National greenhouse gas inventories: Understanding uncertainties vs. potential for improving reliability

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Abstract

An investigation into the national Austrian greenhouse gas emission inventory allows to reconstruct reliability and usability of the inventory. Overall uncertainty of the inventory (95%-criterion) is just over 10% of the total emission, with N_2O from soils clearly providing the largest impact. Uncertainty of the trend the difference between two years is clearly lower near 5% points, as important sources like soil N_2O are not expected to show different behavior between the years, and thus exhibit a high covariance. The result is very typical for industrial countries, with subjective decisions taken by individuals during uncertainty assessment being responsible for the major part of discrepancies between countries. Uncertainty assessment will thus not help in the evaluation of the Kyoto target attainment. Instead, for this purpose a more rigid emission accounting system is proposed, which allows for little individual flexibility in order to provide a harmonized evaluation not influenced by the respective targets. Setting of post-Kyoto emission targets will require the evaluation of achievements, by way of independent assessment of emissions. Part of this process will be emission inventory validation and thorough uncertainty assessment.

1 Introduction

Emission inventories are instruments of environmental policy. Typically covering material flows into the atmosphere, fluxes of atmospherically active substances (air pollutants or greenhouse gases) are accounted for as annual totals for specified regions. Estimation of emissions typically follows predefined guidelines [1, 2], which leave some freedom for individual (country-specific) refinements. As direct measurements of emissions are rarely performed, the assessment of emission is based on a multiplication of a statistical parameter activity, and the relation of this parameter to the emission, the emission factor. Emission inventories do not necessarily cover all emission sources: National obligations to report emissions often do not include what is termed natural emissions.

Increasing regulatory demands require to also improve the quality of an inventory. In situations of a well-defined relationship between source and receptor of pollution an emission estimate may provide sufficient basis for regulatory action. Current atmospheric issues of multi-compound chemistry, transboundary aspects of air pollution, or emission trading demand for a much more intrinsic understanding. Consequently, efforts to improve emission inventories, validate inventory output and assess reliability and uncertainty of inventories have been initiated [3].

2 Methodology: How to assess the uncertainty of national emission inventories

Assessing the quality of any model result may take one of two diverse pathways:

- Independent validation allows an unbiased assessment of model performance.
- Sensitivity analysis is possible without independent information, determining the range or the variability of model input information and extrapolating its significance to the output is the other option.

Due to lack of independent validation data, quality of emission inventories currently can be fully covered only by investigating their input data.

In a study accompanying the official Austrian Greenhouse Gas (GHG) emission inventory [4], all input information has been systematically inspected for its uncertainty. Magnitude and shape of the respective probability density function have been assessed using discrepancies between statistical data, measurements or literature information as main sources. Still for a number of parameters no such reliable data was available. Structured interviews with experts of the respective sector have been used to obtain a well-documented expert estimate to the uncertainty of those parameters.

While this approach is able to fully cover the variability of the underlying information, a potential systematic error will not be detected. The nature of such an error would require correction at the time it is discovered, and therefore not contribute to variability. In order to still assess also systematic errors, in the above-mentioned study data that is clearly erroneous is not corrected but dealt with as discrepancies, assuming that any systematic error still remaining unidentified would be in the same order of magnitude as those actually discovered.

Combination of uncertainties can be performed by error propagation, or by Monte-Carlo methods. While application of error propagation is restricted to some theoretical limitations, the Monte-Carlo approach requires more computing power as it is based on random variations of the input parameters according to their respective probability density, and statistically evaluating the output. Addressing the fairly simple computations involved in emission calculation, computing time is no real issue and the advantages of a Monte-Carlo simulation, especially regarding treatment of co-variation between two parameters, become obvious. Sensitivity analysis demonstrates that independent of the shape of the input probability functions the output will approximate a normal distribution (Fig. 1).

3 Results

The uncertainty of an inventory can be expressed most conveniently as percentage of the total emissions. Following the guidelines [3], we apply two standard deviations of the Monte-Carlo output in order to cover 95% of the results. Overall uncertainty of the inventory described in [4] is just over 10% of the total emission, with N_2O from soils clearly providing the largest impact. Uncertainty of the trend the difference between two years is clearly lower near 5% points, as important sources like soil N_2O are not expected to show different behavior between the years, and thus exhibit a high covariance. This is important to note, as national obligations according to the Kyoto protocol are expressed in terms of trends, and for a retrospective analysis it will not make much difference which specific years to select.

The sensitivity analysis also allows identifying the strongest contributors to the total uncertainty. At the level of aggregation chosen for the uncertainty assessment, the clearly largest contribution derives from incomplete understanding of N_2O emissions from soils. While the driving statistical parameters (agricultural area or fertilizer input) are known, largely different estimates are available on the fraction that actually is emitted. Other important contributors are uncertainty in the amount of solid waste that is deposited (or, more clearly, in the correct classification of organic material prone to decomposition and methane formation), and on the extent of land-use change.

Analyzing the underlying assumptions taken to perform the calculation shows that the exact shape of a probability function is not important, but the subjective selection of literature information available for soil N_2O emissions causes a significant effect.

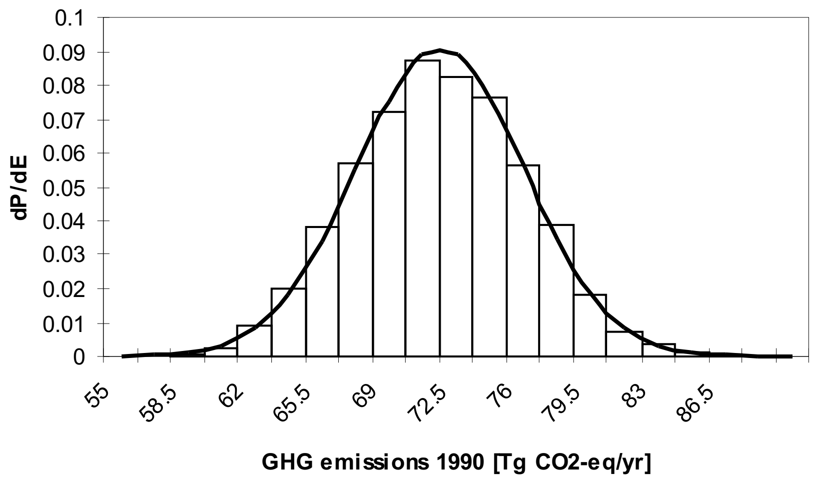

Figure 1: Probability density of Austrian greenhouse gas emissions (data from [4] in column-shaped bins) resembles the shape of a normal distribution function (solid line).

When comparing studies of GHG emission uncertainties from different countries [5], just this subjective personal interpretation of one factor is seen responsible for the much higher overall uncertainty of 20% presented by other developed countries (Norway, UK) compared to the roughly 10% for Austria (and also U.S.A., or the Netherlands), even if seemingly justified by literature. Other than that, the Austrian result may be seen as very typical for industrial countries. The resulting uncertainty will mostly depend on a few single input parameters, as can be shown by sensitivity analysis. The most sensitive individual contribution always derives from N_2O emissions from soils.

Further detailed analysis of this source sector and especially an elucidation of the processes leading to the emissions will help to further decrease inventory uncertainty, or at least to bring different subjective selections into compliance. Still one must not expect uncertainty to completely disappear. It can be shown from a theoretical perspective, that at least trend uncertainty can not decrease below 3% points, as it relies in part on past information which impossibly can be improved ex post. Appropriate selection of the sources included in the emission inventories (specifically: exclusion of land-use change sources) could however also reduce this uncertainty.

As consistently N_2O soil emissions prove to contribute most to uncertainty, and moreover are also responsible for the most important differences between country inventories, it is useful to further investigate into this source sector. Such investigation first of all aims to improve knowledge on the process and so narrow down its uncertainty. But also an increased understanding of the magnitude of the uncertainty itself will contribute to alleviate differences between countries.

An assessment of European N_2O emissions [6] reveals further differences in the understanding of applying official guidelines [2]. According to the guidelines, accounting should be made of different pathways of nitrogen input to soils. There is at least one country which attributes the important pathway of applying animal manure as animal emissions, not as soil emissions. While not affecting the overall emission balance, such a difference may influence the interpretation and relative weighing of abatement measures. Again, the evaluation is guided by a subjective decision. On a scale of the 15 old member countries of the European Union, national data have been collected to yield an improved version of the soil N_2O inventory [7], still following the methodology of the guidelines. The results are different to the national emission reports, but not more different than other approaches which should be considered independent: a regression model based on field measurements, or process-oriented models. Most remarkably, these individual results remain in a range of less than a factor of two for each individual country, while uncertainty estimates of up to two order of magnitude [2] have been presented. Certainly all these approaches can not be considered fully independent, as the results are well-known in the scientific community and any discrepancy needs to be well explained before publishable. Implicitly, the large uncertainty margin may contain an element of subjective safeguarding to account for unknown systematic errors.

4 Uncertainty in the context of the Kyoto protocol

With trend uncertainties of several percentage points being typical of industrialized countries, reduction targets of $6-8\%$ as formulated in the Kyoto protocol can not be monitored unambiguously. For most countries, national GHG emissions will be in the uncertainty margin, with only a few either clearly meeting the target or failing to do so. Uncertainty assessment will thus not support the control emission targets. But it should neither be seen as a tool to alleviate these targets, just as the targets themselves do not aim at reducing atmospheric concentration of GHGs.

Emission reductions as proposed by the signatories of the Kyoto protocol are far too small to change the current trends of increasing atmospheric GHG concentrations. Instead, the protocol may only provide a first step in emission reduction, with further target setting to come. In these revisions of the targets the assessment and evaluation of measures taken will be performed. In order to understand and evaluate achievements, the inventory uncertainty will have to be considered. For an agreement of new targets, also the uncertainty involved in assessing them should be considered (and possibly by way of appropriate target definition minimized).

Instead of directly applying uncertainty to the evaluation of a countrys obligation, experience with uncertainty assessment teaches to rather address the subjectivity still involved in many aspects of an inventory. Individual decisions and different approaches can provide very valuable contributions to emission inventories, especially if specific national information is brought in which can not be covered by generic guidelines. Still if such individuality is permitted in direct connection with target evaluation, the potential of a desired result determining such decisions is quite high. We propose a rigid emission accounting system instead of a scientifically perfected emission inventory to fulfill this task. Within this system, adherence to the accounting rules must be top priority, not the attempt to reflect a real situation of material flows. Such an accounting system needs to be based on scientific knowledge and could be based on existing information [2], but it should allow only minimal individual choice. Once fixed it should be kept constant for a commitment period.

A rigid, scientifically based scheme has already been developed for other aspects of GHG gases. The greenhouse warming potential (GWP) expressed as the mass of CO_2 emissions which over a 100-year period would contribute the same radiative effect as one mass unit of the compound in question, is a factor which is commonly used, even if its exact magnitude for the respective GHGs is still matter for discussion, and may be subject to future change.

Development and establishing such a rigid emission accounting system certainly requires considerable resources. Previously, resources available for emission inventories were scarce, however. Emission estimates were derived from data collections (statistics), which have been established for completely independent reasons and could be considered reliable for the purpose of emission estimation. As now such emission estimates become tradable assets, there is additional reason for converting the system to an accounting system. Evaluation, control and improvements of emission inventories will require considerable effort, which needs to be seen in perspective (and in proportion) to the assets covered. A reasonable emission accounting system will provide confidence in the emission inventory and even more protect the assets covered.

A periodic review of the emission reduction targets, following the needs to limit anthropogenic climate forcing, will need to consider inventory uncertainty. As an element of such a review, also the rules for emission accounting need to be adapted to reflect the latest state of science.

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