ESTIMATING UNCERTAINTIES IN GHG EMISSIONS FROM FUEL COMBUSTION

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ABSTRACT

This paper describes the basics of estimating Greenhouse Gas emissions by fuel combustion processes, including both stationary (power and heat plants, industry etc.) and mobile (transport) sources. The paper is meant as background material for the Expert Group Meeting on *Good Practice* in Inventory Preparation for Energy, Transport and Fugitive Emissions.

The paper analyses a simple methodology to assess the uncertainties in a (national) greenhouse gas emissions inventory for combustion of fuels. The methodology is from the preliminary approach as given in the *IPCC Guidelines* and designed to accompany the simplest emission estimation methods as described in the “Reference Approach” and the so-called Tier 1 methods in the Revised 1996 IPCC Guidelines (IPCC Guidelines).

The result of the methodology is an **indicator of uncertainty** rather than a scientifically well developed uncertainty quantifier, and therefore should be regarded as a “Tier 1” uncertainty estimate. The proposed Tier 1 uncertainty estimation method is based on simple error propagation theory, assuming that the possible errors in parameters and variables in the emission estimation method are normally distributed.

Although this assumption will clearly not be true for a number of variables and parameters in the Reference Approach and Tier 1 methodologies, we still propose to use the method as a Tier 1 indicator of uncertainty because:

- The uncertainty estimation methodology should be at the same level of sophistication as the emission estimation methodology it accompanies. Both Reference Approach and Tier 1 methodologies are simplifications of the real world and are applied to averages over broad sectors and technologies. A complicated and elaborate uncertainty analysis accompanying an inventory based upon such simple methods seems to be overdone!
- The larger uncertainties tend to occur in the sectors and pollutants that are quantitatively less important. Data on energy and emission factors for CO_2 are generally better known than input data for other sectors and other gases. Uncertainty ranges in fuel use data and CO_2 emission factors generally are low enough to justify the assumption that errors show a normal distribution function, and
- A recent Monte Carlo study Van Aardenne (in preparation) showed that in a realistic case (N_2O emissions from agriculture for the Netherlands) the propagation of uncertainties through the rather complicated estimation method with many activity data and emission factors, was largely insensitive to the exact form of the error distributions in the individual parameters and variables.

The paper presents default values for the uncertainty indicators in both activity data (energy used) and emission factors on a highly aggregated level. In addition the paper describes a few preliminary applications of the methodology and analyses the sensitivity of the method to the assumed uncertainty ranges in variables (= fuel combusted) and parameters (= emission factors). The result of this assessment is compared with an analysis of the differences between Second National Communications and a simple Tier 1 method applied to the energy statistics as available at IEA.

It is shown that the proposed Tier 1 method to estimate uncertainties in the emissions due to combustion of fuels produces a useful indicator.

1 INTRODUCTION

One of the most important issues in the economic and societal development of a country is how the economy and the inhabitants are meeting their energy demands. Parameters like energy efficiency (the amount of energy needed to earn the countries national income) and energy elasticity (the amount of energy needed for earning an extra unit of money) describe to a certain extent the level of development of the country.

Since the major source of emissions of greenhouse gases (GHG) is combustion of (fossil) fuels, knowledge on the energy system of a country is essential for estimating GHG emissions and to understand the uncertainties in that information. Fuel combustion is occurring in several IPCC source sectors: Energy and Transformation Industries, Industry, Transport, Small Combustion, Other and Traditional Biomass Burned for Energy (items 1A 1 through 6).

Figure 1 and Figure 2 show this for countries that submitted a second national communication and for different regions in the world as derived from the EDGAR database.

The figures show that the share of energy related GHG emissions varies greatly between countries and regions of the world, depending on their state of development (60 to 90 % in de industrial world, to about 20 to 30 % in Latin America, Africa and the India Region). Furthermore, the energy share in GHG emissions of countries using nuclear power, hydropower or other non fossil fuel energy sources (France, Norway, Iceland) is lower than for those that heavily rely on fossil fuels (Eastern Europe, United States).

In this paper we present the following:

- A short overview over the Reference Approach (CO_2) and Tier 1 (other gases) methodology for energy related GHG emissions, presenting the basic formula and an error assessment thereof (chapter 2);
- An assessment of input data quality to get a feel of how errors propagate through the RA and Tier 1 methodologies. This will yield a feeling for the level of uncertainties in the methodology, and
- A comparison between:
    - national communications and
    - application of the RA and Tier 1 methodologies on data available at IEA

Along this path we will show both a possible Tier 1 methodology for the assessment of the uncertainties in the GHG inventory as applied to a simple estimation method and relate this result with an estimate of uncertainties could be obtained by comparing (national) methodologies applied in the National Communications and the simple methods described in this paper.

2 MANAGING UNCERTAINTIES

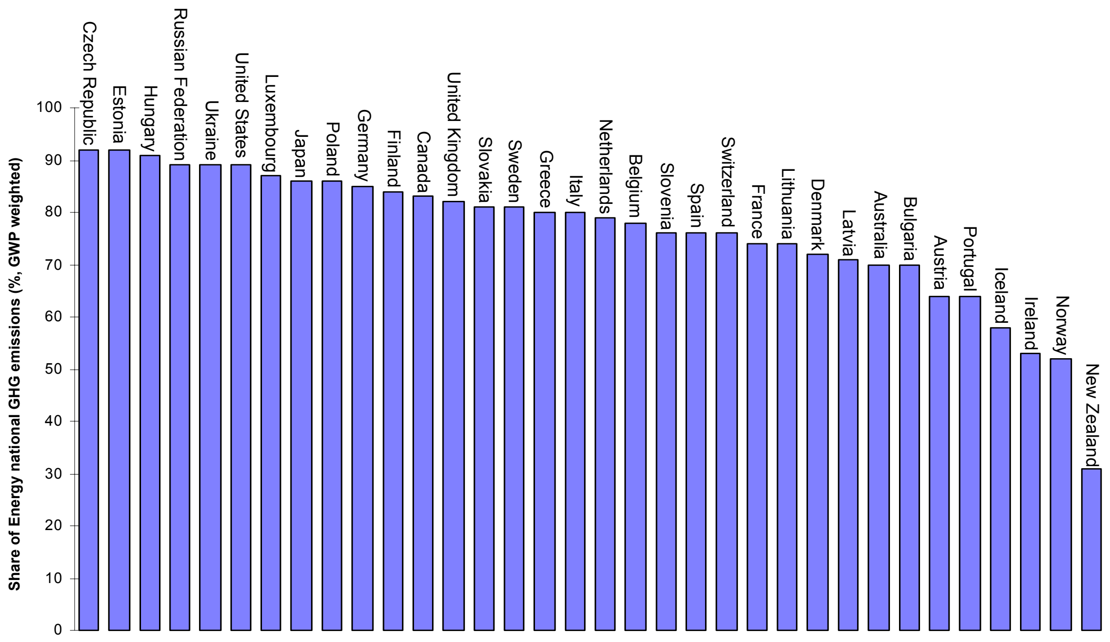
2.1 Introduction

This section deals with the issue of inventory quality in relation to the activities of the Expert Group Meeting on Good Practice in Inventory Preparation within the IPCC/IEA/OECD programme on national greenhouse gas inventories.

The intended use of data and models is relevant for any analysis of the concept of quality and quality criteria. Two major fields of application of air pollution data and models can be discerned:

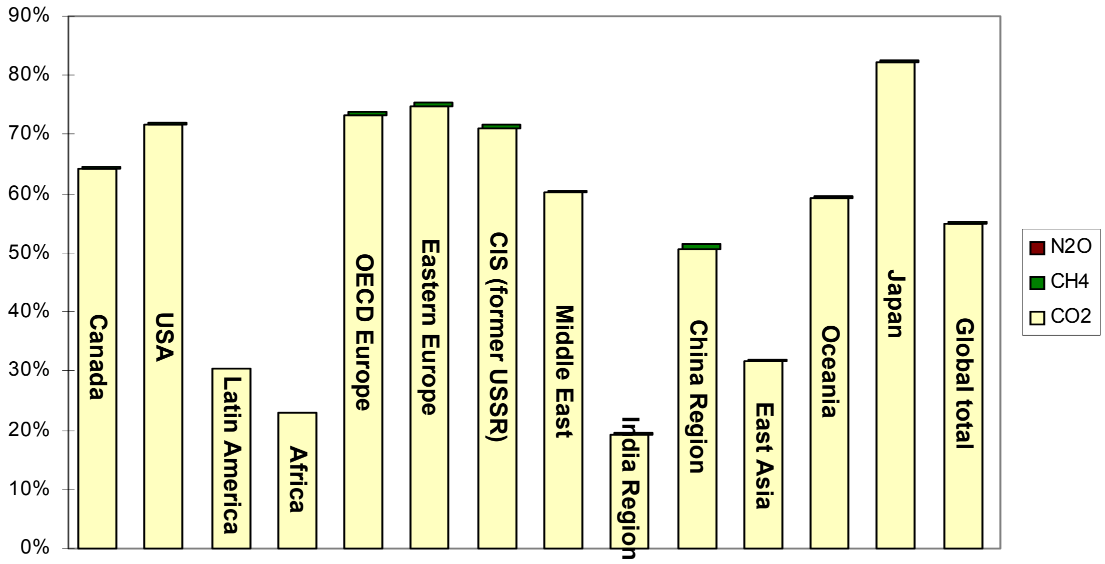
- for policy purposes:
    - monitoring of progress of environmental policy;
    - compliance checking, both of individual polluters with respect to permits and emission standards and of countries in relation to international treaties and protocols, and
- for scientific purposes, including the assessment of the effectiveness of abatement strategies.

Figure 1 Percentage of GHG emissions, caused by fuel combustion; Data from the Second National Communications to the UN FCCC



Source: UNFCCC document FCCC/SBSTA/1998/7, page 47.

Figure 2 Percentage of GHG emissions, caused by fuel combustion (CO_2, CH_4 and N_2O)



Source: EDGAR data (Olivier, Bouwman, van der Maas, Berdowski, Veldt, Bloos, Visschedijk, Zandveld, Haverlag (1996) Description of EDGAR Version 2.0 RIVM Report n2. 771060 002 / TNO-MEP Report nr. R96/119)

If data are being used in (inter)national policy making, users will be mainly interested in the acceptance of the data by the different institutions involved in a specific policy process. Users in scientific applications will be very eager to know the quality of the data in terms of the 'true values'. From this we might derive three different perspectives on the concept of data quality in emission inventories. Table 1 presents these perspectives. The perspective on data quality will also influence the perspective on "truth" and "quality" and hence on *verification* and *validation* of emission inventory data and of models. The Paris meeting report defines these concepts as follows (Paris Meeting, 1998):

Validation (EEA Guidebook, 1997)

Validation is the establishment of sound approach and foundation. The legal use of validation is to give an official confirmation or approval of an act or product. In the context of emission inventories validation involves checking to ensure that the inventory has been compiled correctly in line with reporting instructions and guidelines. It checks the internal consistency of the inventory

Verification (EEA Guidebook, 1997)

Verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help to establish its reliability for the intended applications of that inventory. Typically, methods external to the inventory are used to check the truth of the inventory, including comparisons with estimates made by other bodies or with emission and uptake measurements determined from atmospheric concentrations and/or concentration gradients of these gases

This paper concentrates on the policy perspective of inventory quality. In this perspective important attributes, determining the quality of an inventory are:

- **Timeliness:** the inventory should be delivered on time, as required in the various; policy makers cannot wait until all scientific problems have been solved;
- **Comparability:** In the IPCC inventory context inventories are said to be *comparable* with the Guidelines if they are produced using the Guidelines, or by using methods that are mathematically equivalent to those in the Guidelines, or which can be shown to give more accurate estimates than the methods in the Guidelines for source categories contained in the Guidelines;
- **Transparency:** Transparency is used to represent the condition of being clear and free from pretence. In the context of compiling emission inventories under the United Nations Framework Convention on Climate Change (UNFCCC) this means (a) the construction of the emission estimates is clearly explained; (b) the documentation of the inventory is sufficient for another party to reconstruct it; (c) the documentation sufficiently clarifies the major causes of emission trends in the inventory. Transparency will be greatly increased if the data collected and reported by different agencies will be similar and, therefore, easily understood by other parties and comparable to the data presented by the other Parties;
- **Consistency:** An *estimator* (depending on the sample size of *n*) is said to be *consistent* if the probability that it will assume a value arbitrarily close to the parameter it is intended to estimate *approaches one* when *n* becomes infinite. In the IPCC inventory context, consistency can mean that the methods used are the same throughout the time series being reported, and
- **Accuracy:** The tendency of values of an *estimator* to come close to the quantity they are intended to estimate. See also *Precision*. So far as inventories are concerned accuracy means that estimates are neither over-estimates nor underestimates of true a value as far as can be judged, and that the uncertainties are reduced as far as practicable

From this it must be concluded that, in the policy makers' perspective, inventory quality is not just some mathematical aggregation of data quality. The concepts of "*comparability*", "*transparency*" and "*consistency*" will refer to other inventories or to the guidelines agreed for the relevant protocol. If the reporting guidelines are followed in full, comparability and transparency should be ensured. Matters of "*completeness*", "*accuracy*", "*transparency*" and the like therefore should be dealt with in the guidelines. Once they are, they will be incorporated into the policy makers' perspective of inventory quality.

TABLE 1

PERSPECTIVES ON DATA QUALITY DEPENDS ON THE INTENDED USER OF THE DATA

(ADAPTED FROM PULLES AND BUILTJES, 1998)

	Perspective	High quality if …
"Scientist"	Scientific debate: search for weaknesses and errors; falsification. This approach is chosen in scientific studies dealing with global climate models	… it produces predictions that are confirmed
"Policy maker"	Political debate: search for consensus and agreement; compromise This approach is often important when negotiating targets	… everybody involved agrees
"Lawyer"	Judicial debate: search for proof or doubt; persuasion This approach is important for compliance reporting and checking	… it convinces a judge or jury

2.2 Three levels of quality

Information on methods, emission factors and source of activity data in the inventory documentation sent to the UNFCCC secretariat is rather limited. Parties do not follow the guidelines and the reporting instructions to the full extent. The documentation provided differs among Parties and only in a few cases it can be considered to be complete and transparent [1*]. From the above reasoning improving inventory quality for policy applications should be seen as a two level process:

- Improving the quality of the guidelines and reporting instructions, and
- Improving the quality of inventories compiled according to the guidelines.

In addition to that a third issue should be considered: *"good practice*" which points to such issues as applying the "right" methods for the right sectors and pollutants and adequate documentation of the inventory compilation.

2.2.1 Good practice

a) QA/QC procedures

Good practice is related to QA/QC procedures. Once guidelines are accepted, *good practice* and QA/QC procedures can help in compiling the inventories in such a way that application in national and international environmental policy is possible. A well developed QA/QC system, complying with ISO 9000 or equivalent, will prescribe adequate documentation of the inventory compilation process and enable independent reviewers to track all methods and data used. Such a system would greatly facilitate any validation of the national inventory.

b) Applying the "correct" methods

A second issue, related to *Good Practice* is the choice of appropriate estimation methods in a national inventory. The *IPCC Guidelines* allow parties to choose between different alternative methods to estimate the emissions. In additions the party might apply a national methodology, using specific emission factors and estimation algorithms. Below we will present a simple decision tree that could guide national experts in selecting the appropriate method

2.2.2 Procedural quality

Assuming that the guidelines and/or guidebook have been developed completely, the issue of improving the inventories using these guidance becomes relevant. Two issues will be dealt with here:

- Harmonisation by means of tools to compile an inventory, and
- Validation of national inventories

It should be stressed that the above assumption of complete development of the guidance documents include the default emission factors. Hence, improvement of such default emission factors should be regarded as an improvement of the guidelines (see below).

2.2.3 Scientific quality

The IPCC Guidelines contain extensive sets of activities, of which the emissions should be reported (*IPCC Guidelines, 1996)*. For many activities default emission factors are provided to help the national expert compiling the inventory. In addition the *IPCC Guidelines* provide templates for data tables and summary tables to be delivered by the countries.

Improving the quality of the guidelines therefore can happen in several areas:

- improving the activity definitions and source sector splits;
- completing the guidelines (providing estimation methods for all source categories), and
- Improving the (default) emission factors.

2.3 Managing uncertainties

Against this background the activities of the Expert Group Meeting on Good Practice in Inventory Preparation within the IPCC/IEA/OECD programme on national greenhouse gas inventories could be aimed at:

- stimulating the use of *Good Practice* and QA/QC procedures to increase inventory transparency;

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[1] Mareckova, K. and Tichy. M.; Methods used by parties to estimate and report GHG emissions. Technical paper to UNFCCC secretariat, Bonn 1998

- propose methods to assess the uncertainties in any national inventory, assuming that parties will apply the methods as available in the Guidelines, and
- propose reporting guidelines for uncertainties in cases where parties do not apply the guidelines in their national communications.

This paper therefore mainly deals with how to manage uncertainties and how to report them, rather than how to decrease the uncertainties.

3 METHODOLOGICAL ISSUES

3.1 Reference approach and Tier 1 methodology

Simple methods for estimation of CO_2 emissions from the use of fuels assume that the carbon in the fuel used for each activity will enter the atmosphere in the short or long term. Tier 1 methods and the Reference Approach are simple methods that calculate the amount of carbon released into the atmosphere and express it as CO_2 or the emissions of other greenhouse gases using (default) emission factors.

Both in the Reference Approach and in Tier 1 methods related to combustion of fuels, emissions of GHG are calculated using the following basic formula:

$$\boxed{Emission_{gas} = \sum_{activity} \sum_{fuel} Energy\,used_{activity,fuel} \times Emission\ factor_{activity,fuel,gas}}$$

Where:

Emission$_{gas}$: the total emissions of a certain greenhouse gas, obtained by summing all emissions of energy use in all sectors and for all fuels.

activity: an economic or societal activity ("sector") causing the emissions.

fuel: a fuel, used in each of the activities.

It is stressed that we here regard the Reference Approach and the Tier 1 methodology for fuel combustion as (mathematically) equivalent. The difference between the two is caused by the source categories that, according to the guidelines, should be used for the different gases.

An important issue in applying the above formula is the level of aggregation of the activities or sectors and of the fuels used in the calculation. Within the Reference Approach and the Tier 1 methodology, the aggregation level is quite high. In that case averaged emission factors are to be used.

3.2 Uncertainties: a mathematical treatment

3.2.1 Uncertainties

Any emission inventory will be inaccurate by its very nature (Pulles and Baars, 1991). The data collected are mostly based upon extrapolation of sample measurements or upon the use of emission factors and activity data. The accuracy of the data will be determined by uncertainties occurring in all stages of the inventorying process. Four sources of uncertainties are discerned.

- Uncertainties originating from the real variance of the emissions in time and between different comparable units: some cars have higher emissions than others and emissions of individual cars will vary depending on the state of maintenance, and
- Uncertainties originating from variability in the external conditions in which the units are working: heating emissions will be higher in a cold winter as compared to a warm winter.

These uncertainties are due to "naturally" occurring variances in the emissions. As emissions are mostly being estimated by means of sampling, extrapolation of the sample to the total emission might induce errors. Two other sources of uncertainties stem from the fact that no measurement and no inventory can be perfect:

- Uncertainties in the measurements of emissions, emission factors and activity data, and
- Possible errors in the databases itself.

The uncertainties will cause a certain level of inaccuracy of the data collected: any value in the inventory may contain an error. All uncertainties in both energy data and emission factors applied to calculate a national emission inventory will be reflected in uncertainties in the final result.

Below we will present a simple mechanism to calculate the uncertainties in an inventory, when the uncertainties in the input values (fuel combusted and emission factors) are known.

3.2.2 Uncertainty propagation

Results of an application of the emission inventory will show some uncertainty:

$$E_{real\,world} = E_{inventory} + \varepsilon$$

Where:

$E_{real\,world}$: the "real" emission to be determined;

$E_{inventory}$: the emission value derived from the inventory; and

ε: an unknown error.

If we assume that the probability distribution of the error, ε, is gaussian:

$$P(\varepsilon) = \frac{1}{\sqrt{2\pi\sigma}} \times \exp\left\{-\frac{(\mu-\varepsilon)^2}{2\sigma^2}\right\}$$

Where:

$P(\varepsilon)$: the probability of error value ε;

μ: the mean error, also called a systematic error; and

σ: the standard deviation of errors, a measure of the uncertainty of the result.

A systematic error, μ, might be due to data later discovered to be incorrect or effects that were not taken into account while collecting the data. Such a systematic error should of course be corrected as soon as it is recognised. After such correction $\mu = 0$. Hence the resulting error will have a zero average.

An uncertainty in emission data should be clearly distinguished from the real variance in the apparatus and in the external conditions. The real emission of a certain apparatus at a certain time might be expressed as:

$$E_{app\,t} = E + \delta_+$$

Where:

$E_{app\,t}$: the "real" emission of the apparatus at time t;

E: the averaged "real" emission; and

δ_+: a deviation of the mean value due to specific peculiarities of the unit and to external conditions.

The probability distribution of the deviations, δ_+, has to be determined empirically. In a simple approach as described in this paper, variability in equipment will be averaged out by using averaged emission factors.

It still is unclear how much of the variability which is present in the measurements underlying emission factors is due to measurement errors or to a real variance in the emissions. In those cases where the high variability in emission measurement is due to a real variability in the process, averaged emission factors might be very well suited to estimate national total or global total emissions. In many applications of such emission factors, not the variance in the original data is relevant, but the error in the mean value. The “standard deviation of the mean” in most cases is much lower than the standard deviation in the distribution. It is the “standard deviation of the mean” that is important in aggregated emission inventories, more so than the standard deviation of the distribution functions.

The uncertainties in the above formula will be induced by known uncertainties occurring in measurements and calculations used to estimate the "real" emission. The next paragraph discusses the propagation of such uncertainties in the successive steps of the determination of the emission value. Besides these uncertainties there is always the possibility that also unknown errors are made in the process of inventorying. On the basis of the values present in the inventory it is impossible to quantify such unknown errors. We will therefore not discuss such errors here.

In general the emission value to be determined will be a function of a number of variables:

$$E = f(x_1, x_2, \ldots, x_k)$$

Where:

E : the emission value to be determined

x_i (i=1..k) : variables (activity rates, energy use) and parameters (emission factors) influencing the emission.

One or more or even all of the variables and parameters x_i will be known with some uncertainty. Hence the values of each of these variables and parameters may contain an error:

$$x_{i,real} = x_{i,meas} + \varepsilon_{xi}$$

Where:

$x_{i,real}$: the "real" value of the variable;

$x_{i,meas}$: the measured or calculated value of the variable; and

ε_{xi} : an unknown error.

Again we will follow common practice and assume that the errors ε_{xi} are normally distributed and, if no systematic error is recognised, with zero mean. The errors in the variables will propagate through the calculation and result in an error in the calculated emission:

$$E_{real\,world} = E_{meas} + \varepsilon_E$$

Where:

E_{meas} : the calculated emission, which is a function of the variables and parameters, f ($x_{i,meas}$; i = 1,k);

ε_E : an unknown error.

Assuming that all probability functions of the errors in the variables and parameters x_i are gaussian, that they are small compared to the value of x_i and that the errors in variables and parameters are not correlated, the error, ε_E, has also a Gaussian distribution function and

$$\sigma_E^2 = \sum_i \sigma_{xi}^2 \times \left(\frac{df}{dx_i}\right)_{(x_i = x_{meas})}$$

Where:

σ_E^2 : the squared standard deviation of errors of the result;

σ_{xi}^2 : the squared standard deviation of errors in the variables and parameters;

(..) : the partial derivative of the function with respect to x_i at the measured value of x_i.

In the case of a first order function (sum of values), the above formula reduces to the sum of the squared errors ε_{xi}. In case of a multiplicative function, it can be proven that the squared relative error, $(\sigma_E/f)^2$, equals the sum of the squared relative errors, $(\sigma_{xi}/x_i)^2$.

3.2.3 How to do it?

The algorithm as presented above can be applied whenever the standard deviations of the errors in all variables and parameters are available. To find the standard deviation, find an interval in which approximates a 95 % confidence interval. In a normal distribution the 95 % confidence interval is almost equal to two standard deviations to both sides of the mean value. If such data are not available, as a first estimate the values from Table 3 and Table 4 could be used.

If standard deviations are available the following procedure should be applied:

- While calculating the emission for each activity and fuel combination, the relative uncertainty in this emission should be calculated as the square root of the sum of squares of the relative uncertainties in both the fuel use and the emission factors (multiplicative operation ⇒ use relative errors!);
- The absolute uncertainty in the emission of each activity and fuel combination should be derived by multiplying the relative uncertainty with the emission value;

- The absolute uncertainty in the inventory should be calculated as the square root of the sum of squares of the absolute uncertainties in each separate activity - fuel combination (additive operation $\Rightarrow$ use absolute errors!), and
- The relative uncertainty in the inventory should be calculated by dividing the absolute error by the total emission.

This procedure can be applied at the complete inventory, but also by pollutant or for any sector separately. It could also be applied in combining the uncertainties in fuel combustion with the uncertainties in other sectors (industry, agriculture etc.)

3.2.4 Limitations

The above description of error propagation in inventory compilation, is based upon an assumption that in many cases will not be true. For a number of input data, uncertainties are large compared to the absolute value. Ranges of a factor of 2 to 5 in the emission factors occur for certain gases and certain activities. This makes it impossible that the errors in the values used are distributed normally. In principle, this problem could be solved by introducing a different probability distribution for each of these variables and parameters. A possible candidate would be a so-called lognormal distribution, in which the logarithms of the errors are distributed normally. Error propagation in a case where some or all of the error distributions are not normal is more complicated. Some authors therefore apply a so-called “Monte Carlo” approach in which random sampling techniques are used to calculate error propagation.

Despite this limitation, we propose to apply the above simple error propagation method for the following reasons:

- The uncertainty estimation methodology should be at the same level of sophistication as the emission estimation methodology it accompanies. Both Reference Approach and Tier 1 methodologies are simplifications of the real world and are applied to averages over broad sectors and technologies. A complicated and elaborate uncertainty analysis accompanying an inventory based upon such simple methods seems to be overdone!
- The larger uncertainties tend to occur in the sectors and pollutants that are quantitatively less important. Data on energy and emission factors for CO_2 are generally better known than input data for other sectors and other gases. Uncertainty ranges in fuel use data and CO_2 emission factors generally are low enough to justify the assumption that errors show a normal distribution function, and
- In a recent Monte Carlo study (Van Aardenne, in preparation) showed that in a realistic case (N_2O emissions from agriculture for the Netherlands) the propagation of uncertainties through the rather complicated estimation method with many activity data and emission factors, was largely insensitive to the exact form of the error distributions in the individual parameters and variables. This is compatible with the two observations above.

In the sections to follow, we will apply the procedure as described above in a few sample cases and add a simple sensitivity analysis for the assumed uncertainties in emission factors and activity data. Finally the results of that analysis will be discussed in relation to the outcomes of a comparison of National Communications with a Tier 1 approach performed by IEA on data available at IEA (section 3.5).

3.3 Uncertainties in input data

3.3.1 A country’s energy data

A country’s energy data are crucial when compiling a GHG emission inventory. The first step in compiling a GHG emission inventory for fuel combustion therefore always will be the identification of national energy data for the base year of the inventory. This section describes shortly how to interpret national energy statistics and provides a few clues on how to find data if such energy statistics is not available.

a) Energy statistics

Energy data for individual countries in many cases are summarised in “official” energy statistics, compiled by the country’s national bureau of statistics. Such energy statistics are also published regularly by IEA. To indicate the level of detail of these data, an example of such an energy statistics is reproduced in Figure 3 and Figure 4 for The Netherlands in 1990. Similar data are published annually, in many cases by national bureaus of statistics, by IEA and by the United Nations (UN Energy Statistics,1998)

Figure 3 Energy statistics for the Netherlands 1990 (part 1)

IEAFlow_Name	1: Coking coal	2: Steam coal	4: Lignite	6: Oven and gas coke	7: Pat fuel and BKB	**Coal)**	8: Crude oil	9: NGL	10: Feedstocks	12: Refinery gas	13: LPG + Ethane	14: Motor gasoline	15: Aviation gasoline	16: Jet fuel	17: Kerosene	18: Gas/Diesel
Production				2,922		**2,922**	2,845	479		3,562	2,698	12,794	46	4,979	229.0	18,316.0
From other sources		0				**0**			0							
Imports	4,816	10,151	35	328	12	**15,342**	52,905	3,255	0		2,565	3,552	7	409	598.0	7,684.0
Exports	-6	-2,190	0	-1,176	-9	**-3,381**	-977	-3			-1,137	-9,088	-49	-3,287	-314.0	-17,752.0
Intl. marine bunkers						**0**										-2,138.0
Stock changes	-91	250	0	2	0	**161**	-1,122	-32			83	187	1	-17	-68.0	185.0
Domestic Supply	**4,719**	**8,211**	**35**	**2,076**	**3**	**15,044**	**53,651**	**3,699**	**0**	**3,562**	**4,209**	**7,445**	**5**	**2,084**	**445.0**	**6,295.0**
Transfers						**0**			14,400	-99	-1,648	-3,813	-1	-168	-360.0	-338.0
Transfers	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**14,400**	**-99**	**-1,648**	**-3,813**	**-1**	**-168**	**-360.0**	**-338.0**
Statistical differences	162	3	2	3		**170**	128	-5	0	0	-6	-41	0	5	0.0	87.0
Statistical differences	**162**	**3**	**2**	**3**	**0**	**170**	**128**	**-5**	**0**	**0**	**-6**	**-41**	**0**	**5**	**0.0**	**87.0**
CHP plants		7,842				**7,842**				305	0					32.0
Heat plants						**0**										
Transformation (electricity heat)	**0**	**7,842**	**0**	**0**	**0**	**7,842**	**0**	**0**	**0**	**305**	**0**	**0**	**0**	**0**	**0.0**	**32.0**
Transfer to gases				1,003		**1,003**										
Transfer to solids	4,105					**4,105**										1.0
Petroleum refineries transformatio						**0**	53,779	3,694	14,400							
Petrochemical industry						**0**				0	0				0.0	0.0
Transformation (conversion)	**4,105**	**0**	**0**	**1,003**	**0**	**5,108**	**53,779**	**3,694**	**14,400**	**0**	**0**	**0**	**0**	**0**	**0.0**	**1.0**
Oil and gas extraction						**0**										
Petroleum refineries energy						**0**				2,372	6	0				20.0
Electricity, CHP+heat plants						**0**										0.0
Other energy sector						**0**										
Energy Sector	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2,372**	**6**	**0**	**0**	**0**	**0.0**	**20.0**
Distribution losses						**0**				0						
Distribution losses	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.0**	**0.0**
Iron and steel	776	0		881		**1,657**					1	0			0.0	4.0
Chemical and petrochemical		222		9		**231**				782	1,585		0		6.0	86.0
Non-ferrous metals		0				**0**										0.0
Non-metalic minerals		21	29	41	0	**91**					3				1.0	22.0
Transport equipment						**0**					1	0			0.0	6.0
Machinery		0		10		**10**					4	1			0.0	13.0
Mining and quarrying						**0**										16.0
Food and tobacco		67		0		**67**				4	4	0			1.0	11.0
Paper pulp and print		0				**0**					2					2.0
Wood and wood products						**0**										6.0
Construction		0				**0**					0					119.0
Textile and leather		2				**2**										2.0
Non-specified industry		2	1	0		**3**					1	0			0.0	3.0
Industry Sector	**776**	**314**	**30**	**941**	**0**	**2,061**	**0**	**0**	**0**	**786**	**1,601**	**1**	**0**	**0**	**8.0**	**290.0**
International civil aviation						**0**							1	1,863		
Domestic air						**0**							3	58		
Road						**0**					862	3,590				3,646.0
Rail						**0**										0.0
Internal navigation						**0**						0				660.0
Non-specified transport						**0**									0.0	
Transport Sector	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**862**	**3,590**	**4**	**1,921**	**0.0**	**4,306.0**
Agriculture						**0**					24					81.0
Commerce and publ. serv.						**0**										
Residential		18	7		1	**26**					41				20.0	149.0
Non-specified other		32	0	0	2	**34**					21				57.0	1,165.0

Source: IEA Energy statistics reports

Figure 4 Energy statistics for the Netherlands 1990 (part 2)

IEAFlow_Name	19: Heavy fuel oil	20: Naphtha	21: Petrol_coke	22: Other prod_	Oil	**23: Natural gas**	25: Coke Ovens	26: Blast furnaces	Gas	28: Gas/Liquids from biomass	29: Municipal waste	Combustion of renewables and waste	31: Electricity	32: Heat
Production	14,711	9,773	0	4,436	####	**#######**	27,849	30,750	2,943,253	3,435	11,601	15,036	####	18,804
From other sources					0				0			0		
Imports	6,657	8,016	0	1,823	####	**98,413**			98,413			0	8,905	
Exports	-9,864	-8,841	0	-2,495	####	**#######**			-1,430,130			0	-227	
Intl. marine bunkers	-9,352			-87	####				0			0		
Stock changes	43	156	0	-16	-600	**-66**			-66			0		
Domestic Supply	**2,195**	**9,104**	**0**	**3,661**	**####**	**#######**	**27,849**	**30,750**	**1,611,470**	**3,435**	**11,601**	**15,036**	**####**	**18,804**
Transfers	-949	-6,294	0	-694	36				0			0		
Transfers	**-949**	**-6,294**	**0**	**-694**	**36**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Statistical differences	3	-5	0	6	172	**21,761**	0	-3	21,758			0		
Statistical differences	**3**	**-5**	**0**	**6**	**172**	**21,761**	**0**	**-3**	**21,758**	**0**	**0**	**0**	**0**	**0**
CHP plants	239		0	142	718	**400,122**	4,625	19,273	424,020	985	11,601	12,586		
Heat plants	0				0	**0**			0			0		
Transformation (electricity heat)	**239**	**0**	**0**	**142**	**718**	**400,122**	**4,625**	**19,273**	**424,020**	**985**	**11,601**	**12,586**	**0**	**0**
Transfer to gases					0				0			0		
Transfer to solids			0	0	1				0			0		
Petroleum refineries transformatio					####				0			0		
Petrochemical industry	0	0		0	0				0			0		
Transformation (conversion)	**0**	**0**	**0**	**0**	**####**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Oil and gas extraction					0	**33,406**			33,406			0	141	
Petroleum refineries energy	835	0	0	363	####	**21,863**			21,863			0	1,805	
Electricity, CHP+heat plants					0				0			0	2,706	
Other energy sector					0		10,197	1,559	11,756			0	125	
Energy Sector	**835**	**0**	**0**	**363**	**####**	**55,269**	**10,197**	**1,559**	**67,025**	**0**	**0**	**0**	**4,777**	**0**
Distribution losses					0				0			0	3,244	2,820
Distribution losses	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3,244**	**2,820**
Iron and steel	1				6	**16,565**	10,747	9,915	37,227			0	1,950	
Chemical and petrochemical	23	2,805		0	####	**253,151**	2,280		255,431	91		91	####	
Non-ferrous metals	0			0	0	**3,999**			3,999	131		131	4,872	
Non-metalic minerals	88			0	114	**31,564**	0	0	31,564			0	1,649	
Transport equipment	0				7	**4,074**			4,074			0	525	
Machinery	3			0	21	**16,598**			16,598			0	2,789	
Mining and quarrying	0				16	**169**			169			0	109	
Food and tobacco	25				45	**56,684**			56,684	172		172	5,060	
Paper pulp and print	0				4	**18,152**			18,152	61		61	3,012	
Wood and wood products	2				8	**1,158**			1,158			0	281	
Construction	0		0		119	**4,291**			4,291			0	500	
Textile and leather	2				4	**5,990**			5,990			0	530	
Non-specified industry	6			0	10	**1,756**	0		1,756			0	183	
Industry Sector	**150**	**2,805**	**0**	**0**	**####**	**414,151**	**13,027**	**9,915**	**437,093**	**455**	**0**	**455**	**####**	**0**
International civil aviation					####				0			0		
Domestic air					61				0			0		
Road					####				0			0		
Rail					0				0			0	1,385	
Internal navigation	0				660				0			0		
Non-specified transport					0				0			0		

Source:data from IEA Energy statistics reports

Both the flows, as given in the first column of both figures, and the fuels (upper row) are in fact a hierarchical system, where the higher level (printed in **bold** in the figures) is calculated by adding all underlying lower levels. Both the activities ("flows") and fuel hierarchy is given in appendix 2 and 3.

To extract the relevant information from a countries energy statistics to estimate the GHG emissions, all "flows" within the "FlowType" "Combustion" should be taken into account in as much as they are occurring with non-zero values in the columns representing the fuels "Coal", "Oil", "Gas" and "Renewables and Waste Combustion".

b) Other data sources

In some countries complete energy statistics data are not available or not available on time to be used in the GHG emission inventory. In such cases the following possibilities are open to the inventory specialist:

- use earlier versions of the energy statistics and update where possible using information on the development of the economy of the country;

- Use data as available at IEA or compile a set of independent data; the latter might be a very elaborate and time consuming task, and
- use "default values" per country group, to derive from averaged data: see Table 2 and Table 3.

It will be clear, that whenever a national expert applies the latter possibility, the accuracy of the resulting estimates is low and the uncertainties will be quite large. Below we will discuss this point in a bit more detail (section c).

TABLE 2

TOTAL PRIMARY ENERGY SUPPLY / POPULATION (GJ/CAPITA)

1996	Coal	Oil	Gas	Combustible Renewables and Waste
OECD North America	56	107	64	9
OECD Pacific	34	90	19	3
OECD Europe	29	56	28	5
Africa	5	5	2	13
Latin America excluding Mexico	2	22	8	9
Former USSR	25	28	68	3
Non-OECD Europe	22	24	23	2
Middle East	2	52	31	0
China	23	6	1	7
Asia excluding China	5	7	2	8
World	16	24	14	8

Source: IEA, Paris

The data in Table 2 are derived from the IEA database. Especially for non-OECD countries, not much information is available for the biofuels used. These fuels are not relevant for the estimates of emissions of CO_2, because these emissions should be excluded in the national totals, due to the definitions in the *IPCC Guidelines*. Emissions of other GHG however (i.c. Nitrous oxides N_2O and Methane CH_4) have to be included in the national reports. The revised guidelines provide the user with default emission factors for these fuels.

c) Completeness and uncertainties

In the Reference Approach, based upon energy statistics, it is helpful to check whether or not all energy combustion sources have been identified. Figure 3-3 shows national per caput, per fuel and per sector averaged energy use in combustion for the 9 different groups of countries as indicated. This figure can be used for a first check of the completeness in a national inventory: all fuel-sector combinations containing data in this figure should have been dealt with. From the figure it can be concluded that when an inventory does not contain emissions of coal use in fuel combustion (energy exploration and exploitation) or gas and coal in the transport sector, this will not be an omission. In all other sector-fuel combinations countries have significant energy uses.

As indicated above, the national expert might use different sources of energy data while compiling the national inventory. The data sources are listed in Table 3 in order of priority. The table also gives a first estimate of a relative uncertainty for these data and some explanatory remarks.

Table 3 shows that the uncertainties in the energy data a national expert could use, as expected, increase when the data are obtained from sources that are more and more distant to the national data. Energy data will for most countries be available with uncertainties below several percent.

In the "worst" case, when no specific data are available, the uncertainties might be as high as an order of magnitude for the fossil fuels. The situation is less clear for the biomass fuels as presented in Table 3. The uncertainties in this estimate will not be less than those in the estimates of fossil fuels, based on averages of Figure 5.

TABLE 3
UNCERTAINTIES IN ENERGY DATA FOR GHG EMISSION ESTIMATION

Data source	Error range	Remarks on uncertainties and error range
The national (official) energy statistics	0 %	The official energy statistics of a country will in principle be fixed data, with no uncertainty. In fact however an indication of the uncertainties of the data could be derived from the entry under "Statistical Differences" representing the mismatch between production and consumption.
An update of last year's energy statistics, using gross economic growth factors	2-5 %	The energy system of a county will probably not shift more than a few percent between successive years. Hence, if an update of last year's data is used, an uncertainty of a few percent seems reasonable
IEA Energy statistics	OECD: 2 - 3 % non-OECD: 5 - 10 %	The International Energy Agency (IEA) publishes national energy statistics for many countries. For OECD countries these statistics will ideally be equal to the official energy statistics. For other countries the uncertainties could be expected to be in the order of 5 to 10 % (educated guess)
UN Data bases	5 - 10 %	These data might have a similar uncertainty as the ones provided by IEA
Default values derived from Table 2.	30 - 100 %	From Figure 3-3 it is seen that the variance of per capita energy use data within the country groups as indicated are in the order of one order of magnitude.

3.3.2 Emission factors

a) Availability

Several reference sources of energy related emission factors are available:

- IPCC default emission factors, both for the Reference Approach (CO_2) and for the Tier 1 methodology (other gases) from the *IPCC Guidelines*; emission factors for higher Tiers are also available here;
- UNECE/EMEP and CORINAIR Guidebook on Emission Inventories; these emission factors are compatible with the ones in the IPCC Guidelines at all Tiers;
- US EPA information in the Air Chief databases, both on CD-ROM and on the Internet (http://www.epa.gov/ttn/chief/);
- OLADE (Equador, to be completed, and
- UNDP databases, to be completed.

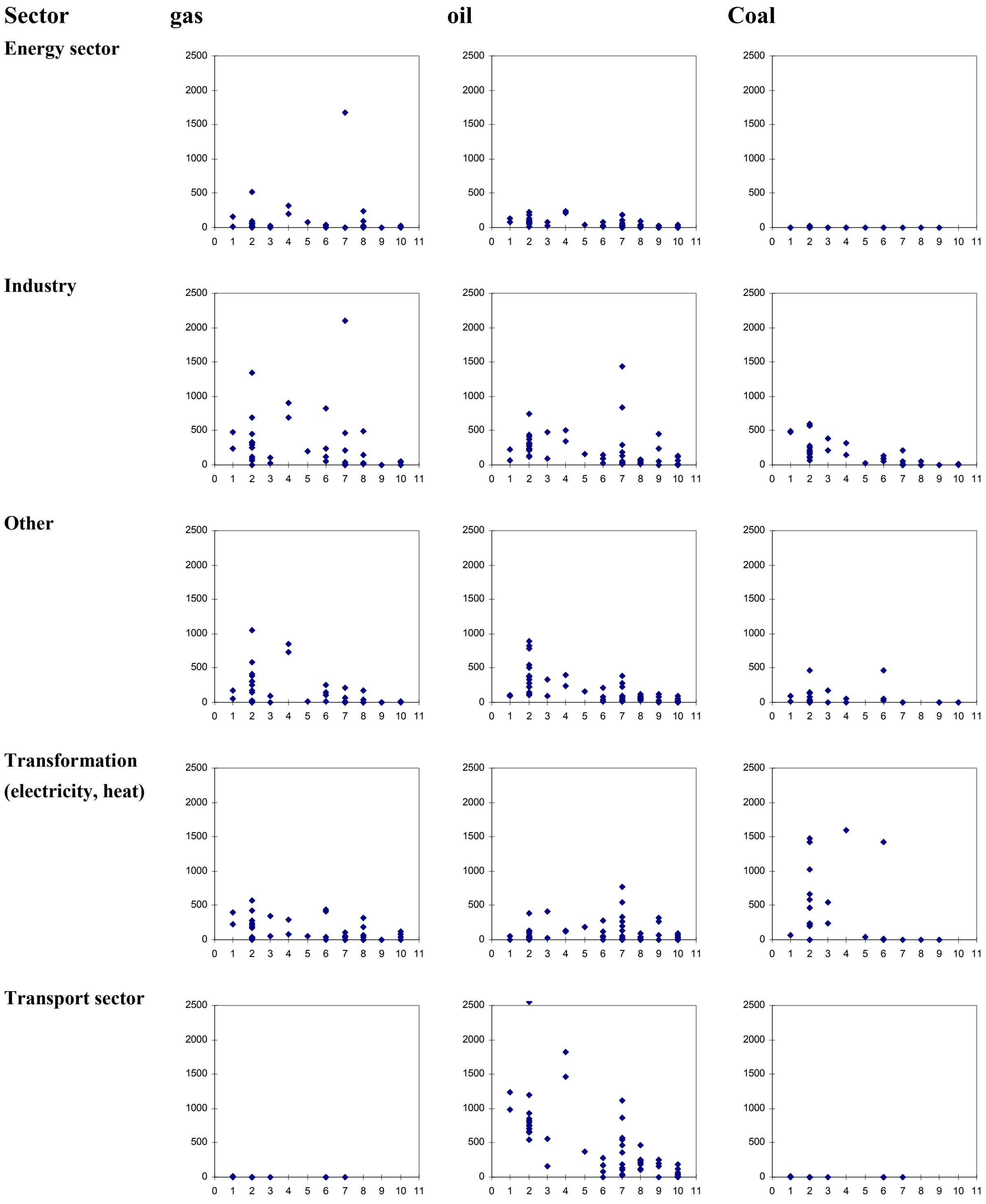
In addition to that, a country might derive its own specific emission factors.

b) Completeness and uncertainties

It is clear that emission factors should be available for all relevant sector-fuel combinations. The set of IPCC default emission factors will provide those, if no "better" values are available. Information on the quality of the default emission factors is not readily available. An estimate of the uncertainties in these emission factors could be derived from the approach chosen by USEPA and elaborated in the UNECE/EMEP and CORINAIR Guidebook on Emission Inventories. Table 4 summarises a possible approach. For this paper the sectors 1, 2, 3, 7, 8 and part of 9 are relevant.

The table reproduces (part of) a table of default quality ratings as given in the Verification and Validation chapter of the Guidebook. The rating definitions are similar to the ones given in the USEPA's AP-42 documents.

Figure 5 National per caput energy use (Coal, Oil: 1000 tonnes/capita; Gas: TJ/capita) in fuel combustion by sector and by fuel in different world regions



1: OECD-Oceania
2: OECD-Europe
3: OECD-Asia
4: OECD-America, N.
5: OECD-America, C.
6: non-OECD-Europe
7: non-OECD-Asia
8: non-OECD-America, S.
9: non-OECD-America, C.
10: non-OECD-Africa

TABLE 4

DEFAULT QUALITY OF EMISSION FACTORS, DERIVED FROM THE UNECE/CORINAIR GUIDEBOOK ON EMISSION INVENTORIES

Source sector	**CO_2**	**CH_4**	**N_2O**
Public power, cogeneration and district heating	A	C	E
Commercial, institutional & residential combustion	B	C	E
Industrial combustion	A	C	E
Industrial processes	B	D	D
Extraction & distribution of fossil fuels	D	D	
Solvent use			
Road transport	B	C	E
Other mobile sources and machinery	C	D	D
Waste treatment	B	C	E
Disposal activities	C	D	E
Agriculture activities	C	D	E
Nature	D	E	E

Definitions of the ratings are derived from USEPA's AP-42, whereas the error ranges are obtained from the EU Guidance Report on Supplementary Assessment under EC Air Quality Directives

Rating	**Definition**	**typical error range**
A	an estimate based on a large number of measurements made at a large number of facilities that fully represent the sector	10 to 30 %
B	an estimate based on a large number of measurements made at a large number of facilities that represent a large part of the sector	20 to 60 %
C	an estimate based on a number of measurements made at a small number of representative facilities, or an engineering judgement based on a number of relevant facts	50 to 150 %
D	an estimate based on single measurements, or an engineering calculation derived from a number of relevant	100 to 300 %
E	an estimate based on an engineering calculation derived from assumptions only	order of magnitude

3.3.3 Applying the approach for a few national inventories

The above method, including the default uncertainty ranges as given in Table 3 and Table 4 are applied to two sets of emission estimates for fuel combustion, estimated from the IEA energy data. These estimates have been performed for Germany and Nepal, as examples of two quite different types of countries, having a low and a high share of biomass in the countries energy supply. For Germany all uncertainties are assumed to be in the mid of the default ranges, whereas those for Nepal are assumed to be at the high end of the ranges.

For Germany the aggregated uncertainty is estimated to be ± 5 % and for Nepal about plus or minus 1.2 times the emission itself. The estimated uncertainties are quite different for the different gases. For Nepal these uncertainties are about twice those for Germany. Since the contribution form CH_4 and N_2O to total GHG emissions by fuel combustion is very low in Germany and considerable (75 %) in Nepal, this translates into the rather different over all uncertainties.

The results of application of the methodology as derived here will depend upon the assumed uncertainty ranges for the different variables and parameters. Figure 6 presents a preliminary result of a sensitivity analysis on these results. In these graphs, the uncertainties are varied independently between the lower and upper boundaries of the ranges given above. These variations are applied in four groups of variables and parameters separately:

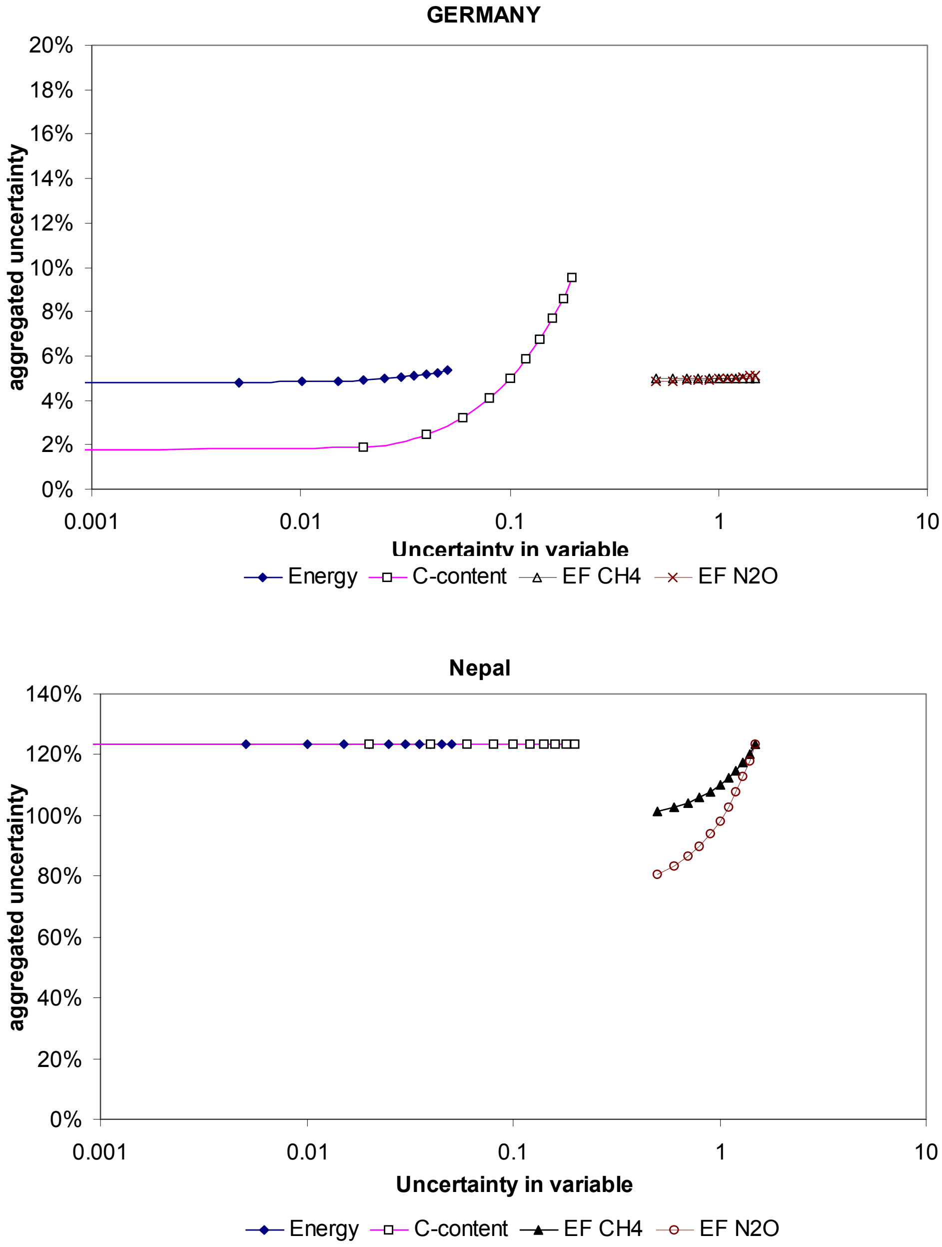
- the energy data;
- the C-content of the fuels (CO_2 emission factors);
- the emission factors for $CH_{4,}$ and

- the emission factors for N_2O

The following conclusions can be drawn:

- For Germany, the most sensitive variable is the C-content of the fuel. The uncertainty in the aggregated emissions for all fuel combustion at national level varies between 2 and 10 % when the uncertainty in the carbon content of the fuels varies between 1 and about 20 %. Varying the uncertainties for the other variables and parameters does not change total uncertainty dramatically
- Fur Nepal the result looks differently: the uncertainty in the total emissions of GHG by fuel combustion is rather insensitive to uncertainties in carbon content and data on the fuel used. The uncertainties in the emission factors of CH_4 and N_2O are more important. However the uncertainty remains in the same order of magnitude as the emission itself.

Figure 6 **Sensitivity analyses for assumed uncertainties in variables and parameters of the Reference Approach and Tier 1 emission estimation methods; further explanation in the text**



3.4 Trends and data updates: "updatability"

One of the issues, relevant for national communications, is the stability of the estimate for a certain year over time and developments in estimation methodologies. In many cases new information and new estimation methods emerge in the course of time. This means that, while progressing towards the years 2008 to 2012, when Parties to the convention have to show compliance with the Kyoto reduction targets, emission estimation methods might have been improved. Applying such improvements to the estimates of both reference year (1990 or 1995, "baseline determination") and base year of the communication might mean one or several of the following:

- the resulting emission estimates might be different from the one obtained with the "old" methodologies;
- the uncertainties in the estimates might have been changed, hopefully in the right direction (decreased), and

Referring to the fact that the inventories are used in National Communications to the UNFCCC Secretariat, the following possibilities could be distinguished:

- the inventory methods, used for the National Communication, should not be changed from the ones as used for the reference year, and
- once the methodology for a communication differs from the (original) one used for the reference year, these should be re-estimated, using the updated methodology.

Whenever information on the uncertainties in the inventory is available, this information could be used to estimate the probability that the emissions have been decreased to a preset target. A Tier 1 approach for such an analysis could again assume a normal distribution of errors in both the estimates for the reference year and the base year of the national communication. The probability of compliance then could be calculated as the overlap of the two error distribution functions.

It is clear that, if the target is a limited reduction relative to a reference year, and the uncertainty range in the inventory is large, this probability will only marginally deviate from 50 %, unless a drastic (equal to the uncertainty or more) reduction in emissions has occurred.

3.5 An Assessment of the proposed method

3.5.1 Introduction

In the previous chapter a method was described to assess the uncertainties in an emission inventory for fuel combustion. For two sample inventories based on a simple Reference Approach and Tier 1 methods (Germany and Nepal) this uncertainty estimation methodology was applied. This chapter will try to get a feeling for the uncertainties, using a completely different approach: a comparison will be made between the inventory data as reported by countries in their Second National Communications and emissions estimated using the Reference Approach and Tier 1 methods and IEA Energy statistics. The comparison is made for fuel combustion related activities only.

3.5.2 Method

A simplified IPCC Tier 1 methodology has been developed for estimation of non-CO_2 GHG emissions from fossil fuel combustion. This methodology enables countries with less extensive statistics to obtain a first order approximation of their emissions.

To obtain an idea of the applicability of the Tier I methodology, the emissions figures given in National GHG Inventories at hand (39 countries) were compared with the results of the Tier 1 methodology applied to the IEA databases.

It must be kept in mind that only limited conclusions can be derived from this comparison:

- Firstly, potential users of the Tier I methodology are all non-OECD countries. But most countries in this sample are OECD countries, whose combustion technology differs in general from the technology employed in non-OECD countries.
- Secondly, most of the developing countries in our sample used IPCC default Tier 2 emission factors to calculate national GHG emissions. These default emission factors are based on American and European emission measurements. The data comparison provides therefore more evidence of how well the Tier 1 emission factors compare to a part of the Tier 2 emission factors. It gives no real evidence of how the Tier I methodology compares to the "true" emissions in non-OECD countries.

The data used in this assessment are obtained from the sources as given in Table 5 and from the IEA Energy statistics. For most countries the base year 1990 has been used for the comparison, except when this year was not available in the national report.

TABLE 5

NATIONAL COMMUNICATIONS USED IN THE ASSESSMENT

Country	Data source
Australia	Electronic submission to the UNFCCC by Ian Carruthers, Executive Manager, Greenhouse Policy Group, Australian Greenhouse Office, September 1998.
Austria	Second National Climate Report of the Austrian Federal Government. June 1997.
Belgium	CCNUCC. Premiere Communication Nationale Belge conformement aux articles 4 et 12 de la convention. January 1997.
Bulgaria	The first national communication on climate change. February 1996.
Canada	Canada's Second National Report on Climate Change. November 1997.
Costa Rica	Country Case Study on Sources and Sinks of Greenhouse Gases in Costa Rica. Final Report. UNEP. May 1995.
Denmark	Denmark's Second National Communication on Climate Change. 1997.
Estonia	Estonian Second National Report under the UNFCCC. February 1998.
Finland	Second National Communication to the UNFCCC. 1997.
France	Second National Communication of France under the Climate Convention. November 1997.
Germany	Climate Protection in Germany.Second National report pursuant to the UNFCCC. April 1997.
Greece	Second National Communication to the UNFCCC. June 1997.
Hungary	Second National Communication on the Implementation of Commitments under the UNFCCC.
Ireland	Second National Communication under the UN FCCC.
Italy	First Italian National Communication to the Framework Convention on Climate Change.
Jordan	Initial Communication report under the UNFCCC. January 1997 (updated November 1997).
Kazakhstan	Initial National Communication of the Republic of Kazakhstan under the United Nations Framework Convention on Climate Change. 1998.
Korea	National Communication of the Republic of Korea. 1998.
Latvia	National Communication of the Republic of Latvia under UNFCCC. 1995.
Lithuania	The First National Communication of the Republic of Lithuania on Climate Change.
Luxembourg	Rapport National du Luxembourg en vue de la 1ère conférence des parties à la convention-cadre des Nations Unies sur les changements climatiques. March 1995.
Netherlands	Second Netherlands’s National Communication on Climate Change Policies. April 1997.
Norway	Norway's Second National Communication under the Framework Convention on Climate Change. April 1997.
New Zealand	Energy Greenhouse Gas Emissions 1990-1997. Ministry of Commerce. June 1998.
Poland	Second National Report to the Conference of Parties to the United Nations Framework Convention on Climate Change. 1998.
Portugal	Portuguese report in accordance with article 12 of the United Nations Framework Convention on Climate Change. 1994.
Romania	Inventory of Romania - Greenhouse Gas Emissions and Sinks 1989-1991. Ministry of Waters, Forests and Environmental Protection. December 1996.
Slovak Republic	Second National Communication of the Slovak Republic.
Spain	Segunda Communicatión Nacional de España.
Sweden	Sweden's Second National Communication on Climate Change.

TABLE 5 (CONTINUED)

NATIONAL COMMUNICATIONS USED IN THE ASSESSMENT

Country	Data source
Switzerland	Second National Communication of Switzerland. 1997.
Costa Rica	Country Case Study on Sources and Sinks of Greenhouse Gases in Costa Rica. Final Report. UNEP. February 1996.
UK	Climate Change, the UK Programme. The UK's second report under the UNFCCC.
Ukraine	Country Study on Climate Change in Ukraine. Development of Greenhouse Gas Inventory.
	US Country Study Management Team and the Agency for Rational Energy Use and Ecology. 1995.
USA	Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1996. US EPA. September 1998.
Venezuela	Country Case Study on Sources and Sinks of Greenhouse Gases in Venezuela. Final Report. UNEP. January 1995.
Zimbabwe	Zimbabwe's Initial National Communication on Climate Change. March 1998.

3.5.3 Results and conclusions

For most countries in our imperfect sample, the Tier 1 methodology was able to give a first order approximation of emissions from fuel combustion. A first order approximation is an estimate which is off by no more than a factor of 10.

The CH_4 and N_2O emissions from fuel combustion contributed in general little to the total national GWP-weighted GHG emissions: between 0.5% and 1%. However, there were some countries that reported a significant contribution of these emissions to the total national emissions, where the Tier 1 methodology estimated a low value.

For most countries in the sample, therefore, the Tier 1 methodology seemed to be able to provide an emissions estimate that is sufficient as a first impression, given the general low contribution to the total national GWP-weighted GHG emissions. But the Tier 1 methodology is not able to make precise emission estimates, or to verify an inventory in an accurate manner.

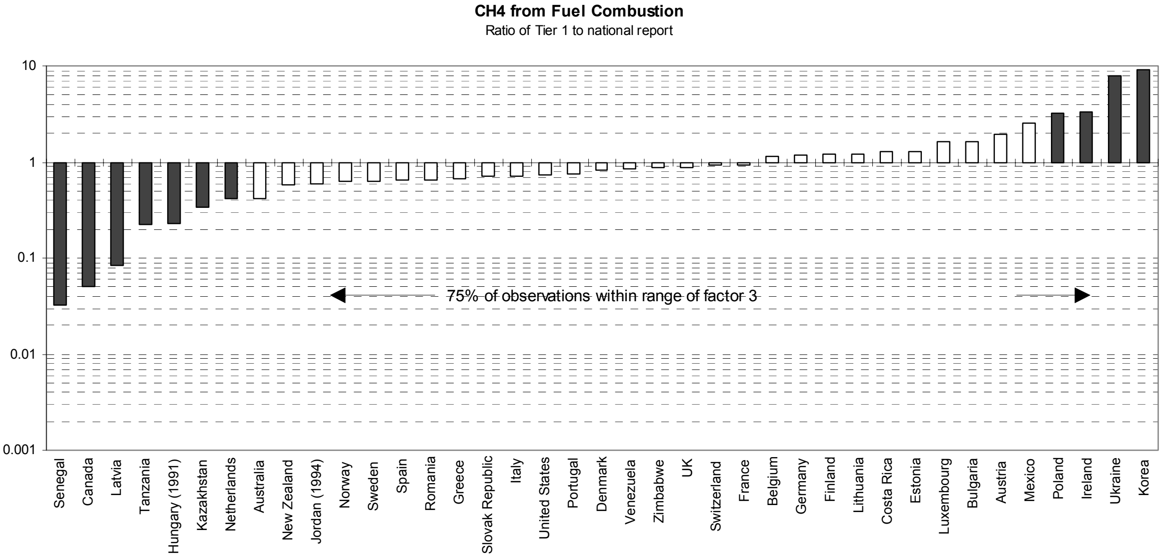
A comparison at a more detailed level might give some impression on the uncertainties in the estimated emissions. In Figure 7 the fuel combustion emissions of CH_4 and N_2O as estimated by a Tier 1 method are compared with the national communications. This figures shows that 75 % of the Tier 1 estimates of CH_4 and N_2O emissions deviate less than a factor of 3 and 7 respectively from the national communications. The uncertainties in these emissions as estimated in Table 6 are well within this range.

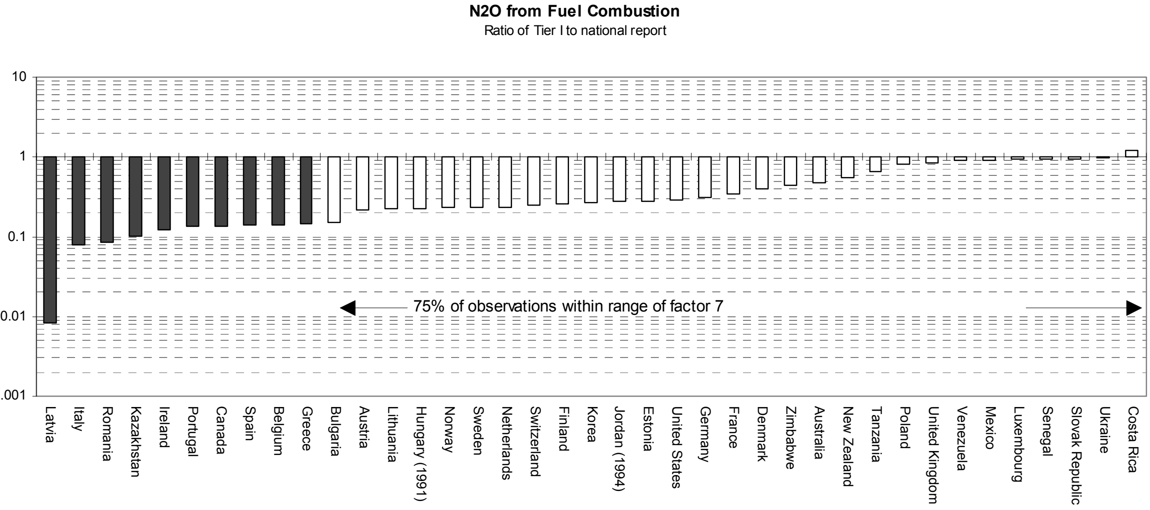
TABLE 6

UNCERTAINTY ANALYSES ON EMISSIONS OF FUEL COMBUSTION, CALCULATED FROM THE IEA ENERGY STATISTICS FOR 1990; USING THE REFERENCE APPROACH AND TIER 1 METHODOLOGY.

Country	Germany			Nepal		
Gas		Uncertainty			Uncertainty	
	Emission Gg CO_2 eq	Absolute Gg CO_2 eq	Relative	Emission Gg CO_2 eq.	Absolute Gg CO_2 eq	Relative
CO2	981.4	47.8	5%	0.6	0.1	12%
CH4	5.0	3.0	60%	1.5	1.7	118%
N2O	3.5	10.6	308%	0.3	2.3	777%
Total	990	49	5%	2.3	2.8	123%

Figure 7 **Comparison of Tier 1 estimates of methane and nitrous oxide emissions from fuel combustion and national communications for 1990**





3.6 Decision trees

In this chapter an analysis is presented, showing possibilities to assess the uncertainties in GHG emissions from fuel combustion. The analysis assumes a hierarchy on the quality of the input data for the emission estimate. This hierarchy is based upon the postulate that in all cases national data are better than default values. Both in the Reference Approach and in the Tier 1 methodology the basic formula given in section 3.1 should be applied and the hierarchy should be reflected in the way the input values for this formula are chosen. Figure 8 shows the resulting decision trees for both selecting fuel use data and emission factors.

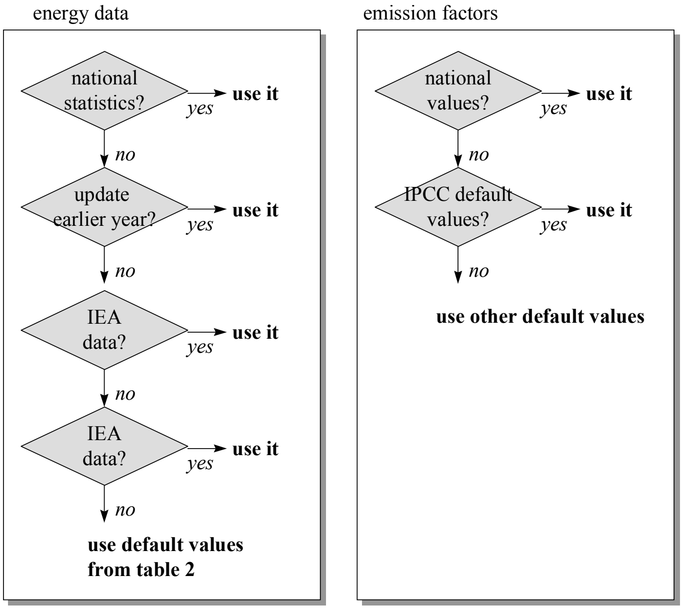
4 REPORTING AND DOCUMENTATION

In the above chapters a Tier 1 methodology for estimating uncertainties in greenhouse gas emissions due to fuel combustion is presented. Application of this methodology will result in a number describing the distribution function of possible errors in the emissions estimate. Since in this method not all assumptions underlying it will be correct, the number should not directly be interpreted as the standard deviation of (normally) distributed random errors around the averaged value. Because of that, estimating for instance the 90 % confidence interval as two times this number around the estimated emission value, will in many cases not be correct, especially when the resulting aggregated uncertainty estimate is relatively large (more than 30 to 50 %).

In the reporting format the estimated uncertainties could be added to the information on the emissions themselves, by simply adding a column in the relevant (summary) tables, where the numeric result of the Tier 1 uncertainty estimate could be placed.

Countries using different error ranges for input into the Tier 1 uncertainty analysis should be encouraged to report these values and the information on which they are based.

Figure 8 Decision tree for the estimation of GHG emissions from fuel combustion



5 CONCLUSIONS AND RECOMMENDATIONS

This paper shows that a relatively simple Tier 1 method to assess the uncertainties in estimates for the emissions of greenhouse gases due to the combustion of fuels is feasible. This method consists of the application of simple error propagation theory.

Simple error propagation theory assumes normal distributions of errors for all variables and parameters. Since this is not the case, the number obtained from applying this theory to an inventory should not be interpreted as the (exact) standard deviation of aggregated errors in the inventory. Instead the result should be regarded as an indicator of the uncertainty in the inventory.

Application of the proposed Tier 1 uncertainty estimation method to two national inventories, showed that:

- the numeric value of the uncertainty indicator is relatively insensitive to the exact assumptions of the error ranges in variables and parameters, when applied to a realistic GHG inventory, and
- the numeric value of the uncertainty indicator is of the same order of magnitude as the differences between emission estimates, published in Second National Inventories and estimates obtained from applying the Reference Approach and Tier 1 methods for the same countries

On the basis of these results, the paper proposes to apply this simple Tier 1 uncertainty analysis whenever a Reference Approach or a Tier 1 methodology is chosen to estimate GHG emissions.

In cases where national experts use more sophisticated emission estimation methodologies, it might be worthwhile to develop a more rigorous uncertainty analysis. Such an analysis might either be a more complicated mathematical error propagation theory, or obtained by simulations using a Monte Carlo approach.

Whereas it is not very “elegant” to apply a sophisticated uncertainty analysis to an emission estimate, obtained by using a simple methodology, the other way around is less of a problem. When an emission inventory is compiled, using higher Tier methodologies, the expert might still get a first impression of the uncertainties in it by applying a Tier 1 uncertainty analysis.

The results described in this paper yield the following recommendations:

- Assess the applicability of the proposed simple uncertainty analysis method in other source sectors those describing fuel combustion;
- Include the simple Tier 1 uncertainty estimation method, as derived here, into the reporting guidelines for UNFCCC as a minimum requirement to indicate the quality of the inventory;
- Encourage countries to provide information error ranges, used as input to the uncertainty analysis, and
- Assess the need for more complicated and sophisticated uncertainty analysis methods to accompany higher Tier emission estimation methods.

When national countries will use the uncertainty analyses as proposed in this paper, this will result in national communications that include information on the quality of the data. This information can be interpreted in the probability that the values are higher or lower than targets set by the protocols. If the distance between target and inventory result is large, these probabilities will be small. When however this distance is in the same order of magnitude or lower than the uncertainties, the probabilities might be quite high. This will most probably be the case in 2008 to 2012 for many Parties

It is not clear yet, how the conference of Parties can and should deal with such information when checking a Party's compliance with the Kyoto agreements. Different possibilities exist, all with different outcomes. To just name two extremes, coinciding with a position of "witness to the defence" or "witness to the prosecution":

- A country could show with 90 or 95 % confidence that the target is met, and
- The UNFCCC secretariat could prove with 90 or 95 % confidence that a country exceeds the target.

In the first case 90 or 95 % of the integrated error distribution should be below the target, in the second case 90 or 95 % should be above the target line. The second case is less stringent than the first. When the target line in itself has an uncertainty, the situation is a bit more complicated, but not essentially different.

Although a scientifically sound methodology cannot be fully designed before the Parties decide on how they want to use the information on uncertainties, it is clear, that the difference between the two extremes decreases when the uncertainties in both the target and the inventory decrease. Unless the uncertainties are decreased to zero, however, different positions of the compliance mechanism will yield different results in a compliance check.

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Appendix 1 Energy Use per Capita by Fuel Type for Different Countries

The following table shows that energy use per capita by fuel type differs considerably from country to country. Within regions, differences between the lowest and the highest value by fuel are often at least a factor 5 or more.

TABLE 7

TOTAL PRIMARY ENERGY SUPPLY/ POPULATION (1996)

(GJ / capita)	Coal	Oil	Gas	Combustible Renewables and Waste	(GJ / capita)	Coal	Oil	Gas	Combustible Renewables and Waste
Canada	36	111	98	12	Australia	93	85	38	11
Mexico	3	38	13	3	Japan	28	91	19	2
United States	78	131	79	11	Korea	28	93	10	1
OECD North America	56	107	64	9	New Zealand	14	70	50	8
Austria	18	61	35	12	OECD Pacific	34	90	19	3
Belgium	36	98	49	2	**OECD Total**	**40**	**81**	**40**	**6**
Czech Republic	84	33	31	2	Algeria	1	11	23	1
Denmark	71	80	29	12	Angola/Cabinda	-	4	1	18
Finland	60	77	24	43	Benin	-	1	-	13
France	12	65	23	8	Cameroon	-	1	-	13
Germany	46	71	38	2	Congo	-	5	0	13
Greece	32	61	0	2	Democratic Republic of Congo	0	1	-	11
Hungary	18	28	42	1	Egypt	0	16	8	1
Iceland	10	125	-	0	Ethiopia	-	1	-	11
Ireland	36	69	31	1	Gabon	-	23	2	31
Italy	8	68	34	1	Ghana	0	3	-	11
Luxembourg	49	190	61	3	Ivory Coast	-	4	-	11
Netherlands	25	71	101	2	Kenya	0	3	-	16
Norway	10	79	29	12	Libya	-	84	36	1
Poland	82	20	10	6	Morocco	3	10	0	1
Portugal	14	56	-	5	Mozambique	0	1	1	16
Spain	17	58	9	4	Nigeria	0	5	2	24
Sweden	15	79	3	36	Senegal	-	5	0	7
Switzerland	1	75	14	9	South Africa	83	9	2	13
Turkey	11	21	5	5	Sudan	-	2	-	14
United Kingdom	32	61	54	1	Tanzania	0	1	-	18
OECD Europe	**29**	**56**	**28**	**5**	Tunisia	0	16	9	5
					Zambia	0	3	-	21
					Zimbabwe	13	6	-	19
					Other Africa	0	2	0	13
					Africa	**5**	**5**	**2**	**13**

TABLE 7 (CONTINUED)

TOTAL PRIMARY ENERGY SUPPLY/ POPULATION (1996)

(GJ / capita)	Coal	Oil	Gas	Combustible Renewables and Waste	(GJ / capita)	Coal	Oil	Gas	Combustible Renewables and Waste
Argentina	1	28	33	3	Bangladesh	-	1	2	5
Bolivia	-	11	4	4	Brunei	-	84	397	3
Brazil	3	21	1	10	Hong Kong (China)	28	49	-	0
Chile	10	31	4	11	India	7	4	1	8
Colombia	4	16	5	8	Indonesia	2	10	7	9
Costa Rica	-	18	-	5	Malaysia	4	44	30	5
Cuba	0	39	0	21	Myanmar	0	1	1	9
Dominican Republic	0	19	-	7	Nepal	0	1	-	12
Ecuador	-	24	-	4	DPR of Korea	36	3	-	2
El Salvador	0	10	-	13	Pakistan	1	5	4	7
Guatemala	-	8	-	11	Philippines	1	11	0	6
Haiti	-	2	-	9	Singapore	0	310	18	-
Honduras	0	8	-	10	Sri Lanka	0	6	-	9
Jamaica	1	51	-	9	Chinese Taipei	38	65	7	0
Netherlands Antilles	-	552	-	-	Thailand	6	27	7	15
Nicaragua	-	8	-	11	Viet Nam	2	3	2	12
Panama	1	23	-	9	Other Asia	0	3	0	4
Paraguay	-	9	-	22	China	23	6	1	7
Peru	1	13	1	7	**Asia**	**12**	**7**	**2**	**8**
Trinidad/Tobago	-	47	207	1					
Uruguay	-	25	-	7					
Venezuela	0	44	49	1					
Other Latin America	0	51	0	7					
Latin America	**2**	**22**	**8**	**9**					

TABLE 7 (CONTINUED)
TOTAL PRIMARY ENERGY SUPPLY/ POPULATION (1996)

(GJ / capita)	Coal	Oil	Gas	Combustible Renewables and Waste	(GJ / capita)	Coal	Oil	Gas	Combustible Renewables and Waste
Albania	0	7	0	1	Armenia	0	2	10	0
Bulgaria	36	28	23	1	Azerbaijan	0	36	28	0
Cyprus	1	119	-	1	Belarus	5	41	48	2
Gibraltar	-	193	-	-	Estonia	107	26	18	11
Malta	-	100	-	-	Georgia	1	1	6	0
Romania	18	24	36	3	Kazakhstan	63	24	20	0
Slovak Republic	39	27	42	1	Kyrgyzstan	5	5	8	0
Bosnia-Herzegovina	5	12	3	2	Latvia	4	35	15	10
Croatia	2	30	18	2	Lithuania	2	34	25	3
Former Yugoslav Republic of Macedonia	35	32	-	4	Moldova	5	9	28	0
Slovenia	24	57	14	6	Russia	29	37	92	5
Federal Republic of Yugoslavia	33	11	9	1	Tajikistan	0	9	7	-
Former Yugoslavia	21	21	9	2	Turkmenistan	0	30	82	-
Non-OECD Europe	**22**	**24**	**23**	**2**	Ukraine	36	15	58	0
Bahrain	-	90	368	-	Uzbekistan	2	12	61	0
Iran	1	37	21	0	Former USSR	25	28	68	3
Iraq	-	42	6	0	**World**	**16**	**24**	**14**	**8**
Israel	36	80	0	0					
Jordan	-	42	2	0					
Kuwait	-	256	109	0					
Lebanon	1	45	-	1					
Oman	-		40	-					
Qatar	-	65	491	0					
Saudi Arabia	-	122	77	0					
Syria	0	34	6	0					
United Arab Emirates	-	162	372	0					
Yemen	-	8	-	0					
Middle East	**2**	**52**	**31**	**0**					

Appendix 2 Activity hierarchy in IEA database

The table below, presents the structure of the activities ("flows") as defined in the IEA energy statistics data.

- "IEA Flow (database)" represent the flows used in the electronic database obtained from IEA (1993 version)
- "IEA Flow (report)" is the range of basic "Supply and Consumption" items l;isted vertically in the "Annual Tables" of the Energy statistics of OECD countries report (1992-1993 issue)
- "FlowGroup_Name" are the bold capital printed items in the same tables.
- "FlowTypes" represent basically different functions of the energy flow within the countries energy system. For this report "combustion" is important.

The only item, that is difficult to interpret in the above way, is the item "Statistical Differences". Basically this item represents a mismatch between two more or less independent estimates of total energy flows in the country.

TABLE 8

STRUCTURE OF ACTIVITES AS DEFINED IN THE IEA STATISTICS DATA

FlowType_Name	FlowGroup_Name	IEA Flow (report)	flow	IEA Flow (database)
Combustion	Energy Sector	Coal mines	EMI	Coal mines
		Electricity, CHP + heat plants	ENU	Nuclear industry
			POW	Electricity, CHP and heat plants
		Oil and gas extraction	OGX	Oil and gas extraction
		Other energy sector	EBK	Lignite briquettes plants
			ECK	Coke ovens
			EGA	Gas works
			ENO	Non-specified energy sector
			EPA	Patent fuel plants
		Petroleum refineries energy	ERE	Oil refineries
		Pumped storage	HYP	Pumped hydroproduction
			PUM	Pumped storage
	Industry Sector	Chemical and petrochemical	CHE	Chemical and petrochemical
		Construction	CON	Construction
		Food and tobacco	FOO	Food and tobacco
		Iron and steel	IRO	Iron and steel
		Machinery	MAC	Machinery
		Mining and quarrying	MIN	Mining and quarrying
		Non-ferrous metals	NFE	Non-ferrous metals
		Non-metalic minerals	NME	Non-metallic minerals
		Non-specified industry	INO	Non-specified industry
		Paper pulp and print	PAP	Paper, pulp and printing
		Textile and leather	TEX	Textiles and leather
		Transport equipment	TEQ	Transportation equipment
		Wood and wood products	WOO	Wood and wood products

TABLE 8 (CONTINUED)
STRUCTURE OF ACTIVITES AS DEFINED IN THE IEA STATISTICS DATA

FlowType_Name	FlowGroup_Name	IEA Flow (report)	flow	IEA Flow (database)
Combustion (continued)	Other Sectors	Agriculture	AGR	Agriculture
		Commerce and publ. serv.	COM	Commercial and public services
		Non-specified other	ONO	Non-specified other
		Residential	RES	Residential
	Transformation (electricity heat))	CHP plants	AHP	Autoproducer cogeneration plants
			CHP	Public cogeneration plants
		Electricity plants	AEL	Autoproducer electricity plants
			PEL	Public electricity plants
		Heat plants	AHE	Autoproducer heat plants
			PHE	Public heat plants
	Transport Sector	Domestic air	DOA	Domestic air transport
		Internal navigation	ILW	Internal navigation
		International civil aviation	INT	International air transport
		Non-specified transport	TRN	Non-specified transport
		Pipeline transport	PIP	Pipeline transport
		Rail	RAI	Rail transport
		Road	ROA	Road transport
Conversion	Distribution losses	Distribution losses	LOS	Distribution losses
	Transformation (conversion)	Liquefaction	LIQ	Liquefaction
		Other transformation sector	TNO	Non-specified transformation
		Petrochemical industry	PET	Petrochemical industry
		Petroleum refineries transformation	TRE	Petroleum refineries
		Transfer to gases	BLA	Blast furnaces
			TGA	Gas works
		Transfer to solids	TBK	Lignite briquettes plants
			TCK	Coke ovens
			TPA	Patent fuel plants
Non Energy Use	Non-Energy Use	Non-energy in industry	NEI	Non-energy use in industry
		Non-energy in other sectors	NEO	Non-energy use in other sectors
		Non-energy in transport	NET	Non-energy use in transport
Production	Domestic Supply	Exports	EXP	Exports
		From other sources	OSO	Other Sources
		Imports	IMP	Imports
		Intl. marine bunkers	BUN	International marine bunkers
		Production	PRO	Indigenous production
		Stock changes	STO	Stock changes
	Statistical differences	Statistical differences	STA	Statistical differences
	Transfers	Transfers	TFS	Transfers

Appendix 3 Fuel hierarchy in IEA database

The table below, presents the structure of the "fuels" as defined in the IEA energy statistics data.

- "IEA Fuel (database)" represent the fuels used in the electronic database obtained from IEA (1993 version)
- "IEA Fuel (report)" is the range of basic items listed horizontally in the "Annual Tables" of the Energy statistics of OECD countries report (1992-1993 issue)
- "FuelTypes" represent the summarising fuels defined in the same tables.

TABLE 9

THE STRUCTURE OF THE "FUELS" AS DEFINED IN THE IEA ENERGY STATISTICS DATA

Fuel type (IEA report)	IEA fuel (report)	fuel	IEA fuel (database)	Unit
Coal (1000 tonnes)	Coking coal	CKC	Coking coal	Gg (=kTon)
	Lignite	LIG	Lignite	Gg (=kTon)
	Oven and gas coke	GCK	Gas coke	Gg (=kTon)
	Oven and gas coke	OCK	Coke-oven coke and lignite coke	Gg (=kTon)
	Pat.fuel and BKB	BKB	Lignite briquetes (BKB)	Gg (=kTon)
	Pat.fuel and BKB	PAT	Patent fuel	Gg (=kTon)
	Peat	PEA	Peat	Gg (=kTon)
	Steam coal	BTC	Anthracite and bituminous coal	Gg (=kTon)
	Sub.-bit. Coal	SBC	Sub-bituminous coal	Gg (=kTon)
Oil (1000 tons)	Additives	ADD	Additives / blending components	Gg (=kTon)
	Aviation gasoline	AVG	Aviation Gasoline	Gg (=kTon)
	Crude oil	CRU	Crude oil	Gg (=kTon)
	Crude oil	NCR	Inputs other than crude or NGL	Gg (=kTon)
	Feedstocks	RFD	Refinery feedstocks	Gg (=kTon)
	Gas/Diesel	DIE	Gas / Diesel oil	Gg (=kTon)
	Heavy fuel oil	HFO	Heavy fuel oil	Gg (=kTon)
	Jet fuel	JET	Jet fuel	Gg (=kTon)
	Kerosene	OKE	Other kerosine	Gg (=kTon)
	LPG + Ethane	ETH	Ethane	Gg (=kTon)
	LPG + Ethane	LPG	Liquified petroleum gas	Gg (=kTon)
	Motor gasoline	MOG	Motor gasoline	Gg (=kTon)
	Naphtha	NAP	Naphta	Gg (=kTon)
	NGL	NGL	Natural gas liquid	Gg (=kTon)
	Other prod.	BIT	Bitumen	Gg (=kTon)
	Other prod.	LIF	Liquid fuel for electricity / heat output	Gg (=kTon)
	Other prod.	LUB	Lubricants	Gg (=kTon)
	Other prod.	OPR	Other petroleum products	Gg (=kTon)
	Other prod.	PWX	Paraffin waxes	Gg (=kTon)
	Other prod.	WSP	White spirit and SBP	Gg (=kTon)
	Petrol. Coke	PCK	Petroleum coke	Gg (=kTon)
	Refinery gas	RGS	Refinery gas	Gg (=kTon)

TABLE 9 (CONTINUED)
THE STRUCTURE OF THE "FUELS" AS DEFINED IN THE IEA ENERGY STATISTICS DATA

Fuel type (IEA report)	IEA fuel (report)	fuel	IEA fuel (database)	Unit
Gas (TJ)	Blast furnaces	BGS	Blast furnace gas	TJ
	Blast furnaces	SGS	Oxygen steel furnace gas	TJ
	Coke Ovens	OGS	Coke oven gas	TJ
	Gas works	GGS	Gas works gas	TJ
	Natural gas	NGS	Natural gas	TJ
Combust. Renew. & Waste (TJ)	Gas/Liquids from biomass	GLB	Gas / liquids from biomass	TJ
	Industrial waste	IWS	Industrial wastes	TJ
	Municipal waste	MWS	Municipal wastes	TJ
	Solid biomass & anim.prod.	SBI	Solid biomass and animal products	TJ
Electricity (GWh)	Electricity	ELE	Electricity	GWh
Heat (TJ)	Heat	HEA	Heat	TJ