CHECKS AND VERIFICATION AT NATIONAL AND INTERNATIONAL LEVELS

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ABSTRACT

National inventories submitted under the UN Framework Convention on Climate Change are updated annually, i.e. the inventory for a new year is compiled and added and the emissions of the other inventory years are being revised when considered appropriate. Since this process requires the handling of much data and often many persons are involved, both in selecting representative emission factors as well data processing, errors and inconsistencies may easily slip in. This paper reviews the needs and possibilities for validation (checking) and verifying procedures, i.e., checking the internal consistency of the inventory and activities using external data to verify the emission estimates, respectively. Concrete options are reviewed that could typically be done at national level, by national teams, and options at the international level that comprise for example inter-country comparisons and comparisons with independently compiled datasets (global emission inventories and international statistics). The latter could most efficiently be done at international level by international bodies or by international co-operation of national experts. In this paper we will primarily focus on what individual countries can do. In addition, procedures, priority setting and reporting requirements of checks and verification activities at national level are discussed, as well as possible institutional arrangements for activities at international level.

1 INTRODUCTION

1.1 The inventory compilation process

Emission inventories may be compiled for a special purpose as a one-time activity. In order to monitor environmental progress, however, periodic updates of these inventories are needed. Under the Kyoto Protocol of the *United Nations Framework Convention on Climate Change* (UNFCCC) countries are required to submit an update of their greenhouse gas emission inventory to the Climate Change Secretariat annually. In year *t* the inventory should contain final figures for the years 1990 up to *t-2* inclusive and preliminary emissions for the year *t-1*. There is no need to re-submit final emission data for earlier years, unless these data have been changed (e.g. due to recalculations, re-allocations or addition of new sources). Any extension or update of existing inventories will build on the existing one: addition of a year, finalisation of preliminary previous year or possible adjustments of the so-called final historical years ('recalculation'). In addition to emission figures, the inventories prepared for the UNFCCC should also include information on the uncertainty estimate for the reported figures.

So, following the activities that take place annually, the annual inventory update process can be split into four parts, building on the existing historical inventory in place (including estimated uncertainties) which is the result of last year's activities, on a source-by-source basis:

- New additions to the emission inventory (new year[s], possibly new sources);
- Finalisation of last year's preliminary data;
- Adjustments to the existing inventory (e.g. recalculation) (if applicable), and
- (Re) evaluation of the estimated uncertainties.

It is this sequel of activities that also provides many opportunities for carrying out internal checks at various stages of the update process.

1.2 The need for checking and verification

Because of the many data and many institutions involved in the emission inventory compilation, as well as – ultimately – in the judgement of representativity of emission factors, small or large errors and inconsistencies (e.g. across sources or in time) may easily slip in. Therefore, checking and verification procedures are important and indispensable elements of the Quality Assurance/Quality Control (QA/QC) system of the inventory management (see Chapter 'QA/QC of inventory systems' in (IPCC, 2000)).

Checking is part of the validation of the inventory, which involves ensuring that the inventory has been compiled correctly, i.e., calculations have been done correctly and in line with guidelines and reporting instructions. Thus *validation* refers to *internal checks* of the consistency of the inventory. *Verification,* on the other hand, refers to activities using *external data* that help to establish the reliability for the intended applications of the inventory viz: external methods to check the truth of the inventory include comparisons with reference calculations, with estimates made by other bodies, with atmospheric concentrations or external review.

This paper aims at presenting concrete options for the internal checking and verifying national greenhouse gas inventories. For each of the components of the inventory process we will describe readily available techniques for performing quick basic checks on apparent errors (order-of-magnitude checks), completeness, consistency, and comparability. This paper will present the practical checks and verification procedures that we recommend to be taken. Using the instructions given, a system can be established for priority setting and for reporting the checks and verification activities performed and their results (see Section 5). In addition, we will discuss other, more elaborate methods of verifying the inventory on these aspects thoroughly, which are beyond the scope of inventory guidelines at this time.

2 DATA QUALITY OBJECTIVES

In order to provide confidence to the inventory system, the establishment of high quality data is indispensable. An inventory system becomes useful in the international context only if it can be proven to meet the objectives it has been devised for as defined in the 'data quality objectives'.

For national and international (UNFCCC) purposes of establishing credibility of the national inventories, the UNFCCC preparation guidelines describe the data quality to be achieved in terms of accuracy and the three c's: Completeness, Consistency and Comparability. *Accuracy* refers to emissions being calculated correctly and unbiased - as far as can be judged - and uncertainties being reduced as far as practicable. This calls for identification and correction of apparent errors in input and calculation (e.g. order-of-magnitude checks) and for efforts being made to reduce the largest uncertainties. *Completeness* means that all relevant sources are included in the inventory. *Consistency* means that per source category for all years the emissions are calculated with the same emission calculation methodology and for all years the same source definition (allocation) is used. *Comparability* means that the emission inventories are comparable across countries. This refers to both emissions and the estimated uncertainty. Emissions of two countries are called comparable if they use the same source definitions, similar emission calculation methodologies and similar emission factors in similar cases. Therefore, they can also be considered comparable if for major national sources the calculated aggregated ('implied') emission factors are well within the estimated uncertainty or if large deviations from others (a set of factors reported by a group of apparently 'similar' countries, or - if these are not available - IPCC defaults) are clarified and justified. In other words, verifying comparability requires checking for and documenting of observed seemingly deviating figures for (aggregated) emission factors.

From the description given above, it shows that for checking comparability it is required that emission data compiled at the international level are made available either by independent organisations or by the UNFCCC Secretariat. Individual countries can perform this type of verification, but also other organisations as well as individual scientists. In this paper we will primarily focus on what individual countries can do.

3 OVERVIEW OF OPTIONS ON THE NATIONAL SCALE

3.1 Approaches in relation to data quality objectives

A number of approaches have been identified for quality control of elements for which the UNFCCC has defined its objectives (EEA, 1997; Lim *et al*, 1999; Van Amstel *et al*., 1999) as follows:

- internal quality checks (comparison between years and inventory versions);
- inventory inter-comparisons (comparison with other independently compiled estimates, with national inventories of other but similar countries and with IPCC defaults);
- comparison of density indicators;
- verification by comparison with direct atmospheric concentration measurements;
- comparison with atmospheric budgets derived from atmospheric models, and
- direct source testing (on site measurement of large emission sources).

The degree to which countries check or independently verify the inventory varies between approaches – as does the capacity required to perform these activities. Therefore, we will distinguish between the more easy, less elaborate ones, referred to as 'checks' (either internal or using external data), and more complex, data intensive, time-consuming activities, referred to as 'verification'. For example, direct source testing is a means of ground truth verification, which however will often not be simple to perform. In addition, for practical reasons we will also distinguish between options using national data only and options which require the availability of international data. Based on the mentioned approaches, a number of options have been identified, which are described in more detail in separate sections, i.e. options for (a) checking and (b) verification using national data, and (c) use of international data.

3.2 Options for checking

In the context of the present paper, the checks at national level considered here relate to checks to be performed when the inventory is finished (as draft or final version). So compared to the QC processes, the same checking methods may be used. The differences arise from the fact that the QC processes include larger checks (for example data management system controls) and start from the beginning of the inventory preparation as described in the 'QA/QC of inventory System' chapter (Cross-Cutting Issues) of this publication. With respect to this matter, we can wonder whether these considered checks at national level are part of QC processes or not. A first reply could be 'yes', in the case that it is done by the national inventory team, but 'no', if it is performed by an external team or organisation. To illustrate the point, we can give the example of related practices with CORINAIR inventories. In case of CORINAIR inventories managed by the European Environment Agency (EEA), after national inventory checks, national individual checks are also performed by the ETC/AE (European Topic Centre on Air Emission) [now merged into: ETC on Air and Climate Change, ETC/ACC]. But it is time (and effort) consuming, especially when there are feedback processes and successive national reviews. Therefore the tendency is no longer to carry out the detailed individual checks ETC level, but to expect countries to perform the QA/QC processes.

There are a number of options to perform quick basic checks on new figures using the existing inventory which has already been quality assured:

- *Comparison of trends and comparison with previous reported data (emissions, but can also be applied to activity levels and emission factors):*

  Purpose: consistency and completeness check;

- *Checking for documentation and any methodological changes in the components of the inventory (activity data, emission factors, emission calculation methodology):*

  Purpose: consistency check; documenting and justifying data and methods used;

- *Order-of-magnitude checks (for example by comparison with IPCC Tier I calculations using IPCC default factors or by comparing an activity to a related one):*

  Purpose: quick indirect check for possible major calculation errors and inclusion of major sources;

- *Reference calculation, such as for CO_2 (based on apparent consumption):*

  Purpose: top-down versus bottom-up comparison to ensure completeness and right order-of-magnitude, in the case of an inventory based on a bottom-up approach, and

- *Checking estimated uncertainties.*

  Purpose: check the order-of-magnitude of the estimated uncertainty for possible errors in input or calculation and for apparent country-specific uncertainty levels in either activity data or emission factors.

3.2.1 Comparison of trends and previous reported data

A consistency and completeness check using the available historical inventory data for multiple years is based on the experience that the emission level of most sources does not abruptly change from year to year, due to gradual changes in both activity levels and emission factors, if any. In most circumstances, the change in emissions will be less than 10% per year. Thus percentage changes of emissions in year *t* compared with year *t-1* are a good indicator of possible input or calculation errors. An additional result of this basic consistency check is - except for correction of identified errors resulting in large differences - that it automatically identifies the areas in the inventory which call for a clarification if not justification.

In case of important emission changes between year t-1 and t, and especially in case of major emission contributing sources, further checks with trends from historical data can be performed respectively for activity rates and emission factors. For example, historical trend analysis on activity data can help the activity checks by comparing the historical activity trend up to the last inventory, with an expected activity trend, or with the trend of a related and correlated indicator. For emission factor trend checks, the historical emission factor for a given pollutant and sector, can be compared to an expected trend (for example from an external expert in the given sector) due to technology evolution or other reasons.

Another routine check that can be made with the newly finalised data for a year *t*, provided that the previous version of the inventory contains *preliminary* figures for that year *t*, is inspection of the difference between the final and the preliminary figures. The actual checking process is identical with the checking of differences between subsequent years, but it is qualitatively a different type of check, since it checks both the accuracy of the newly finalised data and utilises source-specific knowledge about the likely trend in it. Moreover, it provides a review of the quality of the estimation procedure for the reported 'preliminary emissions'.

Phase in compilation process and update types

Routine checks using the internal consistency of the inventory may be applied at three points in time in the inventory update process:

A. Draft sectoral inventories: per sector, per gas;

B. Final sectoral inventories: per sector, per gas, and

C. Final inventory: per gas, total inventory, main source sectors.

The term 'draft' or 'final' may apply to all parts of the update process:

1. Newly finalised emissions for year *t* (in previous version possibly labelled as 'preliminary'): comparison with previous year's emissions (i.e. in year *t-1*) *and* with the 'preliminary' emissions for year *t* in last year's version of the inventory (if available);
2. New preliminary emissions for a year *t+1*: comparison with previous year's emissions (i.e. year *t*), and
3. Revisions of older 'final' emissions: comparison both with previous year's emissions *and* with emissions in last year's version of the inventory.

Procedure for routine consistency checks

- Standard checks (see example below);
- Standard actions (log of check; correction of data or explanation of differences), and
- In case of corrections: re-apply standard checks for corrected sections.

After the calculation of differences, the largest percentage differences (in any direction) can be flagged, either by visual inspection of the list, or visual inspection of graphical presentation of differences (e.g. in a spreadsheet) or by using a dedicated software programme that puts flags and rankings to the list of differences. When dealing with very many sub-sources graphical presentation of differences is a very efficient tool to get an overview of the differences for all sources and to point out the sources with the largest differences. If all data are available electronically, these checks could be done for all sub-categories available without much additional effort. Possibly erroneous results could be flagged, for example, using a dedicated programme or screening the results.

Example of routine consistency check (applicable to any of the points A-C and update types 1-3):

Check annual increase/decrease of emissions per sub-sector available in the inventory, expressed as percentage [figures and percentages used to be evaluated by the individual country according to priorities and national experience]:

1. Check the 5 largest percentage differences for arithmetic errors

Check the reason for the difference and either correct or explain the differences; if differences are larger than 10% and appear to be correct, then justify the figures.

When explaining or justifying observed large differences, one should keep in mind that for more aggregate sectors less change is expected than for sub-sectors. For example, total emissions from petrol cars are not likely to change substantially on an annual basis, but emissions from sub-categories, such as catalyst-equipped petrol cars, may show substantial changes if their market share is not in equilibrium or average technology applied changes quickly.

2. In addition, check all cases with differences larger than 10% for arithmetic errors:

If considered important for the source category or the quality of the update process, one could extend the check to all cases that show differences of over 10%. However, here too, one should keep in mind that annual differences in minor sub-sectors may be larger than in higher aggregates.

Checking the reasons for the differences

Possible causes of major differences are:

1. Printing or arithmetic errors in statistical and emission factor data used:

To be checked by comparing with the values used for the previous year (data at this level can also be routinely checked by systematic comparison with the values used for the previous year as described for the resulting emissions). If these do not differ much, then the following checks should be made:

- Input errors (to be checked by comparing input data with the external source of the activity level and emission factor), and
- Arithmetic errors (to be checked by recalculation).

2. *Large discontinuities in calculation methodology or source definition:*

To be checked for if the first check on printing or arithmetic errors does not provide sufficient clarification of large annual changes:

- Substantial changes (discontinuity) in methodology for establishing the annual activity level for a specific category (to be checked with the agency that compiled the statistics), and
- Discontinuities due to a change of source definitions (may be related to methodological changes too). This may show up as a shift between two or more sub-categories, one increasing and other(s) decreasing, while the change in the total remains small. Examples: different inclusions of off-road vehicles, cogeneration (CHP), some 'miscellaneous' categories (to be checked by asking the people or organisation, which actually did the emission calculation, or the organisation that co-ordinates the overall inventory process for any changes of this nature).

3. *In case of comparison with preliminary figures: unexpected actual developments in the source:*

Differences can be caused by either a trend estimation methodology for preliminary figures that appears to be too simple to capture the real developments of the source or by unexpected developments in the past that the estimators were not aware of at the time when the preliminary estimate was made.

4. *In case of revisions of older 'final' emissions:*

Differences may be caused by any change in underlying activity data, emission factors or emission calculation methodology. *Good practice* is to report (a) for which gases and sectors figures are changed compared to last year's release of the inventory, (b) the size of the largest changes, (c) the cause of these changes, and (d) justification of the largest changes.

3.2.2 Checking for methodological changes

For reasons of transparency and consistency, any methodological changes in the components of the inventory compared to the last year's version, either in the existing final inventory or in the new or newly finalised sections, should be checked and reported as follows: activity data, emission factors, emission calculation methodology. Large changes in any of these should have been identified already in the previous checks of trends and of different versions. In addition, the organisations or people actually doing the sectoral emission calculations should be asked to document and justify any change in data and methods used. In particular, when source definitions have been changed it should be checked that neither overlap nor gap has been created (for example check of proper co-ordination between the sector groups).

3.2.3 Order-of-magnitude checks

This type of quick check for possible major calculation errors and inclusion of major sources is particularly valuable if the emissions have been calculated as the sum of many individual sub-sources (e.g. many point sources in industry and energy sectors or many sub-categories of road transport). Comparison of emissions with a top-down approach for example IPCC Tier I calculations using national total statistics as activity data and IPCC default factors is essential. For an example of this comparison for the UK inventory see Salway (1998). In case of major discrepancies between the emissions, as a further check the underlying sum of activities or the weighted average emission factors can be compared. In some cases another basic check is to compare the emissions with a country of seemingly similar characteristics and size (cf. options involving international data, item 3.4 and 4.1.1).

Comparing the activity of one type to another is a further type of order-of-magnitude check that can be made. Examples are: calculation of average annual fuel consumption per car by dividing total fuel consumption of road transport by the number of cars, dividing total production of animal manure by the total number of livestock, total amount of waste produced by the number inhabitants. If these do not relate to sensible figures per car, per animal or per person, then this is an indication of an input or calculation error.

3.2.4 Reference calculations

In a number of cases where emissions are calculated as the sum of sectoral activities based on consumption of a specific commodity, for example fuels or products like HFCs, PFCs or SF_6, emissions could alternatively be estimated using apparent consumption figures: national total production + import - export ± stock changes. For 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)* . Furthermore, in cases where the inventory is based on a bottom-up approach, a top-down versus bottom-up comparison of activity data is an efficient check of completeness and order-of-magnitude of this part of the inventory.

3.2.5 Checking estimated uncertainties

Irrespective of the Tier used for estimating uncertainty in reported emissions, it is *Good Practice* to compare the quantitative national results for the main source categories with the order of magnitude uncertainty indicator resulting from using the IPCC Tier I default uncertainties (as provided in the *Good Practice Guidance* report (IPCC, 2000) for specific sectoral emissions).

If the results per main sector or for the country total are very different, a calculation or input error could have occurred in estimating the sectoral uncertainty per gas or the national total per gas. In such cases, it is recommended to check whether country-specific uncertainties in key parts of the inventory are indeed very different from the IPCC defaults for Tier I. If that is the case, it is *Good Practice* to document the references for the uncertainties used as input for the calculation of these sectoral uncertainties as well. If inspection shows that the country-specific uncertainties in key parts of the inventory are not quite different, then it is *Good Practice* to do a check on inputs and calculations.

3.3 Options for verification at national level

In some countries there may be more institutions estimating greenhouse gas emissions. It is then feasible to produce complete or partial inventories that have been compiled independently, with their own choice of data sources and methodologies. Comparison of the official national inventory with these independently compiled estimates provides a quick check for apparent errors such as lack of completeness and incorrect source allocation. More elaborate options at the national level take advantage of data that is independently collected. Such data can be derived from actual measurements. Climate change gases generally are characterised by a long half-life in the atmosphere. As a consequence, their typical atmospheric concentrations are relatively stable. Increments due to sources thus are relatively small compared to background concentration. The challenge in identifying the contribution of a source or source area is to identify a minute increase over a stable baseline. In order to assess the maximum increase possible, one may wish to obtain the possibly strongest signal, which is obviously very close to a source: *Direct source testing* involves local measurement of key parameters as a means of ground truth verification of key sources. *Comparison with atmospheric measurements* at national scale serves as independent, ground truth verification of annual emission levels and, possibly, emission trends. Other options for verification are *comparisons with estimates published in scientific literature*, based on a review of the nationally available literature. Also publications analysing the quality of the official national inventory may be used in this respect.

3.3.1 Comparison with other national data

Comparisons with other, independently compiled, national emissions data for the country are a quick option to verify completeness, approximate emission level and correct source allocation – if such an independent inventory is available. It can be made per compound at national, sectoral and sub-sectoral level, as far as the differences in definitions/sectoral nomenclatures enable it. Procedures to be taken resemble those of comparisons with international data. In this respect see Section 3.4 for more details.

3.3.2 Direct source testing

The following approaches for direct source testing have been used previously:

- *On-line stack measurements:*

Currently, many major power plants are equipped with routine monitoring equipment for CO_2 measurements. While this instrumentation helps maintain combustion conditions, usually the C content of fuels is considered a more reliable indicator for CO_2 emissions.

- *In-plume measurements*

The in-plume freight of a constituent may be estimated from its concentration in a cross section and the transport velocity. Emission estimates of this kind have been made to assess volcanic CO_2 emissions (Allard *et al*., 1991) or conventional pollutants in city plumes (Klemm and Ziomas, 1998), which however already include a multitude of single sources.

- *Remote measurements*

Open-path FTIR spectroscopy has been successfully shown to assess SF_6 (Hashmonay *et al.,* 1999) and NH_3 emissions of diffuse area sources, but it also has a high potential for CO_2, CH_4, N_2O and other gases (Schäfer *et al*., 1999). Results are obtained with the help of inverse dispersion modelling to reconstruct emissions from concentration measurements.

- *Indirect methods*

Using a tracer (or adding a tracer to the plume of a stack) allows the identification of even small amounts of a compound, once the ratio between the compound and the tracer is known and there is sufficient reason to believe that they behave identically during atmospheric transport. This method has been applied in identifying SO_2 emissions from power plants by adding deuterated methane as tracer (Malm *et al*., 1990).

All these approaches allow the direct attribution of observed concentrations of the emissions from a certain source. However, they do not allow for a complete coverage of a country, as normally only a small part of the emission sources of a country can actually be measured. Especially assessment of area emissions is very laborious and costly, and in practice will only be done to obtain emission factors – maybe with the exception of rare and single sources as volcanoes. In cases when it is unsure if general emission factors may be applied to a certain country, measurements of this kind are advisable. In direct source testing, uncertainty of measurements (including the associated steps for emission calculation, like model uncertainties) are considered to be as low or lower than the uncertainty in the emission inventory. Therefore results may be used to reduce total inventory uncertainty.

3.3.3 Comparisons with atmospheric measurements

The processes between emissions and ambient concentrations are complex even for climate change gases, which do not easily undergo conversion processes. Still at a given site, background concentrations may be assessed from the low concentration levels, and enhanced concentrations (plumes) from high levels. Under certain circumstances, emissions may be considered proportional already to the difference between such low and high levels. Nevertheless, the use of an atmospheric model should be advised in order to adjust for the dilution and deposition processes, and also to cover transport direction. Measurements are to be performed on one or several fixed sites. One option is to compare measured concentrations with modelled concentrations. In terms of emission assessment, it seems more appropriate however to perform inverse modelling, i.e. estimate emissions from measured concentrations.

Clearly, in comparison to the direct source, testing the signal-to-background ratio may prove to be an even stronger challenge. This may be overcome for climate change gases that do not have so high background concentrations (SF_6, CFCs), or by using markers within compounds, which differ strongly from the background. Such markers can be stable isotopes, which occur in different abundance in the background and in the emission source. These markers (^{13}C) have been used for assessing CH_4 emissions (Levin *et al*., 1999). Theoretically, also application on ^{15}N (in N_2O) is possible, as has been shown for NH_3 (Bruckner *et al*., 1996). As for example, the abundance of ^{13}C is not only different between background and emissions, but also between different emission sources, conclusions may be drawn on the relative contribution of each such source to the total.

The applicability of such methods obviously is not limited to areas defined by national boundaries, but rather to areas that are characterised by elevated source strength, since it is only possible to differentiate areas of differing emissions strengths. As industrial and population centres are frequently situated at both sides of a national boundary, however, an evaluation for just one country is not possible because emissions can only be assessed for the whole area. In such a case, the methods become valuable only on a bilateral or international level.

In practice, due to the limitations, uncertainty associated with measurements and inverse modelling may become rather high, and a careful evaluation of the measurement/model system uncertainty with respect to the inventory uncertainty becomes essential (see Chapter 'Quantifying uncertainties in practice' in IPCC (2000)). For performing a significance test, the following results are possible:

- Measurement/model results are significantly different from the inventory
  → Falsification of the inventory; sources are missing, inadequate emission factors or statistics used, calculation error.
- Measurement and inventory do not differ significantly; uncertainty of measurement is lower than uncertainty of inventory.
  → Measurement results may be used to reduce inventory uncertainty.
- Measurements and inventory do not differ significantly, uncertainty of measurement is higher than uncertainty of inventory.
  → Measurement results are not useful in terms of the inventory, except that it confirms previous assumptions on completeness and lack of errors.

3.3.4 Comparison with scientific publications and external review

Although the government is responsible for the compilation and submission of the national greenhouse gas inventory, there may be other independent publications on the same subject, for example in scientific literature. This provides another option for comparison with other national estimates. Also publications analysing the quality of the official national inventory may be used in this respect. While scientists are basically limited to the methods described above, other results may be already available. In practice, such a comparison implies reviewing the nationally available literature and compare data on paper. The review report should document the results of the comparison and be included in the report on QC activities performed.

In addition, external review of the national inventory, either peer review commissioned by the compilation agency or public review encouraged by the agency, is an opportunity to compare methods and data used by the inventory preparation agency with the judgement of scientific experts or stakeholders and others with specific knowledge in this field.

3.4 Options for verification involving international data

There are several different comparisons that can be performed using international data:

- *Comparison of emission density indicators with similar countries* (for example emissions per capita; industrial emissions per unit value added; transport emissions per car; emissions from power generation per kWh of electricity produced by fuel type (coal, oil, gas) (excluding cogeneration), etc.):
  Purpose: quick indirect check and verification;
- *Performing comparisons of emissions with other estimates*: with independently compiled authoritative estimates (international datasets e.g. from IEA, CDIAC, GEIA/EDGAR or WRI):
  Purpose: checking completeness, consistency, correct source allocation, order-of-magnitude;
- *Comparisons of emission factors:*
  - with IPCC defaults;
  - with literature values;
  - with those used by similar countries, and
  - with the set of implied factors reported to UNFCCC (as proposed in the 'Common Reporting Format', CRF):

  Purpose: checking comparability and country-specificity;
- *Comparisons of activity data:*
  - with independently compiled estimates (IEA, UN, FAO), and

- with activity density indicators from similar countries (for example activity rate per inhabitant, per employee, per unit of GDP, per number of households or per number of vehicles, etc., according to the source sectors):

  Purpose: checking completeness; order-of-magnitude check;

- *Comparisons of uncertainty estimates of data reported to UNFCCC:*

  Purpose: checking order of magnitude of own uncertainty estimates against others.

It will be clear that for a given source, different parallel comparisons can be performed:

- Comparisons with other independently compiled emissions data for the specific country: checking completeness, magnitude, and proper source allocation, and
- Inter-country comparisons: for a specific year, the comparison of background data (activity levels, aggregated emission factors or other factors used in the methodology) from different countries.

The first kind of *comparison with other estimates* for the country under investigation is a quick check for completeness, approximate emission level and correct source allocation. It can be made per compound at national, sectoral and sub-sectoral level, to the extent that is allowable taking into account the differences in definitions/sectoral nomenclatures. In Section 4.1.1 examples of reference databases are presented. Existence of large discrepancies does not necessarily mean that one or both inventories contain flaws, but rather points to possible inadvertent errors, which are also aspects of uncertainty within inventories that can only be evaluated using this method. In those cases, one may wish to do a further check on activity levels or emission factors in that sector. In case of large differences for sub-sectors, one should also be aware that in either inventory the sum of the sub-sources might well be comparable by hiding shifts of part of the emissions between these sectors. Comparison with reference inventories developed by other authoritative sources is also a check of the comparability, when the reference inventory uses a common methodology for all countries. If inventory preparers have calculated national emissions using the Tier I methodologies of *IPCC Guidelines* (IPCC, 1997), then comparing emissions automatically means also a check against the default emission factors recommended by IPCC - if activity levels used in the reference dataset are similar to national data.

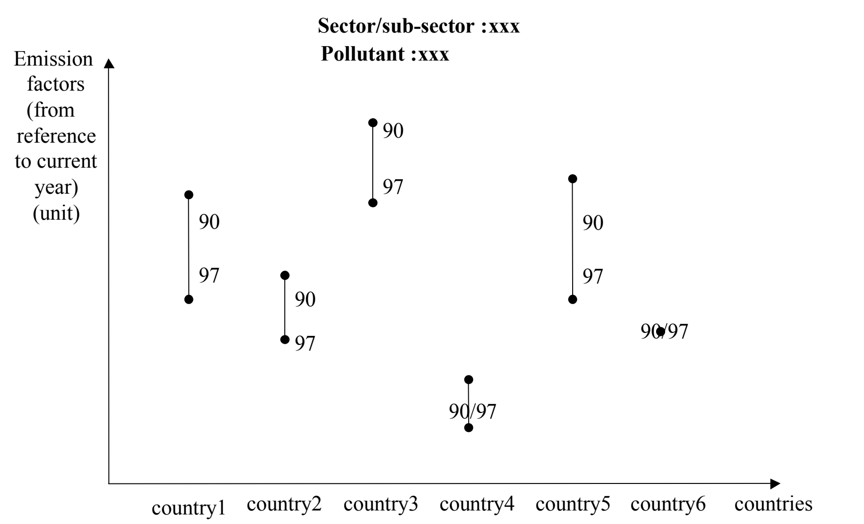
Concerning the latter kind of *inter-country comparison* of emissions, emission density, reported or background emission factors, activity or activity density: such checks can be based on reported results from international checks (cf. options on the international scale, item 4.1.1) but with a delay in time, or based on national initiatives to get/calculate such data/density indicators for the more recent inventoried year as well as for other countries. The inter-country comparison of reported aggregated emission factors could be combined by plotting in a single graph: for the different countries, the reference year data (1990), the more recent year data, and the minimum and maximum value, for each source sector and possible aggregations and according to the fuel types when relevant (see Figure 1). The comparison of data is relevant if the data are comparable. Consistency checks of trends in emission factors at national level and cross-country comparisons of emission factors can be processed as far as units are fixed (there are a few exceptions). These can be based on the sectoral background tables of the ‘Common Reporting Format’ (CRF) trend. Thus, comparisons of (aggregated) emission factors can be made with the set of implied factors reported to UNFCCC (as proposed in the ‘Common Reporting Format’, CRF). If some national emission factors appear to be outliers, further comparison could be made by checking with those used by similar countries. Furthermore comparison with the recommended IPCC Tier I default values and with literature values may be informative in establishing the comparability or the country-specificity of the emission factors used.

Concerning checking of *activity rates*, on the basis of the CRF, common comparable indicators should be defined for the purpose of international comparison (for example, activity rate per inhabitant, per employee, per unit of GDP, per number of households or per number of vehicles, etc., according to the source sectors). This will enable order-of-magnitude checks as well as checks for outliers that may be caused by input or calculation errors. Comparing with international statistics for national countries, which were in principle independently compiled from the greenhouse gas inventory preparation agency, can make a similar check.

Countries have to submit *uncertainty estimates* by source or sink categories for each compound given. An international comparison of the figures submitted could be performed on the basis of relative uncertainties (as percentage). For this purpose the following steps could be taken next:

1. Check the uncertainty given by the individual country for each category/compound combination. Values which have an unusually low uncertainty associated with their emissions should be checked individually for consistency of their reporting;
2. Check/calculate total uncertainty of a country for a given compound, and
3. Check consistency of given number/uncertainty with verification measurement/uncertainty.

Figure 1 Example: Graph 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

These comparison processes do not always represent verifications of the data themselves, but verification of the reliability and the consistency of data (in trend and across countries). Practically, these comparison processes will enable reviewers to focus on more limited cases of inconsistencies or doubts for which deeper data verifications will need to be performed. Obviously, the amount of time to be spent on these independent validation and verification activities should be prioritised (see Section 5).

More examples of emission comparisons are given in the Annex.

4 OVERVIEW OF OPTIONS ON THE INTERNATIONAL SCALE

UN bodies, governments, individual scientists, scientific research programmes, NGO's may show interest in scientific peer review or public review of national inventories by analysing and comparing various data sources (official national inventories, other estimates, information available from the UNFCCC Secretariat, etc.). In addition, both IPCC WG I and the IPCC TSU on National Greenhouse Gas Inventories will be encouraging these activities from the perspective of improving current knowledge on global budgets, source strengths and representative default emission factors. The following approaches can be identified: (a) international comparisons, (b) comparisons with scientific publications, (c) evaluation of budgets and source strengths, (d) updating IPCC reports. Each of these will be described below in more detail.

Comparisons of emissions cannot be interpreted without some quantitative knowledge of the associated uncertainty. As the art of estimating country emissions and their associated uncertainty is at different levels of sophistication in different countries, the Good Practice Guidelines recommend a Tiered Approach aiming at quantified uncertainty estimates (see Chapter 'Quantifying uncertainties in practice' in IPCC (2000)). Tier I is a simplified method for calculating a quantitative *indication of the uncertainty* in the total national emissions by means of classical arithmetic methods of combining uncertainties (assuming standard, Gaussian distributions, independent variables and uncertainties smaller than 60%). Subsequent Tiers use more detailed, data-intensive methods for the uncertainty estimates. However, for performing a Tier I calculation of indicator of uncertainty one also needs an estimate of the uncertainty in all underlying activity data and emission factors. It requires at least expert-judgement of the uncertainty as order of magnitude (see Table 1), except for cases where better information is readily available (for example selected from a range as described in the Chapter 'Quantifying uncertainties in practice' in IPCC (2000)).

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TABLE 1 EXAMPLE OF A CLASSIFICATION OF UNCERTAINTIES				
Range(±)	**Uncertainty (±%)**	**Uncertainty Factor***	**Confidence**	**Qualitative description**
2-10%	5%	1.05	High	very small
5-20%	10%	1.1	High	small
10-50%	25%	1.25	Medium (High)	medium
20-100%	50%	1.5	Medium (Low)	large
50-150%	100%	2.	Low	very large
100-400%	200%	3.	Low	extremely large
* An uncertainty factor UF corresponds with the following range around the emissions level EM: from EM/UF to EM*UF.				

For greenhouse gases one could seek guidance from the qualifications and values already used in UNFCCC submissions, e.g. as reported in FCCC/SBSTA/1998/7, Table 14 (p. 36-37).

This will provide a means for generating quantitative uncertainty figures for many countries in the short term. This facilitates cross-country comparison of uncertainty estimates. In addition, it will allow reported levels of uncertainty to be evaluated in a more comprehensive way in assessments of uncertainties in a broader context, for example in regional or sectoral comparisons and in 'chain calculations' from emissions to climate change, which address uncertainty in all elements of the chain in a harmonised way, for example through the use of uncertainty factors.

Examples of applications in which uncertainty estimates are an essential element are:

- cross-country comparison for all countries where inventories are available (for checking comparability, inadvertent errors or identifying highly deviating emission factors and/or apparent country-specific circumstances);
- providing uncertainty estimates for world regions (e.g. Annex I countries to the UNFCCC);
- providing (by extrapolation, if required) uncertainty estimates for the world;
- providing insight in the robustness of reported multi-year emission trends;
- comparison with reference inventories developed by other authoritative sources (for checking completeness, consistency, correct source allocation, and for inadvertent errors, which are also aspects of uncertainty within inventories that can only be evaluated using this method), and
- comparison with independent top-down estimates by reverse modelling of atmospheric concentration measurements (for checking for possible biases in country totals or global or regional sectoral totals).

4.1 International comparisons

Comparison of national greenhouse gas inventories with international data sources can be a means to independently verify the reported figures, in particular with respect to comparability and possible group bias. In addition to the activities described in Section 3.4, which are done from the perspective of a specific country, we also do a more systematic comparison for a larger group of countries and draw conclusions at another level. Here we can distinguish between comparison with other, but independently compiled, *bottom-up* emission estimates and comparison with emissions based on *top-down* estimates from atmospheric concentration measurements.

4.1.1 Comparisons with emissions, emission factors or activity data

Typically, the comparisons are similar to those already introduced in Section 3.4:

- Reference calculation for CO_2 (based on international energy statistics, cf. Section 3.2.4);
- Comparisons of emissions with independently compiled estimates (global emission inventories);

- Comparisons of emission factors (outlier detection in implied factors reported to UNFCCC);
- Comparison of emission density indicators (as a quick indirect check/verification), and
- Comparisons of activity data (including activity density indicators).

Compared to the Section 3.4 (options at national scale), there is an important constraint to focus on, which is the necessity for harmonised reported inventory datasets (Lim and Boileau, 1999). The different detailed cross-country comparisons (of sectoral/sub-sectoral emission factors or activities) assume that such detailed harmonised reported inventories at international level are available.

Comparison of national emission inventories with independently compiled authoritative international datasets will assist in checking completeness, consistency, correct source allocation and magnitude of both inventories - national and international. Such global databases currently exist, for example on CO_2 from fossil fuel combustion only compiled by International Energy Agency (IEA) and by the Carbon Doixide Information and Analysis Centre (CDIAC), global total anthropogenic inventories of all greenhouse gases of the Global Emission Inventory Activity (GEIA, a component of IGAC/IGBP) and of the Emission Database for Global Atmospheric Research (EDGAR) compiled by TNO and RIVM in close co-operation with GEIA, or datasets compiled by the World Resources Institute (WRI) (IEA, 1998; Marland *et al.,* 1994; Graedel *et al.,* 1993; Olivier *et al*., 1999). Emissions of a group of countries (e.g. Annex I, that is OECD countries and Economies in Transition in Central and Eastern Europe) can be compared with regional totals of global inventories that were validated against global, regional and zonal budgets. In particular when emission estimates differ substantially, the emission factors used could be compared, in more detail, with the defaults that the *IPCC Guidelines* recommend. From these evaluations conclusions can be drawn regarding comparability, applicability of defaults and country-specificity. The same type of comparison as described for emissions can be done with the underlying activity data in order to check completeness and as an order-of-magnitude check: these can be compared with *de facto* independently compiled international statistics (e.g. maintained by IEA, UN, FAO, AFEAS). One should, however, not always expect to find exact matches since the activity data used by the inventory compilation team may be taken from different data source or different versions of it. This version will be different from the original national data collected by these international organisations. For examples see Schipper *et al.* (1992).

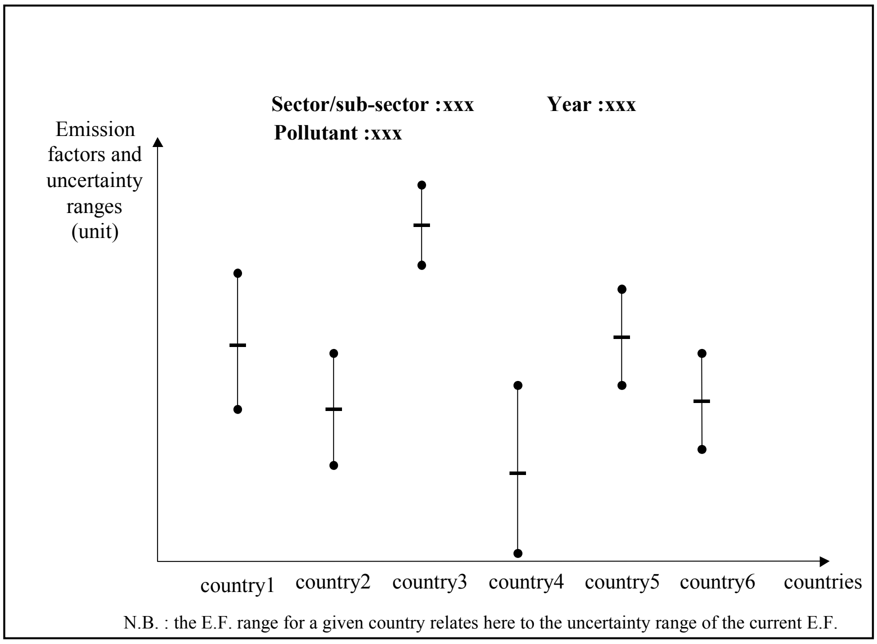
However, when evaluating the results of these comparisons, it should be remembered that various data sources are not always completely independent of each other. For example, EDGAR starts with IEA energy data to calculate CO_2 emissions from fuel combustion and CDIAC/GEIA start with UN energy data. In 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 have established a co-operation in data exchange, and receive common questionnaires for some countries. Nevertheless, there are still differences in the data released by the two organisations due, *inter alia,* to sources of data, methodology, revision in historical series, geographical coverage, etc.

Comparison of emission density indicators, such as emissions per capita, industrial emissions per unit of value added, transport emissions per car, emissions from power generation per kWh of electricity produced etc., provides a quick indirect check and verification of the order of magnitude of the emissions. Of course, the correlation between emissions and an independent variable does not necessarily imply cause and effect. However, it is an easy means to flag certain anomalies at country or sector level, if any. More examples for energy indicators can be found in Schipper and Haas (1997) and Bossebeuf *et al.* (1997).

The cross-country comparison of data is relevant if the data are comparable. For the emission factor comparison, that can be possible on the basis of the sectoral background tables of the ‘Common Reporting Format’ (CRF). The emission factors comparisons can be performed at different aggregation level as far as emission factors have to be reported at different level within the ‘Common Reporting Format’. Of course, cross-country comparisons of emission factors can be processed as far as emission factor units are fixed, or unit conversion ratios are available.

From practical aspects, different kinds of comparison could be combined: for example, cross-country emission factor comparison can be combined with historical trend by plotting in a single graph, for the different countries, the reference year data (1990), the more recent year data, and the minimum and maximum value, for each source sector and possible aggregations and according to the fuel types when relevant (see Figure 2). Another practical example of combined emission factor comparison is the combination with estimated uncertainties when available. In this case, one could plot a single graph for the different countries, the current year emission factor and the related uncertainty range, for a given source sector and according to the fuel types that are relevant. This combined comparison including uncertainties is quite important as far as emission factor discrepancies analysis and checks require complementary information on uncertainty, to be more relevant (Figure 2). Thus, from the comparisons of the implied emission factors reported to UNFCCC (as proposed in the ‘Common Reporting Format’, CRF), if some national emission factors appear to be outliers, further comparison could be made by checking with those used by apparently similar countries. Furthermore, comparison with the recommended IPCC Tier I default values and with literature values may be informative in establishing the comparability or the country-specificity of the emission factors used.

Figure 2 Example: Graph for an inter-country comparison of emission factor uncertainties



As for emission factors, the cross-country comparison of activities requires a harmonised reporting format as the 'Common Reporting Format'. But due to country 'volume' effect, apparent activity discrepancies from such crude comparisons, are not really significant. So on the basis of the CRF and the basis of common comparable indicators to be chosen, activity density indicators can 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, etc., according to the source sectors).

The different levels of comparison will also assist in evaluating the estimated uncertainty estimates of national inventories as well as of global emission inventories, especially by checking for any group bias and by the size of the existing differences at country level.

4.1.2 Comparisons with atmospheric measurements at regional and global scale

Evidently, methods for national and international scale do not differ by definition. Comparisons which are useful on the national scale may also be applied internationally (see Section 3 for details). The difference is that at this scale there are increasing possibilities to concentrate on source regions rather than borderline dependent areas. Methods that are otherwise only valid in large countries may safely be applied here. Additional options become available on the international scale:

- *Continental plume*

  A strong difference between source and non-source (sink) regions may generally be found between continent and sea. Routine measurements may be performed close to an ocean, at offshore islands, or on ships. In evaluation one may consider the difference between clean background air and the polluted plume, taking advantage of wind sector analysis or trajectory analysis. In European continental plume a number of greenhouse gases, including CFCs, N_2O and CH_4, has been detected at Mace Head, Ireland. The results have been used for subsequent quantification of the European emission source strength (Derwent *et al.*, 1998a,b; Vermeulen *et al.*, 1999). For quantification, an inverse modelling procedure is performed.

- *Satellite observation*

  Satellite observations allow retrieving a quasi-continuous concentration profile for all of the globe. The method is still in its infancy, even if specific instruments have already been designed to collect data on climate change gases. A sensor currently active is GOME, which has been validated recently to detect total columns of O_3, NO_2, BrO, HCHO and OClO (Goede *et al.*, 2000). In the near future, SCIAMACHY will be launching a passive spectrometer observing absorption in UV, visible and NIR spectral ranges. It will be able to yield concentrations of O_3, NO_2, N_2O, CO, CO_2, CH_4 both in the troposphere and stratosphere. Maximum horizontal resolution will be 30 km x 60 km. Thus it seems reasonable to assume that plumes may be detected at different scales.

- *Global dynamic approaches*

  Concentration trends of compounds also indicate the result of a discrepancy between sources and sinks. From such trends, conclusions on either of these two may be drawn, once the other is considered fixed. Such approaches have been taken for methane (Dlugokencky *et al*., 1994) and SF_6 (Maiss and Brenninkmeijer, 1998).

The obvious advantage of the methods discussed above is that a large share of global emissions is covered, and monitoring is possible on a routine basis. However, it is almost impossible to trace back to individual sources or source sectors, if their emissions do not contain some sort of 'fingerprint'. This may be a specific type of carbon isotope in case of CO_2 and CH_4 emissions from fossil fuels, or typical temporal profile (seasonality or diurnal variation) or zonal variation (for example, latitudinal distribution), that enables us to distinguish them from other sources.

4.1.3 Comparisons of uncertainty estimates of data reported to UNFCCC

The reporting format for uncertainty estimates has been described in the Chapter 'Quantifying uncertainties in practice' in IPCC (2000). Countries will submit uncertainty estimates by source or sink categories for each compound given. An international comparison of the figures submitted may be performed on the basis of relative uncertainties (as percentage).

The next steps to be taken are as follows:

- Check for each category/compound combination the uncertainty given by the individual country. Values with unusual low uncertainty associated with their emissions should be checked individually for consistency of their reporting;
- Check/calculate total uncertainty of a country for a given compound, and
- Check consistency of given number/uncertainty with verification measurement/uncertainty.

4.2 Scientific publications

In the scientific literature, there may be publications providing other estimates of national emissions or publications in which the quality of the official national inventory is analysed. Comparison of these different national estimates and the results of those analyses are important elements of a critical check of the quality of the official national inventory, which can be used when comparing or integrating the greenhouse gas emissions of various countries.

4.3 Evaluation of global or regional budgets and source strengths

Confronting summed official inventories with global inventories and with global or regional emission levels established as part of a total budget analysis is a means either to update global budgets or to provide feedback to national inventory developers and IPCC TSU on Inventories on apparent biases. Provided that sufficient information is available on spatial and temporal distribution of the sources, including the natural ones, one may be able to draw conclusions on the likely biases in specific major sources, if these have specific own spatial or temporal characteristics, that helps distinguishing them form others (Heimann, 1996, for CO_2; Janssen *et al*., 1999, for CH_4; Bouwman and Taylor, 1996, for N_2O). This type of evaluation is the ultimate verification of bottom-up compiled emission estimates since at the global level all emissions are part of a big chain of material flows from sources to sinks.

4.4 Updating IPCC reports

Comparison of emission factors submitted by countries and the methodologies used with defaults recommended by the current *IPCC Guidelines* and comparison of reported emissions with figures currently used in the scientific literature could also provide important input to revisions of the following sections of IPCC reports:

- Evaluation and updating of defaults methods and emission factors recommended in the *IPCC Guidelines* (IPCC, 1996) (for example by comparing sets of nationally applied emission factors with recommended IPCC default values), and
- Evaluation of global or regional budgets compiled by IPCC Working Group I (WG I), as discussed and published by the scientific community (IPCC, 2001).

5 WORKING PROCEDURES, PRIORITISATION AND REPORTING FORMAT AT THE NATIONAL LEVEL

5.1 Phases and prioritised national approach

This paper describes many concrete options for checks and verification, some of which are very easy to carry out, others are costly and difficult to implement:

- Immediately available procedures (efficient ones for quick checks; priorities for checking and verifying both large and fast changing components) using national data only;
- Procedures using available international data, and
- Procedures to be developed (more elaborated verification, for example direct source testing or comparison with atmospheric concentration measurements).

Thus, there is a clear need for guidelines to decide how much time and money should be devoted to checking and verification versus the effort to be put in the basic compilation process (data gathering, calculations, recalculations, uncertainty estimates, reporting).

Evidently, a number of key basic checks should be routinely incorporated at the appropriate stage in the compilation process. For more guidelines on the procedure, we refer to the Chapter 'QA/QC of inventory systems' in IPCC (2000). Here we point out, that the detailed level of checks and verification will be laid out in the QA/QC plan. Those checks will be important on the performance of those sources that apparently contribute substantially to the national emission control programme. In other words, it is recommended that the monitoring of actual emissions as described in the national inventory will be checked for its credibility. Checks involving international data may be applied in more detail for a one-time verification of the inventory; in subsequent years there will be no need for an extensive check of this kind, except for special sector-gas combinations that have at that time particular importance for the country.

For the more elaborate verification activities based on atmospheric concentration measurements, a semi-continuous and internationally co-ordinated research programme 'at the background' is recommended, aiming at verification at national and international scale. Besides tests of aggregation to the global level and comparison with alternatively established budgets, this is the only really independent method for verifying emissions and checking for major systematic biases. Direct source testing should be carried out as part of an overall programme of reducing uncertainties in the total greenhouse gas inventory. Priority setting will be a function of costs, time, and share in total and sector emissions, both in CO_2-eq. and per gas.

5.2 Defining the national procedures on checks and verification

The inventory update programme has different components, each of which will require different types of checks:

- Existing historical inventory in place;
- New additions to the inventory (new years, possibly new sources to be applied also to previous years);
- Finalisation of preliminary data;
- Adjustments to the existing inventory (including recalculation of the historical inventory, and
- Conclusions for prioritising future activities (short term and longer term).

In order to minimise the required resources, quality checks and verifications should solely be applied where they have not been used previously, i.e. mostly to new data. If the existing historical inventory is left as is, no further checks (or QA/QC programme) are required to confirm this component of the inventory. Thus, apart from a one-time thorough checking of the existing historical inventory, the system would require the following activities to be performed:

1. Comparison of trends and previous reported data (see Section 3.2.1);
2. Checking for methodological changes (see Section 3.2.2);
3. Order-of-magnitude checks (see Section 3.2.3);
4. Reference calculations (see Section 3.2.4);
5. Scientific publications or external review (if available: see Section 3.3.4), and
6. Setting priorities for future inventory improvement, including re-evaluation of uncertainties if necessary (based on results of activities above; see Section 5.1).

As a separate item, verification activities should be performed, focussing either on large sources or on sources with a large uncertainty as follows:

1. Comparisons of indicators;
2. Comparisons with other independent estimates, and
3. Comparison with atmospheric concentration measurements.

Priority setting may be (a) to apply the first two methods for the initial inventory (and to updates for confirmation of trends), and (b) to apply the third method periodically for ground truth verification of absolute emission levels and emission trends.

5.3 Reporting format for national checking and verification activities

Besides annual submission of the annual inventory and associated uncertainty estimate, it is recommended that a separate annual report be published and submitted describing for each of the activities described in Section 5.2:

- *What* has been checked and verified and *why* was that selected and *how* was the QC done;
- *Feedback* from external reviews: summary of key comments, their origin and actions taken;
- *Results:* findings and correction of the inventory, and
- *Recommendations* for inventory improvements.

It is also considered *Good Practice* that as a separate report a description is available (for the public, external reviews and to other Parties to the UNFCCC) of how the QC activities are structured and embedded in the QA system.

6 INTERNATIONAL ACTIVITIES ON CHECKS AND VERIFICATION

Possible activities executed by or encouraged by UN bodies, governments, scientific community, NGOs, IPCC WG I and the IPCC TSU on National Greenhouse Gas Inventories are:

- Public review of national inventories by comparison with other estimates, scientific publications, information available from the UNFCCC Secretariat, inter-country comparisons;
- Evaluation and updating of defaults methods and emission factors recommended in the *IPCC Guidelines* on Greenhouse Gas Inventories, and
- Evaluation of global or regional budgets by the scientific community and IPCC WG I, respectively.

Building up a system for emission verification on the international scale will consist of three stages:

- Exploring the possibilities of integrating existing networks (e.g. WMO's Global Atmospheric Watch programme; the above-mentioned satellite information) into a global network on international greenhouse gas emission monitoring;
- Identifying gaps and further needs to a global network and setting up of missing monitoring sites, and
- Development and use of global models to evaluate and interpret measurements.

Work on this subject may be done by individual organisations or as a concerted action, for example under the encouragement of policy organisations, by a group of cooperating institutes or coordinated into international research programmes (for example of IGBP/IGAC).

Alternatively, an international institution or organisation may be entrusted to handle measurement and evaluation programmes concerning emission verification. The mission of such an institution may also be extended towards scenario analyses using models. It may be operated under the auspices of IPCC. A successful example of such a kind of institution is the European Monitoring and Evaluation Programme, EMEP. Like EMEP, a number of monitoring sites should be operated by the individual countries, which then undergo vigorous quality control procedures in order to validate measurement data. This quality test is organised and run by the central institution. The measurement and validation programme, as much as the modelling efforts, are continuously being reviewed and improved. It will be the task of this institution to confirm reported emission data or to identify missing elements using their knowledge on emissions.

This proposed institution would then be responsible for the continuous monitoring and the evaluation of this monitoring. While it will not (or with great difficulty) be possible to identify single outlying sources, an overview on the general agreement of the emission estimations to the scientific understanding of the processes involved will be achieved.

The role of the scientific community is to take advantage of the data collected at this institution, but at the same time use it to challenge their conclusions, in order to further improve possibilities for emission verification. As this topic is fairly new, it may be expected that significant improvements to the techniques described in the previous sections are to be made in the near future, which should be taken up in the routine process as quickly as possible.

7 CONCLUSIONS

Ample opportunities exist for validation (checking) and verifying national inventories. Many options are available at national level, by national teams, ranging from very basic checks to more elaborated verification activities. In addition, specific options are available at the international level, e.g. inter-country comparisons of emission factors and comparisons with independently compiled datasets (global emission inventories and international statistics) or more scientifically oriented ones. An internationally co-ordinated approach of the international options seems the most efficient way for performing the latter activities, both for the basic comparisons as well as for the more fundamental verification activities. Procedural arrangements of checks and verification activities within the quality system for compiling the national inventories, including priority setting and reporting requirements, are key to establish and guarantee the credibility of the national inventories in terms of data quality objectives. These have been summarised by the UNFCCC guidelines for preparing and reporting national greenhouse gas inventories as accuracy, consistency, completeness and comparability.

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ANNEX I EXAMPLES OF EMISSION COMPARISONS

It is recommended that emission comparisons be performed for each source category as standard QC protocol. The objective of the emission comparisons is to ensure that the emission values are not wildly improbable or that they fall within a range that is considered reasonable. These are often referred to as reality checks. The goal is to identify large mistakes before the inventory process has advanced to its final stages. Also, emission checks can lead to re-evaluations of emission factor and activity data if the estimates seem unreasonable.

One of the most efficient and effective emission checks for large-scale inventories is that based on comparisons of emission values. Comparison checks are often used at later stages of review as well, for verification and validation purposes, but it is important to include them as QC checks as early as possible so that errors in emission estimates can be detected. There are basically four kinds of comparison checks:

- Historical comparisons to past inventories;
- Comparison of estimates based on different methodologies;
- Comparison of estimates from different inventory areas, and
- Comparison of estimates derived from atmospheric measurements.

Historical comparisons should be used as standard QC checks of estimated emission quantities. A historical comparison simply means to check the current inventory estimates against those from a previous year's inventory. This type of comparison is relatively easy to accomplish and can be a very effective way to check for gross errors in the estimated emissions. It is particularly applicable in cases where methodologies have not changed since the calculated emissions should be within the same order of magnitude barring any significant changes in activity or practices. Historical comparisons can also be used to check for expected trends in emission estimates. If, for example, there is a trend of emission reductions for a given source in the years prior to the current inventory and this trend is broken by a spiked increase in the current year's estimates, this should prompt further investigation as to why the trend has shifted so dramatically.

Method-based comparisons can be made depending on whether the emissions for the source category were determined using a top-down or bottom-up approach. For example, if N_2O estimates for nitric acid production were determined using a bottom-up approach (meaning emissions estimates were determined for each individual production plant based on plant-specific data), the emissions check would consist of comparing the sum of the individual plant-level emissions to a top-down emission estimate based on national nitric acid production figures and default factors. If significant discrepancies are found in the comparison, further investigation would be necessary to answer the following questions:

- Are there inaccuracies associated with any of the individual plant estimates, for example an extreme outlier may be accounting for an unreasonable quantity of emissions)?
- Are the plant-specific emission factors significantly different from one another?
- Are the plant-specific production rates consistent with published national level production rates?
- Is there any other explanation for a significant difference, such as the effect of controls, the manner in which production is reported or possibly undocumented assumptions?

This is an example of how the result of a relatively simple emission check can lead to a more intensive investigation of the accuracy of emissions data. It is at this point where someone knowledgeable in the source category may be able to isolate the parameter that is causing the difference and make a decision on whether it points to an actual error or not.

Another recommended comparison is checking the emissions from your national inventory to the emissions for the same source category from a similar country or region. Again, knowledge of the source category and how it may be similar to another country is critical for this check. For example, if solid waste management practices are similar between two countries, it may be possible to compare their estimated methane emissions from landfills. This comparison can be made with a country that uses the same landfill methane estimation method and also with a country that uses a different estimation method. A relative adjustment for the quantity of waste can be accounted for before comparisons are made. A significant discrepancy can be studied to determine if it represents an error in the calculation or actual differences due to methods or other influencing factors.

Another emissions comparison check involves using estimates based on atmospheric measurements. Some countries have access to regional atmospheric measurements for their inventory areas. Emission estimates can be derived for various GHG pollutants from these atmospheric measurements and then compared to the inventory estimates for significant source categories. This approach has been utilised on a global scale to verify global GHG emission estimates with IPCC global budgets (Lim, Boileau, *et al.*). It can also be applied on a national, or local inventory level for specific source categories. For example, estimated SF_6 emissions from a national inventory could be compared to estimates derived from atmospheric measurements of SF_6 for the inventory area. This type of comparison would provide an order-of-magnitude check on the estimated emissions.

Comparison checks to other inventory areas can be extremely useful and efficient, especially where they allow cross-method comparisons (for example., if one country used a top-down approach and another used a bottom-up approach). Also, for source categories where there is an issue of confidentiality associated with estimated emissions, or where there are no alternative methods available to estimate emissions, comparison checks to other inventory areas or to estimates derived from atmospheric measurements can be the only means to get an initial indication of whether emissions have been correctly calculated for a source category or not.

Another emission check can be used for source categories that rely on empirical formulas for the calculation of emissions. Where such formulas are used, final calculated emission quantities should follow stochiometric ratios and conserve energy and mass according to the calculation formula. For example, in estimating emissions from manure management, the total quantity of methane produced should not exceed the quantity that could be expected based on the carbon content in the volatile solids of the manure. Similar checks would apply to fuel combustion sources where there should not be more CO_2 produced than would be expected from the carbon content of the fuel. Mass and energy balance checks such as this should be used in all cases where emissions are algorithmic conversions.