ANNEX 2

VERIFICATION

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A2.1 INTRODUCTION

Verification processes are, in the present context, intended to help establish an inventory's reliability. These processes may be applied at either national or global levels of aggregation and may provide alternative information on annual emissions and trends. The results of verification processes may:

(i) Provide inputs to improve inventories;

(ii) Build confidence in emissions estimates and trends;

(iii) Help to improve scientific understanding related to emissions inventories.

Verification processes may also enhance international cooperation in improving inventory estimates.

There are different approaches to verification. One approach is to evaluate emissions estimates and trends, for example, as part of the United Nations Framework Convention on Climate Change (UNFCCC) review of emissions inventories. Another approach entails an evaluation of aggregate inventories on a global or regional basis, with the objective of providing further scientific insight.

A number of options or tools for verification are discussed in this Annex. Their application, as well as the types of information needed, will vary according to the role and intention of the verification process. International verification of inventories may include comparisons with international or independently compiled activity data, emissions factors, uncertainty estimates, atmospheric measurements, and global or regional budgets and source trends. International verification will usually occur following inventory preparation, including the quality assurance/quality control (QA/QC) process (see Section A2.2.1, National Inventories, in this Annex and Chapter 8, Quality Assurance and Quality Control). International verification may occur in the absence of national verifications. Verification activities require resources, time and technical and intellectual expertise.

Verification processes and results should be reported systematically and in a timely manner, in order to provide feedback to national inventory teams, and to the international community, as appropriate, depending on the role and reason for verification.

Techniques for Verification

Verification techniques include internal quality checks, inventory inter-comparison, comparison of intensity indicators, comparison with atmospheric concentrations and source measurements, and modelling studies. In all cases, comparisons of the systems for which data are available and the processes of data acquisition should be considered along with the results of the studies. These techniques, and their applicability at the national and international level, are discussed below.[1]

A2.1.1 National Level

Verification procedures can be conducted on parts of national inventories as part of the QA/QC process (see Chapter 8, Quality Assurance and Quality Control), or on parts or the whole inventory as a separate exercise.

A2.1.1.1 COMPARISONS WITH OTHER NATIONAL EMISSIONS DATA

Comparisons with other, independently compiled, national or regional emissions estimates are a quick option to verify completeness, approximate emission levels, or allocations to source categories or sub-source categories. The availability of such independently compiled inventories will vary, but possible resources include state or provincial inventories, as well as inventories prepared independently by research organisations. Specific steps for national comparison are similar to those for comparisons with international data, as described in Section A2.2.1, National Inventories.

[1] Some of the options are described in more detail in EEA (1997), Lim *et al.* (1999a, b) and Van Amstel *et al.* (1999).

A2.1.1.2 DIRECT SOURCE TESTING

On-line stack measurements, in-plume measurements, remote measurements, and tracers have been used for direct testing of sources. All these approaches allow the direct attribution of observed concentrations to the emissions from a certain source. So long as it is representative, the uncertainty associated with the measurement and emission calculations in direct source testing is often considered to be lower than the uncertainty of inventory emissions estimates that may have been calculated by other methods. See Chapter 8, Quality Assurance and Quality Control, Section 8.7.1.3, Direct Emission Measurements, for further discussion of this topic.

A2.1.1.3 COMPARISON WITH NATIONAL SCIENTIFIC AND OTHER PUBLICATIONS

Although the inventory agency is responsible for the compilation and submission of the national greenhouse gas inventory, there may be other independent publications of relevance (e.g. scientific and technical literature). Examining such literature sources may identify areas for further research and inventory improvement.

A2.1.2 Additional international comparative tools

Comparison of national greenhouse gas inventories with international data sets may be an independent means to verify inventory estimates. Several types of comparisons can be made, including comparisons with independently compiled bottom-up emissions estimates, comparisons with atmospheric measurements, comparisons with international scientific literature sources, and comparisons with global or regional budgets. Comparisons with inventories from other countries enable cross-checking of assumptions regarding the use of emission factors, completeness of source categories and overall approaches. In addition to comparisons with single country emissions inventories, it is possible to make more systematic comparisons for larger groups of countries.

A2.1.2.1 BOTTOM-UP COMPARISONS

For a given source category, different types of bottom-up comparisons can be performed in parallel. These comparisons can examine overall emission levels, emission factors, or activity data. The broad types can include:

- Comparisons with other independently compiled datasets, in order to check for completeness, magnitude, and source allocation;
- Inter-country comparisons in which input data (i.e. activity levels, aggregated emission factors or other factors used in emission calculations) are compared for different countries for the same year;
- Inter-country comparisons in which trends in emissions or input data are compared for different countries.

These different types of comparisons can also assist in evaluating the uncertainty estimates of national inventories and global emission inventories, and evaluating differences at the country level. These comparison processes do not always represent verification of the data themselves, but instead verification of the reliability and the consistency of data (e.g. in trends and between countries). They can enable reviewers to identify inconsistencies or questions for which more detailed data verification may need to be performed. The time that inventory agencies are able to spend on these independent verification activities will depend upon the resources available and an assessment of the value of these activities compared to other means of improving inventory quality.

Several examples of the types of comparisons are described below:

- *Comparisons of Top-down and Bottom-up Estimates*: For carbon dioxide (CO_2) from fossil fuel combustion, a reference calculation based on apparent fuel consumption per fuel type is mandatory according to the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*IPCC Guidelines*). This type of top-down completeness and order-of-magnitude check may also be applicable in other cases where the inventory is based on a bottom-up approach. In cases where emissions are calculated as the sum of sectoral activities based on the consumption of a specific commodity (e.g. fuels or products like hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) or sulfer hexafluoride (SF_6)), the emissions could be estimated using apparent consumption figures (e.g. national total production + import – export ± stock changes).

- *Comparisons of National Emission Inventories with Independently Compiled, International Datasets*: Some global databases already exist. For example, CO_2 emissions estimates associated with the combustion of fossil fuel are compiled by the International Energy Agency (IEA) and the Carbon Dioxide Information and Analysis Centre (CDIAC). Global total anthropogenic inventories of all greenhouse gases are compiled by the Global Emission Inventory Activity (GEIA, a component of IGAC/IGBP) and the Emission Database for Global Atmospheric Research (EDGAR), as compiled by TNO Institute of Environmental Science and National Institute of Public Health and the Environment (RIVM) in close cooperation with GEIA (IEA, 1999; Marland *et al.,* 1994; Graedel *et al.,* 1993; Olivier *et al*., 1999). These comparisons can assist in checking completeness, consistency, source allocation and accuracy to within an order of magnitude. However, when evaluating the results of these comparisons, it should be remembered that the various data sources are often not completely independent of each other or from the data set used to calculate the national inventory. For example, EDGAR starts with IEA energy data to calculate CO_2 emissions from fuel combustion and CDIAC and GEIA datasets start with UN energy data. In addition, even the IEA and UN energy data are not completely independent. In order to avoid duplication of work, the IEA and the United Nations cooperate in the exchange of data and use common questionnaires for some countries.

- *Comparisons of Activity Data with Independently Compiled Datasets*: Similar comparisons may be made using the underlying activity data to check completeness and order-of-magnitude. These underlying data may be compared with independently compiled international statistics (e.g. maintained by the IEA, and the United Nations Food and Agriculture Organization). One should not, however, expect to find exact matches since the activity data used by the inventory agency may be taken from different data sources or be a different version to that used in the national data collected by international organisations; for examples see Schipper *et al.* (1992). When checking activity data, indicators could be defined for the purpose of international comparison (e.g. activity rate per inhabitant, per employee, per unit of GDP, per number of households or per number of vehicles, according to the source sectors). This could enable order-of-magnitude checks and indicate outliers that may be caused by data input or calculation errors.

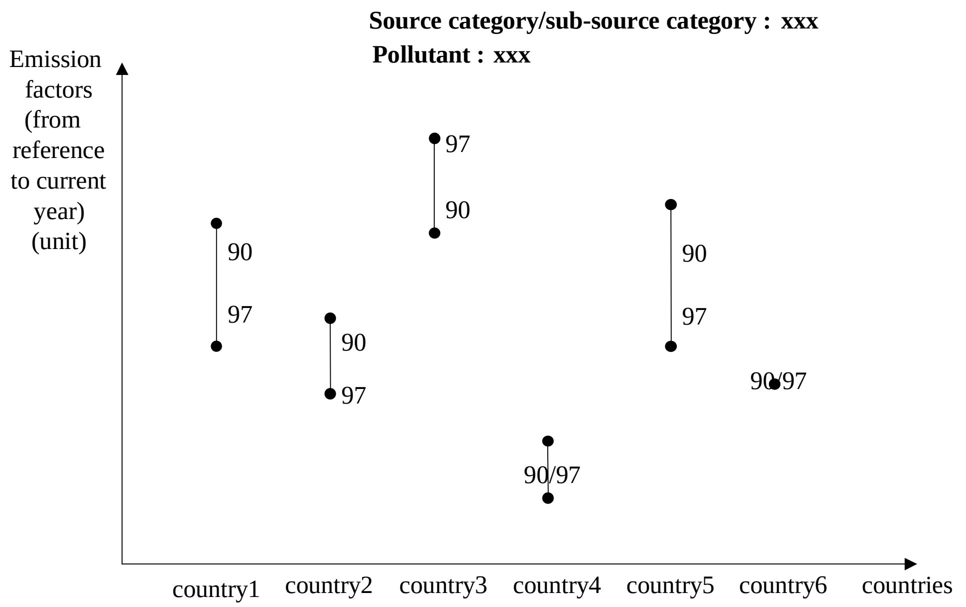
- *Comparisons of Emission Factors Between Countries*: Different kinds of comparisons can be combined in practice. For example, between-country emission factor comparisons can be combined with historic trends by plotting, for different countries, the reference year data (e.g. 1990), the more recent year data, and the minimum and maximum values. This analysis could be made for each source category and possible aggregations. Sub-source categories such as fuel types may also be included when relevant (see Figure A2.1, Illustrative Plot for an Inter-country Comparison of Emission Factors). Comparisons between countries can also be made using implied emission factors (which are top-down ratios between emissions estimates and activity data). This type of comparison may enable outlier detection based on the statistical distribution of values from the sample of countries considered, bearing in mind that differences in national circumstances can significantly affect the implied emission factors. Since implied emission factors are ratios of emissions to activity data, comparisons based on them should help verify both the emission factors and the activity data in the original calculation. Finally, a comparison with the IPCC Tier 1 default values and with literature values may be informative in establishing the comparability or country-specificity of the emission factors used.

- *Comparisons Based on Estimated Uncertainties*: Comparisons based on the estimated uncertainties of emission factors, when such data are available, can also be useful. For example, Figure A2.2, Illustrative Plot for an Inter-country Comparison of Emission Factors and their Uncertainties, shows on a single plot current year’s emission factor and the related uncertainty range for different countries. This can be done for a given source category and, when relevant, sub-source categories such as different fuel types. This type of comparison may help to identify data outliers where uncertainty ranges do not overlap.

- *Comparisons of Emission Intensity Indicators Between Countries*: Emission intensity indicators may be compared between countries (e.g. emissions per capita, industrial emissions per unit of value added, transport emissions per car, emissions from power generation per kWh of electricity produced, emissions from dairy ruminants per tonne of milk produced). These indicators provide a preliminary check and verification of the order of magnitude of the emissions. It is not expected that emission intensity indicators will be correlated across countries. Different practices and technological developments as well as the varying nature of the source categories will be reflected in the emission intensity indicators. However, these checks may flag potential anomalies at country or sector level.[2]

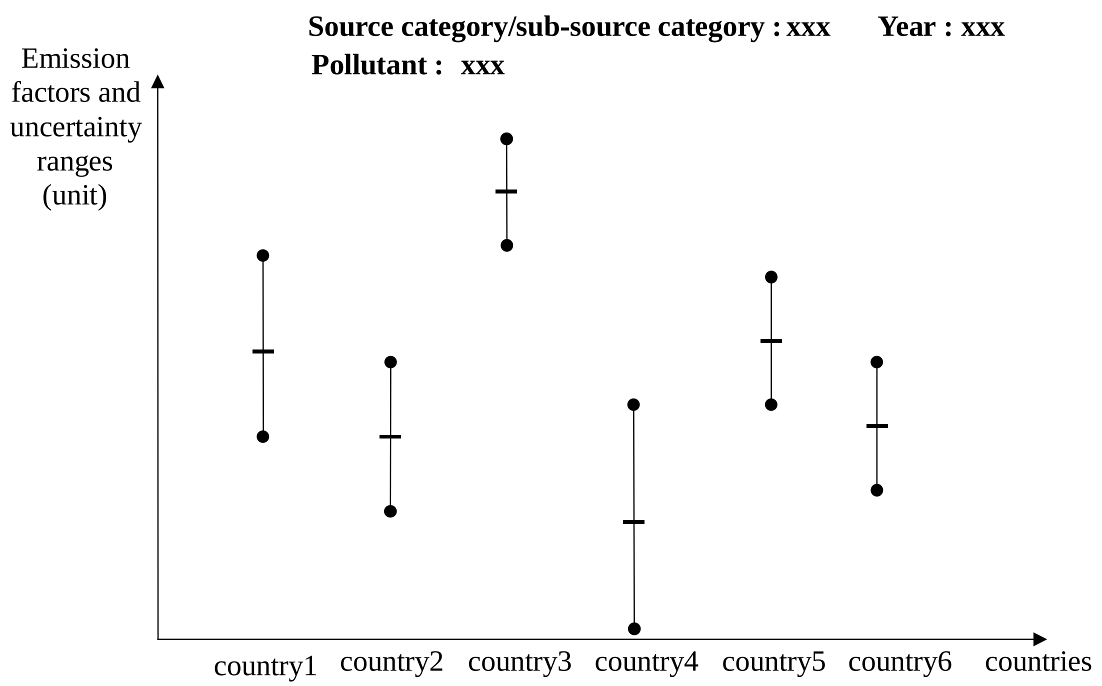
[2] More examples for energy indicators can be found in Schipper and Haas (1997) and Bossebeuf *et al.* (1997).

Figure A2.1 Illustrative Plot for an Inter-country Comparison of Emission Factors



N.B. : The E.F. range for a given country relates here to the minimum and maximum E.F. during the period 90-97.

Figure A2.2 Illustrative Plot for an Inter-country Comparison of Emission Factors and their Uncertainties



N.B. : The E.F. range for a given country relates here to the uncertainty range of the current E.F.

A2.1.2.2 COMPARISONS OF UNCERTAINTY ESTIMATES BETWEEN COUNTRIES

Chapter 6, Quantifying Uncertainties in Practice, describes how to estimate and report uncertainties. The uncertainty estimates developed for various source categories may be compared in several ways, including:

- Comparing the uncertainty estimates of various source categories and gases within a country's inventory;
- Comparing the uncertainty of a given gas for specific source categories between countries;
- Comparing the uncertainty estimates reported in the national inventory with those provided in related regional or other national inventories or other documents used for verification purposes.

Many factors influence the uncertainty estimates for different gases in different source categories and these are not expected to be identical. However, such comparisons may alert the inventory agency to possible areas for improvement.

A2.1.3 Comparisons with atmospheric measurements at local, regional and global scales

For some regions, emission source categories, or compounds, comparisons with atmospheric measurements may provide useful information on the validity of the emissions estimates in the context of overall atmospheric trends. Several options may be employed, including:

- *Local and Regional Atmospheric Sampling*: At a given site, background concentrations may be inferred from low concentration levels, and enhanced concentrations (plumes) from high concentration levels. Measurements can be performed at several fixed sites upwind and downwind thus allowing the comparison of measured concentrations with modelled concentrations. In terms of emission assessment, however, it is more appropriate to perform inverse modelling (i.e. estimate emissions from measured concentrations). As an example, markers (^{13}C) have been used to assess methane (CH_4) emissions (Levin *et al.*, 1999) in atmospheric sampling. Such methods are not limited to areas defined by national boundaries. Indeed, they are best suited to regions where emissions are concentrated in a small area. As industrial and population centres are frequently situated at both sides of a national boundary, an evaluation for just one country may not be possible because emissions can only be assessed for the whole area. In such cases, the methods are only useful at a bilateral or international level.
- *Continental Plumes*: A strong difference between source and non-source (sink) regions may generally be found between a continent and an ocean. Routine measurements may be performed close to an ocean, at offshore islands, or on ships. The difference between background air concentrations and the offshore plume concentrations, taking advantage of wind vector analysis or trajectory analysis, may provide an indication of emissions on a broad scale. For example, a number of greenhouse gases, including chlorofluorocarbons (CFCs), nitrous oxide (N_2O) and CH_4 from the European continental plume, have been detected at Mace Head, Ireland. These results have then been used for subsequent quantification of the European emission source strength by inverse modelling (Derwent *et al.*, 1998a, b; Vermeulen *et al.*, 1999).
- *Satellite Observations*: Satellite observations allow users to retrieve quasi-continuous concentration profiles for all or part of the globe.
- *Global Dynamic Approaches*: Trends over time in the atmospheric concentration of particular compounds may also indicate a change in the global balance between sources and sinks. This may be particularly useful where the background concentration of the gas in the atmosphere is low. Such approaches have been taken for CH_4 (Dlugokencky *et al.*, 1994) and SF_6 (Maiss and Brenninkmeijer, 1998).

These methods allow a large proportion of global emissions to be covered and monitoring is possible on a routine basis. However, it is almost impossible to trace emissions back to individual sources or source categories if their emissions do not contain some sort of 'fingerprint' that characterises them. This 'fingerprint' may be a specific type of carbon isotope in the case of CO_2 and CH_4 emissions from fossil fuels, or a typical temporal profile (seasonality or diurnal variation) or zonal variation (e.g. latitudinal distribution).

A2.1.4 Comparisons with international scientific publications, global or regional budgets and source trends

The international scientific literature may provide other estimates or analyses to compare with national inventory estimates. Comparison of these estimates with such literature is a valuable check on the quality of the official national inventory that can be used when comparing or integrating the greenhouse gas emissions of various countries.

Comparisons of national inventories with independently compiled global inventories and with global or regional emission levels included as part of a more comprehensive analysis are a means to update global budgets or provide feedback to national inventory developers or both. Provided that sufficient information is available on spatial and temporal distribution of the sources, including natural sources, it may be possible to trace the reasons for inconsistencies between different reports of emissions for major sources (Heimann, 1996, for CO_2; Janssen *et al*., 1999, and Subak, 1999, for CH_4; Bouwman and Taylor, 1996, for N_2O).

A2.2 PRACTICAL GUIDANCE FOR VERIFICATION OF EMISSIONS INVENTORIES

There is value in independent verification of individual national greenhouse gas inventories at the international level (e.g. inter-country comparisons). Such verification activities could serve the following purposes:

- Support the national verification activities;
- Improve efficiency by avoiding duplication of effort at the national level;
- Provide input to evaluation of the *IPCC Guidelines*;
- Inform the public, scientists and government reviewers.

A2.2.1 National inventories

If an independent verification is considered a valuable means for improving inventory estimates, it would be *good practice* to have the following:

- Availability of sufficient independent expertise;
- National inventory report;
- Uncertainty estimates and QA/QC documentation included in the report;
- Reports of existing national verifications.

It is also useful to identify gaps in the inventory prior to undertaking any verification process.

The list in Box A2.1, Verification of a National Inventory, summarises and ranks the tools in order of approximate ease of implementation. The best combination for a particular user will depend upon the available data, and resource constraints (e.g. funding, time, expertise).

BOX A2.1
VERIFICATION OF A NATIONAL INVENTORY

A. Checks:

- Check for discontinuities in emission trends from base year (usually 1990) to end year.

B. Comparisons of emissions and other such features:

- Compare the Reference Approach for CO_2 emissions from fuel combustion with other approaches.
- Compare inventory emissions estimates by source category and gas against independently compiled national estimates from international databases.
- Compare activity data against independently compiled estimates and perhaps activity data from countries with similar source categories and sectors.
- Compare (implied) emission factors for source categories and gases with independent estimates and estimates from countries with similar source categories and sectors.
- Compare sector intensity estimates of selected source categories with estimates from other countries with similar source categories and sectors. If necessary, calculate emission intensity estimates based on international statistical compendia.

C. Comparisons of uncertainties:

- Compare uncertainty estimates with those from reports of other countries and the IPCC default values.

D. On-site measurements:

- Perform direct source testing on *key source categories*, if possible.

Some of these activities may have been conducted as part of the QA/QC processes and results may be included in the inventory report. After the selected processes in Box A2.1 have been completed and issues to be reviewed in more detail have been identified, the following information may also support the verification processes:

- National reports;
- Additional tools such as scientific literature on emission factors;
- Results from atmospheric sampling relevant to *key source categories* and sectors.

Findings should be summarised and feedback sought from the inventory agency. Findings of the verification process should be made publicly available wherever possible.

A2.2.2 Aggregated global or regional inventories

There is also value in examining emissions inventory information between countries and as totals of groups of countries. Such evaluations could, for example, compare global or regional totals and trends against atmospheric concentrations and changes in concentrations. Comparison of global or regional totals of selected source categories against isotopic signature analysis may provide additional information. This type of verification may provide an indicative range for emissions estimates.

The explicit steps, and the data required, will be determined by the intent and scope of the verification effort and analysis. Discrepancies identified by verification processes on aggregate national inventories and comparisons with atmospheric concentrations may guide future priorities for research on national inventories and atmospheric science.

A2.3 REPORTING

For the verification process to be most useful, findings should be made publicly available.

The report should include the following items:

- What has been verified;
- How the verification was performed;
- What criteria were used for the selection of verification priorities;
- Limitations in the processes that have been identified;
- What feedback was received from external reviewers summarising key comments;
- Actions taken by the inventory agency as a result of the verification process;
- Recommendations for inventory improvements or research at an international level arising from the findings.

To facilitate use of the reports and wide dissemination, verification reports should use the common units recommended by the *IPCC Guidelines* and the official languages of the United Nations.

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