losses at consumer premises.	--	Aircraft surveys of pipeline leakage.
	Oil Refining	--	Quantify and improve databases on refinery losses	--	--
	Biofuel Combustion	+/- 35%	Improve statistics and emission factors for small sources, domestic stoves and industrial biomass usage.	Comparison between countries and within countries.	Remote sensing and direct measurements offer significant potential.
Agriculture and Land-use Change	Enteric Fermentation	+/- 20%	Complete disaggregation into animal species, housing, feed, management, age and population statistics on country-specific basis.	--	Remote sensing and direct measurements offer significant potential.
	Manure	+/- 40%	Need to separate intensive management lagoons, and disposal on arable and non-arable land.	--	--
	Rice	+/- 30%	Scaling with respect to cultivar type, rice management, water regimes, use of organic waste and fertiliser.	Comparisons are difficult because most countries use the same methodology.	Imagery for area under rice cultivation, isotopic analysis with measurements.
	Large Scale Biomass Burning	+/- 50%	Attention should be given to area burnt, biomass density, previous extent of burning, ecosystem burnt, statistics of fuel burning, actual emission factors and measurements for different crop residues.	--	Remote sensing of fires Land-use data from satellites Large scale experimental campaigns.
Waste	Landfills	+/- 30%	More attention to be given to historical waste disposal rates, reporting landfill operations by extent and volume, landfill gas extraction, measurement of landfill gas decay functions.	--	--

5.3 Nitrous oxide

Three sectors were considered for N_2O: Energy; Industrial Processes and Agriculture. The issues of uncertainty in GHG inventories, quantifying uncertainty and reducing uncertainty were discussed.

Uncertainty in GHG inventories

Participants expressed uncertainties as a percentage range. It was felt that biases are introduced into inventories when an emission factor is measured in one world region, and then applied to another. The ranges in Table 5-3 take this bias into account. Uncertainty of agricultural emissions result from two sources, the range of default emission factors in the *Guidelines*, and the cumulative errors propagated throughout the calculations. For other sectors, uncertainties are cited from the EDGAR database. The highest uncertainties originate from agriculture, and the lowest from industrial processes. Globally, there are only a few major sources of industrial N_2O, which makes it easier to obtain site-specific emissions.

Quantifying uncertainty

The possibility of unidentified sources and sinks contributes to uncertainty. Potential candidates in this area are soil sinks and an atmospheric source of N_2O through oxidation of NH_3.

Reducing uncertainty

To reduce uncertainties, analytical methodologies to measure emissions from all sectors are a high priority. Another priority is clarification of the term anthropogenic, particularly for biogenic sources, like biomass burning and agriculture.

Table 5-3: Uncertainty and proposed improvements for N_2O emission estimates

Sector	Category	Uncertainty	*Inventory quality assurance*	*Inventory comparisons*	*Direct emission measurements*
Energy	Fossil Fuel	30-70%	IPCC should provide a recommended methodology.	IPCC should provide a recommended methodology.	Promote research to quantify emissions from: mobile sources (emissions from 3-way catalysts), fluidised bed reactors.
Industry	-	30%	IPCC should provide a recommended methodology.	IPCC should provide a recommended methodology.	Direct measurement of major sources by recommended methods.
Agriculture and Land-use Change	Biomass Burning	70-80%	IPCC should provide a recommended methodology.	IPCC should provide a recommended methodology.	Remote sensing of the extent of forest fires.
	Agricultural soils • Direct • Animal Waste Management • Indirect	 70-80% 70-80% 80-100%	Clarification of the term anthropogenic. IPCC should provide a recommended methodology. Research on process modelling.	Compare countries and regions with similar conditions.	
	New Sources/Sinks	?	Promote research to quantify/verify: the unknown soil sink, industrial sources, atmospheric source of N_2O through oxidation of NH_3		

6. Expert group recommendations

The expert meeting recommended several steps to advance current understanding of sources and removals of GHG inventories. These steps were seen as critical to producing better emissions estimates, and for further revisions of the *Guidelines*.

Inventory quality assurance. In the immediate term, further research on *inventory quality assurance* is a high priority for verifying and for assessing the quality of national GHG inventories for all gases.

Inventory comparisons. Existing inventories (national and scientific) should be compared with default and independently derived emission factors and international statistics, at a range of scales to find the largest differences. These differences should be explained using the details of activity data and emission factors. This applies in particular to sectors with high uncertainty such as agriculture.

Model comparisons. In the longer term, *model comparisons* show potential for validation and verification of global, regional, and national GHG inventories. The use of *model comparisons* is recommended, using both forward and inverse models. To improve the reliability and accuracy of GHG emission inventories, *model comparisons* should be carried out at various levels. More GHG measurements would be needed over continental areas in order to use the full capacity of models.

Direct emission measurements. In the medium term, *direct emissions measurements* are a priority for improving estimates of CH_4 from several emissions sources. These include: oil and gas leaks; landfills; biomass burning; and rice paddies.

Uncertainty. A high priority is a framework to define, estimate, and report degrees of uncertainty in GHG inventories. First, the IPCC should study how countries estimate uncertainties for their national inventories. Second, a framework on uncertainties should be developed through the IPCC process. This framework should allow degrees of uncertainties to be reported at a higher level of sectoral detail than in the current *Guidelines.* Clearer reporting of the sources of uncertainty could be achieved by explicit reporting of uncertainties for emission factors, activity data and the algorithms used in calculating estimates.

Codes of practice. To help reduce uncertainties in national GHG inventories, *codes of good practice* for the preparation of national inventories and the measurement of emission factors and direct emissions of CO_2, CH_4 and N_2O should be developed through the IPCC process. These codes of good practice should be based on accepted procedures currently employed in countries with mature research programmes. They should be applied to obtain more comprehensive emissions data in regions where good quality data are lacking. The number of direct measurements of industrial N_2O from major point sources should be increased.

Data generation. To reduce uncertainties in national inventories, a higher priority should be placed on data generation.

> ***Carbon dioxide.*** In all countries, improved activity data need to be collected for land-use, forest inventories, rates of reforestation, deforestation and afforestation. Priority should be given to flux measurement from forests and a better understanding of soil carbon exchange processes.

Efforts should focus on reducing systematic rather than random error in energy statistics. For verification, participants strongly recommended comparing emissions estimated using both national methodologies and the IPCC Reference Approach.

Methane. Every effort should be made to improve the disaggregation and systematic collection of basic data. Priority should be given to documenting and reporting of historical waste disposal rates, land area and volume extents, landfill gas extraction and landfill organic matter decay functions. Other priorities include carrying out large-scale measurements to determine emission rates from coal, oil and natural gas production and distribution.

Nitrous oxide. For improving inventory quality, participants agreed that existing N_2O inventories should be compared at a range of scales and the largest differences identified, particularly for biogenic (agricultural) emissions. Furthermore, there is a need to clarify which part of agricultural emissions are anthropogenic and which are natural.

Anthropogenic. Broad consensus on this term should be developed to differentiate anthropogenic from natural sources and removals of GHG. This will help reduce uncertainty in land-use change and forestry inventories and agricultural sources. Several interpretations of anthropogenic are possible. Their appropriateness depends, in particular, on the requirements of the Convention.

Emission factors. Country-specific emission factors should be compared with data from the literature.

Glossary of terms. A glossary of common terminology relating to the quality of national GHG inventories should be developed through the IPCC process.
The *Glossary of Terms* prepared for this meeting is a useful starting point and it could be incorporated into the *Guidelines.*

Co-operation. There is a need for increased co-operation between the inventories and modelling communities. This will result in a better assessment of anthropogenic influence and its overall effect on the climate system.

Halocarbons and sulphur hexafluoride. A high priority should be placed on improving the IPCC estimation methodologies for HFCs, PFCs, and SF_6.
These gases are included in the national targets under the Kyoto Protocol. The IPCC Reporting Tables should be disaggregated so that emission estimates for the individual gases can be monitored against atmospheric measurements.

7. Next steps

Following technical review and incorporation of comments, the final meeting report will be distributed to governments for information. Opportunities to enhance the co-operation between the Inventories Programme and Working Group I of IPCC will be explored.

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Annex 1: Working Group Reports

Modelling: carbon dioxide, methane, nitrous oxide

6 November 1997
Chairs: Leon Janssen, Leonor Tarrason
Rapporteurs: Dick Derwent, Carolien Kroeze, John Taylor

The working group discussed Approach 3 described in the issues paper and three questions listed below.

QUESTION 1. What do we achieve by introducing *model comparisons* in inventory validation?

Opportunities for the comparison of atmospheric models with inventories include:

1. Testing inventories, e.g. forward methods (short term)
   - consistent with atmospheric growth rate
   - consistent with spatial distribution at monitoring sites
   - consistent with seasonal variation at monitoring sites
2. Refinement of guidelines, e.g. emission factors from rice paddies and biomass burning (short term).
3. Data generation, e.g. inverse methods to estimate national inventory where no other data are available (long term).
4. Accuracy, e.g. compare inventory with inverse methods - validation? (long term).

Recommendation 1:

> The expert meeting recommends the use of model/inventory comparisons, both forward and inverse at a range of scales, in order to improve the reliability and accuracy of greenhouse gas emission inventories.

QUESTION 2. How can *model comparisons* be used as validation tools for emission inventories? (Identify methods and application areas).

Table 1. Overview of modelling approaches for estimating GHG fluxes

Budget	Concentration measurement	Modelling approach
Global budget	- global growth rate - stratospheric gradient - ice core data	0-D box model
Zonal budgets e.g. 10 degree latitude belts	Zonal gradient (pole to pole) at surface	- multi-box model - 2-D advective-convective transport model
Regional budgets, e.g. continental scale	- satellite measurements - global networks at background locations	- 3-D global tracer transport models - GCMs
Local budgets, e.g. country	- local measurement networks (not background) - aircraft	- 3-D regional models nested in global models

The following tables (Tables 2-4) summarise our response to the present uncertainty in the budgets and the potential for use of modelling to constrain the budgets.

Table 2. Present uncertainty and potential for use of modelling for CO_2

CO_2	Present uncertainty	Potential for use
Global scale	+/- 1 Gt C	Land use (deforestation) (*); systematic bias can be determined
Zonal scale	+/- 1 Gt C	Sources and sinks can be discriminated roughly in latitudinal bands
Regional scale	Need for measurements over continental areas at stations and from aircraft	In the coming years, possible regional budgets of the biosphere
Country/local scale	There is a need for feasibility studies	

Note *: Recognising that fossil fuel emission and sea-air exchange are reasonably well known.

Table 3. Present uncertainty and potential for use of modelling for CH_4.

CH_4	Present uncertainty	Potential for use
Global scale	+/- 20%	Global estimates "with improved accuracy"
Zonal scale	> 20%, depending on latitude	- zonal estimates - rough sector analysis
Regional scale	20 - 40% Need for more measurements	- country budgets - rough sector analysis
Country/local scale	20 - 40% Need for more measurements from stations, aircraft and satellites	- country scale GHG budget validation - rough sector disaggregation

Table 4. Present uncertainty and potential for use of modelling for N_2O.

N_2O	Present uncertainty	Potential for use
Global scale	+/- 50%	- estimate stratospheric sink - constrain anthropogenic source
Zonal scale	4 zonal bands +/- 30%	estimate zonal budget
Regional scale	- need measurements of GHGs over continents - satellite data	- continental/country budget - country budget validation
Country/local scale	+/- 40% for some countries	country scale GHG budget validation

Recommendation 2:

The expert meeting recognises that more greenhouse gas measurements over continental areas are needed in order to use the full capacity of models to improve the confidence in greenhouse gas emission inventories.

Note: Inverse modelling requires the focus on the design of the monitoring networks to shift from background measuring stations to new stations allocated downflow from polluted areas (continental areas) (relevant for compliance).

QUESTION 3. Are the uncertainties in the models and observations sufficiently quantified to allow for a useful comparison? See above table.

Methane: agriculture and waste

6 November 1997
Chairs: Ron Sass and D.C. Parashar
Rapporteur: Dr. Susan Subak

The meeting began with a discussion about the difference between validation and verification. Most agreed that a narrow definition for validation was useful, related to access to the primary information needed to derive an emissions inventory. Most of the subsequent discussion was on the problems in achieving improved accuracy without reference to these terms, but was generally concerned with problems of validation rather than verification.

Initially, however, it was pointed out that the main methane inventory comparison, between EDGAR and IPCC results, was verification rather than validation and had been useful in identifying where the gaps were.

- The general point was made that sometimes changes in annual flux were due to natural variability rather than changes in activities, e.g. variability in temperature can affect methane from rice paddies, so it follows that emissions factors are not naturally static over time.
- The group agreed that Table 2-1 would look quite different if countries tried to estimate the uncertainties for their own countries, for both emissions factors and activity data, and that they should be encouraged to do so.
- Top-down air sampling approaches hold the potential for decreasing uncertainty from all methane sources discussed.

Rice cultivation

Results from a process model were presented showing very good agreement between modelled results and measured results of annual aggregates in Texas and China. The model is related to cultivar, temperature, water regime, soils and fertiliser type and application. The research reporting said that the greatest variation in flux was due to cultivars rather than the other parameters that have been studied to a greater extent in the past. This researcher said that in their experiments, in cases where the cultivar type was known, the level of accuracy appeared to be quite high (within 10%). Another rice specialist present said that he agreed that there should be more research on cultivars but that nutrient supply and soil texture are related to a given cultivar and that it is helpful to know the organic content of soils in addition to soil texture.

Given the scarcity of detailed data for the relevant flux parameters it was discussed whether there may be any useful socio-economic proxies for flux. It was believed that yield was a good crude proxy because it correlated with higher fluxes on an area basis. GNP per capita has been proposed as a proxy for type of fertiliser application, with higher GNPs denoting greater use of inorganic as opposed to organic fertilisers. While detailed information is often not available about the type of fertilisers used, it was felt that assuming certain fertiliser applications based on agricultural culture would be better than using the GNP proxy.

The point was also made that often the poorest people in the world grow rice, that this group has used traditional agricultural techniques and would continue to do so unless given strong incentives to change. Therefore, rice management is fairly predictable in those regions that are least likely to have formal data.

- The results from process models are encouraging and should be used as default emissions factors in countries that do not have their own measurements.
- Improvement in data is needed for all parameters, especially cultivar type.
- It was proposed that surveys should be sent out to improve our understanding of rice management practices.
- While isotopic analysis does not clearly separate rice paddies from wetlands, isotopic constraints may be useful in regions with few wetlands.
- Inverse techniques based on air sampling at the regional and local, not just global, scale would be helpful.
- Better scaling up of site air measurements from heterogeneous sites is needed.
- Summation of country totals based on 1996 default IPCC emissions factors totalled 33-49 Tg, as compared with 60 Tg point estimate given for the global balance (within 20-100 Tg), (33-49 Tg is based on flux density of 20, 25 and 30 g/m^2 as a world average).
- Additional crop sources exist, such as cranberries and jute, but these were not judged to be important enough to warrant a methodology.
- One participant suggested that it may be useful to invite countries to scale parameters from 0-1 instead of using absolute values, e.g. rice completely submerged during the growing season would be scored 1.0 for the water regime parameter.
- There was some agreement that it might help to set individual country default factors for all parameters and then ask them to explain how and why they changed them.

Livestock

The USA has broken down the Tier 2 categories in greater detail (age groups, management practices, feed types, dairy production). They believe that the uncertainty is now below 20%. The Dutch representative said that he believes that the uncertainty for the inventory from the Netherlands is also now lower than 25% for the emissions factor and 10% for the activities.

The existing inventory accounting structure does not help in integrated analysis. This is especially the case for methane emissions from enteric fermentation that over time inventories may show a decline in methane emissions due to improvements in animal productivity, but these reductions may come at the expense of increased carbon dioxide emissions related to fossil fuels for better feed production. An alternative accounting approach measures emissions per unit of product, e.g. carbon dioxide equivalent per pound of beef or milk. In the long run, it is hoped that process assessments could be compared with national inventories.

Landfills

The USA bases much of its inventory on estimates from about one hundred of the largest landfills and then extrapolates to include the thousands of small sites, although it acknowledges that this extrapolation is hard to make. It is difficult to include the time dynamic in that many landfills produce methane for more than three decades, and even the USA waste composition statistics only go back for about one decade. In the Netherlands, a comparison between the revised method and earlier estimates confirmed that it was important to consider the time dynamic. First-order decay functions can be used for regions that do not have historical waste generation and landfilling statistics

It would be useful if countries included information estimating the range of landfill sizes by area extent and volume, and estimated the proportion of the total waste disposed of in the different size categories.

Biomass burning

There was insufficient time to discuss this category in any depth. It was recalled that some verification exercises had been completed. Researchers at King's College London had estimated methane from biofuels used for energy production for many countries, and these results were found to differ from national inventories from this category by as much as one thousand fold. Better emissions factors were needed for most developing regions for all categories of biomass burning.

Carbon dioxide: energy, industrial processes and land-use change

6 November 1997
Chairs: Youba Sokona and Gregg Marland
Rapporteur: Tim Simmons

The aim of the Group was to identify and suggest means of improving the quality of CO_2 inventories so that they represented unbiased estimates of actual emissions at the lowest practicable variance. New mechanisms for emissions estimation were also sought.

Inventories were seen as serving three main functions:

- to permit control of compliance with targets established by the UNFCCC
- to provide data and rationale for emissions mitigation policies
- to assist in the development of global climate models.

It was recognised that the first of these functions requires only total emission figures but that greater spatial and activity detail will be required for the others.

Quality improvements

It was recommended that national CO_2 inventories be systematically compared with those of a similar country and with the IPCC reference approach in order to reveal any omissions and confirm correct application of the methodologies. Inventories should also be accompanied by an account of which of the IPCC standard source categories have been estimated in the inventory and the reasons for any omissions or additions.

The methods for estimation of emissions in the energy and industrial processes sectors were now considered reasonably complete and further refinement unnecessary at the moment.

The random variations in activity data for the larger countries were felt to be below the current estimates of uncertainty given in the *Guidelines*. These uncertainty estimates include systematic bias in activity figures. This led to a situation in which the trends in activity data and emissions showed greater stability than individual data points. The group recommended that efforts be made to estimate the magnitude of systematic bias as well as random error and to reflect them in uncertainty ranges on the main aggregates in the inventories. Despite the general acceptability of data quality in the major countries, it was thought that many countries would wish to see improvements in some elements of their data and that, in particular, the developing countries would benefit from investment in their data collection systems arrangements which would permit them to assess their emissions and participate more actively in inventory formulation.

Methodologies for CO_2 from land-use change were still under development and it was thought premature to consider improvements to quality whilst fundamental choices on the HWP module remained to be made.

It was not clear to the Group that direct flux measurements would lead to cost-effective improvements to the estimation of CO_2 from Energy and Industrial Processes. Anthropogenic sinks were not considered as the Group had no expert in these matters.

New methods

In reviewing the completeness of the existing methodologies for emissions from land use it was noted that remote sensing by satellites could be added as a means of providing rapid estimates of activity data.

Nitrous oxide: validation and verification

6 November 1997
Chairs: Arvin Mosier and G.X. Xing
Rapporteur: Jos Olivier

Introduction

Dominating sources of N_2O on a global level are:

- agriculture
- industrial processes
- large-scale biomass burning
- road transport (in future).

Agriculture is by far the dominant source, in particular in developing countries, although in most industrialised countries too, this source contributes a large share to the national total.

Agricultural emissions vary widely in time and space. They depend on:

- different climates, agricultural practices
- seasonal variation, crop rotation effects
- soil variables: wetness, temperature, mineral N content, available C

Actual emissions from soils are usually much lower than the potential emissions due to limitations imposed by the soil variables mentioned above. Emissions often occur as bursts over short periods due to (short) interruptions of these limiting conditions. These bursts may give rise to high contributions to annual emissions. measurements and emission compilations should therefore be done over a sufficiently long period, and detailed enough to cover both such bursts of emissions and the seasonal variations (e.g. integration over one or more years). Currently, about half of global of N use is in Asia, and the fraction need there and in other developing countries will increase. However, the main research on emissions has been done in Western Europe and North America, with very different climates and agricultural practices from those of Asia and other continents.

Approach 2: inventory comparisons

National inventories can be compared using three methods:

1. Intercountry comparison.
   (e.g. emission densities or aggregated emission factors comparisons)

2. Comparison with a well-defined reference method (e.g. simple Tier 1 + default IPCC emission factors). This could be identical or similar to the *IPCC Standard Data Tables 1-6* in the original *IPCC GHG Inventory Guidelines*.

This could also be a comparison with authoritative databases using the defined reference method, analogous to, for example, the IEA database for CO_2 from energy combustion.

3. Comparison with authoritative scientific databases, again analogous to the IEA database for CO_2 from

energy combustion and GEIA/EDGAR data for other sources.

Validation, an independent check of national inventories, is only possible by the first method, because data of different countries are in principle independently determined (except for cases where default IPCC factors were used). The other methods are not independent, since the activity data basically comes from the same source; emission factors may be independently estimated, if the national factors are based on country-specific information, e.g. local measurements.

Verification is possible with all three methods:

- methods 2 and 3 can be used for a quick screening of completeness and correctness of allocation to source categories;
- all methods can be used as a screening test for identifying outliers in sectoral emissions.

Outliers flag that either country-specific circumstances should be substantiated (e.g. application of specific reduction technologies), or that there are possible errors/weak assumptions in emission factors in either of the inventories.

Each of these verification methods requires:

- well-defined sectoral reporting formats;
- sufficient detail in *standard* reporting tables;
- for easy comparison and first analysis of reasons for outliers.

The current *IPCC Overview/Summary Tables* do not supply sufficient detail, nor does the requirement for submission of all underlying tables because of the lack of uniformity in these tables (except for countries using the ‘Worksheets’). However, the original *IPCC Standard Data Tables 1-6* or similar tables do in general give the required minimum detail.

Approach 4: Direct emission measurements

National total emissions of N_2O vary largely in time and space. Validation of national totals, essentially the sum of the dominating sources mentioned above, may be possible on a sectoral basis because the emission of the different source categories may show a different seasonal variation and are also distributed differently in the national territory. This is also true for the natural sources, which may be discriminated in this way. So, validation may be possible by sectoral assessments.

Agriculture

Direct flux measurements of agricultural sources at representative sites can be used for improving or validating emission estimates, since present estimates are generally based on only a few measurements, which do not cover the ‘full cycle’ of crop production, or specific agricultural and animal management practices (including waste management).

Local flux measurements need to cover complete annual cycles, which includes the important stages of total production cycles. Also they need to be done in the appropriate climate and management circumstances. In addition, the location of possible other large sources nearby needs to be known, to exclude interference by these other sources.

It is strongly recommended to base measurement practices on existing methods used in Western Europe and North America.

Industrial sources

Stack measurements will be sufficient to get accurate estimates for these sources.

Biomass burning

As in agriculture, sufficiently long measurements are required for covering the important post-burn effects in the case of deforestation.

Inherent uncertainty

Agriculture

Upscaling, i.e. integration in time and space, will always be necessary and is an intrinsic source of uncertainty.

Industrial sources

Small (for identified sources).

Biomass burning, more general land-use change

The difficulty in monitoring the spatially wide spread activity data causes an intrinsic uncertainty in the emission estimates. Also, uncertainty in future land-use after the biomass burning causes uncertainty in the net emissions over a number of years.

Annex 2: Glossary[1]

Absolute error

The absolute deviation of x (a variate) from its 'true' value.

Activity data

Data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time.

Accuracy

The exactness of an estimate. (*Accuracy* is to be contrasted with *precision*)

Anthropogenic

Man-made, resulting from human activities. (*Anthropogenic* emissions are to be distinguished from *natural* emissions)

Bottom-up

In the context of the discussions, emissions inventories derived from activity data, emission factors and algorithms such as those provided in the *IPCC Guidelines.*

Census

The complete enumeration of a population or groups at a point in time with respect to well-defined characteristics.

Confidence

Refer to **confidence interval**

Confidence Interval

Define two statistics t_1 and t_2 (functions of sample values only) such that, θ being a parameter under estimate,

$$\Pr\left(t_1 \leq \theta \leq t_2\right) = \alpha$$

where α is some fixed probability, the interval between t_1 and t_2 is called a confidence interval.

Consistency

Concerned with the internal agreement of data or procedures. (*Consistency* is to be contrasted with *validity*)

COP

The Conference of the Parties under the UN Framework Convention on Climate Change.

Distribution function

Function F(x) of a variate x is the total frequency of members with variate values less than or equal to x.

[1] All definitions have been extracted from M.G. Kendall and W.R. Buckland (1975); *A Dictionary of Statistical Terms*; International Statistics Institute; U.K., or the *Revised IPCC Guidelines for National Greenhouse Gas Inventories*; Paris, 1997; except Accuracy, Precision and Uncertainty extracted from Mirriam-Webster 1997.

Emission factor

A coefficient which relates the activity data to the amount of chemical compound emitted.

Error of estimation

In regression analysis where the regression equation is used to estimate the ‘dependent’ from given values of the ‘independent’ variates, the difference between the estimated and the observed value of the dependent variate.

Estimate

The particular value yielded by an **Estimator** in a given set of circumstances.

Estimator

A rule or method of estimating a constant of a parent population.

FAO

Food and Agriculture Organisation of the United Nations.

IEA

The International Energy Agency. An autonomous body attached to the OECD.
See also OECD.

IPCC

The Intergovernmental Panel on Climate Change. A special intergovernmental body established by UNEP and the WMO to provide assessments of the results of climate change research to policy makers.

Mean

The value obtained by summing all variates in a distribution and dividing by the number of variates.

Median

That value of the variate which divides the total frequency into two halves.

Mode

The variate which occurs most frequently in the distribution.

OECD

The Organisation for Economic Co-operation and Development. A regional organisation of free-market democracies in North America, Europe and the Pacific.

Precision

Repeatability of an estimate. In general the precision of an estimator varies with the square root of the number of observations upon which it is based. (*Precision* is to be contrasted with *accuracy*)

Probability distribution

A distribution giving the probability of a value x as a function of x.

Qualitative data

Relates to data in the form of expressions or descriptive text. (Qualitative data is to be contrasted with quantitative data)

Quantitative data

Relates to data in the form of numerical quantities such as measurements or counts. (Quantitative data is to be contrasted with qualitative data)

Quality control

Tracing and eliminating systematic variations in quality, or reducing them to an acceptable level, leaving the remaining variation to chance.

Quartile

In the particular case of a continuous distribution, the value at which 25% of the variates have values above (upper quartile) or below (lower quartile) it.

Reliability

That part which is due to permanent systematic effects, and therefore persists from sample to sample, as distinct from error effects.

Standard deviation

A measure of the dispersion of a frequency distribution; equal to the positive square root of the **variance.**

Stochastic approximation procedure

A non-parametric method of iterative estimation for a functional or regression relationship which incorporates random elements.

Top-down

In the context of these discussions, emission inventories derived or correlated with atmospheric concentrations using computer models.

Uncertainty

The range of error of an estimate. (Also loosely defined as the range between the upper and lower quartiles)

UNECE

United Nations Economic Commission for Europe.

UNEP

United Nations Environment Programme.

UNFCCC

United Nations Framework Convention on Climate Change.

US EPA

United States Environmental Protection Agency.

Validation

A procedure which provides, by reference to independent sources, evidence that an inquiry is free from bias or otherwise conforms to its declared purpose. (*Validity* is to be contrasted with *consistency*)

Variance

The mean of the squares of variations from the arithmetic mean.

$$\int_{-\infty}^{\infty} (x - \mu_1')^2 \, dF$$

Verification

A procedure to test the internal agreement of data or procedures. (*Verification* is to be distinguished from *validation*)

WMO

The World Meteorological Organisation of the United Nations.

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