Uncertainty analysis of Dutch greenhouse gas emission data, a first qualitative and quantitative (TIER 2) analysis

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Abstract

This paper presents the main findings of a research project to determine the uncertainties in the Dutch emissions using a TIER 2 method to investigate the viability of this approach. A typology of uncertainty is used to describe the underlying sources of uncertainty and the results for CO_2 and for N_20 emissions are presented. The quantitative results for 1990 and for the trend 1990-1999 are based on Monte Carlo uncertainly analysis and include standard b coefficient. The major key sources TIER 2 are quit different for those in the TIER 1. As data are now under recalculation it is expected that the uncertainties will change and that the experiences will be used in an update of a TIER 2 analysis that might be conducted in 2005.

1 Introduction

For many years now the Netherlands has used a pollutant emission inventory system that collects data on emissions to air, water and soil. This system is also used for reporting the greenhouse gas (GHG) emissions the UNFCCC. In 2002, within the framework of the Greenhouse Gas Inventory Programme, a project 'Sources of Uncertainties in the Dutch Emission Registration' was commissioned. The broad objective was to investigate the viability of the TIER 2 uncertainty approach within uncertainty management related to the annual production of the National Inventory Report (NIR) in the Netherlands.

We start with the results from the qualitative study and introduce the typology of uncertainty that was use to describe the qualitative uncertainties for the major greenhouse gas emissions that are presented in section two for the two major GHGs. In section three we deal with some of the quantitative results from the project. The analysis is based on data from 1990 and 1999 as used for the NIR 2001. Some data has been recalculated afterwards and at the moment addition recalculation is under way for industrial and feedstock emissions. This should be kept in mind when interpreting and using the results as presented here. In the project the quantitative TIER 2 analysis results are compared with uncertainty estimates using the TIER 1 approach, but these are not presented in this paper, as these were to stimulate further discussions and improvements in this regard within the Netherlands. In section four we summaries the key sources for the TIER 1 and TIER 2 analysis and we end with some conclusions.

2 Qualitative analysis

The qualitative information was collected using literature searches and through a series of structured interviews and a workshop with emission inventory experts. To structure the qualitative uncertainties a new typology was used.

2.1 Typology of uncertainty used in the qualitative study

The qualitative study aimed to identify the underlying sources of uncertainty in the Dutch national greenhouse gas emissions inventories. Researchers of the qualitative study used the 'typology of uncertainty', to identify the underlying sources of uncertainty [1]. This is a fundamentally different way of identifying uncertainty. While quantitative methods such as TIER 1 and TIER 2 focus on the **amount** of uncertainty, the typology of uncertainty focuses on the underlying **sources** of uncertainty.

At the highest level of aggregation, this typology defines two types of uncertainty: uncertainty due to variability (see Figure 1, left side) and uncertainty due to limited knowledge (see Figure 1, right side).

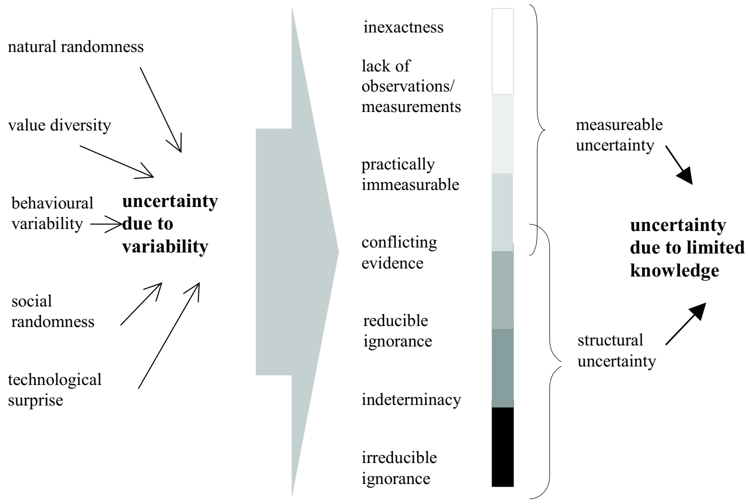

Figure 1: Typology of uncertainty

On the second level of aggregation, these two types of uncertainty have distinctly different sources that make it possible to qualify the origin of uncertainty. The first type, uncertainty due to variability, contains five distinctly different sources: natural randomness, value diversity, behavioural variability, social randomness and technological surprise. The second type, uncertainty due to limited knowledge, contains seven distinctly different categories: inexactness, lack of observations/measurements and practically immeasurable uncertainty (these three categories are also known as 'measurable uncertainty'), conflicting evidence, reducible ignorance, indeterminacy and irreducible ignorance (the last three categories are also known as 'structural uncertainty').

2.2 Qualitative results

The uncertainties in a qualitative sense are conducted for the four important greenhouse gases (CO_2, N_2O, CH_4 and the F-gases) [2]. We restrict us in this paper to CO_2 and N_2O, using the typology of uncertainty and the scheme as presented ahead to illustrate the relationship between the various categories. The following figures include the abbreviations AD (activity data), EF (emission factor) and EM (emissions).

Uncertainties in the **CO_2 emissions** are well known and can be characterised to a large extent as 'measurable uncertainty'. The results show that where oil and natural gas are used as basic materials for synthetics, this concerns a complex chemical process that is often not easy for 'outsiders' to understand. In many other cases the carbon content of the material or the fuel generally gives enough information to determine the *emission factor* (see Figure 2). However, this does not mean that the emission factor can always be clearly determined. With the stationary burning of natural gas this is not very practical, because a mixture is used in locally changing compositions with different carbon contents and this carbon percentage is sensitive information in the corporate environment.

The uncertainties in the *activity data* appear to be connected to the large amounts and thus to the mathematical statistics. A spot check is generally employed to see if there is a gap between a top-down and a bottom-up approach, for example as a result of insufficient information about the size of imports and exports. However, the total amount of natural gas consumed is an exception as this depends on the measuring point (distributor or consumer) and the choice for one (or both) seems to be scientifically based.

The *emission* from cement production and other industrial sources produces a relationship between an indirect measuring of the total carbon amount/content (end product or disposal) and the activities data/information (produced volume). This relationship is not clear for cement production, so that an uncertainty concerning the size of the loss during the production process will still exist. The result is a sort of paradox in which a lot of information regarding a relatively simple process exists, yet appears insufficient to provide a real grip on a structural certainty.

The uncertainty in the reported values of a large number of the **N_2O emission** sources is characterised by the experts as 'structural uncertainty' as well as 'measurable uncertainty'. The former can often be attributed to the unfamiliarity of the process; i.e. the process itself is a black box. It is then often a matter of different circumstances for which the influence on the process is not (entirely) known. However, since a lot of measurements can be taken to determine the final emissions, there is also the question of 'measurable uncertainty'.

Because the (road) vehicles and the agriculture emission measurements only determine an emission factor and not the total emission, the question arises as to how universal these emission factors are, and if they give judgement on a real

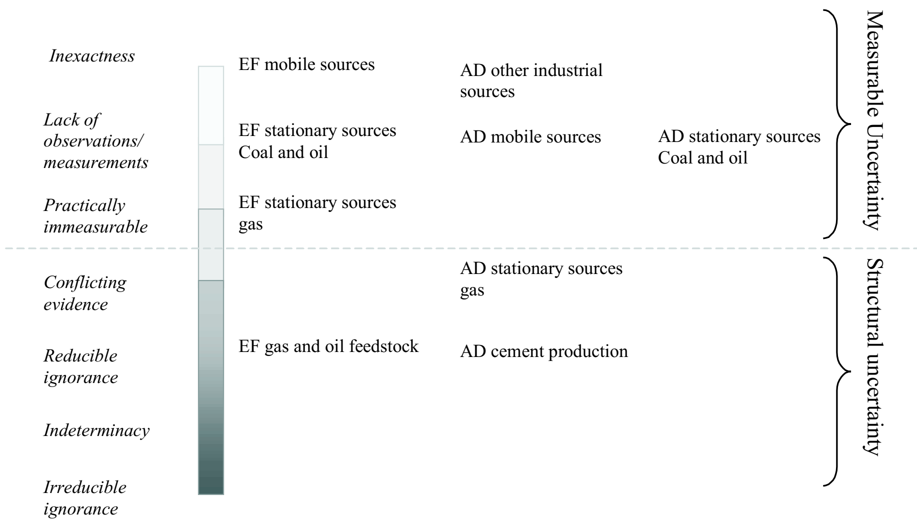

Figure 2: Qualitative uncertainties for CO_2 emissions

differentiation of activities data. This is currently also the case for stationary burning, but basically a direct measuring here is possible, as with the production of nitrous acid.

The question of possibilities for the ameliorations cannot be clearly answered, because it is a part of the aforementioned scientific debate/discussion. The other 'basic/structural uncertainty' is, as mentioned, the result of the 'uncertainty through variability' known as human activities/behaviour (activities data mobile sources/ (road) vehicles).

2.3 Conclusions regarding qualitative uncertainty

The researched contribution to the uncertainty in the total greenhouse gas emissions in the Netherlands, show that the experts consulted for most of the factors consider 'unreliability' to be the nature of the uncertainty. Closer qualification shows that the greater part of the factors studied by the experts are attributed to 'inaccurate data' and 'a shortage of measurements'. This implies that a new collection of data could contribute significantly to reducing the reported uncertainty in Dutch emission statistics.

It is generally assumed that uncertainty as a result of 'inaccuracy', 'shortage of measurements' and 'impracticability' can be better estimated by using statistical techniques. However, uncertainty arising from 'conflicting information', 'ignorance' and 'unreliability' are generally a lot harder to qualify - these kinds of uncertainties have a connection with, for example, if and how much the supposed causal relation is true. This does not necessarily mean that the degree of uncertainty is greater, but it does mean that if uncertainties of this kind have considerable influence on the main key sources, then these uncertainties cannot be included (in the quantitative sense) in either a TIER 1 or TIER 2 analysis. In that case the calculated 95% interval gives an overly positive picture in relation

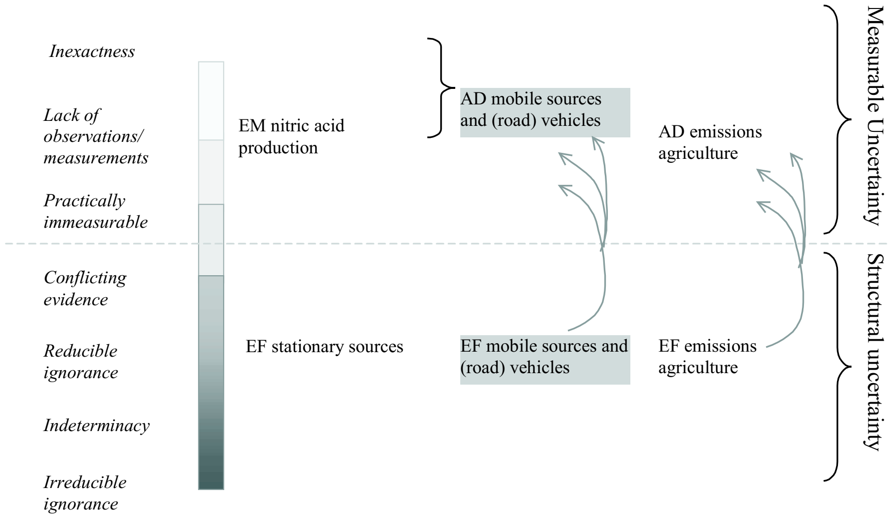

Figure 3: Qualitative uncertainties for N_2O emissions

to the actual uncertainty, which cannot be expressed qualitatively.

3 Quantitative results of TIER 2

The first body of work constituted the collection of information with respect to the various aspects of uncertainty in the inventory. Examples of such aspects are the uncertainties in the quantitative sense (probability density functions for every variable of the emission model) and the underlying sources of these uncertainties [3]. Here we present the pdf's for total GHG emissions for 1990 and 1990-1999. As this was the first time a TIER 2 quantitative analysis had been conducted, several assumptions had to be made regarding the data and the model, particularly the IPCC source category 1A and feedstock emissions. The analysis is based on data from 1990 and 1999 as used for the NIR 2001. Some data has been recalculated afterwards and at the moment addition recalculation is under way for industrial and feedstock emissions. This should be kept in mind when interpreting and using the results as presented here. The quantitative TIER 2 analysis results are compared with uncertainty estimates using the TIER 1 approach, but these are not presented in this paper, as these were to stimulate further discussions and improvements in this regard within the Netherlands.

3.1 Results of TIER 2 for the years 1999 and 1990

The outcomes of the TIER 2 uncertainty analysis [3] for the total emissions in 1999 (230 Mtonnes) are presented in Figure 4 and consist of overall:

- Uncertainty: 3.6%;
- Range of 95% confidence: 222-238 Mtonnes;

- Standard deviation: 4.097 Mtonnes.

The uncertainties for the greenhouse gases range from almost 30% (N_2O: 29.3%) to less than 2%, (CO_2: 1.6%), while those for CH_4 and for F-gases are 14.6% and 20.0% respectively.

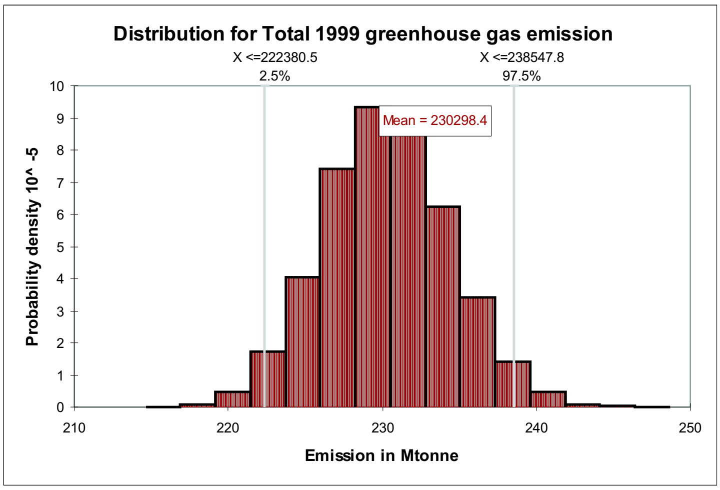

Figure 4: Probability density of greenhouse gas emissions 1999

For the year 1990 the outcome of the TIER 2 uncertainty analysis for the total emissions amounts to 218 Mtonnes. The overall uncertainty (3.4%) is only slightly less than for the year 1999. As the standard deviation is 3.719 Mtonnes, the overall range of 95% confidence is 210-225 Mtonnes. This lower uncertainty is mainly due to the change in contribution, particularly the 1999 N_2O emission from manure management.

The Monte Carlo uncertainly analysis results include the so-called standard β coefficient, which indicates how sensitive the output (i.e. the emission or trend) is to the value of an emission model input. Table 1 shows the highest coefficient values for the years 1999 and 1990. This shows that for both years the 1990 emissions of nitric acid production produces a much higher coefficient than the other variables. It also shows that it is the variables relating to non-CO_2 gases that produce the highest values.

3.2 Results of TIER 2 trend (1990-1999)

The total emission increased by 5.8% between 1990 and 1999. The 90% confidence represents an increase from 3.5% to 8.6%. Figure 5 shows the probability density function of the emissions trend (i.e. the percentage change of 1999 emissions relative to those of the base year(s). The uncertainty in the trend itself is lower (2.6%).

The standard β coefficients are also calculated for the trend. Again there are two variables with a value higher than 0.3. The main variable concerns the emission factors for N_2O emissions from the use of manure (coefficient value 0.584). Although the emission from this activity (emissions from animal wastes applied to soils) is only minor (0.8% and 1.4% of all emissions in 1990 and 1999

Ranking		Variable	Standard β coefficients	
1999	1990		1999	1990
1	1	1990 emissions for nitric acid production (N_2O)	0.592	0.554
2	9	Emission factor manure/slurry injected/incorporated into fields (N_2O)	0.409	0.182
3	2	Polluted surface water E-factor	0.286	0.317
4	6	HCFC-22 manufacturing 1995 (HFC-23)	0.225	0.218
5	3	Fraction organic carbon reacting to gaseous material (methane landfills)	0.183	0.257
6	10	Measured gross emission grassland (N_2O)	0.161	0.179
15	4	Organic C-content of waste that is landfilled	0.100	0.251
>26	5	Domestic consumption of oil and oil products (CO_2)	<0.050	0.234

Table 1: Sensitivity of GHG emissions to input in the emission model, 1999 and 1990

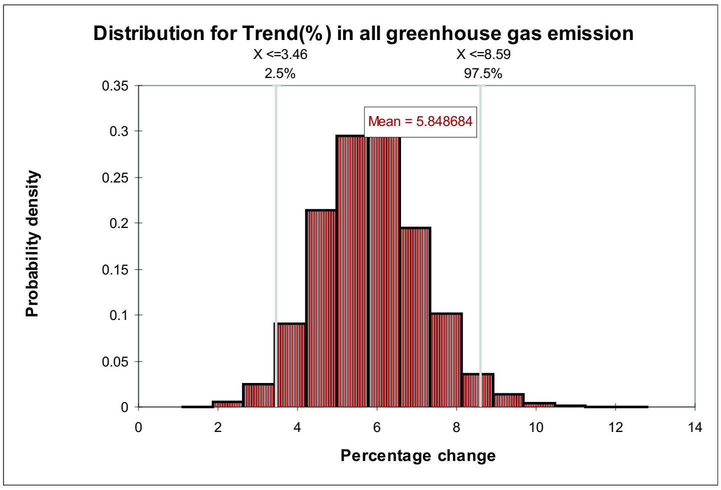

Figure 5: Probability density function of the 1990/1995-1999 trend (%) in greenhouse gas emissions

respectively), it is important to the trend for two reasons. Firstly, the uncertainty in the emissions factors is high and it is assumed that the uncertainties in both factors are not correlated. The second variable concerns domestic consumption of oil and oil products in 1990 (-0.328), due to the high uncertainty (in the absolute sense) in energy consumption, which has a significant impact on overall uncertainty. The uncertainties in fuel use were also assumed to be unrelated over time.

Variable	Standard β coefficient
N_2O emission factor manure/slurry injected/incorporated into fields	0.584
Domestic consumption of oil and oil products 1990 (PJ)	-0.328
Total consumption natural gas 1990 (PJ)	-0.284
N_2O emission factor manure/slurry on mineral soils (%N), if spread over land	-0.246
Consumption by oil refineries (PJ) 1999 /	0.221
Export of natural gas 1999 (PJ) / (Gg)	-0.210
Organic C-content of waste that is landfilled (kg/tonne)	-0.208
B 1999 oil and oil products (PJ)	-0.207

Table 2: Sensitivity of the 1990-1999 trend in greenhouse gas emissions

4 Key sources TIER 1 and TIER 2

This section presents the results related tot the key sources for the TIER 1 analysis as included in the NIR 2001 [4] combined with the results of the TIER 2 analysis [3].

4.1 Different key sources for TIER 1 and TIER 2

The NIR 2001 [4] presents the results according to the TIER 1 approach to registration of the greenhouse gases in the year 1999 en for the trend 1900-1999. The research study results is key sources using a TIER 2 approach. Table 5 gives an overall view of the ranking of all gases and sources of the two TIER methods.

The first row, for example, shows that N_2O emissions from nitric acid production are the most contributing source of uncertainty in the Dutch emission inventory, according to both TIER 1 and TIER 2 approaches for the year 1990. The percentage given in the first column is the TIER 1 uncertainty as a percentage of total national emissions (1999). The next cell in this row shows that 'N_2O emissions from nitric acid production' are ranked fifth (5^{th} place) according to the TIER 1 approach for the trend 1990-1999. The last cell is empty, because this N_2O source was not mentioned in the top seven ranking of the TIER 2 approach for the trend 1990-1999.

There are only two key sources that are included two or three times in the top seven of the four uncertainty analyses, and only one is related to CO_2. These are:

Three times: N_2O: emissions from nitric acid production;
HFC: HFC-23 emission from HCFC-22 manufacture.
CO_2: emissions from stationary combustion: gas.

Twice: N_2O: emission factor manure/slurry injected/incorporated into the fields;
CO_2: emissions from stationary combustion: gas.

For the year 1999 three out of seven key sources are the same for both the TIER 1 and TIER 2 uncertainty analyses, i.e. emissions from nitric acid production, HFC-23 emission from HCFC-22 manufacture (both have already been mentioned), and polluted surface water (N_2O emission). For the trend, none of the seven TIER 1 key sources was the same as for TIER 2.

Some additional data for N_2O Emissions from nitric acid production (row 1) are following. The emission uncertainty for 1999 is more or less the same for TIER 1 and 2 (51% and 50%). The TIER 2: standard b coefficient for the year 1999 is 0.592. The combined uncertainty in the TIER 1 trend is 0.85% while this for CO_2 Emissions from stationary combustion 1.5% is. More figures are presented in [5].

5 Conclusions

The majority of the uncertainties in the greenhouse gas emissions are caused by 'measurable uncertainty' and only a small part is caused by 'structural uncertainty'.

The result of the present analysis points to considerable uncertainty in assessing the changes in emissions. This uncertainty is partly due to certain emission processes that have changed over the years (e.g. emissions from the application of manure). Efforts to reduce uncertainty in the trend of emissions research should also pay specific attention to this type of base year emissions. The qualitative component of the project resulted in estimation of uncertainties by experts, but also (and more valuable) in insight into the sources of these uncertainties. This insight can also be used to manage reductions in uncertainties.

Major results of the TIER 2 uncertainty analyses that have been performed are the calculations of the Standard β coefficient for the variables and parameters of the emission models. These lists can be seen as an additional justification and guidance for current research programmes that include research to assess emissions more effectively.

The quantitative results has to be use with restriction. This was the first in-depth discussion on uncertainties and it showed that experts often hold conflicting opinions. Recent research and surveys also provided new useful results relating to uncertainties, especially as a recalculation of fuel combustion emissions resulting in a change of several Mton CO_2 is undertaken. The Greenhouse Gas Inventory Programme continues to commission improvement projects. For example, after the TIER 2 analysis was conducted, a study into updated emission factors for fuels was finalised, as well as a study on feedstock. As part of the development of a National System a process has now been started to improve the documentation of greenhouse gas emissions using specific monitoring

Gas	Source	Year 1999		trend 1990-1999	
		TIER 1	TIER 2	TIER 1	TIER 2
N_2O	Emissions from nitric acid production (2.5%)	1^{st} place	1^{st} place	5^{th} place	-
N_2O	Direct N_2O emissions from agricultural soils (1.7%)	2^{nd} place	-	-	-
CH_4	CH_4 emissions from solid waste disposal sites (1.3%)	3^{rd} place	-	-	-
N_2O	Indirect N_2O emissions from nitrogen used in agriculture (1.3%)	4^{th} place	-	-	-
N_2O	Polluted surface water (1.1%)	5^{th} place	3^{rd} place	-	-
CO_2	Emissions from stationary combustion: gas (1.0%)	6^{th} place	-	1^{st} place	-
HFC	HFC-23 emission from HCFC-22 manufacture (1.0%)	7^{th} place	4^{th} place	6^{th} place	-
N_2O	Emission factor manure/slurry injected/incorporated into the fields	-	2^{nd} place	-	1^{st} place
N_2O	Polluted surface water. E-factor (kg N_2O per kg N)	-	3^{rd} place	-	-
CH_4	Fraction of organic carbon reacting to gaseous material	-	5^{th} place	-	-
N_2O	Measured gross emission grassland	-	6^{th} place	-	-
N_2O	Emission factor (as N) from use of fertiliser		7^{th} place		
CH_4	CH_4 emissions from solid waste disposal sites (1.0%)	-	-	2^{nd} place	-
CO_2	Misc. CO_2 (0.9%)	-	-	3^{rd} place	-
CO_2	Mobile combustion: other (0.8%)	-	-	4^{th} place	-
CO_2	Emissions from stationary combustion: coal (0.6%)	-	-	7^{th} place	-
CO_2	Domestic consumption oil and oil products (1990)	-	-	-	2^{nd} place

CO_2	Total consumption natural gas PJ 1990	-	-	-	3^{rd} place
N_2O	Emission factor manure/slurry on mineral soil (%N), if spread	-	-	-	4^{th} place
CO_2	Consumption of Oil Refineries (PJ) 1999	-	-	-	5^{th} place
CO_2	Export of natural gas 1999 (PJ/Gg)	-	-	-	6^{th} place
CH_4	Organic C-content of waste that is landfilled (kg/tonne)	-	-	-	7^{th} place

Table 3: Combination of key sources

protocols. Uncertainties are a special subject within these protocols, and the PDFs and underlying sources of uncertainties (as used in the TIER 2 analysis), will be discussed by the task force that approves the monitoring protocols. An update of the TIER 2 analysis for the year 2005 using more actual data is now under discussion.

References

[1] Asselt, M.B.A. van, (2000), Perspectives on Uncertainty and Risk: The Prima Approach to Decision Support, Kluwer, Dordrecht, The Netherlands

[2] International Centre for Integrative Studies (ICIS) (2002), Discussiememo, Bronnen van onzekerheid in de Nederlandse emissieregistratie: een kwalitatieve analyse, July 2002 Universiteit Maastricht, The Netherlands (in Dutch).

[3] Olsthoorn, X, A. Pielaat (2003), TIER 2 uncertainty analysis of greenhouse gas emissions in the Netherlands, Institute for Environmental Studies (IVM), Report R-03/06 June 2003, Vrije Universiteit Amsterdam, The Netherlands.

[4] Olivier, J.G.J. et al. (2001), Greenhouse Gas Emissions in the Netherlands 1990-1999. National Inventory Report 2001, RIVM, Bilthoven, The Netherlands.

[5] Vreuls, H.H.J. (2004), Uncertainty analysis of Dutch greenhouse gas emission data, a first qualitative and quantitative (TIER 2) analysis, SenterNovem, The Netherlands