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Interim Report IR-10-003

Reporting GHG Emissions: Change in Uncertainty and Its Relevance for Detection of Emission Changes

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Foreword

This report is the second of two authored by Khrystyna Hamal during her stay in IIASA's Young Scientists Summer program in 2007. At that time she was a Ph.D. student in Applied Mathematics at Ukraine's Lviv National Polytechnic University. The first report is titled *Preparatory Signal Detection for the EU-25 Member States under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2004)*.[1]

This report advances the preparatory detection of uncertain greenhouse gas emission changes (also termed emission signals) under the Kyoto Protocol. Uncertainty becomes important for countries under compliance conditions if it is equal to, or greater than, the countries' commitment to reduction in emissions. Preparatory signal detection (PSD) provides useful knowledge that countries would like to have available prior to agreeing to environmental targets. A typical assumption to date is that our knowledge of uncertainty in the commitment year/period will be the same as today's in relative terms. PSD allows us to factor in a change in uncertainty, which can advance and facilitate the setting of 'detectable' emission targets.

The increase in knowledge and its effect on reducing uncertainty is widely discussed within and across scientific communities that focus on climate change and its projections. However, rigorous knowledge does not exist in the form of solid numbers necessary to quantify this effect. By revisiting emission estimates of the European Union (EU-25) for the time period 1990–2005, Hamal is able to measure and distinguish between changes in uncertainty due to learning and structural changes in emitters. To my knowledge, this has never before been accomplished; it is the first time that a rigorous result of this type has been produced.

Matthias Jonas
Supervisor, Forestry Program

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[1] Her first report circulated as IIASA Interim Report IR-08-036.

CONTENTS

Abstract

Uncertainty in the inventories of greenhouse gas emissions that countries report under the Kyoto Protocol to demonstrate that they are in compliance can obstruct, and in some cases paralyze, implementation of the Protocol. If uncertainty in emissions is equal to, or greater than, a country's committed change in emissions, it is not possible to determine the direction of these changes at the end of the commitment period – even if the country reports emission inventories that comply with its commitments. As a consequence, uncertainty also poses difficulties for trading of emissions quotas. This study analyzes the relative uncertainty in emissions of greenhouse gases over time that countries report in their annual national inventories under the Kyoto Protocol to the United Nations Framework Convention on Climate Change. The analysis shows how to take advantage of emissions estimates that are recalculated annually and how this knowledge can be used to estimate biases (systematic errors) that are included in the reporting (first-order approximation or one-sided view). This study focuses on the EU-15 as a whole, with examples drawn from individual countries. The study advances the use of preparatory signal detection techniques (developed by Jonas *et al.* in IR-04-024). These techniques assume that our knowledge of uncertainty in the commitment year/period in relative terms will be as good as the knowledge we have today. The study provides first-ever estimates of changes in uncertainty due to learning and structural change.

Acknowledgments

I wish to thank my supervisor, Matthias Jonas, of IIASA's Forestry Program, for many useful discussions, comments and guidance. I would also like to thank Larry Willmore for editing the report, and the YSSP Team – Tanja Huber, Barbara Hauser and Serge Medow – and all of the participants in IIASA's YSSP 2007 for making my stay at IIASA pleasurable.

About the Author

Khrystyna Hamal graduated in 2006 from Lviv Polytechnic National University, Ukraine, with a Master's degree in Applied Mathematics. She completed her Ph.d. at the same university in 2009. This study is the product of the Hamal’s participation in IIASA’s 2007 Young Scientist Summer Program. Khrystyna Hamal was supervised by Matthias Jonas of IIASA’s Forestry Program.

Reporting GHG emissions: change in uncertainty and its relevance for detection of emission changes

Khrystyna Hamal

1 Background and Objective

To implement the Kyoto Protocol correctly, it is not sufficient to know the countries' greenhouse gas emissions at the end of the commitment period. The quality of these emissions also matters, e.g., in specifying whether a country meets its commitments, trading carbon quotas, etc. An important component of emissions data quality is their uncertainty. Ideally, uncertainty takes into account all possible errors and knowledge gaps. In the case of inventories of greenhouse gas emissions there is currently little experience in assessing and compiling uncertainties (Rypdal and Winiwarter, 2001); and to date temporal change in relative uncertainty has not been investigated or exploited. However, knowledge of uncertainty, including knowledge of the principal parameters that cause uncertainty to change, can provide a cost-effective key for reducing uncertainty in future emissions inventories.

Uncertainty can significantly influence the implementation of the Kyoto Protocol. For example, Parties to the Kyoto Protocol might report that targeted reductions in emissions were met, or even exceeded, at the end of the commitment period. However, the uncertainty in emissions might be larger in absolute terms than the reported emissions reduction. In this case it is impossible to unambiguously ascertain compliance, and the question arises whether excess emissions (the difference between reported and target emissions) should be eligible for trading at all or only with a specified risk. *This study assumes that a country's emissions reduction can be ascertained unambiguously only if reported emissions plus absolute uncertainty are smaller than, or equal to, the country's target emissions.* Failure to adequately account for uncertainty in emissions trading schemes can doom the trading mechanism under the Protocol to failure and lead to a situation where sellers over-report emissions reductions and buyers purchase emission reduction credits with a face value higher than warranted (Gupta and Rotenberg, 2003). For this reason, uncertainty in inventory data and the problem of how to reduce uncertainty are of great interest.

In IIASA Interim Report IR-04-024, Jonas *et al.* (2004a) presented the class of so-called preparatory signal detection (PSD) techniques. This class of techniques is useful for detecting uncertain emission changes (also termed emission signals) under the Kyoto Protocol. It probes the question of how much do we need to know concerning net emissions if we want to detect a specified emission signal after a given time. The authors provide a methodology that allows determining the so-called verification time[2], which is the time when a greenhouse gas (GHG) emissions signal becomes detectable. Detectability occurs when the absolute change in emissions (since the beginning of the observation period) outstrips the uncertainty band surrounding the emissions. Of course, countries should like to have such information on hand before agreeing to environmental targets and before planning national environmental protection strategies. To apply this technique to countries under compliance conditions, one needs to know at a minimum the countries' GHG emissions in base years (first year of the observation period) and their target emissions at the end of the commitment period, together with the corresponding ranges of uncertainty. Uncertainty becomes important when it is equal to, or greater than, the countries' committed emissions reductions. In such cases it would not be possible to state – even if the countries comply with their committed reductions – that the achieved emissions reductions are 'real'; they could be perceived simply as variations within a band of uncertainty.

So far, it is assumed in applying PSD techniques that our knowledge of uncertainty will be as good in the forthcoming commitment year/period as it is today in relative terms. But when examining whether a country will manage to achieve a given emissions reduction, and when specifying the date when an emission signal will become detectable, it is best also to consider changes in relative uncertainty over time, and the reasons for these changes. This knowledge allows us to determine the verification time more precisely. Also, understanding why uncertainty changes over time is an important step toward improvement of future emissions estimates by factoring in structural change, e.g., change in the consumption of fossil fuels. This knowledge is not yet taken into account even though it is crucial for reaching agreement on future emission reduction targets.

The study focuses on the following questions:

1. *Do the uncertainties that countries report in their National Inventory Reports under the United Nations Framework Convention on Climate Change (UNFCCC) reflect the full uncertainty level*? Answering this question allows us to identify those parts of uncertainty which were ignored, unknown, underestimated or overestimated in the countries' submissions.
2. *How can annual recalculations of historic emissions be used to analyze uncertainty in terms of precision and accuracy?* Disaggregating uncertainty into precision (degree of reproducibility) and accuracy (degree of veracity) is important and necessary 1) to better understand its magnitude (i.e., to avoid underestimating uncertainty); and 2) to study its variation over time (see third question). Comparing initially submitted with recalculated emission estimates may be useful in identifying how accuracy changed over time.
3. *How does relative uncertainty change over time*? It is typically assumed that relative uncertainty is constant over time and, beginning in the year 1950 it is

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[2] The term 'verification time' was first used by Jonas *et al.* (1999) and by other authors since then. A more correct term is 'detection time' as signal detection does not imply verification. However, we continue to use the original term as we do not consider it inappropriate given that signal detection must, in the long-term, go hand-in-hand with bottom-up/top-down verification of emissions (see Jonas and Nilsson, 2007: Section 4).

equal to about 6% for estimates of emissions from burning of fossil fuels and from cement production (Marland and Rotty, 1984). But, our knowledge of GHG emissions has no doubt improved: new methods of GHG inventory and uncertainty calculation have been developed, and most countries have experienced significant structural changes in fossil fuel use. In short, it is an oversimplification to assume that relative uncertainty is constant over time.

4. *What are the main factors that affect changes in relative uncertainty?* Answering this question allows to better understand the structure of uncertainty and to identify the most efficient ways to increase our knowledge of uncertainty change
5. *How can knowledge of uncertainty change be applied to PSD*? At the present time relative uncertainty of GHG emissions is assumed constant in PSD techniques. Knowing the change in uncertainty over time will be highly useful for improving PSD techniques.

The study builds on official data submitted to the UNFCCC by EU Member States and by the EU-15 as a whole. Under the UNFCCC Parties to the Convention (so-called Annex I countries) are required to submit National Inventory Reports and to report their annual GHG emissions. Information on uncertainty by gas and sector is also requested. Furthermore, countries are encouraged to improve and recalculate previous emissions estimates, which generally leads to revision. Unfortunately, uncertainty data are incomplete and most EU-15 Member States began to estimate the uncertainty in their emissions much later than their emissions. For most countries uncertainties were first reported with reference to emissions in 2000. At the present time, there is little experience in assessing and compiling inventory uncertainties. Missing, and unreliable, uncertainty data create additional problems. Experience so far suggests that researchers have a tendency to *underestimate* systematic errors (Rypdal and Winiwarter, 2001). On the other hand, in more complex fields, researchers are unsure about their results and the approximations they are based on, thus tend to *overestimate* uncertainties (Rypdal and Winiwarter, 2001).

Our analysis focuses on a group of countries (the EU-15) rather than individual EU Member States in order to achieve more robust and reliable results. Individual countries provide examples. CO_2 emissions are considered without emissions/removals in the Land Use, Land-use Change and Forestry (LULUCF) sector, for the following three reasons:

- Uncertainties of CO_2 emissions are smaller if emissions from LULUCF are excluded and they are also smaller compared to other GHG emissions (see Figure 1). CO_2 emissions other than those from LULUCF are almost entirely the product of fossil fuel burning (in 2006 total CO_2 emissions excluding LULUCF in EU-27 were from: fossil fuel burning – 92,6%; industrial processes – 6,7%; fugitive emissions – 0,4%; solvents and other product use – 0,2%; waste – 0,1%) and generally do not depend on the technology used for fuel combustion, the age of the equipment, etc., but rather on the carbon content of a specific type of fuel and the relevant emission factor(s). As a result, the uncertainty of GHG emissions from fossil fuel burning depends almost exclusively on parameters that are believed to be well known.

- CO_2 emission data from fossil fuel burning and cement production are typically available for long time periods. For example, the CDIAC database of Marland *et al.* (2007) provides emissions estimates back to 1750.
- CO_2 emissions from fossil fuel burning are more significant than those of other GHGs (see Figure 1).

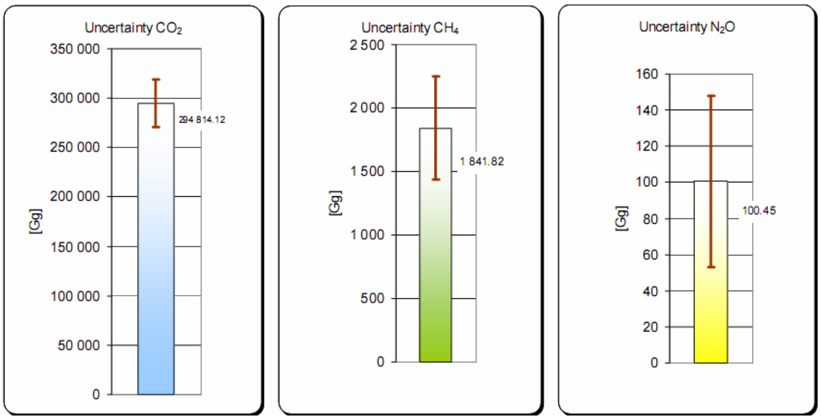

Figure 1. Poland's GHG emissions (in Gg) with uncertainty bars. Source: Poland 2005).

Although CO_2 is the most reliably inventoried GHG, this should not lead to the illusion that all the uncertainties of the calculations are well known (Gupta and Rotenberg, 2003).

In Section 2 the methodology for calculating total uncertainty is developed. It is based on the analysis of uncertainty in terms of precision (degree of reproducibility) and accuracy (degree of veracity). The section also analyzes the emissions and uncertainty estimates reported in National Inventory Reports (under the UNFCCC) and describes the methodology of how to estimate temporal changes in accuracy of repeated (annual) re-estimates of emissions over time.

Section 3 reports numerical experiments that permit determination of a full uncertainty range for the EU-15 as a whole. The general tendency of uncertainty change over time is shown, along with an analysis of determinants of the uncertainty change. The methodology described in the report can be used as a template to analyze the uncertainty of estimates of CO_2 emissions in other economic sectors as well as the estimates of other greenhouse gas emissions. In these cases, uncertainties would be greater and their changes over time more significant.

Section 4 advances the class of PSD techniques by taking change of relative uncertainty over time into account. An advanced PSD technique is applied to the United Kingdom.

Section 5 summarizes the principal results of the report.

2 Methodology

2.1. Total Uncertainty Concept in GHG emissions

We begin by defining the main terms referring to uncertainty, as they are used in this study. In the Good Practice Guidance report of the Intergovernmental Panel on Climate Change (IPCC, 2000: Annex 3) uncertainty with reference to emission inventories are defined as follows: "*A general and imprecise term which refers to the lack of certainty (in inventory components) resulting from any causal factor such as unidentified sources and sinks, lack of transparency etc.*". The 2006 IPCC Guidelines (IPCC, 2006: Volume 1, Chapter 3) list eight broad causes of uncertainty: 1) lack of completeness; 2) model uncertainty (models are simplifications of the real world and are therefore not exact); 3) lack of data; 4) non-representative data; 5) statistical sampling error; 6) measurement error; 7) misreporting or misclassification; and 8) missing data (uncertainties may result where measurements were attempted but no value was available). These causes of uncertainty can be divided in two categories of errors – systematic error and random error. Inventories should be *accurate* in that they are neither over nor underestimated as far as can be judged; and *precise* in that uncertainties are reduced as far as practicable (IPCC, 2006). This statement concludes that both systematic and random errors influence the uncertainty of inventory results. The 2006 IPCC Guidelines (IPCC, 2006: Volume 1, Chapter 3) give the following understanding of these two errors:

"Systematic error refers to the lack of accuracy and can occur because of failure to capture all relevant processes involved or because the available data are not representative of all real-world situations, or because of instrument.

Random errors: Random variation above or below the mean value. Random error is inversely proportional to precision. Usually, the random error is quantified with respect to a mean value, but the mean could be biased or unbiased. Thus, random error is a distinct concept compared to systematic error".

Mathematically, the systematic error is the difference between the true, but usually unknown, value of a quantity being measured, and the observed value as estimated by the sample mean of an infinite set of observations; while the random error of an individual measurement is the difference between an individual measurement and the above value of the sample mean.

Figure 2 illustrates the difference between accuracy and precision graphically. Accuracy is determined by the systematic error, precision by the random error of (repeated) measurements. Only together do they define the measurement's full range of uncertainty.

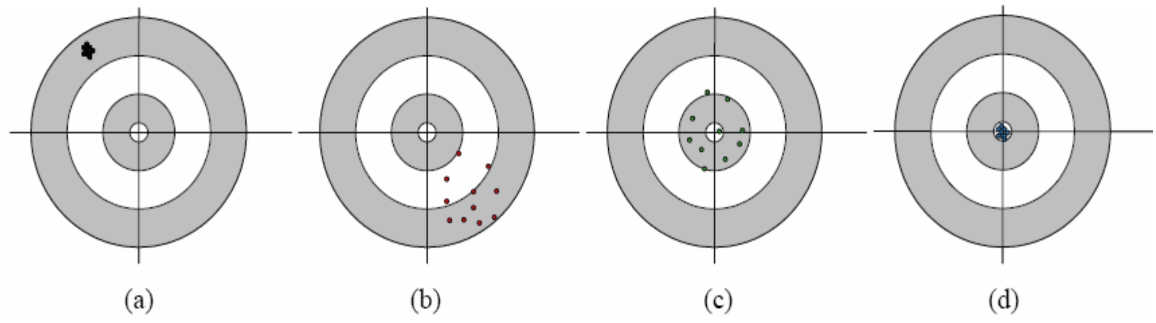

Figure 2. Accuracy and precision: (a) inaccurate but precise; (b) inaccurate and imprecise; (c) accurate but imprecise; and (d) precise and accurate. Source: IPCC (2006: Volume 1, Figure 3.2).

With reference to emissions inventories, the total uncertainty level that countries should include along with initial emissions estimates, in each annual National Inventory

Reports ought to encompass both precision and accuracy. The concept of total uncertainty is illustrated in Figure 3.

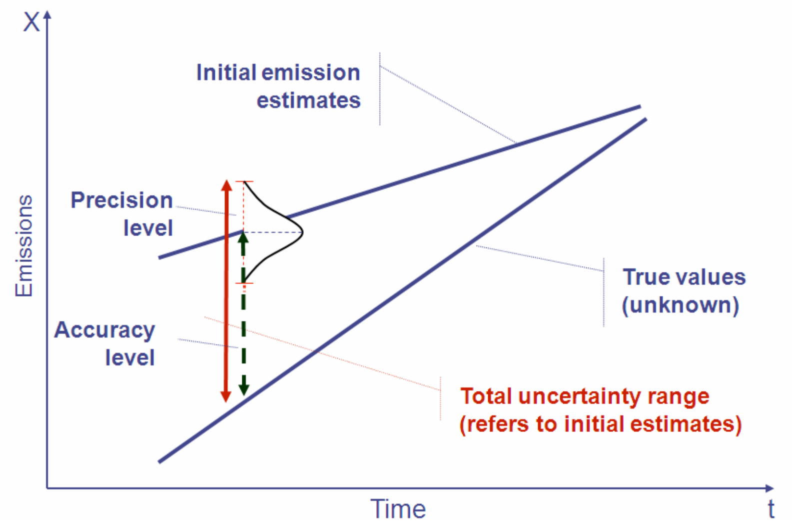

Figure 3. Concept of total uncertainty in the context of GHG emissions inventories.

Precision expresses the degree of reproducibility of repeatedly estimated emissions and accuracy is the difference between the reported emissions estimate and the true emissions value in the year of submission. Here we assume that the reported emissions estimate is identical or close to the mean value. Of course, the true emissions value is unknown, and this difference concept can be applied only with the assumption that all up-to-date information has been used to estimate uncertainty. To overcome the problem that the true emissions value in a given year is unknown, annual emissions recalculations of historic emissions should be done in order to gradually approach the *true value*.

2.2. Annual emissions and uncertainty reporting: National Inventory Reports.

Parties to the UNFCCC are obliged to submit estimates of their greenhouse gas emissions. At present, Parties to the UNFCCC are encouraged, but not obliged, to report uncertainties associated with their GHG emission estimates. Inventory uncertainty is monitored, but not regulated, under the Kyoto Protocol. Reporting uncertainty ought to follow the IPCC Good Practice Guidelines, which refer to a 95% confidence interval. This is the interval that has 95% probability of containing the unknown true emissions value in the absence of biases and is equal to approximately two standard deviations if the emission values are normally distributed. The uncertainties reported in the national inventory reports of countries typically reflect precision and do not take accuracy into account.

An overview of the the uncertainty estimates available from the EU Member States is presented in Annex: Table 1. These uncertainty estimates are taken from the Member States' National Inventory Reports 2006 or 2007 (EEA, 2006a and EEA, 2007) The uncertainty estimates are reported as total or trend uncertainty, in most cases cumulative for all gases, and in some cases even by gas. In this report calculations are based on total uncertainty for CO_2 emissions from fossil fuel burning excluding emissions from LULUCF. For some Member States, either the available National Inventory Report did not contain any quantitative uncertainty analysis, or no national inventory report was available at all.

Uncertainty estimates of countries differ from year to year mainly for the following reasons:

1) knowledge improves for estimating emission factors, activity, etc;
2) methods change for preparing inventories of emissions;
3) structural changes occur in consumption of fossil fuels;
4) national experts who estimate uncertainty are replaced;
5) errors in previous calculations, etc. are identified and corrected.

It is important to understand these changes and how each contributes individually to total change in uncertainty in order to assess how uncertainty might change in the future. Also, knowing the change in uncertainty for a group of countries, e.g., the EU-15, is useful for establishing improved post-Kyoto emission targets. Most EU-15 Member States began submitting their emission uncertainties (precision) in 2002 with reference to emissions in 2000. However, these first estimates were rough over- and under-estimates in most cases. An analysis of subsequent National Inventory Reports reveals that an increasing number of countries calculated uncertainty with greater care. Their estimates became more accurate. Beginning at some point in time, most countries reported slowly decreasing (absolute) uncertainties, because of real improvements in inventorying GHG emissions. Assessing uncertainty for individual countries and generalizing these results allows us to obtain knowledge on how emissions inventories improved over time. This process can be summarized as three steps:

Step 1: Over- and under-confidence in knowledge, thus under- and over-reporting of uncertainty. The first uncertainty estimates, in most cases, were simply assumed and reported to be very small or too high;

Step 2: Increase (or decrease) in uncertainty, because errors in previous calculations were identified, allowing correction of measures of the precision of emission estimates;

Step 3: Decrease in uncertainties following improvements in inventorying of emissions; new methods and methodologies were applied and mistakes were corrected.

Emissions and their structure change from year to year, so it is possible to define these steps only by eliminating the influence of changes in the structure of fossil fuel consumption on relative uncertainty. Although one would expect small, incremental, almost smooth, changes in the countries' relative uncertainty, we find that the changes are very often quite large and not readily understandable. Hence, we decided to analyze a group of countries (here, the EU-15) in an effort to produce robust results (see Figure 4).

Uncertainties change within countries over time, but they also differ between countries. The latter can be explained by natural conditions, differences in national research and improvements of the inventory system, and the amount of recourses allocated for completing national inventories (Rypdal and Winiwarter, 2001).

Uncertainties are comparatively small and believed to be well-defined for CO_2 emissions from burning of fossil fuel, so yearly changes in uncertainty estimates are not significant for this kind of gas. CO_2 emissions from combustion are generally not very sensitive to the combustion equipment and technology in use. Estimation of these emissions requires only knowledge of the oxidized amounts of fossil fuels and their chemical properties. For this reason CO_2 emissions from fossil fuel burning are believed to be well known, better than CO_2 emissions from LULUCF and better than emissions of other greenhouse gases.

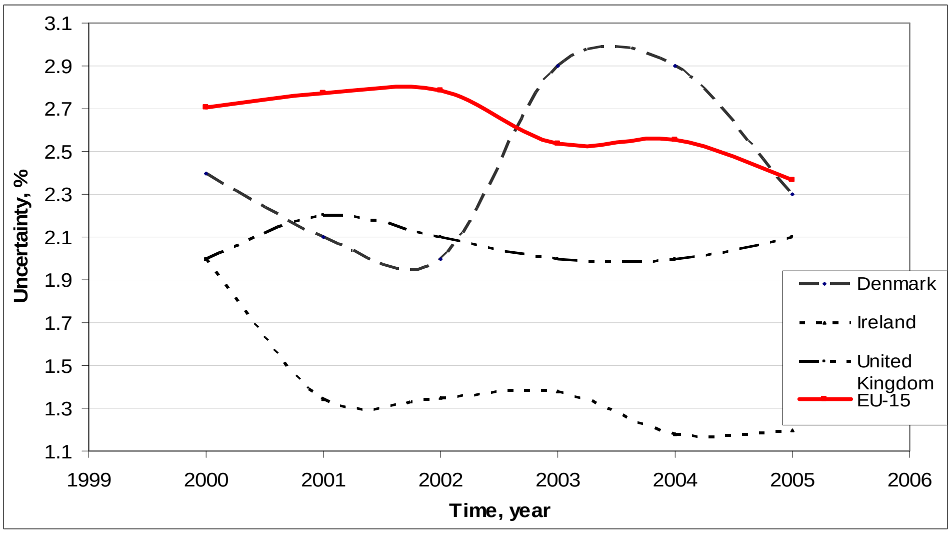

Figure 4. Initial estimates of relative uncertainty as reported by Denmark, Ireland and the UK; and the combined uncertainty for the EU-15. The relative uncertainties for the EU-15 are calculated as average over the Member States' relative uncertainties, weighted by their annual emissions. Correlation of uncertainty between countries was assumed to be zero (which in reality is not true).

2.3. Annual emissions recalculations: reasons and conclusions

The Good Practice Guidance report of the IPCC (2000) recommends recalculating historic emissions whenever inventory methods change or are refined, when new source categories are included, or when errors are identified and need to be corrected. It is important to estimate consistently all emissions in a time series, which means, so far as possible, to calculate all emissions in a time series using the same methodology and data sources. If this is not done, the time series is biased because the estimated emission trend reflects not only real changes in emissions or removals but also methodological changes and refinements. Methodological changes and methodological refinements are defined as follows (IPCC, 2000: Chapter 7):

> *"A methodological change occurs when an inventory agency uses a different tier to estimate emissions from a source category or when it moves from a tier*

> *described in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1996) to a national method. Methodological changes are often driven by the development of new and different data sets. An example of a methodological change is if an inventory agency begins to use a higher tier method instead of a Tier 1 default method for an industrial source category because it has obtained site-specific emissions measurement data that can be used directly or for development of national emission factors."*
>
> *"A methodological refinement occurs when an inventory agency uses the same tier to estimate emissions but applies it using a different data source or a different level of aggregation."*

Methodological changes and refinements are both essential for improving inventory quality. According to the IPCC Good Practice Guidelines (IPCC, 2000: Chapter 7) it is advisable to change or refine methods when:

- Available data have changed.
- The previously used method is not consistent with the IPCC guidelines for that category.
- A category has become key.
- The previously used method does not reflect mitigation activities in a transparent manner.
- The capacity for inventory preparation has increased.
- New inventory methods become available.
- Correction of errors: it is recommended that errors in previously submitted estimates be corrected.

Together with the estimates of annual emissions by gas, countries also submit, in their national inventory reports, recalculated estimates of emissions back to the year 1990. These recalculations disclose the uncertainty of initial calculations because they reveal the systematic error, which is typically not included in submitted uncertainty estimates. This correction of errors in previous emissions estimates is an additional source of information for use in the analysis of uncertainty and correction of initially reports of uncertainty ranges.

In contrast to GHG emissions in general, the quantity of CO_2 emissions are believed to be well known, largely because of the fact that these emissions can easily be estimated, even relying on the rough Tier 1 IPCC inventory method. Estimation of these emissions requires only knowledge of the oxidized amounts of fossil fuels and their chemical characteristics. That is why recalculated values for carbon dioxide emissions do not differ dramatically from those reported initially. The difference between initial estimates of CO_2 emissions and later recalculations are shown for Austria and Ireland as examples in Figures 5 and 6. For other GHGs this difference would be much larger and define an important part of total uncertainty.

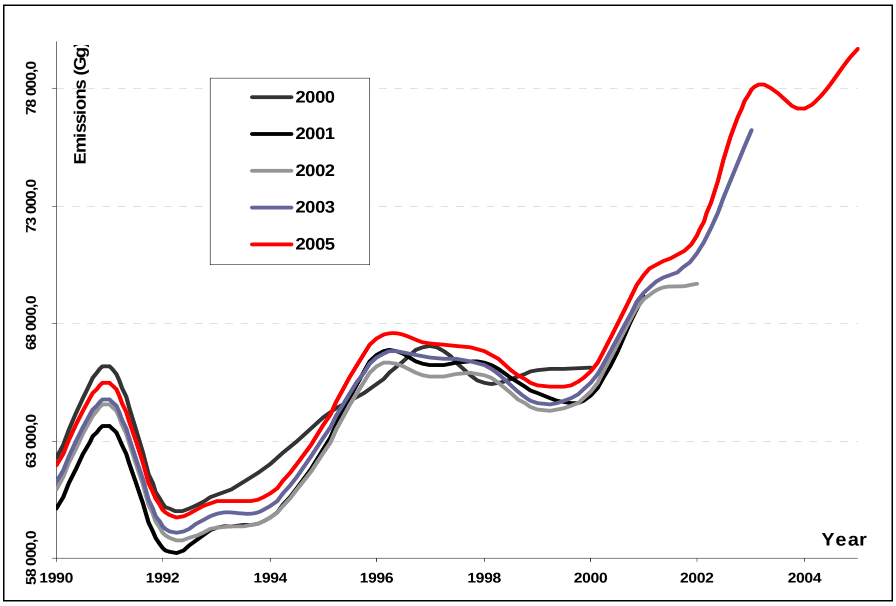

Figure 5. Austria's CO_2 emissions estimated initially in 2000 and recalculated in 2001, 2002, 2003 and 2005. Sources: Austrian National Inventory Reports (2002–2007).

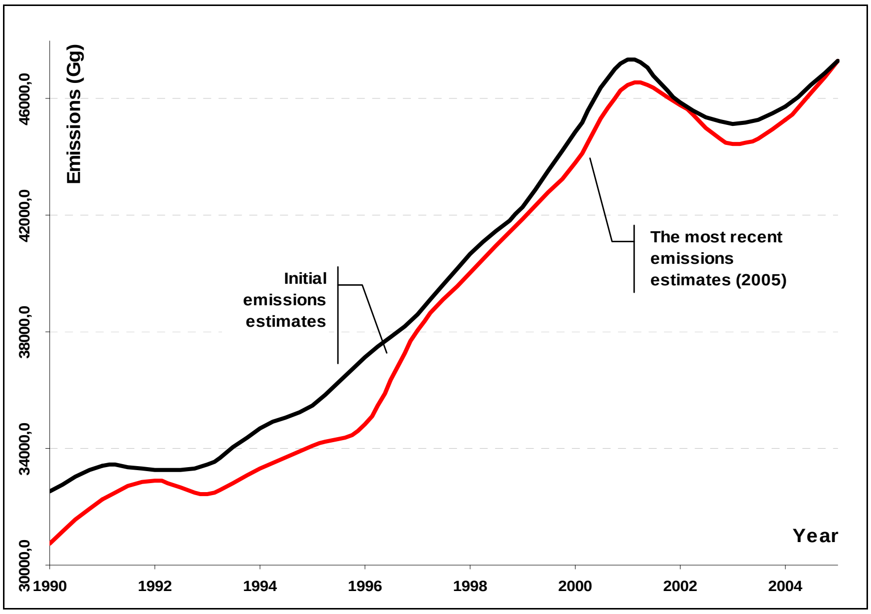

Figure 6. Ireland's CO_2 emissions estimated initially and recalculated in 2005. Sources: Ireland's National Inventory Reports (2001–2007); European Community Greenhouse Gas Inventories (1999–2007).

For comparison, Figure 7 shows the emissions of the EU-15 estimated initially and recalculated in 2005. Values on the blue curve specify CO_2 emission estimates provided for the first time for a certain year (usually published with a delay of two years); values on the red curve represent estimates for these same points recalculated in 2005. Figure 7 shows that the more one goes back in time the greater the observed difference is between initial and recalculated estimates of emissions. This can be explained as gradual correction of the mistakes of previous calculations, i.e., by an increase in knowledge. The two curves meet in 2005 when there is only an initial emissions estimate, without recalculation. Of course, this will change. In the ensuing years, it will be possible to also define a systematic error for 2005 while the accuracy of recalculations of previous years will also change. By then, new and improved inventory techniques will be available.

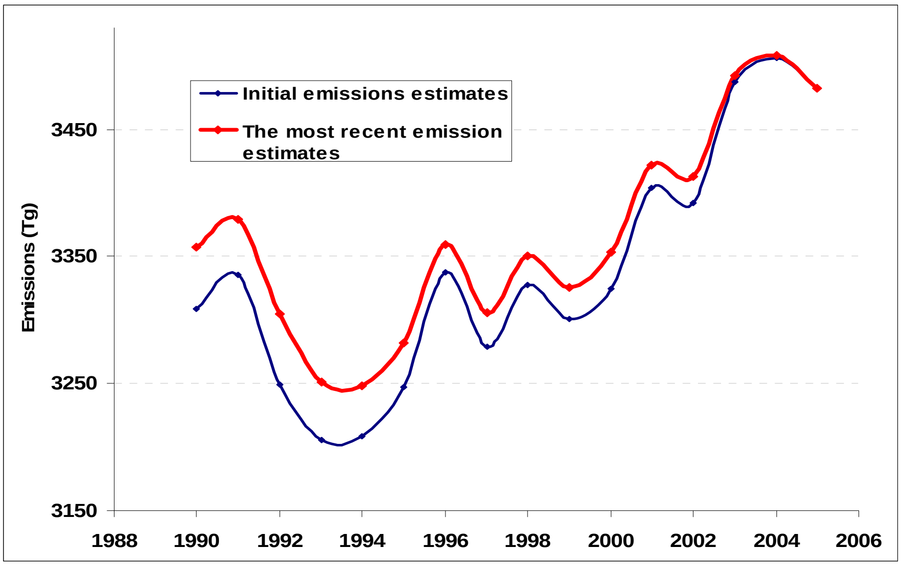

Figure 7. EU-15's CO_2 emissions (without LULUCF) estimated initially and recalculated in 2005. Sources: European Community National Inventory Reports (1999–2007).

In lieu of current knowledge, our emissions knowledge as of 2005 is assumed to be accurate (i.e., with zero bias). Hence, 2005 emissions estimates are treated as "true values". However, their precision is greater than zero and must still be considered, as it is done for recalculated emissions estimates. Recalculated emissions are submitted in the countries' National Inventory Reports, together with corresponding uncertainties. Uncertainties reported in the countries' National Inventory Reports reflect the precision portion of total uncertainty.

Figure 8 shows recalculated CO_2 emissions without LULUCF in Ireland as of 1996. The change in precision during the recalculation process can also be described with respect to the afore-mentioned steps: in early calculations, the precision of emissions estimates was overestimated and reported to be very high. Precision estimates 'stabilized' around 2002 and began to fall because of improvements in real knowledge. The recalculated estimates of 1996 emissions converged to the 2005 estimate of 1996 emissions, which is assumed accurate by definition. The red-marked star (mean of the "true value" range of repeated measurements/observations) has also its own density function with standard deviations less than, equal to or larger than the standard deviations of the corresponding density functions of the blue points (mean of the initial estimates). For a number of countries, it is even possible that the 'precision ranges' around the true mean and initial emissions estimate don't overlap so that the mean of the assumed true value lies outside the 95% confidence interval.

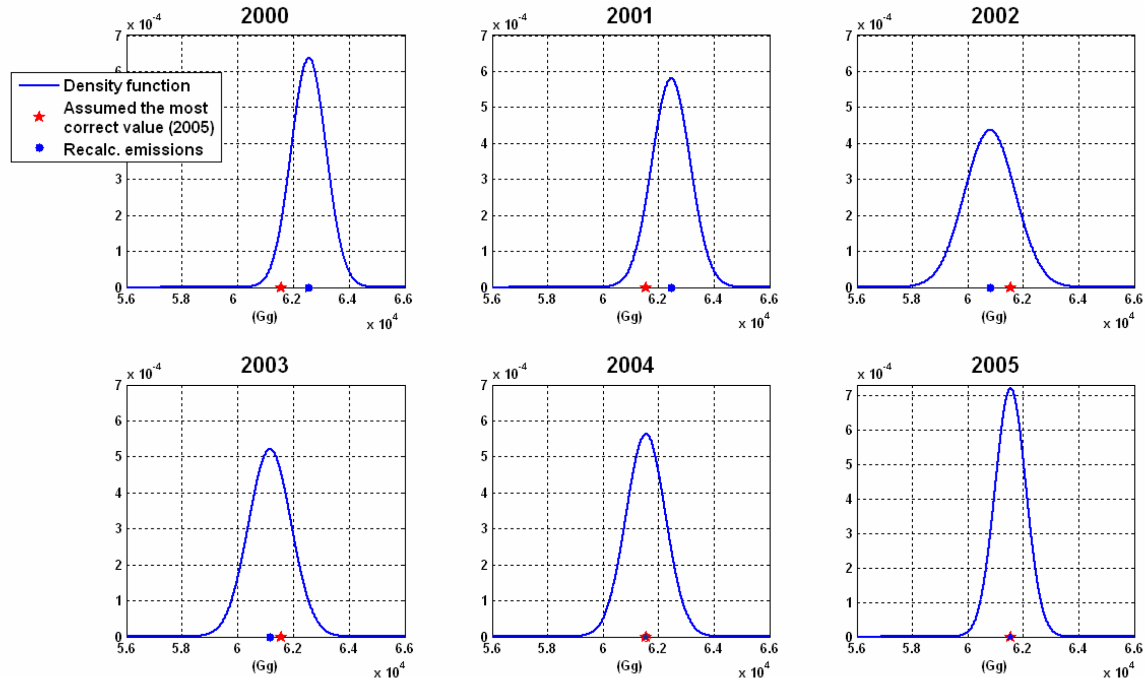

Figure 8. Accuracy and precision: Ireland's recalculated CO_2 emissions as of 1996 without LULUCF. The ordinate reflects frequency, the abscissa CO_2 emissions (in Gg); red star: 2005 emissions estimates for the given year (assumed accurate). Best estimates and standard deviations are sufficient to construct the density functions under the assumption of normally distributed emissions.

Assuming that the emissions (re-)estimated in 2005 reflect our best knowledge (i.e., they are assumed to be accurate) allows us to modify Figure 3. The (unknown) true emissions in Figure 3 (bottom line) is replaced by the 2005 series of emission estimates (see Figure 9):

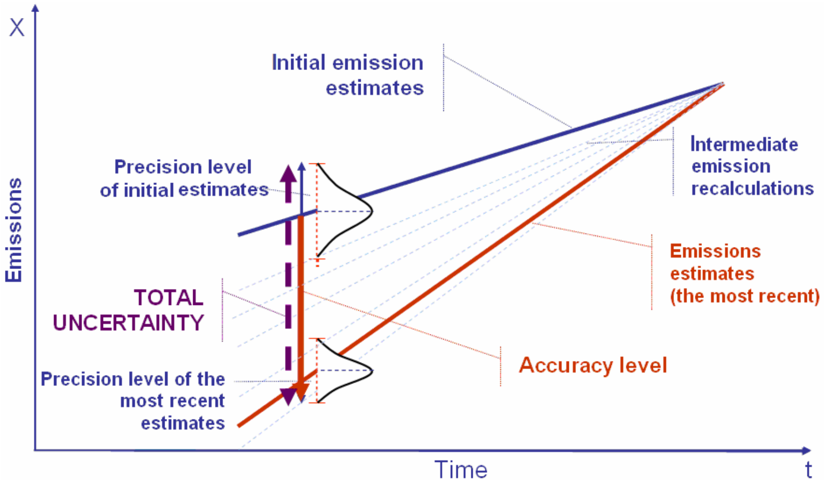

Figure 9. Modifying Figure 3: The (unknown) true emissions line is replaced by the 2005 series of emission estimates. At each point in time, total uncertainty consists of the difference in estimated means between initial and recalculated

emissions plus the two standard deviations that belong to these two estimates. Here the precision is captured as one standard deviation.

According to Figure 9, the (total) uncertainty that a country should have reported for its initial emissions estimates (by means of our knowledge as of 2005) is given by:

$$\boldsymbol{U}_{x,i}^{Total} = \frac{2 \cdot |\boldsymbol{E}_{x,i}^{x} - \boldsymbol{E}_{2005,i}^{x}| + \boldsymbol{U}_{2005,i}^{x} \cdot \boldsymbol{E}_{2005,i}^{x} + \boldsymbol{U}_{x,i}^{x} \cdot \boldsymbol{E}_{x,i}^{x}}{2 \cdot \boldsymbol{E}_{x,i}^{x}}, \qquad (1)$$

where

$\boldsymbol{E}_{x,i}^{x}$ – initial emissions estimate for country *i* as of year x for year *x*;

$\boldsymbol{U}_{x,i}^{x}$ – precision of emissions estimate $\boldsymbol{E}_{x,i}^{x}$ (expressed in relative terms);

$\boldsymbol{E}_{2005,i}^{x}$ – most recent emissions estimate for country *i* as of 2005 for year *x*;

$\boldsymbol{U}_{2005,i}^{x}$ – precision of emissions estimate $\boldsymbol{E}_{2005,i}^{x}$;

$\boldsymbol{U}_{x,i}^{Total}$ – total uncertainty that should have been reported by country *i* for its initial emissions estimate for year *x*.

For normal distributions the 95 percent confidence interval is about two times the estimated standard deviation. Thus:

$$2\boldsymbol{\delta}_{x,i}^{Total} = |\boldsymbol{E}_{x,i}^{x} - \boldsymbol{E}_{2005,i}^{x}| + \boldsymbol{\sigma}_{2005,i}^{x} + \boldsymbol{\sigma}_{x,i}^{x}, \qquad (2)$$

where

$\boldsymbol{\sigma}_{x,i}^{x}$ – standard deviation belonging to $\boldsymbol{E}_{x,i}^{x}$;

$\boldsymbol{\sigma}_{2005,i}^{x}$ – standard deviation belonging to $\boldsymbol{E}_{2005,i}^{x}$;

$\boldsymbol{\delta}_{x,i}^{Total}$ – total standard deviation, $\boldsymbol{U}_{x,i}^{Total} = \frac{2\boldsymbol{\delta}_{x,i}^{Total}}{\boldsymbol{E}_{x,i}^{x}}$.

The values for $\boldsymbol{\sigma}_{x,i}^{x}$ are available only for recent years. Therefore, $\boldsymbol{\sigma}_{2005,i}^{x} + \boldsymbol{\sigma}_{x,i}^{x}$ in Equation (2) is replaced by $2\sigma_{2005,i}^{x}$ (see Figure 9):

$$\boldsymbol{\sigma}_{2005,i}^{x} + \boldsymbol{\sigma}_{x,i}^{x} \approx 2\boldsymbol{\sigma}_{2005,i}^{x}. \qquad (3)$$

The total precision $\boldsymbol{\delta}_{x,i}^{Total}$ does not change significantly for $\boldsymbol{\sigma}_{2005,i}^{x} \approx \boldsymbol{\sigma}_{x,i}^{x}$. Figure 10 graphically displays Equation 2 for four possible cases.

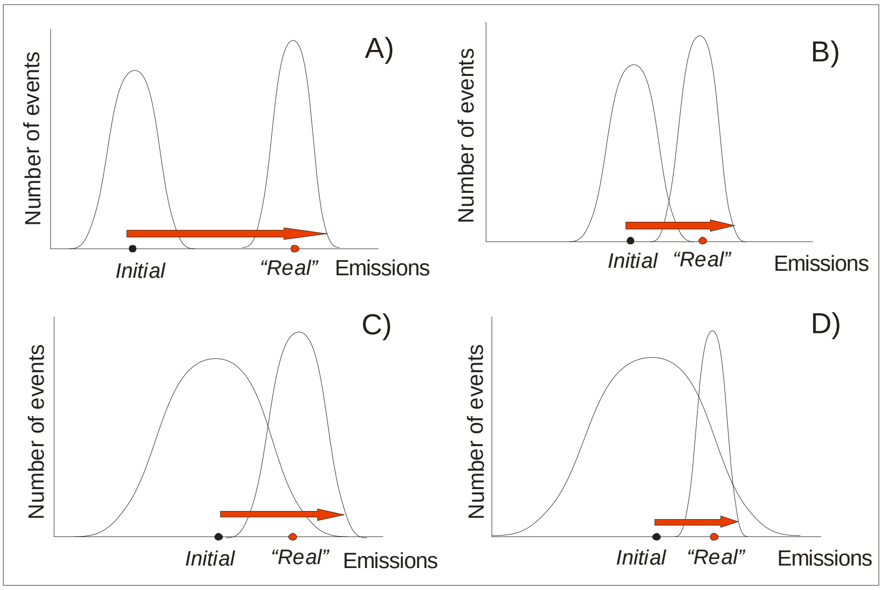

Figure 10. Illustration of Equation (2) for four cases and under the simplification in the form of Equation (3): **Case A**: $\sigma^x_{x,i}$ and $\sigma^x_{2005,i}$ do not overlap; **Case B**: $\sigma^x_{x,i}$ and $\sigma^x_{2005,i}$ overlap but $\sigma^x_{x,i}$ does not include $E^x_{2005,i}$, and vice versa; **Case C**: $\sigma^x_{x,i}$ and $\sigma^x_{2005,i}$ overlap and $\sigma^x_{x,i}$ includes $E^x_{2005,i}$; **Case D**: $\sigma^x_{x,i}$ and $\sigma^x_{2005,i}$ overlap and $\sigma^x_{x,i}$ includes $E^x_{2005,i}$ and entirely contains $\sigma^x_{2005,i}$.

An initial emissions estimate is used repeatedly in following years until an emissions recalculation becomes available.

3 Calculations and Results

3.1 Compilation of full uncertainty ranges

Using the concept described above, total uncertainty ranges were calculated for individual EU-15 Member States and for the EU-15 as a whole as a separate Party to the Kyoto Protocol. As input data the following parameters were used:

- CO_2 emissions submitted in the countries' annual National Inventory Reports (Annex I countries compiled and submitted to the UNFCCC Secretariat these reports annually beginning in the year 1999) and the annual European Community Greenhouse Gas Inventory Reports;
- Annual recalculations of CO_2 emissions (available from the National Inventory Reports and the European Community Greenhouse Gas Inventory Reports);
- Uncertainty values of calculated CO_2 emissions and the uncertainties referring to recalculated values of CO_2 emissions (also available from National Inventory Reports and annual European Community Greenhouse Gas Inventory Reports).

CO_2 emissions estimates (excluding LULUFC) together with the corresponding recalculations of these emissions for the EU-15 as a whole are compiled in Table 1. For example, the first column of Table 1 contains all available recalculations of 1990 CO_2 emissions from 1997 to 2005 (1990 emissions estimates were not provided for years prior to 1997). Table 2 and Annex: Table 2 lists the reported uncertainty values corresponding to the countries' initially estimated/re-estimated CO_2 emissions, compiled from each EU-15 Member Country's National Inventory Report. As mentioned, the reported uncertainty data are not complete; assumptions were made to fill in the gaps where appropriate. For example, if a country calculates and reports uncertainty levels of CO_2 emissions for the year x and for the year $x+2$ but does not report uncertainty for the year $x+1$, and if between these years there were no significant structural changes in fossil fuel consumption, we assumed that at the year $x+1$ there were no qualitative changes in estimating uncertainty methodologically and the inventory procedure. (Otherwise the new uncertainties and their calculation methodology would be reported and described.) In this case we took the same relative uncertainty level as in the year x while correcting for the structural change in emissions. This assumption basically states: if the country does not report uncertainty levels for a specific year this means that neither knowledge about inventory process nor the methodology of uncertainty calculation has changed dramatically compared to the previous year.

The calculations focus mainly on the EU-15 as a whole, because solid and general conclusions cannot be provided for individual countries. In addition, the main characteristics and factors of uncertainty change over time for the EU-15 can also be applied later to individual countries.

		Emissions estimates for															
		1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Years of recalculation	**1997**	3308410				3208808	3247367	3337872									
	1998	3320481	3335636	3248949	3205347	3217380	3260298	3335895	3278534	3327520							
	1999	3325370	3350679	3277471	3208245	3220706	3258070	3332938	3272091	3316965	3300520						
	2000	3341803	3366897	3290290	3223445	3232829	3270286	3340775	3280294	3330477	3308494	3324800					
	2001	3329139	3354486	3282261	3222223	3227362	3262960	3339599	3279607	3329936	3308900	3329314	3403556				
	2002	3334677	3358137	3284820	3228195	3232188	3269734	3347082	3281236	3333097	3306447	3328207	3392202	3392270			
	2003	3334938	3359112	3284578	3231520	3230134	3267233	3343263	3287864	3330534	3304377	3328296	3394289	3387885	3487354		
	2004	3360069	3381916	3308134	3254493	3252072	3283083	3361204	3309903	3354458	3331040	3355018	3420364	3415514	3485007	3506539	
	2005	3357427	3379611	3304568	3251488	3248667	3282193	3359348	3305882	3350778	3325966	3353686	3421895	3413219	3492277	3508074	3482238
	mean	**3334701**	**3360809**	**3285134**	**3228119**	**3230016**	**3266803**	**3344219**	**3286926**	**3334221**	**3312249**	**3336553**	**3406461**	**3402222**	**3488213**	**3507306**	**3482238**
	Max	**3360069**	**3381916**	**3308134**	**3254493**	**3252072**	**3283083**	**3361204**	**3309903**	**3354458**	**3331040**	**3355018**	**3421895**	**3415514**	**3492277**	**3508074**	**3482238**
	Min	**3308410**	**3335636**	**3248949**	**3205347**	**3208808**	**3247367**	**3332938**	**3272091**	**3316965**	**3300520**	**3324800**	**3392202**	**3387885**	**3485007**	**3506539**	**3482238**

Table 1. EU-15: initially submitted and recalculated estimates of CO_2 emissions (Gg) without LULUCF. The table was compiled using Annex I countries' National Inventory Reports (available at: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php)

Member State	ISO Code	1950[1]	2000	2001	2002	2003	2004	2005	Tier (according to IPCC)
Austria	AT								2
Belgium	BE	6,0	3,6[2]	3,6[3]	3,6	3,6	3,6	1,9	1
Cyprus	CY								
Czech Republic	CZ								
Denmark	DK	6,0	2,0	2,1	2,0	2,9	2,9	2,3	1
Estonia	EE								
Finland	FI	6,0	6,0[2]	6,0	6,0	2,0	3,0	2,6	2
France	FR	6,0	5,0						1
Germany	DE								
Greece	GR	6,0	3,7[2]	3,7	3,7	3,7	3,7	3,7	1
Hungary	HU	6,0	4,0	4,0	4,0	4,0	4,0	3,0	1
Ireland	IE	6,0	2,0	1,3	1,4	1,4	1,2	1,2	1
Italy	IT								
Latvia	LV	6,0					3,4		1
Lithuania	LT	6,0					3,1	3,1	1
Luxembourg	LU								
Malta	MT								
Netherlands	NL	6,0	3,0	3,0	3,0	3,0	3,0	3,0	1
Poland[4]	PL						7,4	7,3	1
Portugal	PT								
Slovakia	SK								
Slovenia	SI								
Spain	ES								
Sweden	SE	6,0	2,0	2,0	3,0	3,0	2,3	2,2	1
United Kingdom	UK	6,0	2,0	2,2	2,1	2,0	2,0	2,1	2
EU-15[5]	**EU-15**	**6,0**	**2.69**	**2.77**	**2.78**	**2.54**	**2.56**	**2.37**	

Table 2. Reported relative uncertainty values (%) for initial CO_2 emissions without LULUCF.

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[1] Relative uncertainties of global emissions for 1950 are available from Marland and Rotty (1984).

[2] Uncertainty estimates as of 2003 for emissions in the year 2000.

[3] Brown shaded cells are filled on the assumption that when a country fails to submit its uncertainty level, this remains unchanged from the previous year..

[4] Uncertainty of CO_2 emissions with LUCF.

[5] Uncertainties for the EU-15 are calculated as weighted averages of individual countries, the weights being each country's emissions.

The calculations were carried out according to the methodology described in Chapter 2 above. The methodology is shown graphically in Figure 11 for the EU-15 11.

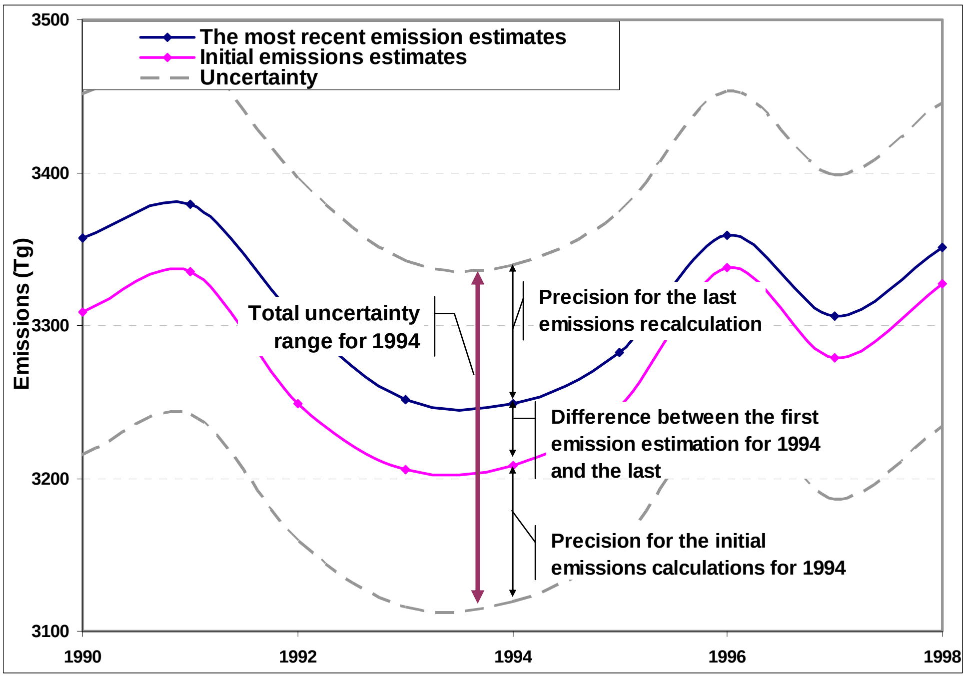

Figure 11. Graphical performance of the total uncertainty concept using real data for EU-15 CO_2 emissions without LULUCF (Tg). When uncertainty of initial emissions calculations was not reported in the year of submission it was assumed to be twice the standard deviation of the last emissions calculation.

The initial precision of submitted CO_2 emissions estimates for some countries was assumed at the beginning of the observation period, but the effect of large inaccuracy of the initial estimates helps to eliminate the influence of this assumption on the total uncertainty range. The summary input parameters used in calculations and the results obtained for the EU-15 are compiled in Table 3.

EU-15	Initial GHG emissions estimates	Recalculated in 2005 GHG emission estimates	Recalculated relative uncertainty in 2005	Reported relative uncertainty	Difference between the first emissions estimation and the most accurate in 2005	Relative uncertainty (combined)
	(Gg)	**(Gg)**	**(%)**	**(%)**	**(Gg)**	**(%)**
1990	3308410,00	3357426,62	2,81		49016,62	**4,33**
1991	3335635,74	3379611,00	2,81		43975,26	**4,16**
1992	3248948,89	3304568,25	2,78		55619,35	**4,54**
1993	3205346,93	3251488,30	2,78		46141,37	**4,26**
1994	3208808,00	3248666,67	2,80		39858,67	**4,07**
1995	3247367,00	3282192,64	2,81		34825,64	**3,91**
1996	3337872,00	3359347,63	2,80		21475,63	**3,46**
1997	3278533,85	3305881,76	2,80		27347,91	**3,66**
1998	3327520,42	3350777,63	2,82		23257,21	**3,54**
1999	3300520,00	3325966,47	2,55		25446,47	**3,34**
2000	3324799,65	3353686,29	2,56	2,69	28886,64	**3,45**
2001	3403555,51	3421894,62	2,46	2,77	18339,11	**3,02**
2002	3392270,48	3413218,99	2,47	2,78	20948,50	**3,10**
2003	3487354,19	3492277,48	2,38	2,54	4923,30	**2,53**
2004	3506538,81	3508073,96	2,38	2,56	1535,14	**2,43**
2005	3482238,42	3482238,42	2,37	2,37	0,00	**2,37**

Table 3. Input data used in Equation 1 and calculated total uncertainty ranges for CO_2 emission estimates without LULUCF for the EU-15 as a whole.

The recalculated combined relative uncertainties for the EU-15 (last column in Table 3) are plotted at Figure 12 and fitted with a trend function, which exhibits exponential behavior with a decrease of approximately 4.24% each year.

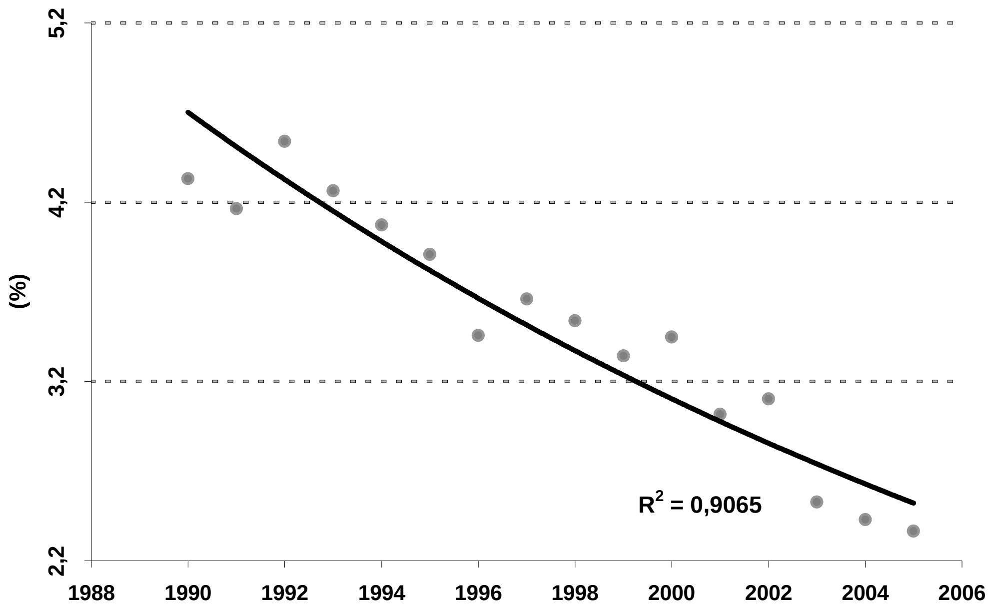

Figure 12. Recalculated combined relative uncertainty (%) of CO_2 emission estimates for the EU-15 (without LULUCF) fitted to an exponential trend function.

A 4.24% decrease of relative uncertainty of CO_2 emissions (excluding LULUCF) per year is not a large change, but we should expect significantly larger changes per year for the LULUCF sector and the other GHGs.

3.2. Analysis of influence on uncertainty change

This chapter seeks to answer the question "*what are the main reasons of uncertainty change in relative terms?*" It is important to answer this question because otherwise it is not possible to use properly our knowledge about uncertainty change. For example, without information about the reason for uncertainty change in relative terms it is impossible to use the general tendency of uncertainty change to project future uncertainty levels according to given scenarios of structural change in emissions (increasing/decreasing fossil fuel consumption in some sectors, substitution of one fuel type by the others, etc.).

Each type of fuel has a different uncertainty level of CO_2 emissions due to differences in combustion, i.e., combustion of liquid fossil fuels involves greater uncertainty than combustion of solid or gaseous fossil fuels while solid fossil fuels are characterized by greater CO_2 emission factors than their liquid and gaseous equivalents. For this reason, a structural change in the type of fuels in use may have a significant effect, on the one hand because of a reduction/increase in consumption of fuels with highly uncertain emissions, and on the other hand because of an increase or decrease in CO_2 emissions.

Let us, in a first comparison, look at the structure of fossil fuel consumption over the time period under investigation. From 1990 to 2005 the structure of fuel consumption in the EU-15 has not changed significantly (Figure 13). The main change was a shift of approximately 12% from solid to gaseous fossil fuels in the structure of total fuel consumption. This shift and changes in the total amount of emissions do not have a significant influence on the change in relative uncertainty (see Figure 14: the blue curve shows uncertainty change in the case of structural changes while the red curve shows the above change in relative uncertainty). Thus we can assert that the exponential curve in Figure 12 reflects changes in relative uncertainty primarily due to knowledge increase (≈95%). Figure 14 also reflects two sensitivity tests of uncertainty for specified changes in the structure of fossil fuel consumption.

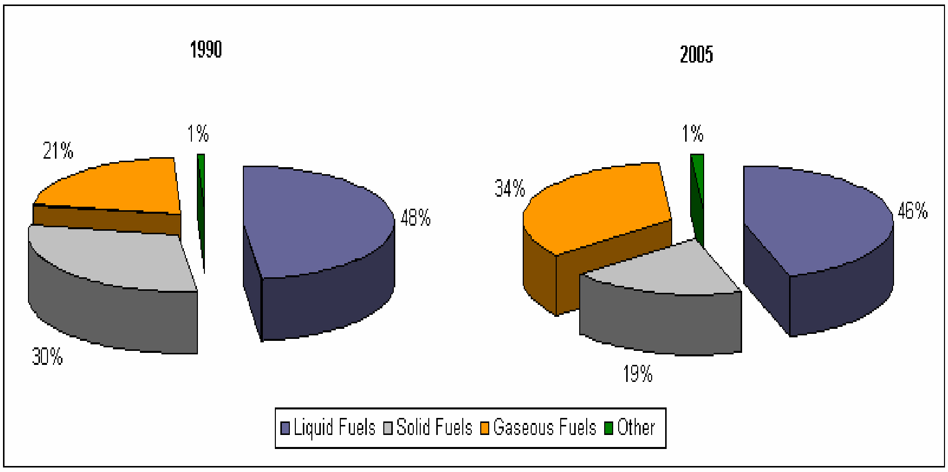

Figure 13. The ratio (%) of types of fossil fuels used for combustion in the EU-15 during 1990 and 2005.

Knowledge of factors that determine relative uncertainty change enables us to base projections into the future on expert judgment and on projected structural changes in fossil fuel consumption in EU countries. The possibility of eliminating individual factors that influence relative uncertainty is also important for allowing relative uncertainty to vary over time in various climatic models; to establish new emission reduction targets for individual countries and for the EU-15 as a whole; and to significantly advance existing monitoring techniques in which, until now, relative uncertainty has been held constant over time (e.g., PSD techniques).

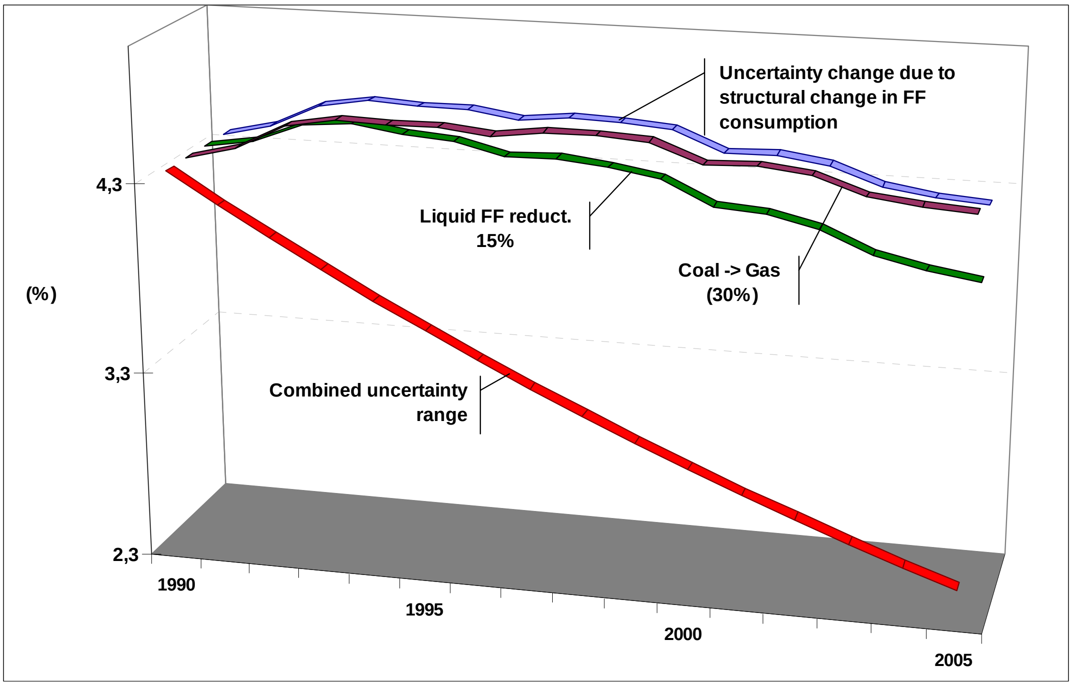

*Figure 14***.** The change in total uncertainty estimates of CO_2 emissions in the EU-15 due to learning and structural change. The blue curve shows the change in relative uncertainty due to structural changes in fossil fuel consumption (emission factors are kept constant from 1990 on). The red curve shows the exponential decay of relative uncertainty. The green and brown curves show how the blue curve shifts if presumed targets for 2005 are introduced: green curve – liquid fuels are reduced by 15% between 1990 and 2005; brown curve: coal experiences a 30% replacement by gas during the same time. To make a replacement fuels were estimated in calories.

4 Numerical experiments

Preparatory Signal Detection (PSD) techniques were developed in the IIASA Interim Report IR-04-024 in order to generate useful prior information as to how great uncertainties can be depending on the emission signal one wishes to detect and one's tolerance for risk (Jonas et al., 2004a). In the past, it has been assumed that our knowledge of uncertainty in the commitment year/period is as good as it is today in relative terms (see Figure 15a), i.e. relative uncertainty was held constant over time.

It is important to advance these techniques by taking into account changes in relative uncertainty. In Figure 15(a) a PSD technique is shown schematically; Figure 15(b) shows the transition to a more advanced application of this technique, where emission levels are extrapolated and the corresponding levels of relative uncertainty are allowed to vary over time.

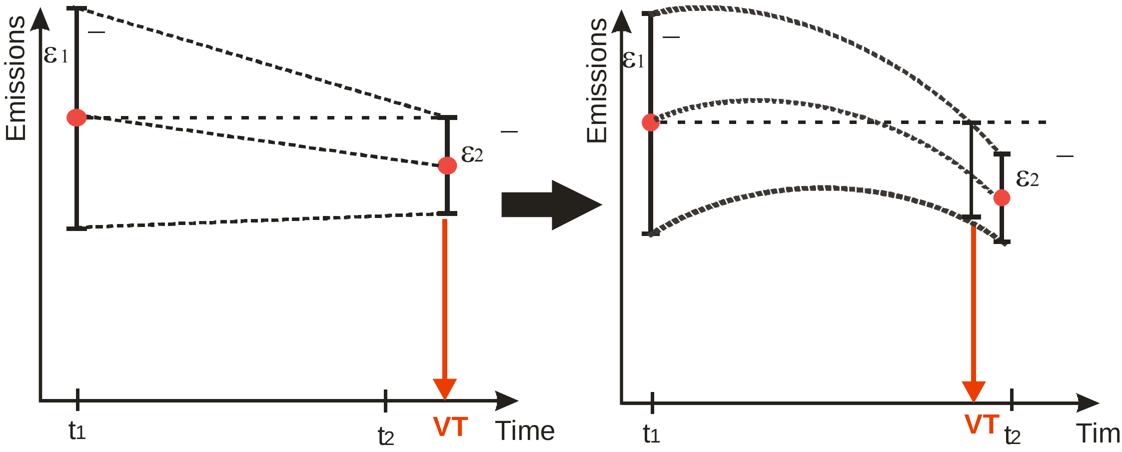

Figure 15. Illustration of a PSD technique: a) linear emissions target path and constant relative uncertainty in time; b) emissions described by a polynomial of the second order while considering a change in relative uncertainty. The red dots in the two figures indicate the agreed target. The VT can differ depending on how uncertainty is treated and emissions are modeled. Source: Modified from Jonas *et al.* (2004b).

The numerical experiments carried out in this report assume that the EU Member States will comply with their commitments under the Kyoto Protocol, i.e., that they will achieve their committed emission targets by the end of the commitment period. To comply with these conditions, known historical emissions were approximated by a second-order polynomial that is forced to cross the committed target in the commitment year (t_2). Emission values were taken from the CDIAC database (Marland *et al.*, 1999). They cover the period from 1835 to 2004. The potential capacity for complying with targets through 2010 is tested for each EU Member State by making use of the distribution of relative changes in historical emissions during 5-year intervals. These are compared with the country's required changes. This comparison allows us to determine if any given country can achieve its committed emission reduction by the year 2010. Extreme observations were dropped by cutting samples at the 2.5% and 97.5% percentiles. As an example, Figure 16 shows the distribution of all possible changes in historical emissions for Belgium in steps of five years beginning in 1835 and the emissions change required for 2005–2010. To comply with its 2010 emissions target, Belgium needs to reduce its 2010 GHG emissions by approximately 5.5% compared to 2005. This reduction corresponds to the red point in Figure 16 (≈0.95) which falls within the 95% confidence interval. That is, Belgium has the potential to meet its reduction target.

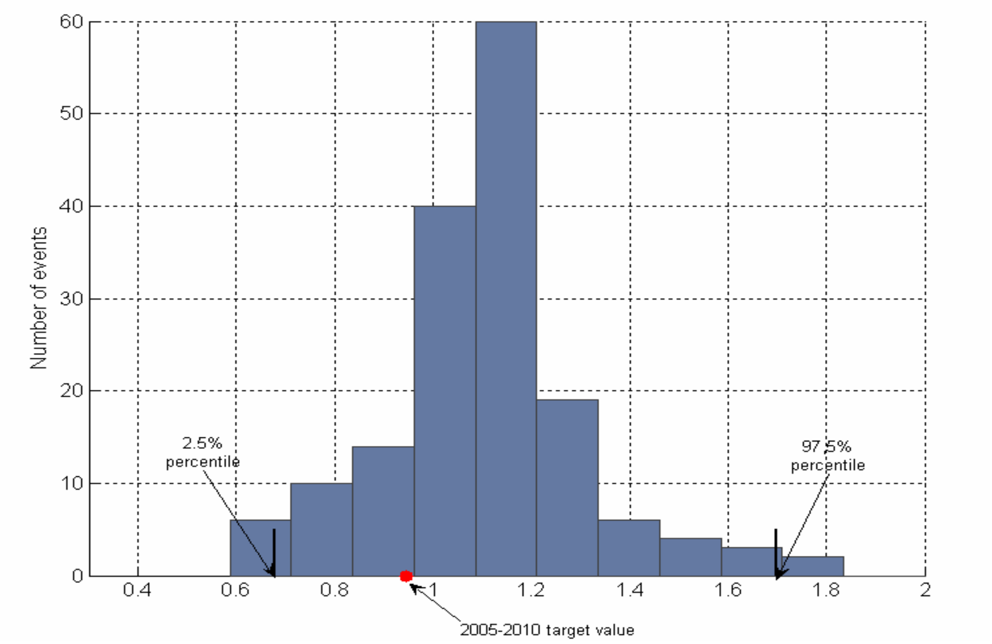

Figure 16. Belgium's distribution of five-year changes in CO_2 emissions (in relative terms) from fossil fuel burning and cement production beginning at 1835.

If the country is potentially able to meet its commitment in 5 years it is important to determine when the emission signal will become detectable (using the knowledge of relative uncertainty change in time). For this, we have to solve numerically the following equation and find the smallest time t:

$$|\boldsymbol{F(t)} - \boldsymbol{F(t_0)}| > \boldsymbol{\varepsilon(t)}, \quad \boldsymbol{t} > \boldsymbol{t}_0, \tag{4}$$

where:

$\boldsymbol{F(t)}$ - emissions at time t (in Mt CO_2/yr);

$\boldsymbol{\varepsilon(t)}$ - absolute uncertainty at time t (in Mt CO_2/yr);

$\boldsymbol{t}_0$ - base year (in yr).

Emissions data are fitted by a second-order polynomial and the associated relative uncertainty by a first-order polynomial. The equation above will then take the following form (Gusti *and Jeda*, 2002: Eq. 3.17):

$$\left|\boldsymbol{F}'(\boldsymbol{t}_0)\cdot(\boldsymbol{t}-\boldsymbol{t}_0)+\frac{1}{2}\cdot\boldsymbol{F}''\cdot(\boldsymbol{t}-\boldsymbol{t}_0)^2\right| > \ldots$$

$$\left(\boldsymbol{R}(\boldsymbol{t}_0)+\boldsymbol{R}'(\boldsymbol{t}_0)\cdot(\boldsymbol{t}-\boldsymbol{t}_0)\right)*\left(\boldsymbol{F}(\boldsymbol{t}_0)+\boldsymbol{F}'(\boldsymbol{t}_0)\cdot(\boldsymbol{t}-\boldsymbol{t}_0)+\frac{1}{2}\cdot\boldsymbol{F}''\cdot(\boldsymbol{t}-\boldsymbol{t}_0)^2\right), \tag{5}$$

where $R(t)$ – uncertainty at time t in relative terms and $R'(t_0)$ the first derivative of relative uncertainty in the base year. This derivative can be obtained from the above exponential function which describes the change of relative uncertainty in time. For example, for the EU-15 the change of relative uncertainty in CO_2 emissions (without LULUCF) is given by Equation 6:

$$\boldsymbol{R(t)} = 4{,}9004\cdot\boldsymbol{e}^{-0{,}0424\cdot\boldsymbol{t}}, \tag{6}$$

where t – time, is expressed in years (e.g. 1990, 1991, ….).

Solution of Inequality 5 requires application of numerical methods. The smallest positive root which satisfies Inequality 5 defines the verification time (VT) (t-t_0) – the time when the emission signal outstrips uncertainty (see Eq. 4). For the purposes of this report, 1990 was selected as base year because the Kyoto Protocol came into force at 1990 and the targets for most countries were established with regard to this year. CO_2 emission values were taken from National Inventory submissions under the UNFCCC treaty. Figure 17 shows the results of numerical experiments defining the verification time for the United Kingdom as an example. Four lines on the plot refer to different possible initial relative uncertainties; the bold one refers to the reported relative uncertainty at the base year for United Kingdom.

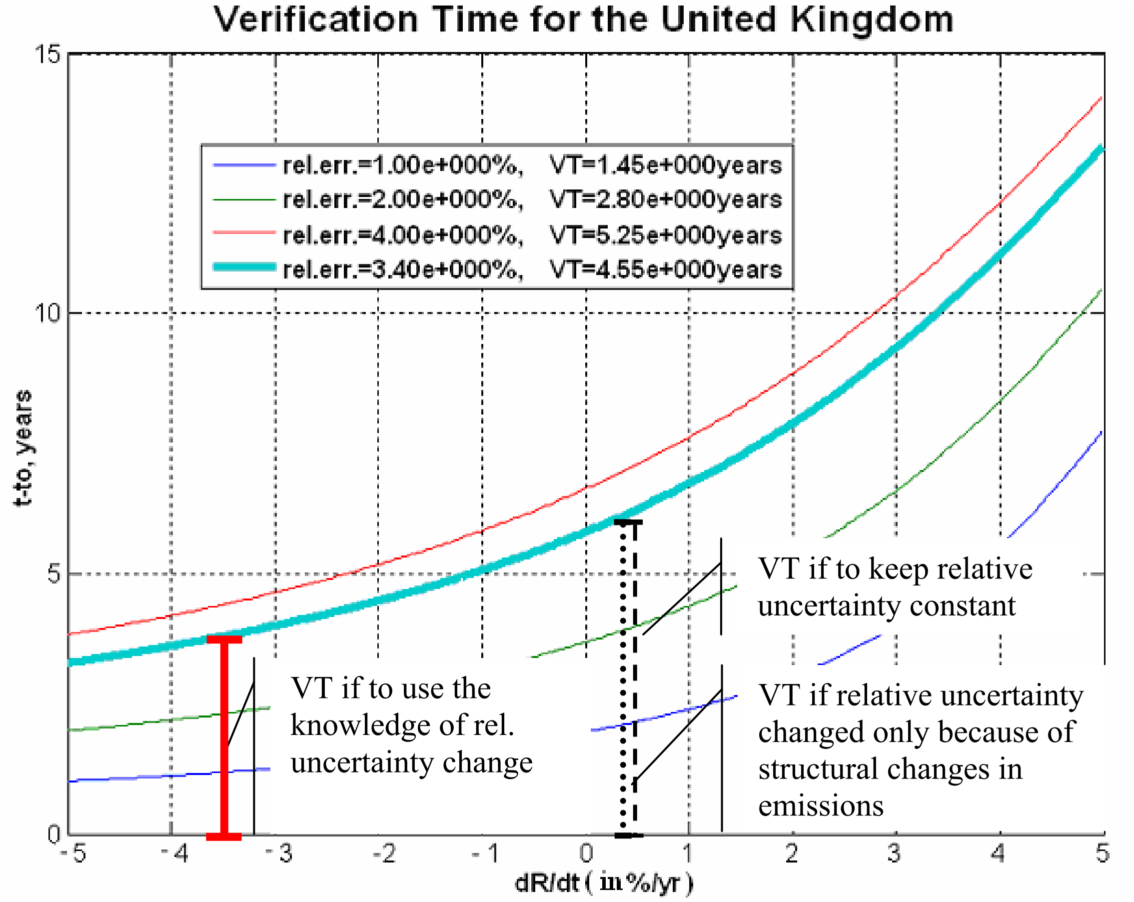

Figure 17. The VT with reference to the fossil fuel emissions of the UK for $R(t_0)$ ranging from 1% to 4% as a function of the rate of uncertainty change (dR/dt) given in %/yr. The ordinate gives the VT in yr.

The UK example shows that if relative uncertainty remains constant in time or changes only little as a result of structural changes, more than 6 years are required to detect the emission signal (see thick blue line). But if the knowledge of relative uncertainty change is allowed to change as a result of increases in knowledge, only about 4.55 years are needed to detect the signal. The change of relative uncertainty for the United Kingdom is calculated to be 3.5% per year. The more than 24% reduction of the verification time may well play an important role in planning national measures to achieve Kyoto targets.

5 Conclusions

Uncertainty values reported by Annex I countries under the UNFCCC do not cover the full uncertainty range - they reflect mostly the precision of emission estimates and neglect uncertainty with respect to the systematic error. Therefore, the accuracy of inventory estimates is not taken into consideration. This study presents a way to address this shortcoming by taking into account the systematic error, at least that part which can be revealed using all knowledge available as of today. Annual recalculations of historic emissions are recommended as an additional source of information on systematic error. Recalculations of historic emissions were treated as a process through which to gradually approach the true emissions value.

The revised relative uncertainty values fail to show any pronounced behavior across countries. This is due to the fact that different countries introduced on different dates the calculation of uncertainty in their emission estimates. Thus, the quality of uncertainty analysis varies significantly from country to country and not all the countries make use of the same tier method in their uncertainty assessments. On the other hand, there is no clear general tendency for within-country changes in uncertainty that might be explained by the so-called learning process – first, countries merely assumed or calculated roughly the uncertainty of their emissions estimates (this resulted in under- or overestimation of uncertainty); uncertainty levels were then modified due to gradual correction of mistakes in previous uncertainty calculations, methodological refinements, etc. Given this, it is better to analyze the change in emissions uncertainty for the EU-15 as a whole rather than for individual countries. The EU-15 is also treated as a separate Party under the UNFCCC. This allows us, we believe, to obtain robust conclusions which can be applied afterwards to individual countries.

The revised relative uncertainty for CO_2 emissions (excluding LULUCF) follows an exponential trend with a decrease of approximately 4.24% each year during the period 1990-2005. Such a decrease is a rather small one for CO_2 emissions, but it would be much larger for other, more uncertain, GHG emissions.

Estimates of change of relative uncertainty due to learning and structural changes reveal that approximately 95% of the change in relative uncertainty is caused by learning, i.e., "knowledge increase"; and only 5% is caused by structural changes in fossil fuel consumption and the total change of CO_2 emissions. Separating these factors allows us to project future uncertainty for scenarios of fossil fuel consumption and also to include the "knowledge change" factor in various climate models.

Applying the knowledge of relative uncertainty change to a specific PSD technique for the United Kingdom results in a significant reduction of verification time compared to the case where relative uncertainty is held constant. It is important to note that only CO_2 emissions (excluding LULUCF) were considered. These have the lowest level of uncertainty and do not change very much over time (compared to other GHGs).

Assessment of changes in relative uncertainty over time and scientific understanding of the main determinants of that change has obvious implications for models that require values for the uncertainty of future emissions estimates; for techniques to assess the compliance with commitments to reduce on schedule GHG emissions; for projects such as quota trading under the Kyoto Protocol; etc. Uncertainty is a crucial parameter for a country that has a relatively small emissions reduction target, one that is the same order of magnitude as the absolute uncertainty of its emissions. A post-Kyoto treaty ought to take into account the uncertainties of emissions in the year of commitment, before establishing targets; it is here that scientific understanding of changes over time in relative uncertainty is essential.

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Annex:

Table 1. Overview of uncertainty estimates available from Member States (from Member States' national inventory reports 2006 and 2007). Source: http://reports.eea.europa.eu/technical_report_2007_7/en.

Member State	**Austria**		**Belgium**	**Bulgaria**	**Cyprus**	**Czech Republic**	**Denmark**	**Estonia**	**Finland**	
Citation	Austrian NIR Mar 2007, p.46-50		Belgian NIR 2006, p. 15-22	No NIR provided	No uncertainty estimates provided	Czech NIR 2007, p. 24-25	Danish NIR 2007 p. 51-54	NIR Apr 2006	Finnish NIR Mar 2007 p. 27-28	
Method used	Tier 1, Tier 2		Tier 1			Tier 1	Tier 1		Tier 1, Tier 2	
Documentation in NIR (according to Table 6.1/6.2 of GPG)	Annex 6 (planned for April version)		Yes			Yes: Table 1.3	Yes	No information provided	Yes: Annex 1	
Years and sectors included	Tier 1: base year and 2004 -Key sources Tier 2: 1990, 1997 (from year 1999) – All sectors		2003-All sectors except LULUCF; for Flanders, a complete uncertainty study was conducted both on Tier 1 and Tier 2 level			1990, 2005 -All sources (key sources and "others")	1990, 2005 -The sources included in the uncertainty estimate cover 99.9% of the total Danish greenhouse gas emission (CO2 eq., without CO2 from LUCF).		1990, 2005 – All sources [percentages below are calculated by EEA on basis of the NIR]	
Uncertainty (%)	Tier 1	Tier 2	Tier 1			Tier 1	Tier 1	Tier 1	Tier 1 (including LULUCF)	Tier 2 (excluding LULUCF)
CO2	Base year: 0.9% 2004: 0.9%	1990: 2.3% 1997: 2.1%	1.9%				2005: 2.3%			1990: -4%/+2% 2005: -4%/+2%
CH4	Base year: 13.1% 2004: 11.6%	1990: 48.3% 1997: 47.4%	24.0%				2005: 23%			1990: -25%/+25% 2005: -24%/+22%
N2O	Base year: 24.6% 2004: 26.8%	1990: 89.6% 1997: 85.9%	27.0%				2005: 42%			1990: -47%/+113% 2005: -31%/+69%
F-gases	Base year: 33.5% 2004: 32.8%		100				2005: 49%			1990: -44%/+44% 2005: -11%/+11%
Total	Base year: 2.42% 2004: 1.81%	1990: 9.8% 1997: 8.9%	7.5%			6.7%	2005: 5.4%		2005: 58.8%	1990: -7%/+13% 2005: -4%/+7%
Uncertainty in trend (%)	Tier 1		Tier 1			Tier 1	Tier 1		Tier 1 (including LULUCF)	Tier 2 (excluding LULUCF)
CO2							1.9 percentage points			
CH4							10.2 percentage points			
N2O							11.6 percentage points			
F-gases							64 percentage points			
Total	2.97%		2.7%			3.0%	2.2 percentage points		15.5%	-12/+8 percentage points

Table 1: continued.

Member State	**France**	**Germany**	**Greece**	**Hungary**	**Ireland**	**Italy**	**Latvia**	**Lithuania**	**Luxembourg**	**Malta**
Citation	French NIR 2007, p. 30-31	German NIR April 2007, p. 90-94	Greek Short-NIR 2007, p. 17-18.	Hungarian short NIR 2007, p. 16	Irish NIR 2007, p. 15-16, 21-22 (Tab. 1.8)	Italian NIR Aug 2006, p. 18, Annex 1	Latvian NIR Mar 2007, p. 16-17	Lithuanian NIR 2007, p.14	Luxembourg NIR 2006	No NIR provided
Method used	Tier 1	Tier 2	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1		
Documentation in NIR (according to Table 6.1/6.2 of GPG)	Yes: Annex 2	Yes: Annex [Anhang] 7 (according to Table 6.2 of GPG)	No	No	Yes: Table 1.8	Yes Annex 1 (Table A1.2)	Yes: Annex 2	Yes: Annex 2	No	
Years and sectors included	1990, 2005 – All sources	2005 -All sources	1990, 2005 - Almost all sources (not included sources represent less than 1% of total emissions)	1985-2004	1990, 2004 – All sources	1990, 2004 – All sources	1990-2004, All sources	1990-2005 (1995-2005 for F-gases), all source categories (except LULUCF and solvent sector)		
Uncertainty (%)	Tier 1	Tier 2	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1
CO2		2005: +3.31%/-2.85%	4% (without LUCF)	+/-2 to 4%	1.5%		3.4%	+/-3.1%		
CH4		2005: +.4.52%/-4.51%	33% (without LUCF)	+/-15 to 25%	4.1%		16%	+/-10.2%		
N2O		2005: +.109.13%/-45.82%	104% (without LUCF)	+/-80 to 90%	32.7%		28%	+/-77.9%		
F-gases			113,7% (without LUCF)		0.02%			+/-0,0%		
Total	+-17.7%	2005: +11.68%/-5.77%	11% (without LUCF)	4.92%	6.2%	3,3% net 8,3% with LULUCF	5.1%	+/-9,55%		
Uncertainty in trend (%)	Tier 1		Tier 1	Tier 1	Tier 1	Tier 1	Tier 1			
CO2					3.3%		1.3%			
CH4					3.2%		8%			
N2O					6.3%		13%			
F-gases					0.04%					
Total	3.0%		10.0%	2.45%	3.6%	2,6% net 7,9% with LULUCF	2.1%	+/-2,1%		

Table 1: continued

Member State	**Netherlands**	**Poland**	**Portugal**	**Romania**	**Slovakia**	**Slovenia**	**Spain**	**Sweden**	**United Kingdom**	
Citation	Dutch NIR 2007, Mar 2007 p.29-33	Polish NIR Apr 2007, p. 5	Portuguese NIR 2007, p. 14-16	Romania NIR Mar 2007, p.28	Slovakian NIR July 2006, p.15	Slovenian NIR Mar 2007 p. 19	Spanish NIR Mar 2007, p. 1.26 - 1.30	Swedish NIR 2007, p. 34-36	UK NIR April 2007, p. 68	
Method used	Tier 1	Tier 1	Tier 1			Tier 1	Tier 1	Tier 1	Tier 1, Tier 2	
Documentation in NIR (according to Table 6.1/6.2 of GPG)	Annex 7, Table A7.1 and A7.2	Partially in Annex 5	Yes: Annex B	No information provided	No	Yes: Annex 7	Yes: Table A7.1 and A7.2	Partially (Annex 2)	Yes: Tables in Annex 7 p. 417ff	
Years and sectors included	1990/95, 2004 – All sources	2005 -All sources	1990-2005 -All sources			1986, 2002, 2003 -All sources	Base year, 2003, 2004 -All sources	1990 and 2005 for all sectors and gases	1990, 2005 – All sources, AD, EF	
Uncertainty (%)	Tier 1	Tier 1	Tier 1 2005		Tier 1	Tier 1	Tier 1	Tier 1	Tier 1 2005	Tier 2 2005
CO2	3%	7.3%	5%				-	2,4% (1990) 2,2% (2005)		2.1%
CH4	25%	22.2%	27%				-	2,8% (1990) 2,1% (2005)		21.2% (net)
N2O	50%	47.1%	103%				-	5,3 % (1990) 5,1% (2005)		233%
F-gases	50%	HFC 44.1% PFC 20% SF6 100%	65%					0,2% (1990) 0,3% (2005)		HFC 15% PFCs 5.8% SF6 24.5%
Total	5%		9.3%		9.7%	1986: 16% 2002: 13,1% 2003: 12%	Base year: +/-9.0% 2003: +/-6.9% 2004: +/-7.0%	6,4% (1990) 6% (2005)	16.5%	14.3%
Uncertainty in trend (%)	Tier 1		Tier 1		Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 2 (range)
CO2	+/-2.5%									-8.9 to -3.7%
CH4	+/-10%									-65 to -34%
N2O	+/-15%									-89 to 215%
F-gases	+/-7%									HFC 10 to 68%, PFCs -68 to -63%, SF6 -15 to 71%
Total	+/-3%		13.2%		3.6%	2002: 4% 2003: 3%	2003: +/-3.3% 2004: +/-4.2%		2.6 %	-28.7 to 0%

Member State	ISO Code	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Austria	**AT**	2	2	2	2	2	2	2	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2
Belgium	**BE**										3,6	3,6	2,75	2,75	1,9	1,9	1,9
Cyprus	**CY**																
Czech Republic	**CZ**																
Denmark	**DK**	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3	2,3
Estonia	**EE**																
Finland	**FI**	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,6
France	**FR**																
Germany	**DE**																
Greece	**GR**	4	4	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7	3,7
Hungary	**HU**	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3,0
Ireland	**IE**	2	2	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,2
Italy	**IT**																
Latvia	**LV**																
Lithuania	**LT**	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1
Luxembour	**LU**																
Malta	**MT**																
Netherlands	**NL**	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3,0
Poland	**PL**																
Portugal	**PT**																
Slovakia	**SK**																
Slovenia	**SI**																
Spain	**ES**																
Sweden	**SE**	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,2
UK	**UK**	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1
EU-15	**EU-**	**2,81**	**2,81**	**2,78**	**2,78**	**2,80**	**2,81**	**2,8**	**2,8**	**2,82**	**2,55**	**2,56**	**2,46**	**2,47**	**2,38**	**2,38**	**2,37**

Table 2. Reported uncertainty recalculations in 2005 that refer to initial CO_2 without LULUCF emissions estimates. Table compiled from National Inventory Reports.