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Uncertainties in Emissions of Long-Range Air Pollutants

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Abstract

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Stochastic simulations have been used to estimate the uncertainty of the pollutants SO_2, NO_x, NMVOC and NH_3 in the official Norwegian emission inventory. The relative uncertainty in emission level is lowest for SO_2, 4-5 per cent, and highest for NMVOC and NH_3, more than 20 per cent. The uncertainty in individual sources can be considerably higher. The new generation of protocols under the convention on long-range transport of air pollution specifies targets as emission ceilings rather than percentage reductions. That means that the absolute uncertainty in emission level is more relevant than the trend itself. The confidence interval is widest for NO_x and NMVOC where emissions are highest in absolute terms. The inventory of NMVOC and in particular NH_3 can be systematically underestimated by 5-10 per cent in all inventory years, while the SO_2 inventory can be overestimated, but especially in the base year. Sensitivity analysis has been used to identify the key sources of the inventory, that is the sources with the highest influence on the overall uncertainty. Shipping (activity level, SO_2 and NO_x), oil loading (NMVOC), agriculture (NH_3) and road transport (all pollutants) are the most important key sources. These are all sources that have been prioritised in the inventory system in recent years, but still have an intrinsically high uncertainty. The analysis has also identified potentials for improvements of parts of the inventory, e.g. sulphur content of heavy fuel oil and marine diesel oil and the reported estimates of emissions from production of silicon carbide.

Contents

Preface

Norway has signed the protocol on restrictions of Long-Range Transport of Air Pollution in Europe (LRTAP) (UNECE 1999). This protocol gives restrictions on each country's emissions of sulphur dioxide (SO_2), nitrogen oxide (NO_x), ammonia (NH_3) and non-methane volatile organic compounds (NMVOC).

The emission figures are partly based on measurements at large industrial plants and partly on model calculations. The task is undertaken as a collaboration between Statistics Norway and the Norwegian Pollution Control Authority. All input data in the inventory are more or less uncertain. It is expected that the emission estimates of SO_2 have a quite low uncertainty. The estimates of the other pollutants may, on the other hand, be quite uncertain as they are more dependent on technology. Uncertainties arise due to lack of accurate estimation data, wrong assumptions, intrinsically complicated and variable processes and data processing errors.

The uncertainty in both level and trend is of interest. Earlier work has shown that the trend uncertainty is quite low when the obligations are formulated as percentage reductions from a base year (Rypdal and Zhang 2000). In the Gothenburg protocol from 1999 the goals are formulated as absolute emission ceilings. This work will evaluate how that affects the uncertainty.

An emission inventory contains a large amount of input data. It is part of good practice in inventory preparation to improve these data when new information becomes available, through either national or international studies and recommendations. A concept of identifying key sources in the inventory has been developed for the greenhouse gases (Rypdal and Flugsrud 2001). These sources are those that contribute most to the total inventory uncertainty in level and trend. The concept of key sources is useful for prioritising inventory resources. The main part of the resources spent for quality control and systematic inventory improvements may be directed towards these. In this report the concept of key sources is expanded to cover the non-greenhouse gases and to reflect cases where obligations are formulated as emission ceilings rather than percentage reductions.

As the uncertainties in the input data may be high and their distributions may be non-normal, simple statistical theory will fail as a tool to combine the uncertainties of input data to give an assessment of the uncertainties in the complete data set. Furthermore, the statistical properties of the input data, including the true mean, the statistical variance, distribution function and correlation between parameters are in most cases not known. This report will assess the statistical properties of the input data and apply an appropriate statistical tool in order to derive the uncertainties in the combined data set. The uncertainties of the inventory of each pollutant and in the trend from 1990 to 1998 and 1990 to 2010 are estimated. These uncertainties are finally used to evaluate the contribution of each single input parameter to total uncertainty in the data set. The implications of the uncertainties will be discussed in more depth in a separate paper.

1. Overview of the statistical problem and emission data

The emission estimates are based on an emission estimation model, as the emissions from all sources cannot be measured directly. Consequently, the uncertainties in the emission estimates have to be derived using other methodologies than when deriving the uncertainties of an empirical data set. Furthermore, the emission model contains a large amount of individual emission data. In order to assess the combined uncertainty, we will have to reduce it (aggregate it) to a more workable dataset, without losing too much of the properties of interest.

Below we will describe the steps in the design of a statistical model and the design of the emission estimation input data set of which the analysis in this report is based.

1.1. Statistical problem

Emission data from a pollutant (i) and source (j) are usually estimated by the basic equation:

1.1 $Emission_{ij} = Activity\_data_{ij} * Emission\_Factor_{ij}$

In a few cases[1], the estimation equation is more complicated than this, but in this work all emission estimation algorithms have been transferred to this form. In some cases, emission data have been measured directly or been estimated by the plant itself. These are fitted into the equation with activity data equal to 1 and an emission factor equal to the measurement output.

The total emissions of a pollutant (i) is the sum of the emissions from each source (j):

1.2 $Emission_{i} = \Sigma Activity\_data_{ij} * Emission\_Factor_{ij}$

Emissions are estimated separately for the gases SO_2, NO_x, NH_3 and NMVOC.

In the analysis of emissions of greenhouse gases (Rypdal and Zhang 2000), the assessment was made for the total emissions, each gas weighted by the global warming potential. The emission ceilings for the LRTAP gases have been determined from an assessment of contribution to total load of all gases seen together. The emission ceilings have, however, been determined for each gas separately. Although the total acid equivalent emissions may be easily calculated, we have chosen to perform the analysis for each gas separately according to the obligations.

All input data (both emission factors and activity data) are uncertain, and some parameters will be highly uncertain. In the design of a statistical model, we will have to assign to each input parameter the statistical properties:

- A mean
- A measure of the spread in data (variance or standard deviation)
- A density (probability distribution)
- The degree of dependencies (or correlation) with other input parameters

As explained in chapter 2, accurate information about the values of the statistical properties of the parameters in equation 1.2 is available only in a few cases. Instead, we will have to derive information indirectly or based on expert judgements.

The statistical property of the function in equation 1.2 is difficult to track analytically. This is due to the mixture of different distributions of the parameters - some of the parameters have very large variances and normal distribution would be unsuitable for them, as well as the complex dependence structure and mutual constraints within the data set. Instead, the statistical properties will be derived by means of stochastic simulations. Basically, a parametric simultaneous distribution of the data set can be regarded as a reasonable approximation of the emission estimation model. Repeated sampling under the simulation model then gives the various statistical properties of the process. The methodology is explained in detail in chapter 3 of this report.

[1] Road traffic, solvent use and ammonia from agriculture are the main examples for the non-GHG.

1.2. Emission estimation model and emission data

1.2.1. The Norwegian emission model

The emission estimates are made in collaboration between Statistics Norway and the Norwegian Pollution Control Authority (SFT). Statistics Norway is responsible for collecting activity data, the development of emission models and performing the actual calculations. SFT is responsible for emission factors and emission estimates for large plants.

The emissions are estimated separately for sources related to combustion and non-combustion sources.

The emissions from energy use (combustion) are in the national emission model estimated from the following equation:

$$1.3 \quad E_{ijklm} = \left[C_{jklm} - CPS_{jklm} \right] * EF_{ijklm} + EPS_{ijklm}$$

Where

E_{ijklm}	=	Emission of pollutant *i* from combustion of fuel *k* in source *j* in sector *l* in municipality *m*.
C_{jklm}	=	Consumption of fuel *k* in source *j* in sector *l* in municipality *m*.
CPS_{jklm}	=	Consumption of fuel *k* in source *j* in point sources in sector *l* in municipality *m*.
EF_{ijklm}	=	Emission factor for pollutant *i* from combustion of fuel *k* in source *j* in sector *l* in municipality *m*.
EPS_{ijklm}	=	Emission of pollutant *i* from combustion of fuel *k* in source *j* in point sources in sector *l* in municipality *m*.

Emissions from road traffic are estimated in a technical satellite model (Bang et al. 1999).

The *non-combustion emissions* are estimated in a free format, depending on the emission type. Some emissions (in particular SO_2) are estimated from measurements at each plant. Frequently also the plants make special estimates based on the particular technology in use (SO_2 and NO_x). For ammonia from agriculture and solvents there have been developed special calculation models. Some estimates based on general emission factors are made by Statistics Norway. The non-combustion emissions are assigned an emission carrier, source, sector and municipality in order to be consistent with the data set of combustion emissions.

The total emissions are the sum of the combustion and non-combustion emissions. The emission model and emission estimation methodologies of each gas and source are explained in detail in Flugsrud et al. (2000).

1.2.2. Simplifications of the emission model

The model used to estimate the emissions explained in chapter 1.2.1 is far too detailed to be a basis for an analysis of the statistical properties. This is both due to the complexity of assessing the statistical properties of the large number of input data and the computer time required to process the combined statistical properties. The following simplifications have been made:

- The municipality dimension has been aggregated to national level.
- The sectors and sources have been combined into approximately SNAP level 2 (SNAP 3 for particular processes, further aggregation for solvents (SNAP 06)). This implies that some emission factors have been averaged.
- Some adjustments and splits have been adopted, e.g. where different pollutants from a source-sector have to be connected to different activity measures. Also some necessary splits have been made to account for different assumptions and methods within a SNAP category. Road traffic has been split according to rough technology (cars with and without catalytic converters).
- Energy carriers have been grouped into five main types; oil, gas, coal, waste and bio energy.
- As mentioned, estimates based on measurements or provided by the plant have been assigned activity level equal to 1 and emission factor equal to the estimated value.
- Emissions from ammonia from agriculture, solvent use and some other sources have been transferred into the form of emission_factor *activity rate, in spite of the fact that the estimates are based on more complex estimation models (using several activity data and emission factors).

1.2.3. Emissions in 1990 and 1998

The historical emission estimates are the official emission figures presented in 2000 (SSB 2000; Flugsrud et al. 2000. The data from the national model have been converted into the SNAP source categories. Although the emission figures used in this report are likely to be recalculated in the future due to better knowledge, it is expected that these recalculations in the short term only will have small effects on the main conclusions from this study. The estimates are shown in Appendix A.

1.2.4. Emission projections for 2010

The Gothenburg protocol has set emission ceilings for the four gases with reference to the year 2010. The current emissions (1998) are for all pollutants higher than the ceiling. The goals may theoretically be reached in many different ways. In order to reach the best conclusion on the uncertainty of the trend of the emissions, it is necessary as far as possible to use realistic data sets for the target year. For this purpose, the official projected emission data will be used. The projection is based on the reduction measures plans (SFT 1999a, SFT 1999b, SFT 1999c, SFT 1999d). From a baseline emission scenario measures are introduced in the appropriate SNAP source/sector in order of increasing costs until the emission ceiling is reached. It is consequently assumed in the analysis that the ceilings are exactly met, that growth in activity rates are according to standard forecasts and that the most cost-effective measures are introduced. Note that the projected data used in this report have been constructed to a level of detail that goes beyond any official projections, so that detailed results of the sensitivity analysis including 2010 are indicative only and does not reflect the opinion of neither the background references nor Statistics Norway.

The aggregated data and estimated trend used in the analysis are shown in table 1.1.

Table 1.1. Total emissions of the conventional LRTAP gases in 1990, 1998 and 2010[1]. Tonnes of each gas

	SO_2	NO_x	NH_3	NMVOC
1990	52 698	218 855	22 949	300 396
1998	29 770	223 971	27 114	344 747
2010[2]	22 004	155 805	23 016	195 064
Emission ceiling 2010	22 000	156 000	23 000	195 000
Absolute change 1990-2010	-30 698	-62 855	0	-105 332
Reduction 1990-2010 (%)	58	29	0	35

[1] Estimates as published in 2000, data are slightly different from those published and reported in 2001 due to recalculations. This also applies to projections. This does, however, not influence the main conclusions made in this report.

[2] Projected growth and measures to meet the emission ceiling.

Source: Statistics Norway and Norwegian Pollution Control Authority, Ministry of Finance.

2. Determination of uncertainties in input parameters

Uncertainties in inventory data have different explanations. Processes generating emissions may be variable in time and space and consequently it will be difficult to set up an appropriate emission model and define representative emission factors. Representative emission factors (or activity data) may be inaccurate, lacking and substituted by assumptions - or emissions may not have been estimated at all. Furthermore, inventories may contain errors originating from data processing or basic data. In this analysis, no distinction will be made between these types of errors, and assessed uncertainty in the model is as far as possible attributed to the emission factors. This simplification is necessary, as at this stage there is little information on uncertainties (see below) and shortcomings of standard emission estimation models. Such simplification is, however, not desirable, as separation of variability, uncertainty in data and uncertainty in models would have been useful. Furthermore, it is not theoretically justified (Cullen and Frey 1999). In the future, if uncertainties in input data become available, it would be useful to make a separate estimate of model uncertainties. It should also be emphasised that this type of analysis will not be suited for identifying data processing errors, omitted emission sources and systematic errors in general.

An emission inventory data set is not an empirical data set where the uncertainties can be derived directly from individual observations. For each of the input data in Appendix A, we will have to assess the variance, density and possible dependencies. In a few cases we have good knowledge of this. However, for most data we will need to base the assessment on indirect sources, while in some cases they will have to be based on expert judgements. See Cullen and Frey (1999) for a justification of this type of subjective assessment of probability.

Morgan and Henrion (1990) discuss systematic approaches to assess statistical properties of input data. This frequently involves independent assessments by several experts. Given the resources allocated to the project described in this work, we have not been able to use these systematic approaches. We have, however, interviewed several sector experts to derive background information on uncertainties. This information has been judged consistent when comparable, and this may be seen as an independent check of the expert assessment. Also the Atmospheric Emission Inventory Guidebook (EEA 2000) has some assessment on uncertainties, but these are partly qualitative. For other sources where there are no particular expert knowledge, the range of published data may give an indication of the uncertainty. All emission data need to be positive by definition, excluding probability functions yielding negative values.

As the data set is a sum of many data with associated assumptions, wrong assumptions for parts of the dataset will frequently not be very crucial. On the other hand, it has been suggested that the mind may be biased towards systematically assessing too high or too low values. According to Morgan and Henrion (1990), the human mind has a tendency to underestimate the importance of systematic errors, so it might in general be assumed that weakly founded assessments may underestimate the uncertainties of the data.

2.1. Means

The true values of the activity data and emission factors are unknown. The parameters that the estimations are based on are frequently called the “best estimate”.

The best estimate is determined in the emission inventory development work and is based on Norwegian measurements, literature data or statistical surveys. Some data are based on expert judgements. See Flugsrud et al. (2000) for an introduction to the origin of the inventory data.

It might be discussed whether these best estimates represent the mean or the median or something else. We have here assumed that the best estimate equals the mean, which not always is the most probable value. Only in case of normal or any other symmetric distributions, would the two values coincide. Otherwise, how 'probable' the mean value is depends on the particular distribution in each case.

2.2. Standard deviation and probability density

A probability distribution model is a description of the probabilities of all possible values in a sample space (Cullen and Frey 1999). This may be represented mathematically as a probability distribution, a *probability density function*. The standard deviation is a property of this function. Further parameters may be needed in order to describe non-normal probability density functions (Cullen and Frey 1999, Morgan and Henrion 1990).

The probability densities used in this study have been divided into three types of model shapes (see Appendix B for an illustration):

1. Normal distribution
2. Truncated normal distribution
3. Lognormal distribution

For low uncertainties, all the distributions above approach the normal distributions. For large uncertainties, the normal distribution may lead to negative values. To avoid this situation the distributions are when necessary truncated at 0, which means that there is a given probability of the value 0. The lognormal distribution is an asymmetrical distribution, giving a heavier tail of probabilities towards higher values.

Sometimes it is not suitable or possible to specify the uncertainty in a parameter directly in terms of its standard deviation. For instance, the expert opinion might suggest that the parameter could take values within a certain range, say, between half to double of the mean. We interpret such an assessment as to imply that "the probability of the parameter taking values in the specified range equals to 0.95". In order to obtain the parameters of the relevant distribution, this equation is solved numerically and determines the corresponding standard deviation.

2.2.1. Directly reported data

As mentioned, emissions from the plants having the highest emissions in Norway are treated as point sources in the model. The significance of point sources is highest for SO_2 emissions where they add up to a large fraction of total emissions (nearly 2/3 of the total). Point source emissions are frequently abated and also contribute to the change in trend.

The point source emission data are based on each plant's report to the Norwegian Pollution Control Authority. These may be based on measurements or estimates. The plants are responsible for the quality of the data they report, but further consistency checks are made before using the data in the inventory. The quality of the reporting has improved the last ten years. That means probably that the uncertainty was higher in 1990 than in 2000. We have, however, not been able to quantify this and incorporate this change into the analysis.

The uncertainty in point source emission data was assessed by interviewing a contact person in each plant. The contact person was the person responsible for reporting of environmental data to the Norwegian Pollution Control Authority. Frequently there are several plants with similar production and technology. When the answers given were consistent, not all plants were contacted. For ferroalloy production, we were directed to a central contact person. In other cases, there were differences in technology and/or demand for measurements in plants having the same type of production. In these cases, we made a rough weighting of the uncertainties. We felt that the expert judgements of uncertainties made by the plants were fairly consistent when circumstances were comparable.

We made it clear to the plants that uncertainty not should be interpreted in a narrow manner. For example are errors in measurements often negligible compared to errors in sampling and possible other systematic errors. The consistency between measurements was used as a guide for quantifying the uncertainty, but taking into account other systematic errors contributing to total uncertainties.

Additional uncertainties may arise as the data are applied. There may be uncertainty connected to the amount of fuel used by plants reporting emission data to be subtracted according to Equation 1.3. This may lead to double counting or loss of emissions. Also in the case of reports from the oil refineries there may be danger of double counting of emissions from the distribution chain of oil products.

The conclusions are summarised in table 2.1.

Table 2.1. Summary of expert judgements of uncertainties in point sources

Production type	Number of plants	Pollutant	Emission determination method and uncertainty evaluation	Assessment (average)
Pulp and paper	6	SO_2	Continuous emission measurements and estimations from sulphur content of fuel. Diffuse emissions of sulphur compounds when producing sulphite pulp. The latter has a higher uncertainty than both the measured and estimated stack emissions.	± 4 %
Oil refineries	2 (3)	SO_2	Continuous emission measurements and estimations from sulphur content of fuel.	± 5 %
		NO_x	Based on measurements and calculations.	± 10 %
		NMVOC	Combination of point measurements and calculations. Emissions are variable with possibilities of systematic errors. Emissions from loading of products have lower uncertainty than the fugitive. Differences between the refineries due to different technology, products and operations.	± 45 %
Petrochemical industries and gas terminal	4	NO_x	Annual measurements and/or calculations	± 7 %
		NMVOC	Several emission points. Difficult to measure properly and high variability. Uncertainty is in any case lower than for the refineries as mostly gas is handled (high demand for security).	± 25 %
Cement	2	SO_2	Continuous measurements and annual measurements/calculations. High variability as cement plants incinerate special waste.	± 12 %
		NO_x	Continuous measurements and annual measurements/calculations. High variability as cement plants incinerate special waste.	± 12 %
Ammonia and fertiliser	2	NO_x	Continuous/weekly measurements.	± 7 %
		NH_3	Several emission points. Several measurements performed each year. Low variability.	± 10 %
Silicon carbide (SiC)	3	SO_2	Emissions are estimates based on consumption and sulphur content of coke. The sulphur content is measured independently for every delivery. There is, however, uncertainty connected to the end products and degree of oxidation and definition applied, so reporting can seem inconsistent.	± 20 %
Ferroalloys	16	SO_2	Emissions are estimates based on consumption and sulphur content of coke and the sulphur in products. The sulphur content is measured independently for every delivery. The sulphur content of products is measured regularly, but shows small variability.	± 2 %
		NO_x	Estimates using emission factors. Emission factors are based on measurements. Emission factors are, however, only available for some types of ferroalloys and emissions are not estimated for the others.	± 10-20 %*
Aluminium	8	SO_2	Monthly measurements (covering emissions from stack and ceiling)	± 7 %
		NO_x	Emissions are estimated based on emission factors (see table 2.3).	-
Waste incineration	8	SO_2	Annual representative measurements. Variable emissions due to the waste fraction incinerated.	± 7 %
		NO_x	Annual representative measurements.	± 10 %

[1] Additional uncertainty due to possible incomplete reporting.

2.2.2. Activity data

The activity data are frequently statistical data based on sample surveys or censuses. The standard deviation and probability density of survey data are usually not available. However, the uncertainty of statistical data may also have contributions from errors in the population/sampling, processing errors etc., which are not properties of the data set itself. Statistics Norway does not have any investigations of uncertainties in survey data that can be utilised directly in this work.

A few activity data are indirectly derived, based on old surveys or based on expert judgements; this gives rise to additional uncertainty. Most activity data have been assumed to be normally distributed. The assessments of standard deviations are mostly based on Rypdal (1999), with additional assessment of activity data only used for the LRTAP gases.

The most important activity data are of course energy use. The total energy data are determined from the sales statistics (for oil products) or consumer surveys (fuel wood). The total energy use may also be determined from *Production + Import - Export*. These two data sets are independent and the spread in data gives an indication of the statistical error. Generally, the total energy use is less uncertain than the energy use in each sector. For some sectors (e.g. the energy and manufacturing industries), the energy use is well known, while the energy use in households and service sectors is more uncertain. However, the energy use in the sectors where the consumption is most uncertain, has been adjusted in the official energy statistics so that the sum of energy use in all sectors equals the total sales. In the analysis, we have differentiated between variable uncertainties in different sectors, but with restrictions on the uncertainty of the total of each fuel. Also the split between various applications of gasoline and diesel (off-road vehicles and machinery, cars equipped or *not* equipped with catalytic converters) is assumed to be more uncertain than total consumption. Furthermore, the errors in the various energy carriers may be correlated (as respondent mix energy carriers in surveys). We have ignored this, as the energy carriers in this analysis have been aggregated to main fuel categories.

A higher uncertainty has been assigned to domestic fuel for aircraft and shipping, as (especially in the case of shipping) these are difficult to distinguish from bunker fuel for international transport. Norway has in particular a high sale of bunkers for international shipping. These errors are assumed to be random, though unknown systematic errors could be present in the shipping sector. Also data on consumption of wood waste, black liquor and other waste used as fuel are uncertain and not completely covered by current statistics. The assessed standard deviations and corresponding density shapes are given in table 2.2.

2.2.3. Emission factors

The ideal of an emission factor is derived from a set of measurements, where there are no systematic errors in the measurements and the condition of which the emission factor has been derived represents the “real world”. In this case, the standard deviation and probability density of the emission factor may be directly derived from the empirical data which it is based on. However, this ideal of an emission factor does not exist. Only in a few cases, the standard deviation and mean of the emission factors may be *approximated* from a consistent set of empirical data. Consequently, for most of the emission factors in our dataset, the standard deviation and probability density must be derived from indirect sources. One possibility, partly used in this work, is to consider the spread in published data. The weakness of this approach is that published values may origin from the same original measurements and may contain the same systematic errors due to lack of knowledge of the emission source and the same systematic errors of determination. Frequently, also a high spread may indicate a high variability in space and time, while the uncertainties of average values are lower. Hence, the assessment must frequently be based on expert judgements funded on knowledge of each particular emission source and national conditions. National source experts have contributed to the expert judgements.

Table 2.2. Summary of standard deviation and probability density of activity data

SNAP category	Pollutant source	Important for	Standard deviation (2σ). %	Density shape	Source/Comment
01, 02, 03	Gas combustion	NO_x	± 4	Normal	Directorate of oil and gas
01, 02, 03, 07, 08	Oil combustion (total)	SO_2, NO_x	± 3	Normal	Spread in data.
0102	Waste combustion - Energy industries	SO_2, NO_x, NMVOC	± 5	Normal	Expert judgement
0202	Coal and coke combustion - Residential	SO_2, NO_x, NMVOC	± 20	Normal	Expert judgement
090201	Waste combustion - Other sectors	SO_2, NO_x, NMVOC	± 30	Lognormal	Expert judgement
01, 02, 03	Wood combustion - All sectors	SO_2, NO_x, NMVOC	± 30	Lognormal	Expert judgement
01, 03	Coal and coke combustion-Industry	SO_2, NO_x, NMVOC	± 5	Normal	Spread in data
07, 08	Oil, road/off-road/catalytic/non-catalytic	SO_2, NO_x, NMVOC, NH_3	± 20	Normal	Comparisons of data
0805	Oil combustion - Aviation	SO_2, NO_x, NMVOC	± 20	Normal	Expert judgement
0804	Oil combustion - Shipping	SO_2, NO_x, NMVOC	± 10	Normal	Comparisons of data
0401	Refineries (throughput)	NMVOC	± 3	Normal	Expert judgement
040301	Aluminium production	NO_x	± 3	Normal	Expert judgement
040302	Ferroalloy production	NO_x	± 3	Normal	Expert judgement
040605	Bread production	NMVOC	± 30	Normal	Expert judgement
040607	Beer production	NMVOC	± 10	Normal	Expert judgement
050202	Loading of crude oil	NMVOC	± 3	Normal	Expert judgement
0505	Gasoline distribution	NMVOC	± 3	Normal	Expert judgement
0601	Solvent use	NMVOC			See emission factor
09	Waste combustion in small scale	SO_2, NO_x, NMVOC	± 50	Lognormal	Expert judgement
090201	Methane incineration (landfills)	NO_x, NMVOC	± 5	Normal	Expert judgement
090204	Flaring of natural gas	NO_x, NMVOC	± 4	Normal	As combustion of gas
090204	"Flaring" of crude oil	SO_2, NO_x, NMVOC	± 10	Normal	Expert judgement
090203/4	Other flaring	NO_x, NMVOC	± 5	Normal	Expert judgement
090207	Incineration of hospital waste	NO_x, NMVOC	± 20	Normal	Expert judgement
090901	Cremation	SO_2, NO_x, NMVOC	± 20	Normal	Expert judgement
10	Animal population	NH_3	± 5-10	Normal	Expert judgement
10	Agricultural soils - Treatment of straw	NH_3			See emission factor
1001	Agricultural soils - Fertiliser use	NH_3	± 5	Normal	Agriculture authorities
1009	Agricultural soils - Manure use	NH_3	± 20	Normal	Expert judgement

Though the spread in data may give indications of the statistical variance, it is more difficult to derive information on the probability density of the data. The assessment of the densities is, however, in general not very crucial for the final results. If more information had been available, the emission factors could have been assigned other densities than the model shapes to better reflect the true situation[2].

The uncertainty determination of the most important parameters is discussed in detail below. A summary of the assigned values is shown in table 2.3.

SO_2

Apart from the emissions from point sources (see section 2.2.1), all emissions are estimated from the sulphur content of fuel. Sulphur content in wood is considered uncertain as there are little data. Sulphur content and ash fraction of coal and coke may be variable; ash fraction and the coal quality used in Norway are not known. This makes the value quite uncertain (factor of two). Coal and coke are, however, only to a very limited extent used outside large point sources.

The sulphur content of oil products is in principle very accurately known (uncertainty less than 1 %). Analyses are made from samples of all the fuel sold in Norway. There are, however, two main factors contributing to uncertainty in sulphur content. The first is that the sulphur content of marine fuel applies to all fuel sold in Norway, while only the domestic share is included in the inventory. It is expected that the bunker share has a higher sulphur content than the domestic share, so that the average value is actually too high for domestic use. The second is that the sulphur content of fuel oil used in point sources (with abatement) is expected to be higher than the average. That means that the average emission factor applied for other sources is too high. We have consequently assessed the uncertainty in sulphur content to a factor of two for marine fuel and heavy fuel oil not used in point sources. See also "systematic errors" below.

NO_x

The national inventory system has given priority to the improvement of emission factors for transport (especially road traffic and shipping) and combustion offshore. Other stationary combustion (excluding point sources) accounts for only a few per cent of the total emissions in Norway due to the high use of electricity for heating, and the emission factors are not based on any exact knowledge of the technology in use. These differences are reflected in the uncertainty assessments.

For stationary combustion, other than point sources and activities connected to oil and gas production, the uncertainty has been assessed to ± 40-50 %. The emission factors have also been kept constant in the time series in spite of the fact that there have been changes in technology. Combustion processes with contact are mainly treated as point sources.

For activities connected to oil and gas production, the emission factor is uncertain (± 30-40 %). The reason, according to the Norwegian Petroleum Directorate, is that this factor is based on technology in use in the early nineties and does not take into account changes in turbines. New research indicates that new turbines have far higher emissions than the ones the emission factor is based on.

NO_x emissions from processes are mainly point sources. NO_x from aluminium production are estimated using emission factors. The uncertainty has been assessed to a factor of two due to the limited data that the emission factor is based on.

Emission factors for road traffic have been determined from national and international literature (Bang et al. 1999) and take into account actual technology in use as well as changes in this technology. Uncertainties are reflected by the spread in available data as well as uncertainty in the effect of ageing in engines and the relationship between standardised emission cycles and vehicles in use. Uncertainties have been assessed in cooperation with national experts[3]. More emission data are available for vehicles meeting modern emission standards and this is reflected in a lower uncertainty (± 25 %) compared to older technologies (± 30 %). The uncertainty for passenger cars and heavy duty vehicles is assessed to be about the same, while emissions from light duty vehicles have been assigned an uncertainty of (± 30 %) for all technologies. Motorcycles have been assessed to have somewhat higher uncertainty (± 40 %) due to more limited measurement data. The latter emission factor is kept constant in spite of possible changes in technology.

For other mobile vehicles, there are less measurement data. On the other hand, most of the NO_x emissions originate from diesel engines used under stable conditions. This sets a limit to the uncertainty. The assessments are based on spread in literature data. Literature data for shipping emissions show little variations, and the assigned uncertainty is as low as ± 15 %. For aircraft, the value is ± 25 % (EEA 2000).

The uncertainty in the flaring emission factor is assessed to be ± 40 %. Emissions from flares are difficult to measure and have highly variable loads. On

[2] Evidently, if the data had been based on a perfect empirical data set, it would not be necessary to make any assumptions about the density at all, but the analysis could be based on the empirical data as they are (Efron and Tibshirani 1993).

[3] Arild Skedsmo, Institute of Technology, pers. comm.

Table 2.3. Summary of standard deviation and probability density of emission factors

SNAP source category	Pollutant source	Standard deviation (2σ). %	Density shape	Source/Comment
01, 02, 03	SO_2 - Oil combustion, general	± 1	Normal	Expert judgement. Oil companies
01, 02, 03	SO_2 - Oil combustion, heavy fuel oil	-50 - +100	Normal	Expert judgement. Oil companies
01, 03	SO_2 - Coal combustion	-50 - +100	Lognormal	Spread in data
01, 03	SO_2 - Wood combustion	-50 - +100	Lognormal	Spread in data
0804	SO_2 - Oil combustion, domestic shipping	± 25	Normal	Expert judgement. Oil companies
01, 02 (+03)	NO_x - Combustion in area sources	± 40-50	Normal	Spread in data
0105	NO_x - Combustion offshore	± 40	Lognormal	Expert judgement
040301	NO_x - Aluminium production	-50 - +100	Lognormal	Expert judgement
07	NO_x - Road traffic	± 25-30	Normal	Expert judgement, spread in data
0704/0705	NO_x - Motorcycles	± 40	Normal	Expert judgement, spread in data
0801-02, 0806-09	NO_x - Equipment and railways	± 40	Normal	Spread in data
0804	NO_x - Shipping	± 15	Normal	Spread in data
0805	NO_x - Aircraft	± 20	Normal	EEA (2000)
0902	NO_x - Flaring	± 40	Lognormal	Expert judgement
01, 02 (+03)	NMVOC - Combustion in area sources	± 40-50	Normal	Spread in data
0105	NMVOC - Combustion offshore	± 50	Lognormal	Expert judgement
040605/07	NMVOC - Beer and bread production	-50 - +100	Lognormal	EEA (2000)
050201	NMVOC - Oil loading onshore	± 30	Normal	Rypdal (1999), Expert judgement
050202	NMVOC - Oil loading offshore	± 40	Normal	Rypdal (1999), Expert judgement
0505	NMVOC - Gasoline distribution	± 50	Lognormal	EEA (2000)
0601	NMVOC - Solvent use	± 30	Normal	Rypdal (1995)
0701	NMVOC - Road traffic (gasoline vehicles)	± 40-50	Normal	Expert judgement, spread in data
0703	NMVOC - Road traffic (diesel vehicles)	± 20-30	Normal	Expert judgement, spread in data
0704/0705	NMVOC - Motorcycles	± 40	Normal	Expert judgement, spread in data
0801-02, 0806-09	NMVOC - Equipment and railways	± 40	Normal	Spread in data
0804	NMVOC - Shipping	± 50	Normal	Spread in data
0805	NMVOC - Aircraft	± 25	Normal	EEA (2000)
0902	NMVOC - Flaring	± 50	Lognormal	Expert judgement
07	NH_3 - Road traffic	Factor 3	Lognormal	Expert judgement, spread in data
1001	NH_3 - Agriculture, fertiliser	± 20	Normal	Expert judgement
1005	NH_3 - Agriculture, animal manure	± 30	Normal	Expert judgement
10	NH_3 - Agriculture, treatment of straw	± 5	Normal	Expert judgement

the other hand are flares similar in basic emission characteristics given equal conditions.

NMVOC

Literature values for stationary combustion show similar spread in data as for NO_x. Consequently the same values of uncertainties have been assigned. Point sources do not report NMVOC from stationary combustion and the emissions are estimated using emission factors. The uncertainties are assessed to be 40-50 %.

The uncertainties in emissions from bread and beer production have been taken from EEA (2000) (a factor of two).

Emissions from loading of oil offshore are considered more uncertain than loading on shore (Rypdal 1999). The uncertainties are 30 and 40 %, respectively, due to high variability and difficulties in performing measurements. Emissions from on shore activities are considered to be less variable.

Emissions from gasoline distribution are difficult to estimate. The uncertainty is assessed to be ± 50 % based on EEA (2000). Uncertainties in emissions from solvent use were in Rypdal (1995) assessed to be ± 30 %.

Uncertainties in emission factors from gasoline vehicles are considered to be higher than for NO_x. The uncertainty in exhaust emissions are comparable, but emissions from cold start and evaporation lead to additional uncertainty for the gasoline vehicles. For diesel vehicles the uncertainties are similar to NO_x.

For equipment, railway and aircraft the uncertainties are considered being similar to NO_x. NMVOC emission factors for shipping show a higher variation than for NO_x and have been assigned an uncertainty of ± 50 %.

NH_3

Ammonia emissions from road traffic are not regulated and relatively few measurements have been performed. It is difficult to say anything about the uncertainty, but it is expected to be higher than for the regulated pollutants. The effect of the new generation catalytic converters is furthermore not known. We have assigned an uncertainty of a factor three. Sutton et al. (2000) indicate a range of about a factor two.

Ammonia emissions from agriculture are estimated based on national conditions[4]. Uncertainties are still high due to high variability and gaps in data. Uncertainty in the estimate of emissions from ammonia treatment of straw is rather low (± 5 %)[5]. The uncertainty in the estimate of emissions from use of fertiliser is assessed to be about ± 20 %. This uncertainty might have been lower if better data on fertiliser composition was obtained. The uncertainty is higher for animal manure (± 30 %). This is due to uncertainties in several parameters (fraction of manure left on pastures, amount of manure, conditions of storage, conditions of spreading and climate conditions). The assessment of uncertainty is similar to EEA (2000), but higher than in Hutchings et al. (2000) for Denmark of 10-20 per cent. It is expected that the uncertainty is lower in countries having more homogenous conditions.

According to Sutton et al. (2000), there might be additional sources of ammonia emissions not taken into account in the inventory, like biomass burning, household products, landfills and sewage. This systematic error has been modelled in a scenario, see below.

Systematic errors
The standard deviations as specified above are made to reflect the range of possible systematic errors. However, the distribution is assumed so that the mean value of the inventory is reproduced even though we in some cases have an expectation of the direction of the systematic error. In four scenarios we have tried to explicitly model systematic errors assuming a skewed distribution so that the mean value also is changed. The cases illustrate parts of the inventory where we are aware that systematic errors may be present in a known direction[6] as described above.

- Scenario 1 assumes that SO_2 emission factors for shipping and heavy fuel oil combustion other than point sources are half the values given as best estimates
- Scenario 2 assumes that NMVOC emission factors for selected parameters (oil refineries, gas terminal, gasoline distribution, solvent use and gasoline vehicles) are underestimated by 10 per cent in all years
- Scenario 3 assumes that NO_x emission factors for gas combustion offshore have increased by 20 per cent from the 1990 level in 1998 and 2010 (according to expert comments) and that NO_x emission factors for other stationary combustion have decreased by 10 per cent from the base year (taking into account that new boilers have lower emission factors than old ones[7])
- Scenario 4 takes into account sources of ammonia not currently included in the inventory (cats and dogs, biomass combustion, sewage and landfills). Estimates are taken from UK (Sutton et al. 2000) taking into account the Norwegian activity level/population. Uncertainties are assumed to be a factor of two.

2.3. Dependencies between parameters

Some of the input parameters (emission factors and activity data) are for various reasons not independent; their values are dependent (or correlated)[8]. If dependencies are not modelled properly, uncertainties will be over- or underestimated. The assessment of sensitivities will also be influenced if dependencies are ignored or not assessed properly.

The problem of dependencies may be solved by appropriate aggregation of the data or explicitly by modelling. In this work we have partly designed the dataset to reduce the problem, as well as introduced a number of dependency assumptions into the model.

The determination of dependencies is sometimes a difficult task and requires some understanding of the data set and the assumptions it is based on. In Rypdal and Zhang (2000) it was concluded that the assumptions on dependencies generally have little effect on the final conclusions on uncertainties in level, but are very important for the conclusions on sensitivities. The assumptions of dependencies of data between years are, however, crucial for the determination of trend uncertainty (2.3.3).

2.3.1. Dependencies between activity data

The activity data, the statistical data in equation 1.2, are in principle independent. However, the same activity data may be used to estimate more than one emission source. The sum of some of the energy carriers in each sector is fixed. That means that all the energy data in each source-sector for a given fuel are dependent.

More specifically, the cases when activity data are assumed dependent are:
- The consumption of *oil products* in each sector. The sum of all oil products have a lower uncertainty than the consumption in each sector
- The consumption of gasoline and diesel (oil products) for the applications catalytic cars, non-

[4] John Morken, Norwegian University of Agriculture, pers. comm.
[5] When this work was in stage of finalisation, a gross error (double counting) far larger than the uncertainty limit was discovered in this figure for recent years, which will be corrected in the 2002 reporting of data. The uncertainty is, however, in principle small.
[6] Although information currently not is specific enough to actually correct for these in the inventory.
[7] Geir Sollesnes, Norwegian Association of Energy Users and Suppliers, personal communication.
[8] The term "dependency" is used here rather than "correlation" or "covariance" as the coefficients of correlation in the cases considered are 1.

catalytic cars and off-road applications. The split between the various applications is more uncertain than the total

2.3.2. Dependencies between emission factors

The case of dependencies between emission factors is difficult to handle correctly. In a perfect data set, different emission factors from independent estimates would have been used for all the emission sources. However, as information on some type of pollutants is incomplete, frequently the same emission factors will have to be used for several emission sources. Where emission factors have been assumed equal, we have treated them as dependent in the analysis. This is the case for the SO_2 emission factors for each fuel, as factors have been assumed equal in all sectors. Emission factors for shipping (marine fuel) and manufacturing industry (oil) are modelled independently, due to the systematic errors explained in section 2.2.3.

Note that the analysis for emissions of NH_3 from agriculture has been made on an aggregated level, not modelling each animal independently. This implicitly means that we have assumed that these individual estimates are fully correlated.

2.3.3. Dependencies between data in base year and end year

The assumptions made about dependencies between the two years are important for the main conclusion of this analysis concerning the uncertainty of the trend from 1990 to 2010. The estimates made for the two years will to a large extent be based on the same data and assumptions.

Activity data

The activity data are determined independently in the two years and are in principle not dependent. Correlation could be considered in cases where activity data cannot be updated annually, where updates are based on extrapolations or interpolations of data for another year or where annual systematic errors could be present.

This implies that we have assumed that errors in activity data are random, hence that systematic errors are insignificant. It is, however, likely that there is a certain correlation between the activity data as they have been determined using the same methods, and that systematic errors are present to some extent.

Emission factors

Most of the emission factors are assumed unchanged from 1990 and 2010. Those that are not are all based on the same assumptions. This implies that all the emission factors are fully correlated between the two years.

This means that we have assumed that the emission factors assumed unchanged actually are unchanged from the base to end year. In reality, it is expected that most emission factors are changing, but the degree of change is usually not known.

In order to test this assumption, trend uncertainties have also been compiled assuming that some are not dependent between years. These are:

- SO_2 from oil combustion
- Point sources (all pollutants)
- Road traffic (all pollutants)

The output (scenario 5) may be seen as an upper limit of the trend uncertainty as the correlation term reduces the uncertainty when considering differences between two years.

3. The statistical modelling

3.1. Uncertainty estimation

Uncertainty analysis based on probabilistic analysis implies that uncertainties in model inputs are used to propagate uncertainties in model outputs. The modelling was performed as described in Rypdal and Zhang (2000) for greenhouse gases.

Having generated a data set according to the specified parametric simultaneous distribution of the data described in chapter 2, any desired output defined as a function of the data can be calculated. This gives one simulated random realisation of this output, according to its marginal distribution derived from the underlying simultaneous distribution of the data. Independent repetition of the simulation gives an independent sample of the desired output according to its marginal distribution. Based on such an independent and identically distributed sample, we may use the sample mean as an estimate of the mean of the output; we may also use the sample standard deviation as an estimate of the standard deviation of the output.

3.2. Sensitivity analysis

The potential importance of model inputs as contributors to variation in model outputs may be measured using a sensitivity analysis. A sensitivity analysis may be defined as *the computation of the effect of changes in input values or assumptions on the output* (Morgan and Henrion 1990).

Sensitivity analyses, various types and their shortcomings, were described in more detail in Rypdal and Zhang (2000).

In this work, we have modelled the sensitivities based on compiling simple derivations (equation 3.1 below). This approach is not valid for large uncertainties and for non-normal distributions. It was, however, shown in Rypdal and Zhang (2000) that the modelling approach based on compiling the correlation between the output and each input parameter gave approximately the same result.

The simple theory below on sensitivity measures and elasticities is mostly taken from Morgan and Henrion (1990). The normalised sensitivity (or *elasticity*) (U_E) is defined as the ratio of the relative change in output (E) induced by a unit relative change in input (*e*). This expression should be used for comparing the sensitivity of various parameters since it is dimensionless. It is defined as:

$$3.1 \quad U_E(e_i,E) = \left[\frac{\partial E}{\partial e_i}\right]_{E^0} \times \frac{e_i^{\,0}}{E^0}$$

The normalised uncertainty importance elasticy (U_{GE}) is derived as

$$3.2 \quad U_{GE}(e_i,E) = U_E(e_i,E) \times \frac{\sigma_{e\,i}}{e_i^{\,0}} =$$

$$\left[\left[\frac{\partial E}{\partial e_i}\right]_{E^0} \times \frac{e_i^{\,0}}{E^0}\right] \times \frac{\sigma_{e\,i}}{e_i^{\,0}} = \left[\frac{\partial E}{\partial e_i}\right]_{E^0} \times \sigma_{e\,i}/\mathrm{E}^0$$

Where σ_e is the standard deviation of the input parameters.

For the trend, the change in level between two years is evaluated with respect to emission factor for the base year and change in activity. In some cases there were no emissions (or only small emissions) in the base year. This was the case for some sources not important for the analysis and for road transport (catalytic car). As a consequence, technologies for road transport were aggregated in the trend analysis.

4. Results

4.1. Uncertainties

4.1.1. Uncertainties in emission level

The estimated uncertainty in emission level of each pollutant is shown in table 4.1.

The estimated probability densities are shown in appendix C.

Table 4.1 shows that the relative uncertainty in SO_2 is about 4 per cent, the reason for the low uncertainty is that the sulphur content of the most important fuels is well known due to annual reporting. The uncertainty in emissions of the other pollutants is higher, but less than about 20 per cent. Ammonia has a higher uncertainty than NO_x and NMVOC and the NMVOC estimate is more uncertain than NO_x. There are relatively small changes in uncertainty between 1990 and 2010. These changes occur due to changes in source fraction.

Table 4.1. Uncertainty in emission level of pollutants. 1990, 1998 and 2010

	μ (mean) ktonnes	Relative standard deviation (σ/μ)	Uncertainty 2σ (% of mean)	Uncertainty 2σ (ktonnes)
1990				
SO_2	52.7	0.02	4.0	2
NO_x	219.0	0.062	12	27
NMVOC	298.4	0.09	18	54
NH_3	22.9	0.104	21	5
1998				
SO_2	29.8	0.021	4.2	1
NO_x	224.0	0.062	12	42
NMVOC	344.5	0.105	21	72
NH_3	27.0	0.091	18	5
2010[1]				
SO_2	22.0	0.025	5.0	1
NO_x	156.0	0.062	12	19
NMVOC	194.0	0.074	15	29
NH_3	23.0	0.105	21	5

[1] Projected data with uncertainties as if they were historical.

In Rypdal and Zhang (2000), it was estimated that the uncertainty in level of total GHG (Greenhouse Gas) emissions was about 20 per cent. The uncertainty in CO_2 emissions was estimated to be 5 per cent. This is comparable with the SO_2 estimated uncertainty given here. It could be expected that the carbon content of fuel would be better known than the sulphur content, so that the CO_2 uncertainty should be somewhat lower. This is generally true, but the uncertainty is low for many SO_2 sources due to monitoring and annual measurements. Furthermore, the emissions from many sources are determined independently. The CO_2 emission estimates for some main sources in Norway, like gas combustion and metal production, also have a somewhat higher uncertainty than ordinary oil combustion.

The uncertainty in NO_x is generally higher than for SO_2. There have been few studies the last years in Norway directed at improving emission factors[9]. Exceptions are for the mobile sources road traffic, air transport and shipping. This gives a lower uncertainty for these sources. However, uncertainty in road traffic emission factors is still quite high, as indicated by spread in available data. The NO_x emission factors are mostly determined independently, again reducing the overall uncertainty compared to the assessed uncertainty of input data.

The estimated uncertainty of *NMVOC* of 18-20 per cent can be compared to methane of about 20 per cent (Rypdal and Zhang 2000). Methane and NMVOC have partly overlapping sources, like wood combustion and oil loading and the uncertainty in input parameters are of similar magnitude. The NMVOC estimates are mostly independent for individual sources, reducing the overall error compared to the error of individual estimates being in the range 30-50 per cent. In 2010 the uncertainty is reduced, due to the anticipated change in source composition. It could, however, be expected that the NMVOC emissions were systematically underestimated, see the output of scenario 2.

[9] The emission factors for NO_x combustion from offshore gas turbines is currently being improved. NO_x from ferroalloy production has also been improved after this work was completed.

Table 4.2. Uncertainties in emission trends 1990-1998 and 1990-2010

	Absolute change (μ_{2010}-μ_{1990})	% change ((μ_{2010}-μ_{1990})[1]100/ μ_{1990})	Relative standard deviation (σ/(μ_{2010}-μ_{1990}))	Uncer-tainty 2σ (absolute change)	Uncer-tainty 2σ (%-point of change)
1990-1998					
SO_2	-23.0	-43	-0.04	1.7	3.2
NO_x	+4.8	+2	+3.00	28	13
NMVOC	+43.8	+15	+0.40	35	12
NH_3	+4.1	+18	+0.22	1.8	8.0
1990-2010					
SO_2	-30.7	-58	-0.03	1.8	3.4
NO_x	-62.8	-29	-0.21	26.9	12
NMVOC	-104.9	-35	-0.18	38	13
NH_3	+0.0	0	61.3	3.1	13

[1] Projected values with uncertainties as if they were historical.

The uncertainty of NH_3 is also of a comparable size. The uncertainty in input data is somewhat larger, but estimates have been assumed independent, reducing the overall uncertainty. See also the output of scenario 4 accounting for possible missing sources.

It can be concluded that the relative uncertainty in LRTAP[10] gases is lower than for the GHG. The reason is better knowledge than for the GHGs HFCs and PFCs and nitrous oxide, but also the statistical properties of the dataset. When goals are formulated as emission ceilings, the absolute uncertainty is, however, of more relevance than the relative. The size of this confidence interval is a function of the relative uncertainty and absolute size of the emissions. Consequently, the confidence interval is far higher for NO_x and NMVOC than for SO_2 and NH_3.

4.1.2. Uncertainties in emission trends

The estimated trend uncertainties are shown in table 4.2.

The trend uncertainty is lowest for SO_2. For the other gases the uncertainty is considerably higher. This is due to the uncertainty in the input data and other statistical properties of the dataset. Section 3.2 on sensitivity analysis will help to explain the contribution to the high uncertainty.

The uncertainty in trend is, however, not interesting in itself for the LRTAP gases when it comes to policy application. The reason is that the emission obligations are given as emission ceilings. Uncertainties in absolute changes and percentage reductions are given here as a background for discussions.

[10] LRTAP also includes heavy metals and persistent organic pollutants. For most of these the uncertainty is considerable with the current knowledge.

Table 4.3. Uncertainty in emission level and trend of SO_2 (Scenario 1). 1990, 1998 and 2010. ktonnes

	μ (mean)	μ (mean) basis	Difference
1990	48.8	52.7	-3.9
1998	28.1	29.8	-1.7
2010	20.7	22.0	-1.3
	Change	Change (basis)	Difference
1990-1998	-20.7	-23.0	2.3
1990-2010	-28.1	-30.0	1.9

[1] Projected data with uncertainties as if they were historical.

Table 4.4. Uncertainty in emission level and trend of NMVOC (Scenario 2). 1990, 1998 and 2010. ktonnes

	μ (mean)	μ (mean) basis	Difference
1990	313.8	298.4	15.4
1998	356.4	344.5	11.9
2010	203.3	194.0	8.9
	Change	Change (basis)	Difference
1990-1998	40.8	43.8	-3.0
1990-2010	-110.0	-104.9	-5.1

[1] Projected data with uncertainties as if they were historical.

4.1.3. Results of scenarios

The scenarios were formulated in order to test the influence of some main assumptions on the output and were described in 2.3.3.

Scenario 1 assumes that SO_2 emission factors for domestic shipping and combustion of heavy fuel oil in area sources is overestimated by a factor of two in all years. Results are given in table 4.3.

The output of scenario 1 shows that the error is largest in the base year (4 ktonnes or 8 per cent), and is less in the end year due to the anticipated decreasing level of domestic shipping. Also the change in emissions is influenced by this systematic error.

Scenario 2 assumes that NMVOC emission factors for specific sources are underestimated by 10 per cent in all years. This may influence both the estimated level and trend. The results are given in table 4.4. The standard deviation is not given as it proved not to change very much from the basis scenario.

Scenario 2 reflects the possible presence of systematic errors. The analysis shows that such errors may influence the level in all years as well as the difference. The possible error corresponds to about 5 per cent increase in the level.

Scenario 3 assumes that NO_x emission factors for gas combustion offshore have increased by 20 per cent from 1990 and that NO_x emission factors for other stationary combustion have decreased by 10 per cent from the base year (in the inventory emission factors are kept constant). This scenario will have influence on both the level and trend. Uncertainty estimates are only slightly changed and are not shown in the table. The results are given in table 4.5.

This scenario has only a slight effect on the estimated level and change in emissions, about 1 per cent. The reason is that the two assumptions have different signs (emission factors for offshore combustion have most likely increased while those for combustion in boilers have decreased). That implies that the symmetrical error range given in table 4.5 is realistic.

Scenario 4 (table 4.6) takes into account sources of ammonia not currently included in the inventory (cats and dogs, biomass combustion, sewage and landfills). Estimates are taken from UK (Sutton et al. 2000), taking into account the Norwegian activity level/ population. Uncertainties are assumed to be a factor of two.

Table 4.5. Uncertainty in emission level and trend of NO_x (Scenario 3). 1990, 1998 and 2010. ktonnes

	μ (mean)	μ (mean) basis	Difference
1998	226.4	224.0	2.4
2010	158.3	156.0	2.3
	Change	Change (basis)	Difference
1990-1998	+7.4	+4.8	2.6
1990-2010	-61.0	-62.8	1.8

[1] Projected data with uncertainties as if they were historical.

Table 4.6. Uncertainty in emission level and trend of NH_3 (Scenario 4). 1990, 1998 and 2010. ktonnes

	μ (mean)	μ (mean) basis	Difference
1990	24.9	22.9	-2.0
1998	29.2	27.0	-2.2
2010	24.9	23.0	-1.9
	Change	Change (basis)	Difference
1990-1998	4.2	4.1	0.1
1990-2010	0.0	0.0	-

[1] Projected data with uncertainties as if they were historical.

Such missing sources increase the emission level by 8-9 per cent. The change, however, is not influenced as the emission level of these possible missing sources are assumed to be rather stable.

Scenario 5 (table 4.7) was formulated to test the assumption about correlations between years. Only the trend uncertainty is influenced by this assumption. The emission level and change in it is unaltered (slight variations occur in the modelling, though). This scenario, as expected, in most cases gives somewhat higher trend uncertainties compared to the basis. In two cases there is a slight decrease. It can be concluded that the assumptions tested in general are not crucial for the estimated trend uncertainty.

4.2. Parameter contribution to uncertainty - key sources

The methodology to identify key parameters was developed for the GHG. It was decided to include parameters accounting for 90 per cent of the total uncertainty in the level and trend, respectively (Rypdal and Flugsrud 2001; IPCC 2001). We have chosen to use the same methodology for the gases covered in this work in spite of the fact that the methodology has not been tested out on other inventories than GHG. The crucial point here is, however, the fraction of uncertainty to include, not the methodology in itself. Problems with the methodology are in particular expected to be present for ammonia, where there are only a few sources.

4.2.1. Emission level

Compiled uncertainty importance elasticities are shown in table 4.8. The elasticities are given in a separate column. In general, the range by elasticity and uncertainty importance elasticity is more even than for the GHG. The reason is that the uncertainties for a given pollutant are less variable than for the total weighted GHG emissions.

Table 4.7. Effect on trend uncertainty of assumptions about correlation between parameters as given in paragraph 2.3.3 (Scenario 5). 1990-1998. 1990-2010

	Scenario 5			Basis		
	Relative standard deviation ($\sigma/(\mu_{2010}-\mu_{1990})$)	Uncertainty 2σ (absolute change)	Uncertainty 2σ (%-point of change)	Relative standard deviation ($\sigma/(\mu_{2010}-\mu_{1990})$)	Uncertainty 2σ (absolute change)	Uncertainty 2σ (%-point of change)
1990-1998						
SO_2	-0.047	2.2	4.3	-0.04	1.7	3.2
NO_x	3.086	32.8	15.0	+3.00	28	13
NMVOC	0.521	46.4	15.5	+0.40	35	12
NH_3	0.252	2.2	9.6	+0.22	1.8	8.0
1990-2010						
SO_2	-0.033	2.0	3.8	-0.029	1.8	3.4
NO_x	-0.207	26.2	12	-0.214	26.9	12
NMVOC	-0.173	36.6	12	-0.179	38	13
NH_3	31.7	3.5	15	61.3	3.1	13

1 Projected values with uncertainties as if they were historical.

Table 4.8. Uncertainty importance elasticities of key parameters and corresponding values of elasticities. 1990 and 2010. Ranking of parameters accounting for 90 per cent of total uncertainty in level

SNAP	Pollutant/Source	A/EF	1990 Uncertainty importance	Elasticity	SNAP	Pollutant/Source	A/EF	2010 Uncertainty importance	Elasticity
	SO_2					**SO_2**			
0804	Domestic shipping	A	1.3	12.6	01,02,03	Coal	EF	1.6	4.5
040416	SiC production	PS	0.8	8.4	03	Oil, industry	EF	1.3	12.9
01,02,03	Bio energy	EF	0.8	2.3	01,02,03	Bio energy	EF	1.3	3.5
01,02,03	Coal	EF	0.7	1.9	03	Oil, misc. direct fired	EF	0.9	3.6
03	Oil, industry	EF	0.7	6.6	0804	Domestic shipping	A	0.8	7.9
0804	Domestic shipping	EF	0.6	12.6	0804	Domestic shipping	EF	0.4	7.9
03	Oil, misc. direct fired	EF	0.5	2.1	03	Oil, industry	A	0.3	7.1
0703	Heavy duty vehicles	A	0.4	3.6	02	Oil, services	A	0.3	7.1
040301	Aluminium production	PS	0.3	7.9	040301	Aluminium production	PS	0.3	8.5
040302	Ferro alloy prod.	PS	0.2	22.7	0401	Refineries	PS	0.2	9.4
0201	Oil, services	A	0.2	2.1	040416	SiC production	PS	0.2	2.2
0401	Refineries	PS	0.2	7.3	040302	Ferro alloy production	PS	0.2	21.5
03	Oil, industry	A	0.2	6.6	0202	Res. wood comb.	A	0.2	1.2
0202	Oil, residential	A	0.1	1.9	03	Bio energy industry	A	0.1	1.5
0202	Residential wood combustion	A	0.1	0.9	040612	Cement production	PS	0.1	2.2
0806	Diesel, agriculture	A	0.1	0.8	0102	Waste combustion	PS	0.1	3.5
0701	Oil, passenger car	A	0.1	1.9	0202	Oil, residential	A	0.1	1.3
0102	Waste combustion	PS	0.1	2.3					
040603	Paper and pulp, processes	PS	0.1	3.5					
0808	Diesel, industry	A	0.1	0.5					
03	Bio energy industry	A	0.1	0.7					
	NO_x					**NO_x**			
0804	Domestic shipping	A	3.6	35.9	040302	Ferro alloy production	PS	4.1	4.1
0701	Passenger car	EF	3.0	20.2	0804	Domestic shipping	A	3.9	38.7
040302	Ferro alloy production	PS	2.9	2.9	0804	Domestic shipping	EF	2.9	38.7
0804	Domestic shipping	EF	2.7	35.9	0105	Gas combustion oil and gas extraction	EF	2.4	12.0
0703	Heavy duty vehicles	EF	1.7	11.5	0703	Heavy duty vehicles	EF	1.3	10.7
0105	Gas combustion oil and gas extraction	EF	1.3	6.3	0703	Heavy duty vehicles	A	1.1	10.7
0703	Heavy duty vehicles	A	1.1	11.5	0105	Diesel, oil and gas extracion	EF	1.1	4.3
0701	Passenger car	A	1.0	20.2	0806	Diesel, agriculture	EF	0.8	3.8
0806	Diesel, agriculture	EF	0.6	3.1	090206	Flaring	EF	0.7	3.6
090206	Flaring	EF	0.6	3.1	0806	Diesel, agriculture	A	0.6	3.8
0806	Diesel, agriculture	A	0.5	3.1	0701	Passenger car	EF	0.6	4.4
0701	Light duty vehicles	EF	0.5	3.1	0803	Small boats	EF	0.5	2.5
0105	Diesel, oil and gas extraction	EF	0.4	1.5	0808	Diesel, industry	EF	0.5	2.3
					040301	Aluminium production	EF	0.4	0.4
					0803	Small boats	A	0.3	2.5
					03	Bio energy industry	EF	0.3	0.7
					0105	Gas combustion, oil and gas extraction	A	0.2	12.0
					03	Oil - industry	EF	0.2	1.1
					0701	Passenger car	A	0.2	4.4
	NMVOC					**NMVOC**			
050303	Oil loading, off-shore	EF	6.5	32.3	050303	Oil loading, off-shore	EF	5.3	26.6
0701	Passenger car	EF	5.1	20.2	06	Solvent use	A/EF	4.1	27.2
06	Solvent use	A/EF	2.4	16.0	0401	Refineries	PS	1.8	7.8
0401	Refineries	PS	1.1	5.1	0804	Small boats	EF	1.2	6.0
0701	Passenger car	A	1.0	20.2	0701	Passenger car	EF	1.2	4.8
050302	Oil loading, on-shore	EF	0.9	6.3	0505	Gasoline distribution	EF	0.8	3.1
0202	Wood combustion, residential	EF	0.7	3.0	0202	Wood combustion, residential	EF	0.6	2.5
0505	Gasoline distribution	EF	0.7	2.9	0804	Small boats	A	0.6	6.0
0804	Small boats	EF	0.6	2.9	050303	Oil loading, off-shore	A	0.4	26.6
0702	Light duty vehicles	EF	0.6	2.3	050302	Oil loading, on-shore	EF	0.4	2.5
050303	Oil loading, off-shore	A	0.5	32.3	0202	Wood combustion, residential	A	0.4	2.5
0202	Wood combustion, residential	A	0.4	3.0	0804	Domestic shipping	EF	0.3	1.3
0804	Small boats	A	0.3	2.9	0704	Mopeds/MC	EF	0.3	1.3
0804	Domestic shipping	EF	0.2	0.9	0701	Passenger car	A	0.2	4.8
					0809	Household equipment	EF	0.2	0.9
					050302	Gas terminal	PS	0.2	1.2
					0703	Heavy duty vehicles	EF	0.2	1.2
					0705	Heavy MC	EF	0.2	0.8
					03	Bio energy, industry	EF	0.2	0.4
					0810	Snow scooter	EF	0.2	0.6
					040605	Bread production	EF	0.2	0.4
					0105	Gas combustion, oil and gas extraction	EF	0.1	0.6

SNAP	Pollutant/Source	A/EF	1990 Uncertainty importance	Elasticity	SNAP	Pollutant/Source	A/EF	2010 Uncertainty importance	Elasticity
	NH_3					**NH_3**			
1009	Animal manure	EF	9.7	64.7	1009	Animal manure	EF	6.7	44.8
1001	Fertilizer use	EF	2.4	24.0	0701/02	Passenger car/light duty	EF	6.3	10.8
1009	Manure, activity	A	1.6	64.7	1001	Fertilizer use	EF	3.8	38.2
1001	Fertilizer use	A	0.6	24.0	1009	Manure, activity	A	1.1	44.8
					1001	Fertilizer used	A	1.0	38.2
					0701	Passenger car/light duty	A	0.5/0.1	9.8/1.0
					10	Treatment of straw	A/EF	0.4	5.2

A= activity, EF = Emission factor, PS = Point source

The domestic shipping activity is the most important contributor to total uncertainty of *SO_2*. This is due to the large size of this source combined with high uncertainty in the emission level. Silicon carbide (SiC) production consists of three point sources accounting for 8 per cent of total emissions in 1990, and the uncertainty is particularly high here due to some problems with consistent reporting. The most important source of SO_2 emissions in Norway, ferroalloy production, has a low uncertainty and is ranked lower in uncertainty importance.

There are important changes between 1990 and 2010. Emissions from domestic shipping are expected to decline in importance due to the anticipated reductions in sulphur content of fuel. Emissions from SiC production are assumed to decrease, with a corresponding reduction in contribution to total uncertainty. Thus, in the 2010 scenario emissions from coal, oil in industry and bio energy contribute most to the uncertainty.

Domestic shipping is also ranked highest for *NO_x*; both the emission factor and activity are important parameters. Also emissions from ferroalloy production (point source) are important, partly due to the high uncertainty. For road transport both the emission factor and activity level are important. From 1990 to 2010 the most important change is that emissions from road transport (all categories) decrease in importance due to stricter regulations.

In 1990, *NMVOC* emissions from offshore oil loading dominate the uncertainty importance, followed by passenger cars and solvent use. The number of key sources increases considerably from 1990 to 2010. The reason is large reductions in the dominating sources oil loading offshore and road transport. Both these sources, however, remain key.

Animal manure and fertilizer use are most important for the *ammonia* emission uncertainty in 1990 (emission factors, followed by activity data). In 2010 also emissions from road transport become a key source. This is due to the anticipated increase in the number of gasoline vehicles equipped with catalytic converters combined with high uncertainty because of a limited number of measurements.

Note that the analysis of uncertainties in emissions from animal manure was made at an aggregated level. Emissions from cattle, followed by swine and sheep, are most important.

4.2.2. Emission trend

Compiled uncertainty importance elasticities are shown in table 4.9. The corresponding elasticities are given in a separate column.

To a large extent the trend analysis identifies the same sources as the level analysis, but the ranking of sources may be different. Note that the output of the 1990-2010 analysis is very dependent on the assumptions made in the projection, and is indicative only.

Many sources of *SO_2* emissions contribute to the trend uncertainty. Most important are the emission factors for shipping, bio energy and several industrial processes. Due to the historical and anticipated decreasing emission trend, these elasticities are negative. Activity data, on the other hand, are often increasing and contribute with a positive elasticity.

Domestic shipping and road transport dominate the trend uncertainty of *NO_x*. Road transport decreases in level in the period 1990-2010 as stricter emission regulations become effective. In the period 1990-1998 emissions from shipping have increased, while the projection assumes that in 2010 emissions are reduced due to emission control.

The *NMVOC* sources oil loading and road transport also dominate the trend uncertainty. Road transport contributes to a negative trend due to the fact that new technology with lower emissions is introduced in the period considered. Oil loading has in the period 1990-1998 increased due to increased activity. The activity will likely continue to increase, while introduction of new technology will likely reduce the emission factors. This explains the change of sign of the values of elasticities and uncertainty importance.

The contribution to the *NH_3* trend uncertainty reflects the changes in emissions. An increase in emissions from gasoline vehicles is anticipated. The projection for the agriculture related emissions are uncertain, but changes in these are needed in order to meet the 2010 target, so in spite of the fact that the sign of each sub-source is uncertain, they will contribute to the trend.

Table 4.9. Uncertainty importance elasticities of key parameters and corresponding elasticities. 1990-1998 and 1990-2010. Ranking of parameters accounting for 90 per cent of total uncertainty in trend. Sign reflects the sensitivity (+ positive trend, - negative trend)

SNAP	Pollutant/Source	A/EF	1990-1998		SNAP	Pollutant/Source	A/EF	1990-2010	
			Uncertainty importance	Elasticity				Uncertainty importance	Elasticity
	SO_2					**SO_2**			
040416	SiC production	PS	-0.8	-8.4	040416	SiC production	PS	-1.4	-14.0
03	Oil, misc. direct fired	EF	-0.5	-1.8	01,02,03	Bio energy	EF	-0.5	-1.4
0804	Domestic shipping	EF	-0.4	-9.0	0804	Domestic shipping	EF	-0.4	-8.8
0804	Domestic shipping	A	+0.4	+2.8	040301	Aluminium production	PS	-0.3	-8.2
01,02,03	Coal	EF	-0.4	-1.1	040302	Ferro alloy production	PS	-0.3	-25.7
040301	Aluminium production	PS	-0.4	-11.2	03	Oil, industry	EF	-0.2	-2.4
03	Oil, industry	EF	-0.3	-3.3	0202	Res. wood combustion	A	-0.2	-0.8
0703	Heavy duty vehicles	A	+0.3	+1.9	0703	Heavy duty vehicles	A	+0.2	+1.1
01,02,03	Bio energy	EF	-0.2	-0.7	0401	Refineries	PS	-0.2	-6.4
0401	Refineries	PS	-0.2	-9.1	03	Oil, misc. direct fired	EF	-0.1	-0.5
03	Oil, industry	A	+0.1	+4.2	0202	Oil, residential	A	-0.1	-1.2
040302	Ferro alloy production	PS	-0.1	-14.3	0201	Oil, services	A	+0.1	+0.8
040603	Paper and pulp, processes	PS	-0.1	-6.3	03	Oil, industry	A	+0.1	+3.0
0202	Oil, residential	A	-0.1	-1.1	01,02,07, 08	Diesel/fuel oil	EF	-0.1	-15.3
0808	Diesel, industry	A	+0.1	+0.5	040603	Paper and pulp, process	PS	-0.1	-3.2
01,02,07,08	Diesel/fuel oil	EF	-0.1	-16.6	0102	Waste combustion	PS	-0.1	-1.5
01,02,03	Bio energy	A	+0.1	+0.4					
	NO_x					**NO_x**			
0804	Domestic shipping	A	+55	+388	0701	Passenger car	EF	-7.5	-60
0701	Passenger car	EF	-52	-414	0804	Domestic shipping	EF	-2.2	-29
0804	Domestic shipping	EF	+27	+324	0703	Heavy duty vehicle	EF	-1.7	-13
0105	Diesel, oil and gas extraction	EF	+22	+90	0105	Gas combustion, oil and gas extraction	EF	+1.6	+8
0703	Heavy duty vehicles	A	+21	+148	0703	Heavy duty vehicle	A	+1.4	+10
0105	Gas combustion, oil and gas extraction	EF	+19	+95	0105	Diesel, oil and gas extraction	EF	+1.3	+5
0808	Diesel, industry	A	+9.0	+43	0702	Light duty vehicle	EF	-1.1	-7.1
0808	Diesel, industry	EF	+7.6	+38	0804	Small boats	EF	+0.9	+4.6
0806	Diesel agriculture	A	-6.2	-29	0105	Gas combustion, oil and gas extraction	A	+0.5	+18.3
0806	Diesel, agriculture	EF	-6.0	-30	090206	Flaring	EF	-0.4	-1.8
0703	Heavy duty vehicle	EF	+5.4	+43	0806	Diesel, agriculture	A	-0.3	-1.3
0702	Light duty vehicle	EF	-4.5	-30	0701	Passenger car	A	-0.3	-3.7
090206	Flaring	EF	-3.3	-16	0806	Diesel, agriculture	EF	-0.3	-1.3
0702	Light duty vehicle	A	+3.2	+46	0202	Wood combustion, residential	EF	-0.2	-0.7
0105	Gas combustion, oil and gas extraction	A	+2.8	+101	0702	Light duty vehicle	A	+0.2	+3.3
0802	Railway	EF	-2.8	-11	0802	Railway	EF	-0.2	-0.7
040301	Aluminium production	EF	+2.4	+24	0808	Diesel, industry	A	-0.2	-0.8
					0202	Oil, domestic	EF	-0.2	-0.8
					0808	Diesel, industry	EF	-0.2	-0.8
	NMVOC					**NMVOC**			
050303	Oil loading, off-shore	EF	+32.2	+161	0701	Passenger car	EF	-12.3	-6
0701	Passenger car.	EF	-13.8	-55	050303	Oil loading, off-shore	EF	-8.6	-43
050303	Oil loading, off-shore	A	+5.1	+241	050303	Oil loading, off-shore	A	+2.3	+110
0702	Light duty vehicles	EF	-1.2	-5	050302	Oil loading, on-shore	EF	-2.0	-13
050302	Oil loading, on-shore	A	+0.9	+42	0702	Light duty vehicles	EF	-1.4	-6
06	Solvent use	A/EF	-0.9	-6	0202	Wood combustion, residential	EF	-1.0	-4
0505	Gasoline distribution	EF	-0.9	-4	0202	Wood combustion, residential	A	-0.8	-4
0202	Wood combustion, residential	EF	+0.8	+3	06	Solvent use	A/EF	+0.7	+5
050302	Oil loading, on-shore	EF	-0.7	-5	0505	Gasoline distribution	EF	-0.6	-2.5
					0804	Small boats	EF	+0.6	+28
	NH_3					**NH_3**			
0701/02	Passenger car/light duty	EF	+15.7	+27.1	0701/02	Passenger car/light duty	EF	+1 963	+3 385
1001	Fertilizer use	EF	+7.9	+78.9	1009	Animal manure	EF	-1013	-6 751
1009	Animal manure	EF	-2.8	-18.4	1001	Fertilizer	EF	+489	+4 895

A= activity, EF = Emission factor, PS = Point source

* Road transport technologies are modelled aggregated. That means that the contribution of uncertainty due to the distribution of fuel between technologies disappears. This distribution should, however, be considered key.

5. Conclusions

5.1. Inventory improvements

The ranking identifies where most is gained with respect to reduced uncertainty by making inventory improvements. The activity level of domestic shipping is resource demanding to determine accurately (Tornsjø 2001) on an annual basis. For SiC production, the uncertainty of SO_2 emissions is high due to difficulties in definition, but this can likely be solved. Regarding oil combustion (heavy fuel oil) there is, as mentioned, a few systematic errors influencing the SO_2 emissions that in principle can be accounted for. The sulphur content of bio energy and coal (combusted other than in point sources) can in principle be examined, but this can be resource demanding due to a variety of qualities and consumers.

Both NO_x emissions from domestic shipping and road transport have been prioritised for inventory improvements the last years (Tornsjø 2001; Bang et al. 1999). The ferroalloy production estimate has been improved after this analysis was performed. The estimate of emissions from oil combustion offshore might be improved in cooperation with the industry.

Both the sources offshore loading and road transport (NMVOC) have been prioritised in the inventory system the last years. These are, however, both sources with a high variability (dependent on i.e. climate conditions) and where technology is changing. Solvent use has not been prioritised since 1994 (Rypdal 1995) and uncertainty has likely increased since.

Ammonia emissions from agriculture have been prioritised in the inventory system (Flugsrud et al. 2000), but it might be possible to further reduce the uncertainty. This is, however, resource demanding. In order to reduce the uncertainty in ammonia emissions from road transport, more measurement data are needed. This can mostly be considered as an international task.

Few of the prioritised possibilities for reducing uncertainties can be performed by Statistics Norway alone. Most will need cooperation with research institutions and administrative agencies responsible for the particular source-sectors. The methodology used to prioritise does not take into account the effort needed to reduce the uncertainty. This is needed for a final prioritisation.

5.2. Possibilities for deriving thresholds

In Rypdal and Flugsrud (2001) a proposal was made on standard thresholds to indicate the importance of a source without performing a sensitivity analysis. The threshold referred to cumulative emissions and cumulative trend off-set (difference source trend and total trend). This simple methodology can be useful as most countries lack estimates of uncertainty. The threshold was based on inventory data for a number of countries. It is not within the scope of this report to determine such a threshold, but to form the basis for further work we will summarise the results for Norway.

The analysis is made on SNAP level 2 in order to increase the possibility of international comparisons. The sources here are, however, more aggregated than in the analyses made in this report, so the assignment is very rough.

Both the fraction and cumulative fraction can be used as a threshold. However, the cumulative fraction proves to be more robust to the aggregation level used in the analysis. It is also more equivalent to the "90 per cent uncertainty". As a starting point it is suggested that a threshold for key sources could be those sources "adding up to 95 per cent of total emissions".

Table 5.1. Exploration of assessment of key sources in level using standardised thresholds at SNAP level 2. 1998

	SO_2	NO_x	NMVOC	NH_3
1998				
Number of sources accounting for 90 % of the uncertainty in level	14	7	10	3
Fraction of total emissions needed to account for the same sources (%)	0.9	1.8	1.1	4.6
Cumulative fraction needed to account for the same sources (%)	98	95	93	98

The analysis of key sources for the trend shows that hardly any new sources are identified, while the ranking is different. This conclusion was different when the same analysis was made for the GHG.

5.3. Policy implication of uncertainties and sensitivities

This work shows that the LRTAP gases are uncertain. Emission ceilings are given as a maximum emission level in 2010. The confidence interval in ktonnes is widest for gases with a high level of emissions, NO_x and NMVOC, and is higher in other countries than in Norway where emissions are far lower in absolute terms. This has consequences when assessing compliance.

The uncertainty indicates the maximum range of recalculations due to improvements in inventory methodologies used. Such recalculations will directly influence on countries' capability to meet their targets. Emission ceilings are often less robust to recalculations than when obligations are given in terms of percentage change from a base year. These issues will be illustrated by sensitivity analysis and discussed in more detail in a separate paper.

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Appendix A

Emission data and parameter formats used in the study

Parameter format of data (all years)

SNAP			Label
	Boiler		
101	Electricity production		
		Oil	1
102	District heating		
		Oil	2
		Coal	3
		Bio energy	4
		Gas	5
103	Oil refineries		
		Oil	6
		Gas	7
		SO2/NOx - Point sources	8
105	Coal/Oil/Gas extraction		
		Oil	9
		Gas	10
201	Services		
		Oil	11
		Bio energy	12
		Gas	13
202	Residential		
		Oil	14
		Coal	15
		Bio energy	16
		Tobacco	17
203	Agriculture and fishing		
		Oil	18
		Coal	19
301	Manufacturing industry		
		Oil	20
		Coal	21
		Bio energy	22
		Gas	23
		NO_x - Point source waste gas	24
	Direct		
30305	Production of other metals		
		Oil	25
		Coal	26
		Gas	27
		Point sources NOx	28
30311	Cement production		
		Oil	29
		Coal	30
		SO_2/NO_x - Point sources Coal/Oil	31
30319	Leca production		
		Oil	32
		Coal	33
		SO_2 - Point sources	34
30321	Pulp and paper		
		Oil	35
		SO_2 - Point source heavy fuel oil etc.	36
30322	Aluminium production		
		Oil	37
		SO2 - Point source heavy distillate	38
		Gas	39
30326	Other direct fired combustion		
		Oil	40
		Coal	41
		Gas	42
	Processes		
40100	Oil refineries		43
		Point sources	44
40301	Aluminium		
			45
		Point sources	46
40302	Iron, steel and ferro alloys		47
			48
		Point sources	49
40309	Other metals		
		Point sources	50
40401	Sulphuric acid		
		Point sources	51
40407	Fertilizer		
		Point sources	52
40409	Anodes		
		Point sources	53
40410	Titan dioxide		
		Point sources	54
40412	Calcium carbide		
		Point sources	55
40416	Silicon carbide		
		Point sources	56
405	Petrochemistry		
		Point sources	57
40603	Pulp and paper		
		Point sources	58
40605	Bread		
			59
40607	Beer		
			60
40612	Cement manufacture		
		Point sources	61
40616	Extraction of ore		
		Point source	62
40617	Other processes		
			63
50201	Oil loading, on shore		64
50202			
	Oil loading, offshore		65
		Gas extraction etc, Point sources	66
50302	Gas terminal		67
505	Gasoline distribution		68
60100	Solvents		69

SNAP			Label
	Road transport		
701	Passenger cars		
		Catalytic	70
		Non-catalytic	71
702	Light duty vehicles		
		Catalytic	72
		Non-catalytic	73
703	Heavy duty vehicles		
		Controlled	74
		Uncontrolled	75
70400	Mopeds/light motorbikes		76
70500	Heavy motorbikes		77
	Other mobile sources		
80100	Military		78
80200	Railway		79
804	Domestic shipping/fishing		80
804	Small boats		81
805	Aviation		82
80600	Agriculture		83
807	Forestry		84
808	Industry		85
80900	Households		86
81000	Snow scooter		87
	Waste treatment		
90201	Waste combustion		
		Methane	88
		Waste	89
90203	Oil refineries, flaring		90
90204	Flaring, chemical industry		91
90206	Oil and gas extraction, flaring		
		Gas	92
		Oil	93
90207	Incineration of hospital waste		94
90901	Cremation		95
	Agriculture		
1001	Fertilizer use		96
100500	Animals		97
	Treatment of straw		98

Aggregated emission figures. 1990. tonnes

		SO_2	NO_x	NMVOC	NH_3
01	***Combustion in energy and transformation industries***				
101	Public power	9	7	1	-
102	District heating	681	1 092	294	-
103	Petroleum refining plants	411	1 728	57	-
105	Coal mining/oil and gas extraction	206	17 088	770	-
02	***Non-industrial combustion plants***				
201	Commercial and institutional	1 104	749	116	-
202	Residential plants	1 653	2 035	9 241	-
203	Plants in agriculture, forestry and aquaculture	297	133	22	-
03	***Combustion in manufacturing industry***				
301	Boilers, gas turbines and stationary engines	4 360	3 340	680	-
	Processes with contact				
30305	Manufacture of other metals	14	265	6	-
30311	Manufacture of cement	48	2 644	-	-
30319	Manufacture of concrete pumice stone	209	198	5	-
30321	Pulp and paper	663	209	13	-
30322	Aluminium	99	29	2	-
30326	Other processes with contact	1140	485	23	-
04	***Industrial processes***				
40100	Oil refineries	3 863	1 154	15 290	-
40301	Aluminium	4 162	616	-	-
40302	Iron, steel and ferroalloys	11 954	6 524	1 438	
40309	Other metals	545	4	-	-
40401	Sulphuric acid	1 267	-	-	-
40407	Fertiliser	-	2 400	-	464
40412/16	Silicon carbide.	4 438	14	-	-
405	Petrochemical industry	-	-	810	-
40603	Pulp and paper	1 866	-	-	-
40605/07	Food production	-	-	1 066	-
40612	Cement production	584	-	-	-
40617	Other processes	1938	-	-	-
50201	Oil loading on shore	-	-	18 887	-
50202	Oil loading offshore	-	-	96 995	-
50302	Gas terminal etc.	-	-	4 048	-
505	Gasoline distribution	-	-	8 722	-
06	***Solvent and other product use***				
60100	Solvents	-	-	48 162	-
07	***Road traffic***				
701	Passenger cars				
	Catalytic converter	60	486	513	169
	Not catalytic converter	1 015	44 246	60 702	43
702	Light duty vehicles				
	Catalytic converter	-	-	-	-
	Not catalytic converter	554	6 734	6 983	6
703	Heavy duty vehicles				
	Controlled	-	-	-	-
	Not controlled	1 917	25 103	3 412	2
70400	Mopeds and light motorcycles	5	23	3 058	0
70500	Motorcycles	4	48	1 028	0
08	***Other mobile***				
80100	Military	1	16	2	0
80200	Railway	97	1 424	121	-
804	Domestic sea transport and fishing	6 660	78 616	2 603	-
804	Small boats	64	1 038	8 764	-
805	Air traffic (< 1000 m)	36	1 279	603	-
80600	Agriculture - equipment	403	6 804	907	1
807	Forestry - equipment	59	948	773	0
808	Industry-- equipment	282	4 072	392	0
80900	Households - equipment	10	164	1 807	-
81000	Snowscooters	2	9	1 211	0

09	***Waste treatment***				
90201	Combustion of waste	17	24	9	-
90203	Flaring in oil refineries	-	236	723	-
90204	Flaring in chemical industry	-	..	..	-
90206	Flaring in oil and gas extraction	-	6 865	134	-
90207	Hospital waste	0	0	0	-
90901	Cremation	0	1	1	-
10	***Agriculture***				
1001	Fertiliser	-	-	-	5 514
100500	Animals	-	-	-	14 839
	Treatment of straw	-	-	-	1 910
TOTAL		**52 698**	**218 855**	**300 396**	**22 949**

Aggregated emission figures. 1998. tonnes

		SO_2	NO_x	NMVOC	NH_3
01	***Combustion in energy and transformation industries***				
101	Public power	15	6	0	-
102	District heating	638	1 077	402	-
103	Petroleum refining plants	95	1 665	64	-
105	Coal mining/oil and gas extraction	265	26 571	1 281	-
02	***Non-industrial combustion plants***				
201	Commercial and institutional	516	730	121	-
202	Residential plants	1 017	1 833	10 626	-
203	Plants in agriculture, forestry and aquaculture	124	114	17	-
03	***Combustion in manufacturing industry***				
301	Boilers, gas turbines and stationary engines	3 398	3 972	1 026	-
	Processes with contact				
30305	Production of other metals	251	137	4	-
30311	Cement manufacture	143	3259	-	-
30319	Manufacture of concrete pumice stone	58	268	3	-
30321	Pulp and paper	503	357	21	-
30322	Aluminium	20	143	2	-
30326	Other combustion with contact	345	983	24	-
04	***Industrial processes***				
40100	Oil refineries	1 971	751	14 816	-
40301	Aluminium	1 845	739	-	-
40302	Iron, steel and ferroalloys	8 992	6 674	1 939	-
40309	Other metals	442	4	-	-
40407	Fertiliser	-	1 151	-	344
40412/16	Carbide manufacture	2700	37	1	-
405	Petrochemical industry	-	-	912	-
40603	Pulp and paper	571	-	-	-
40605/07	Food production		-	867	-
40612	Cement production	754	-	-	-
40617	Other processes	645	-	-	-
50201	Oil loading on shore	-	-	16 710	-
50202	Oil loading offshore	-	-	168 532	-
50302	Gas terminal etc.	-	-	6 324	-
505	Gasoline distribution	-	-	7 170	-
06	***Solvent and other product use***				
60100	Solvent use	-	-	45 513	-
07	***Road traffic***				
701	Passenger cars				
	Catalytic converter	118	4 642	5 308	1 238
	Not catalytic converter	205	18 903	31 462	22
702	Light duty vehicles				
	Catalytic converter	13	466	343	80
	Not catalytic converter	268	4 748	4 426	6
703	Heavy duty vehicles				
	Controlled	339	13 162	1 299	1
	Not controlled	271	14 132	2 100	1
70400	Mopeds and light motorcycles	1	19	2 523	0
70500	Motorcycles	3	112	1 891	1

08	***Other mobile***				
80100	Military	1	34	3	0
80200	Railway	14	845	72	-
804	Domestic sea transport and fishing	2 948	95 202	3 211	-
804	Small boats	18	1 038	8 764	-
805	Air traffic (< 1000 m)	70	1 688	496	-
80600	Agriculture - equipment	78	5 268	702	0
807	Forestry - equipment	12	749	766	0
808	Industry- equipment	107	6 026	600	1
80900	Households - equipment	3	164	1 807	-
81000	Snowscooters	1	11	1 498	0
09	***Waste treatment***				
90201	Combustion of waste	0	3	-	-
90203	Flaring in oil refineries	-	160	809	-
90204	Flaring in chemical industry	-	128	-	-
90206	Flaring in oil and gas extraction	-	6 001	293	-
90207	Hospital waste	0	0	0	-
90901	Cremation	0	1	1	-
10	***Agriculture***				
1001	Fertiliser	-	-	-	8 799
100500	Animals	-	-	-	14 072
	Treatment of straw	-	-	-	2 549
TOTAL		**29 770**	**223 971**	**344 747**	**27 114**

Aggregated emission figures. 2010. tonnes*

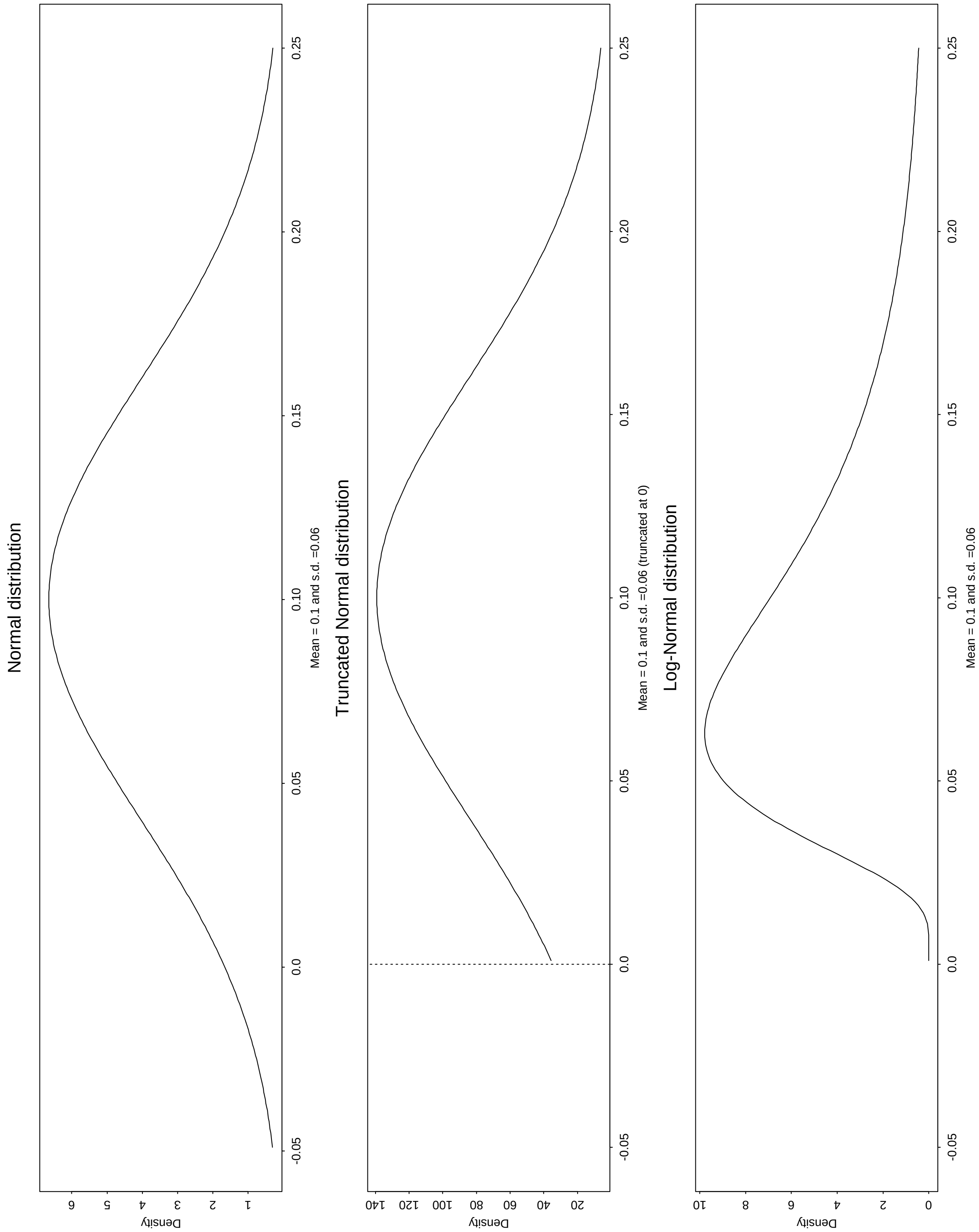
		SO_2	NO_x	NMVOC	NH_3
01	***Combustion in energy and transformation industries***				
101	Public power	41	9	1	-
102	District heating	622	896	402	-
103	Petroleum refining plants	95	266	64	-
105	Coal mining/oil and gas extraction	233	25 404	1 561	-
02	***Non-industrial combustion plants***				
201	Commercial and institutional	676	959	144	-
202	Residential plants	639	1 114	5 033	-
203	Plants in agriculture, forestry and aquaculture	165	152	22	-
03	***Combustion in manufacturing industry***				
301	Boilers, gas turbines and stationary engines	3 632	3 843	1 068	-
	Processes with contact				
30305	Production of other metals	431	344	8	-
30311	Cement manufacture	79	1 852	-	-
30319	Manufacture of concrete pumice stone	69	234	3	-
30321	Pulp and paper	629	272	16	-
30322	Aluminium	0	38	2	-
30326	Other combustion with contact	847	631	29	-
04	***Industrial processes***				
40100	Oil refineries	2 065	1 304	15 190	-
40301	Aluminium	1 863	622	-	-
40302	Iron, steel and ferroalloys	4 735	6 590	-	-
40309	Other metals	446	4	-	-
40407	Fertiliser	-	1 608	-	214
40412/16	Carbide manufacture	500	9	1	-
405	Petrochemical industry	-	-	912	-
40603	Pulp and paper	971	-	-	-
40605/07	Food production	-	-	867	-
40612	Cement production	498	-	-	-
40617	Other processes	645	-	-	-
50201	Oil loading on shore	-	-	4 900	-
50202	Oil loading offshore	-	-	51 840	-
50302	Gas terminal etc.	-	-	16 039	-
505	Gasoline distribution	-	-	6 064	-
06	***Solvent and other product use***				
60100	Solvent use	-	-	53 129	-
07	***Road traffic***				
701	Passenger cars				
	Catalytic converter	140	6 922	9 362	2 255
	Not catalytic converter	-	-	-	-
702	Light duty vehicles				
	Catalytic converter	53	2 278	1 044	235
	Not catalytic converter	-	-	-	-
703	Heavy duty vehicles				
	Controlled	81	16 730	2 293	4
	Not controlled	-	-	-	-
70400	Mopeds and light motorcycles	1	19	2 526	0
70500	Motorcycles	1	96	1 587	1
08	***Other mobile***				
80100	Military	0	14	1	-
80200	Railway	2	997	85	-
804	Domestic sea transport and fishing	1 744	60 214	2 529	-
804	Small boats	7	3 960	11 748	
805	Air traffic (< 1000 m)	72	1 868	512	-
80600	Agriculture - equipment	11	5 988	793	-
807	Forestry - equipment	2	834	838	-
808	Industry - equipment	7	3 583	341	-
80900	Households - equipment	2	168	1 843	-
81000	Snowscooters	0	9	1 235	-

09	***Waste treatment***				
90201	Combustion of waste	0	9	-	-
90203	Flaring in oil refineries	-	267	817	-
90204	Flaring in chemical industry	-	-	-	-
90206	Flaring in oil and gas extraction	-	5 698	212	-
90207	Hospital waste	0	0	0	-
90901	Cremation	0	1	1	-
10	***Agricultutre***				
1001	Fertiliser	-	-	-	8 799
100500	Animals	-	-	-	10 308
	Treatment of straw	-	-	-	1 200
TOTAL		**22 004**	**155 805**	**195 064**	**23 016**

* The details of this table goes beyond the official projections. It is based on a technical interpretation needed for the analysis made in this work, assuming that targets are met and does not reflect any Statistics Norway opinion on future emissions.

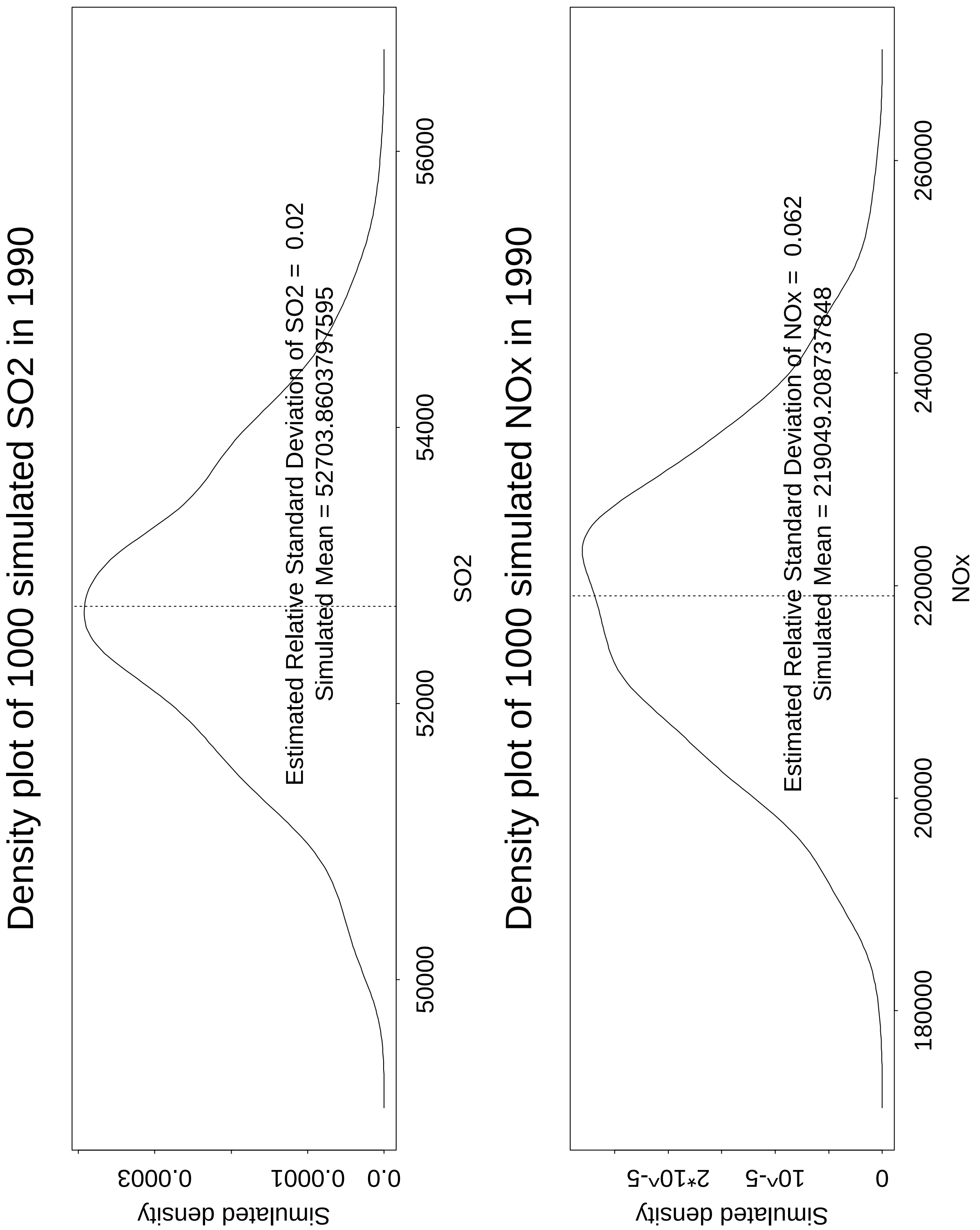
Appendix B

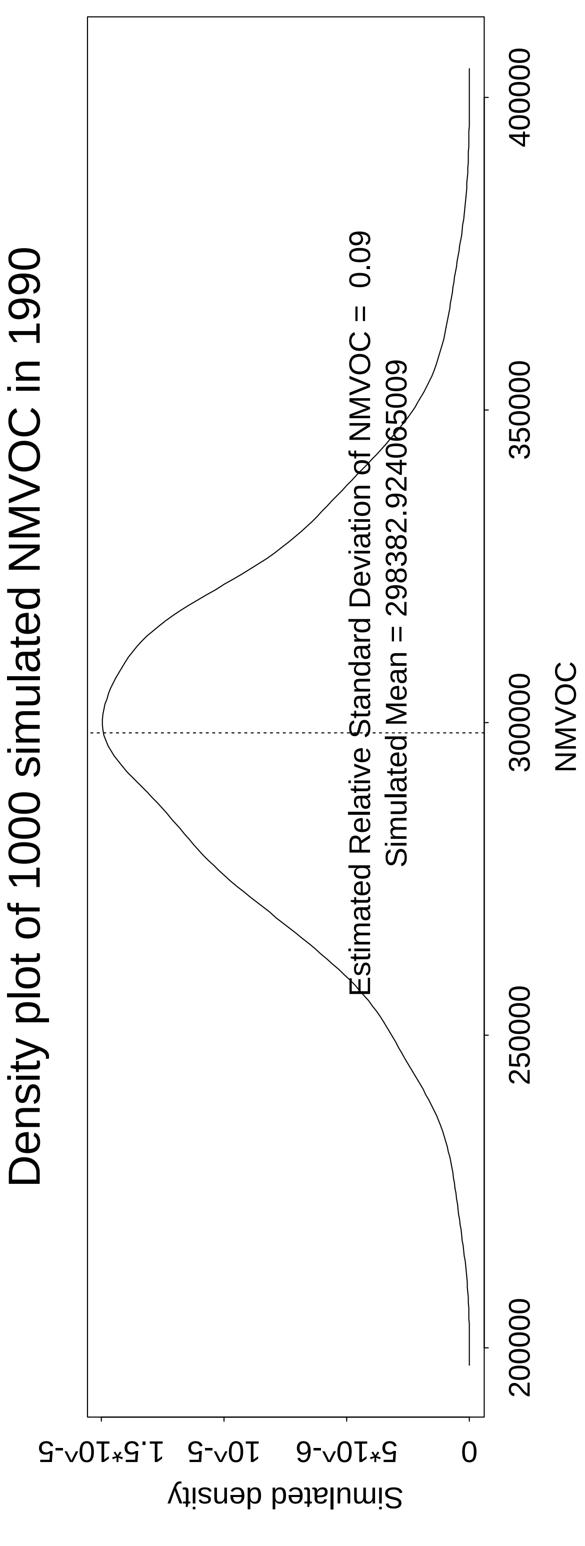
Model probability density functions

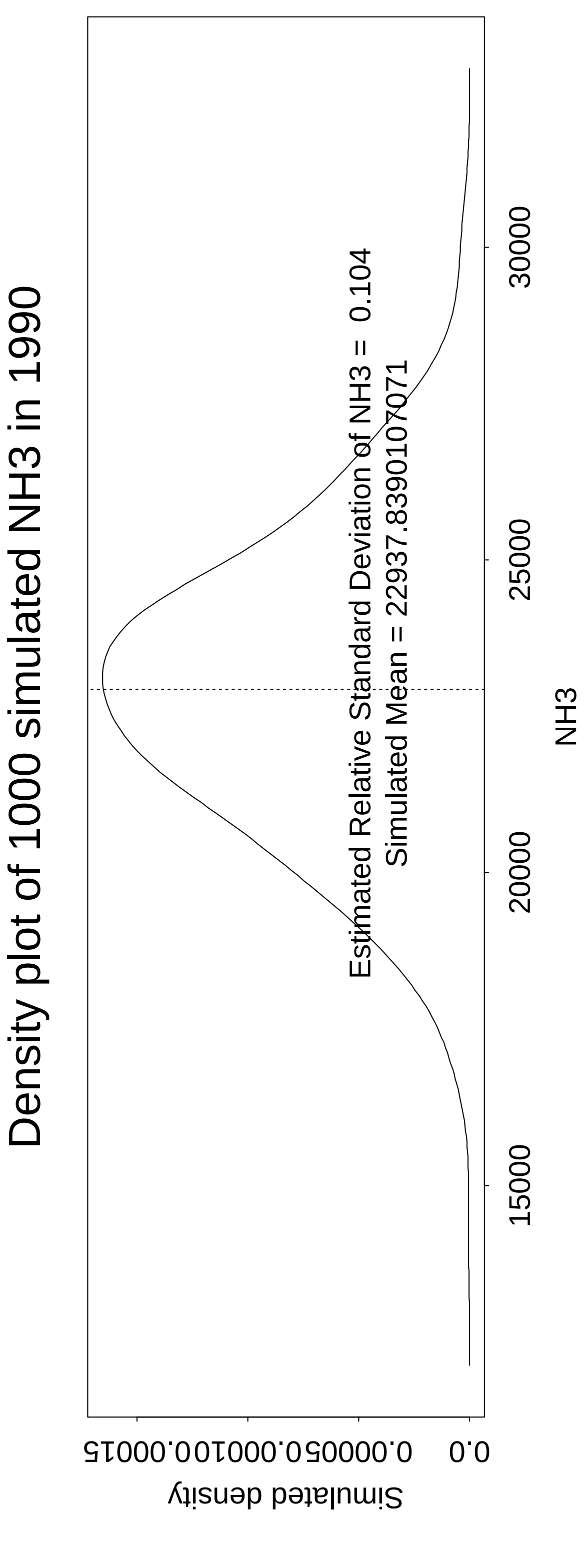


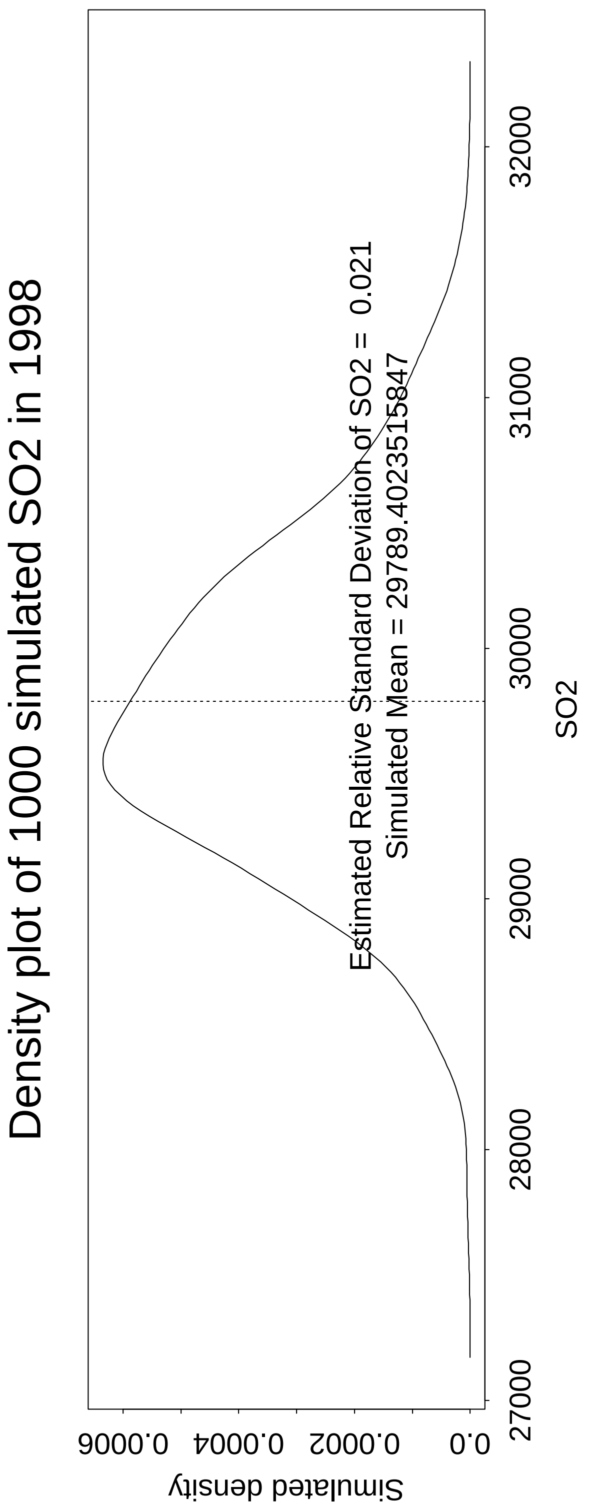
Appendix C

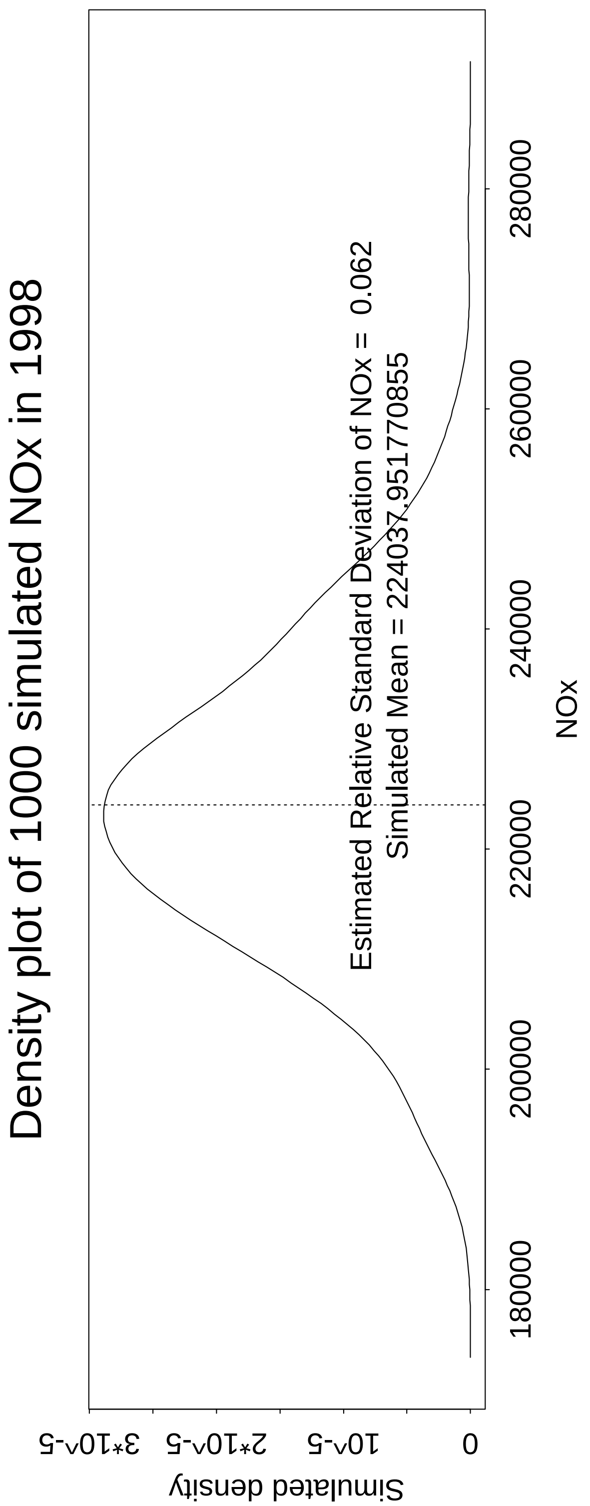
Density plot of final data set

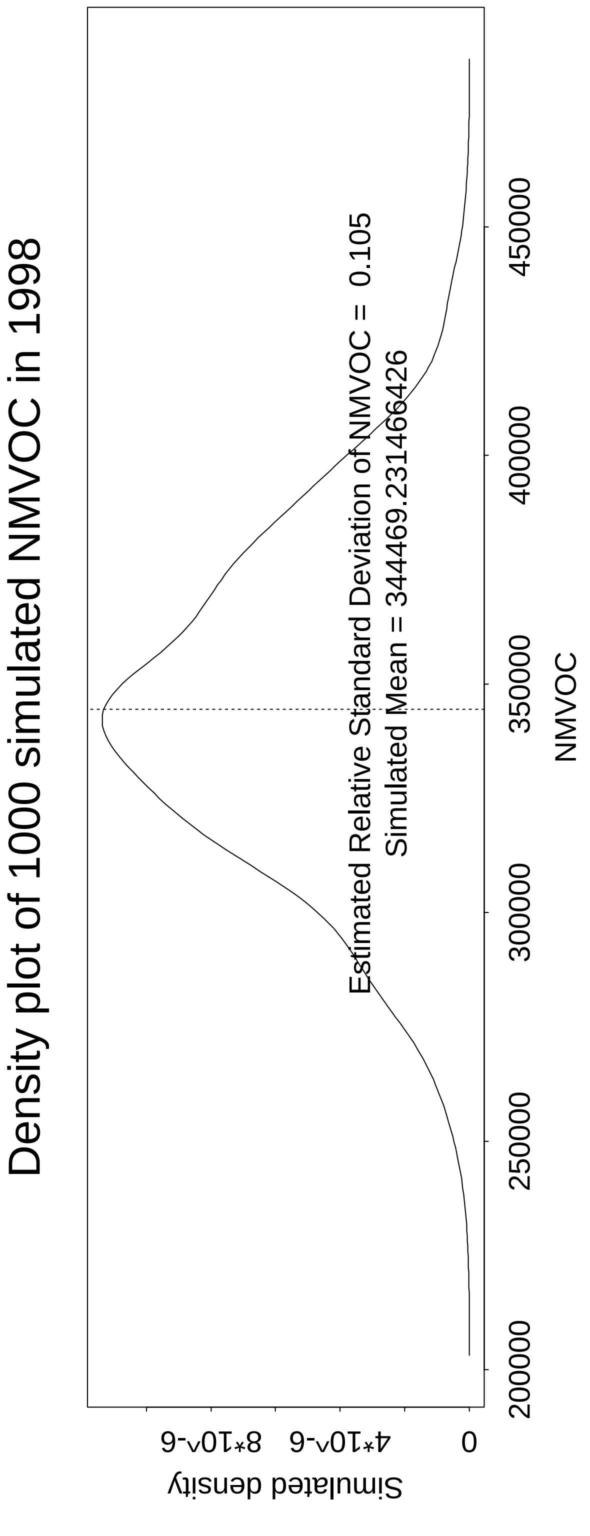


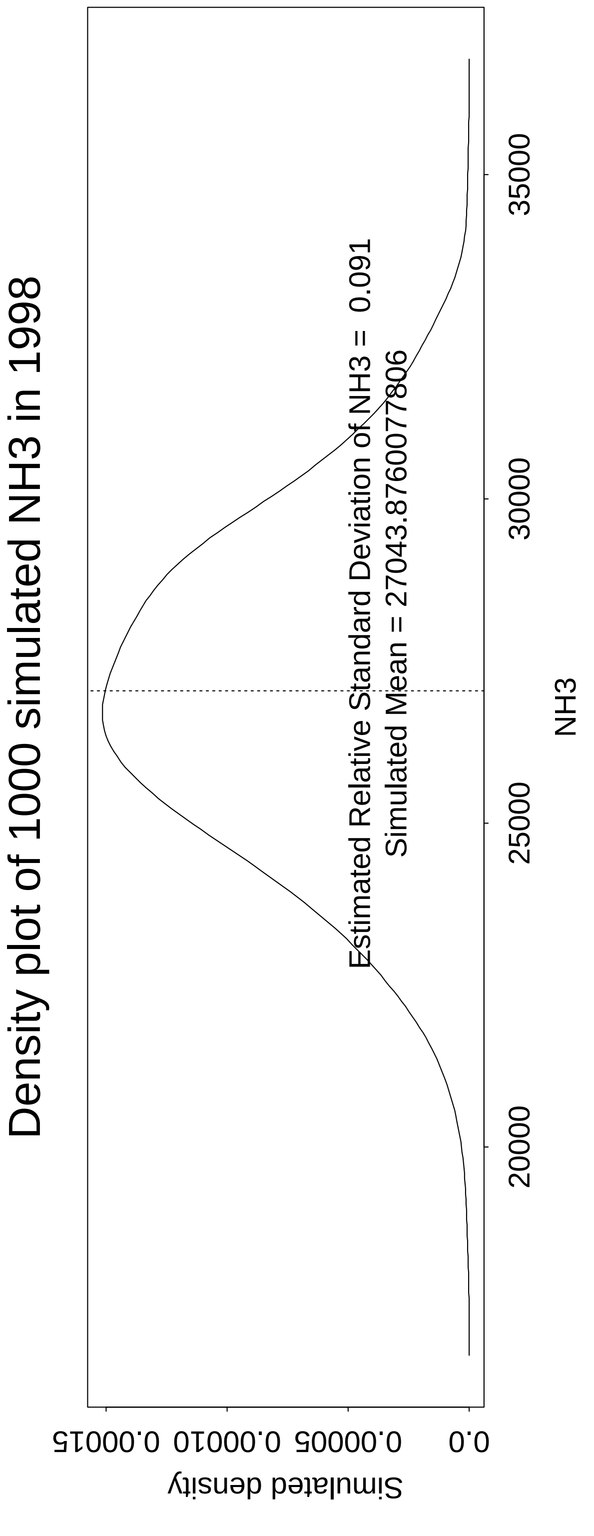

Density plot of 1000 simulated NMVOC in 1990
Estimated Relative Standard Deviation of NMVOC = 0.09
Simulated Mean = 298382.924065009
Simulated density
0
5*10^-6
10^-5
1.5*10^-5
NMVOC
200000
250000
300000
350000
400000

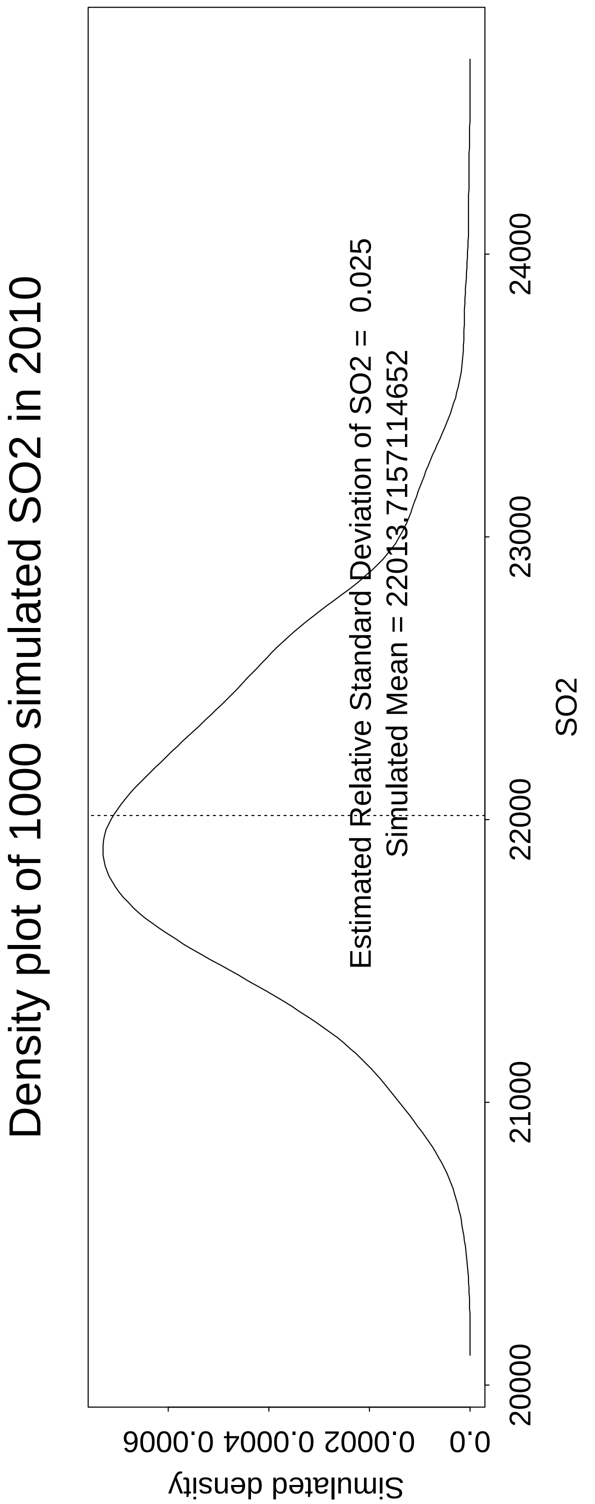

Density plot of 1000 simulated NH3 in 1990
Estimated Relative Standard Deviation of NH3 = 0.104
Simulated Mean = 22937.8390107071
Simulated density
0.0
0.00005
0.00010
0.00015
NH3
15000
20000
25000
30000

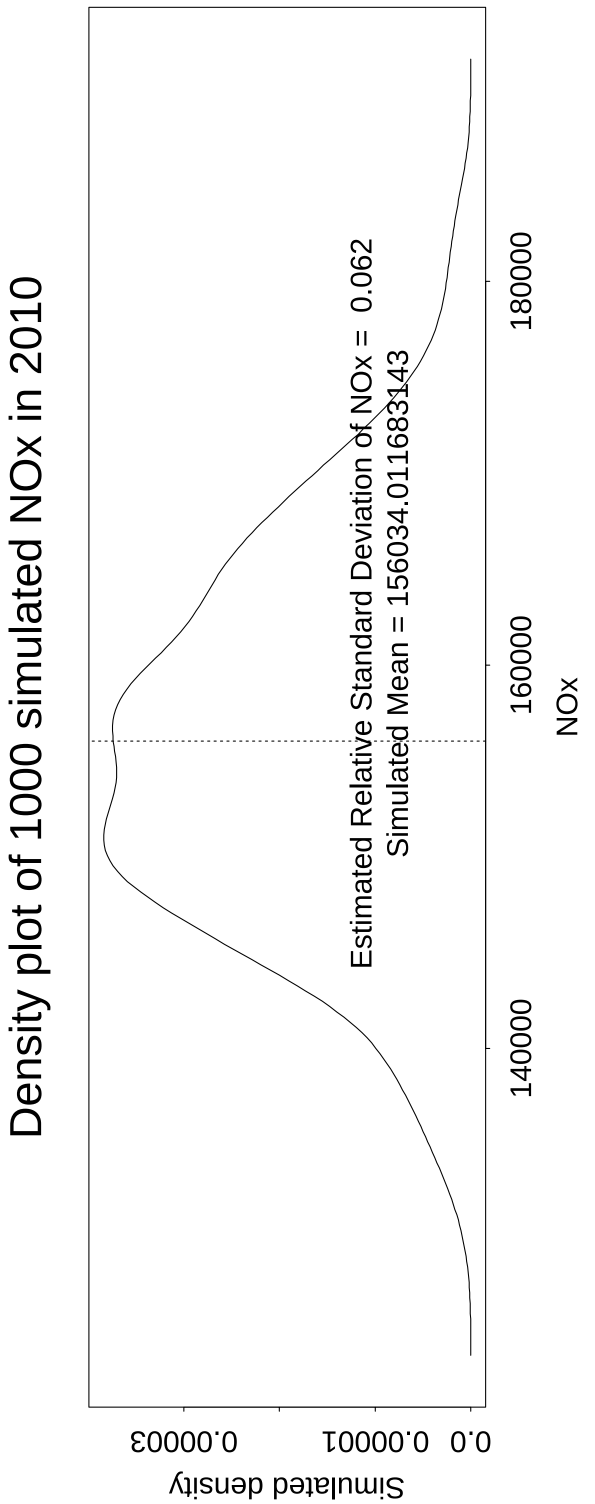

Density plot of 1000 simulated SO2 in 1998
Estimated Relative Standard Deviation of SO2 = 0.021
Simulated Mean = 29789.4023515847
SO2
Simulated density
27000
28000
29000
30000
31000
32000
0.0
0.0002
0.0004
0.0006

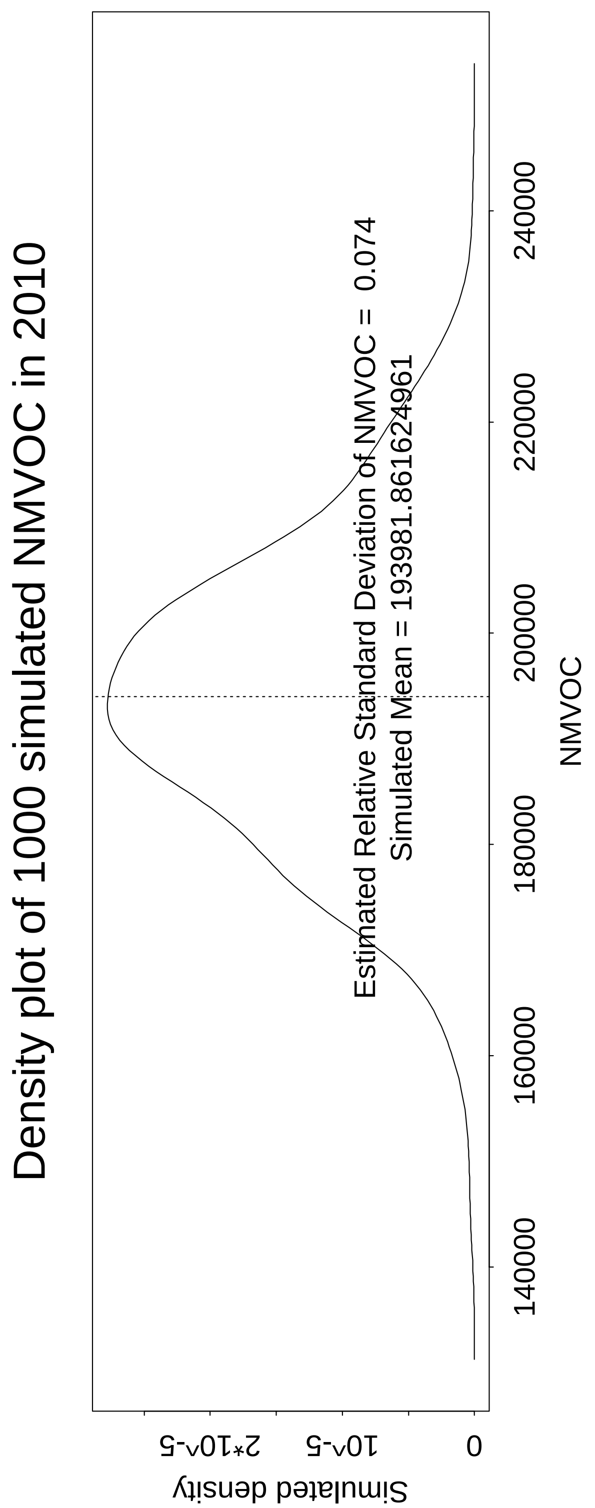

Density plot of 1000 simulated NOx in 1998
Estimated Relative Standard Deviation of NOx = 0.062
Simulated Mean = 224037.951770855
NOx
Simulated density
180000
200000
220000
240000
260000
280000
0
10^-5
2*10^-5
3*10^-5

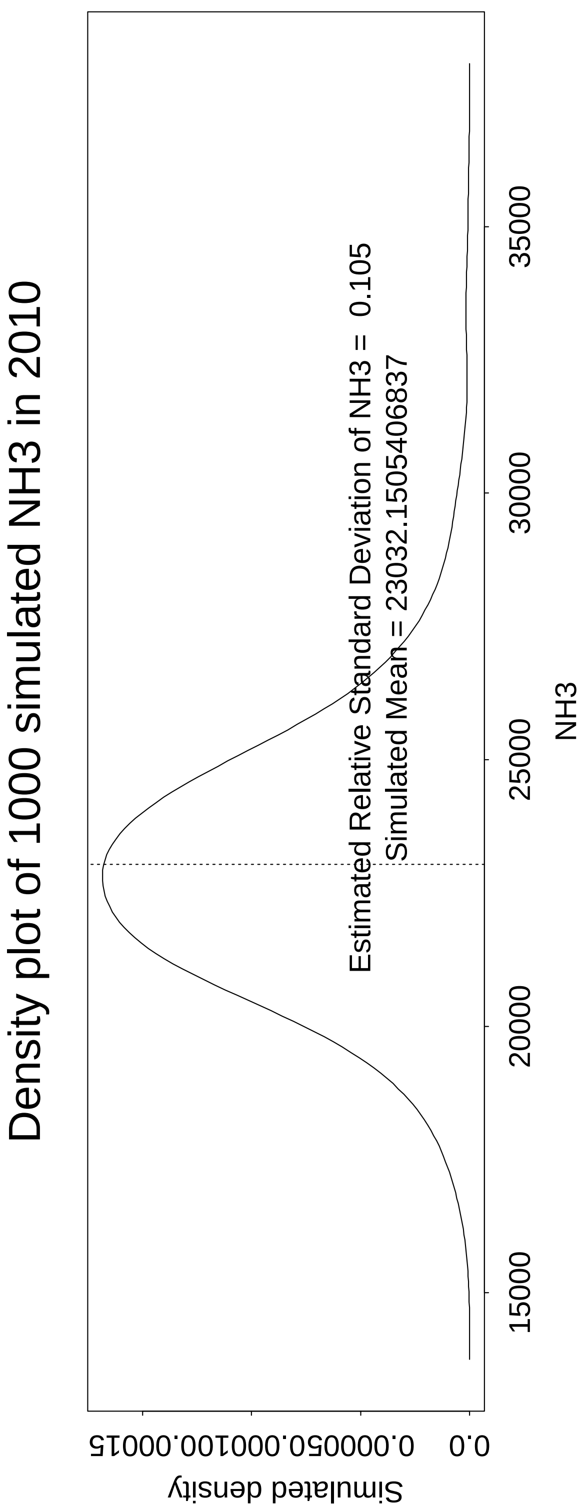

Density plot of 1000 simulated NMVOC in 1998
Estimated Relative Standard Deviation of NMVOC = 0.105
Simulated Mean = 344469.231466426
NMVOC
200000
250000
300000
350000
400000
450000
Simulated density
0
4*10^-6
8*10^-6

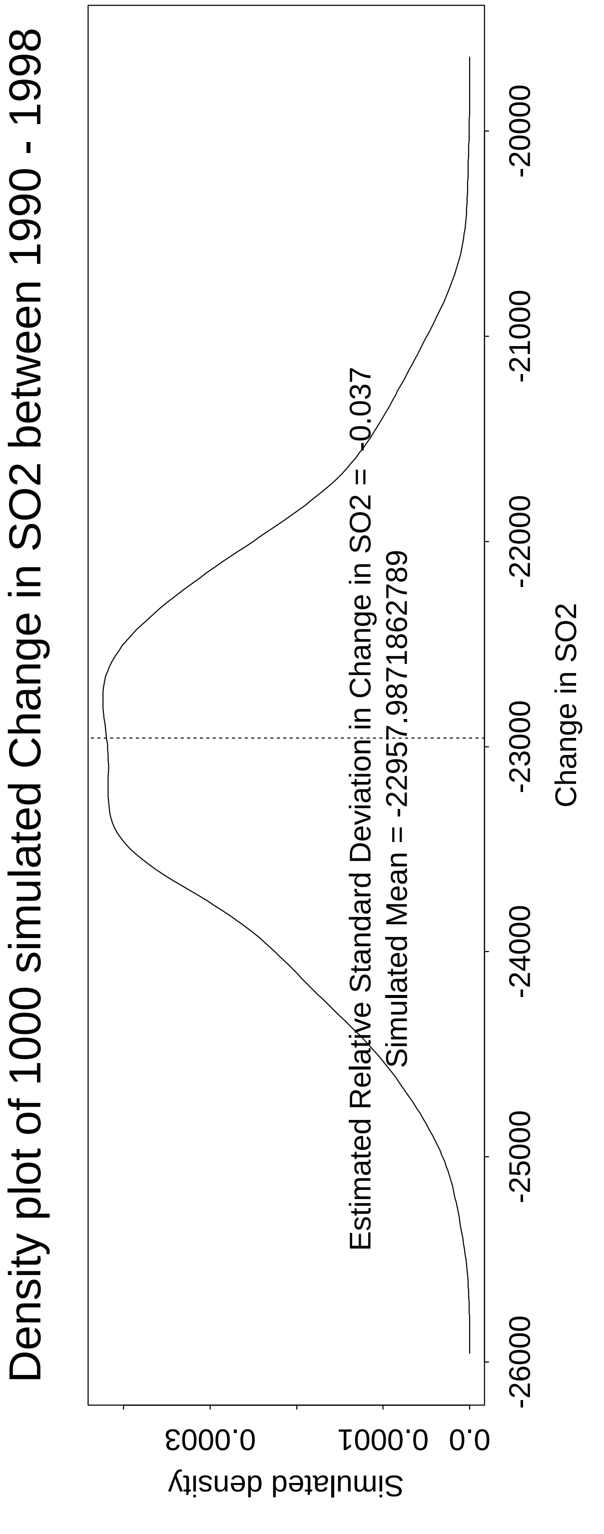

Density plot of 1000 simulated NH3 in 1998
Estimated Relative Standard Deviation of NH3 = 0.091
Simulated Mean = 27043.876077806
NH3
20000
25000
30000
35000
Simulated density
0.0
0.00005
0.00010
0.00015

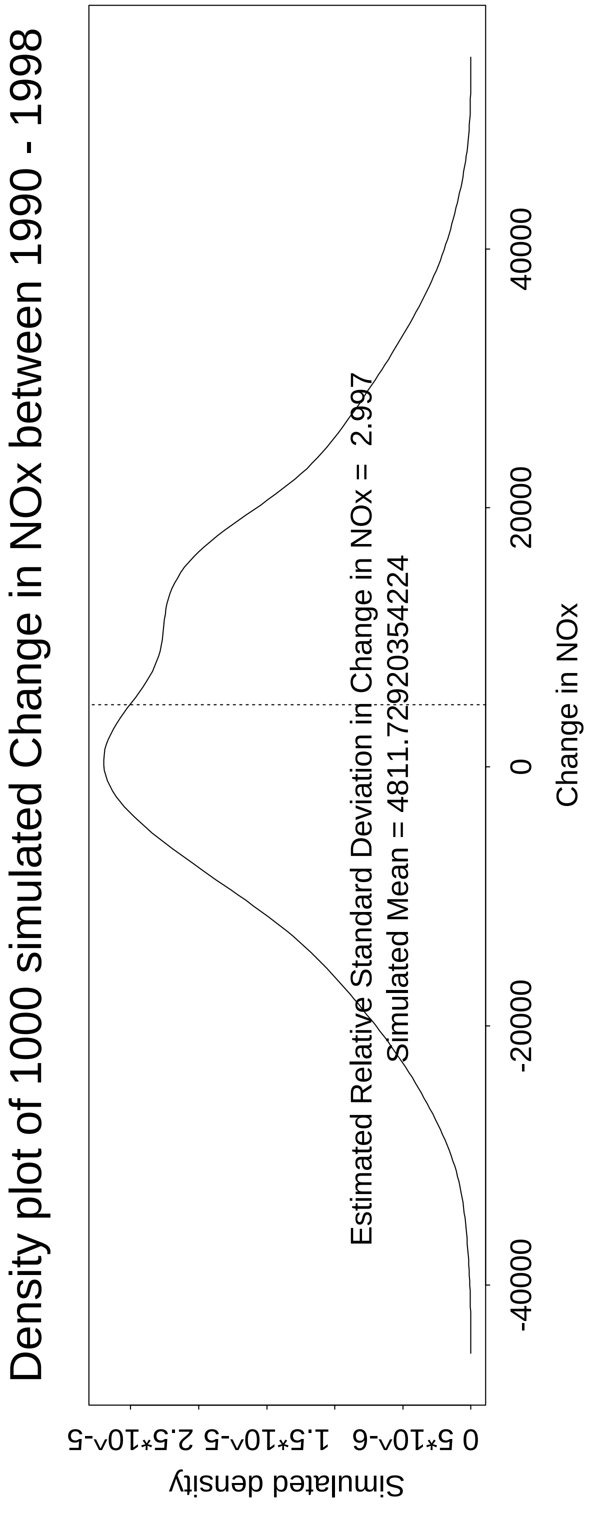

Density plot of 1000 simulated SO2 in 2010
Estimated Relative Standard Deviation of SO2 = 0.025
Simulated Mean = 22013.7157114652
Simulated density
0.0 0.0002 0.0004 0.0006
SO2
20000 21000 22000 23000 24000

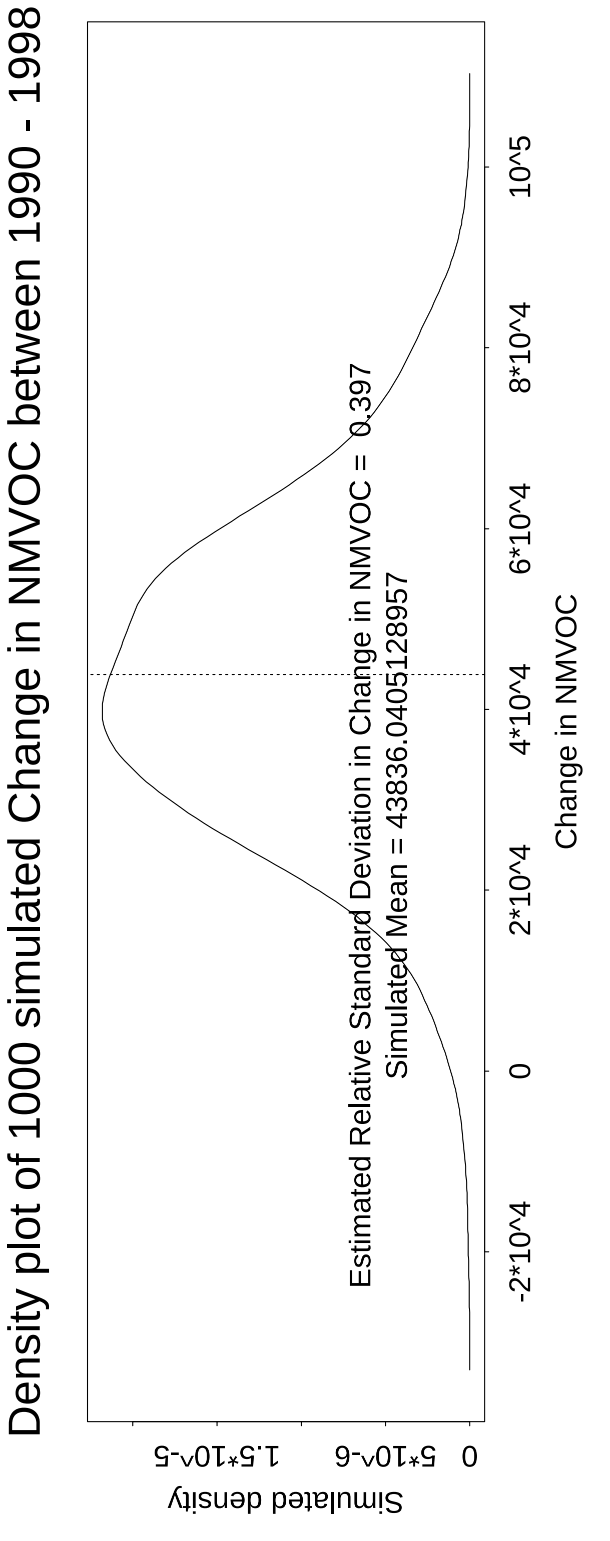

Density plot of 1000 simulated NOx in 2010
Estimated Relative Standard Deviation of NOx = 0.062
Simulated Mean = 156034.011683143
Simulated density
0.0 0.00001 0.00003
NOx
140000 160000 180000

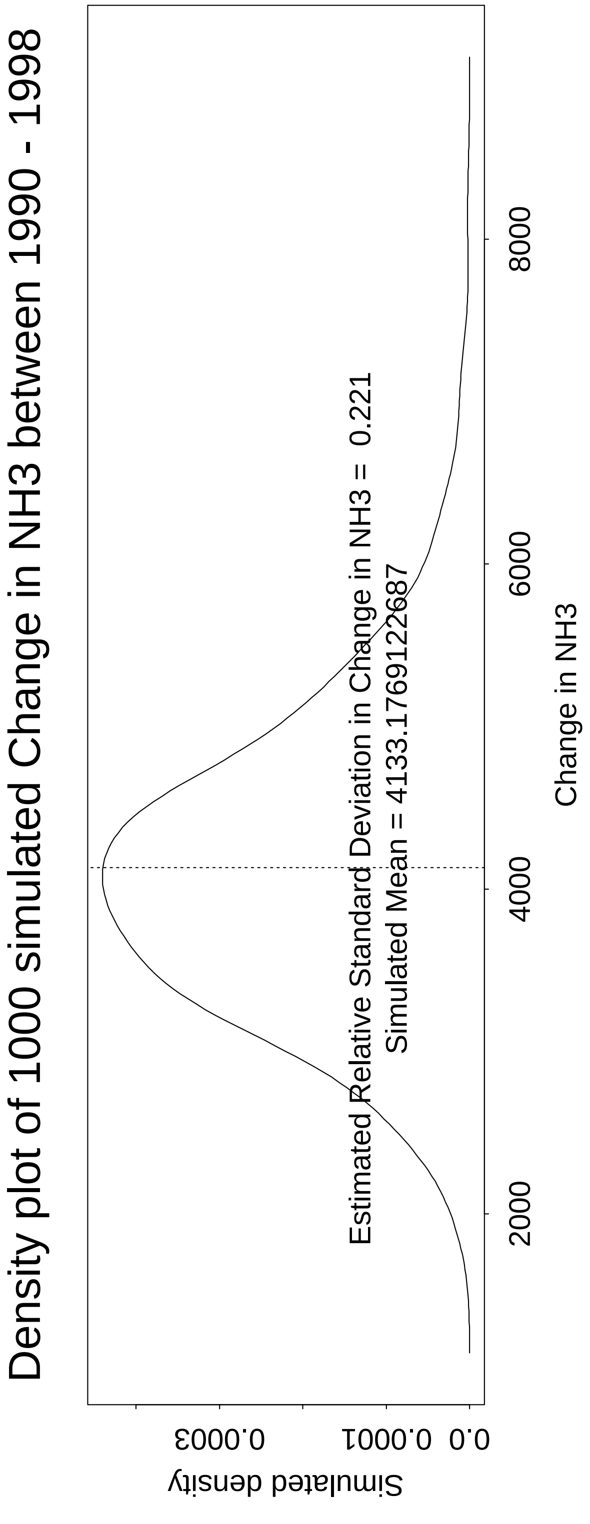

Density plot of 1000 simulated NMVOC in 2010
Estimated Relative Standard Deviation of NMVOC = 0.074
Simulated Mean = 193981.861624961
140000
160000
180000
200000
220000
240000
NMVOC
0
10^-5
2*10^-5
Simulated density

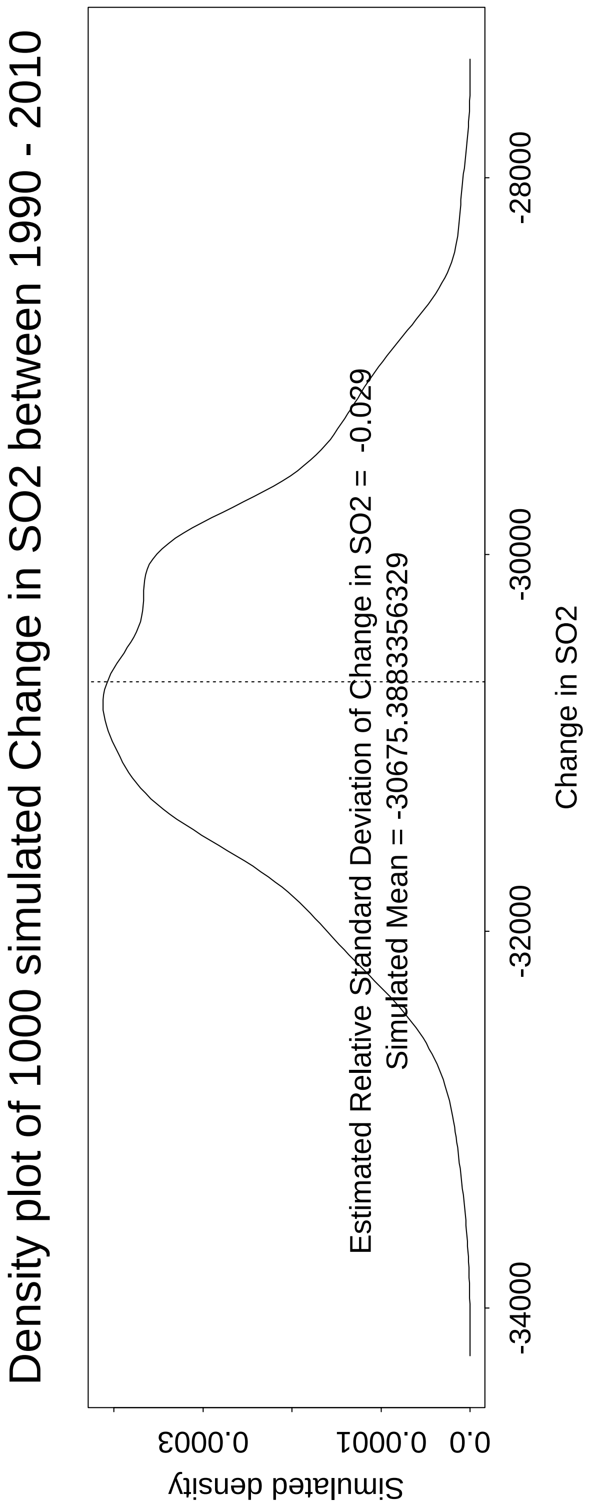

Density plot of 1000 simulated NH3 in 2010
Estimated Relative Standard Deviation of NH3 = 0.105
Simulated Mean = 23032.1505406837
15000
20000
25000
30000
35000
NH3
0.0
0.00005
0.00010
0.00015
Simulated density

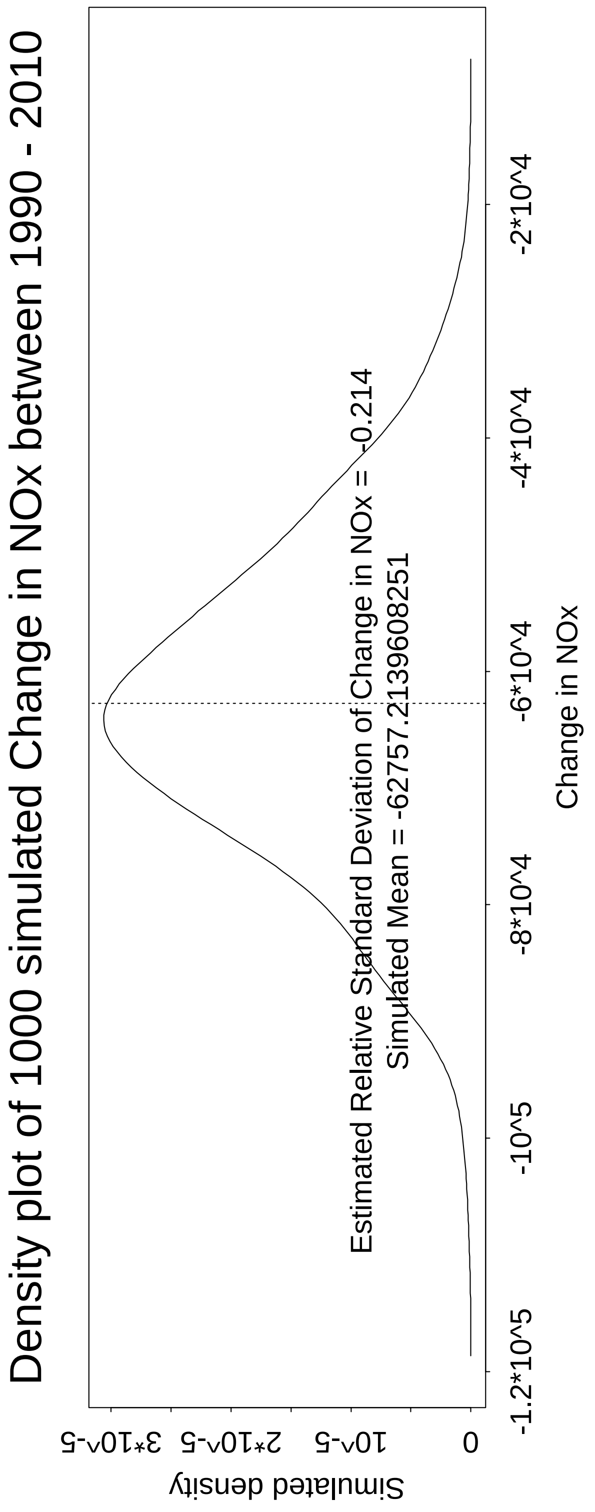

Density plot of 1000 simulated Change in SO2 between 1990 - 1998
Estimated Relative Standard Deviation in Change in SO2 = -0.037
Simulated Mean = -22957.9871862789
Change in SO2
Simulated density

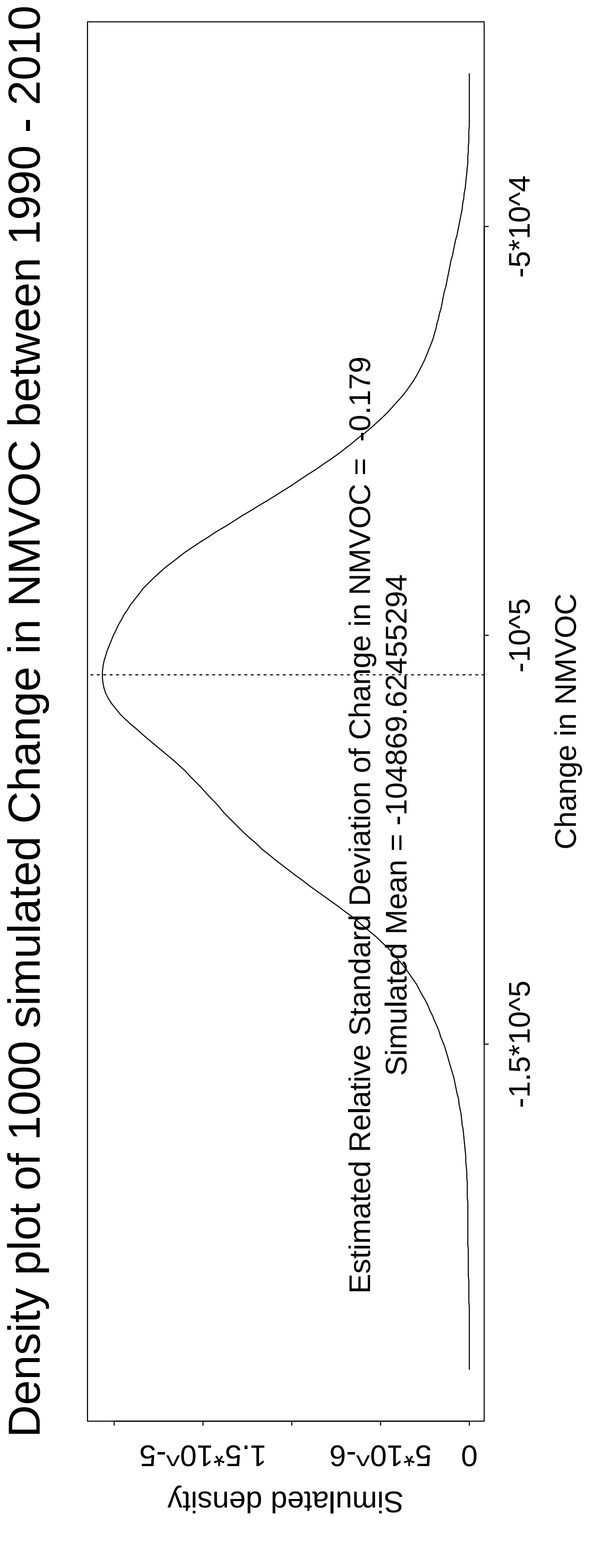

Density plot of 1000 simulated Change in NOx between 1990 - 1998
Estimated Relative Standard Deviation in Change in NOx = 2.997
Simulated Mean = 4811.72920354224
Change in NOx
Simulated density

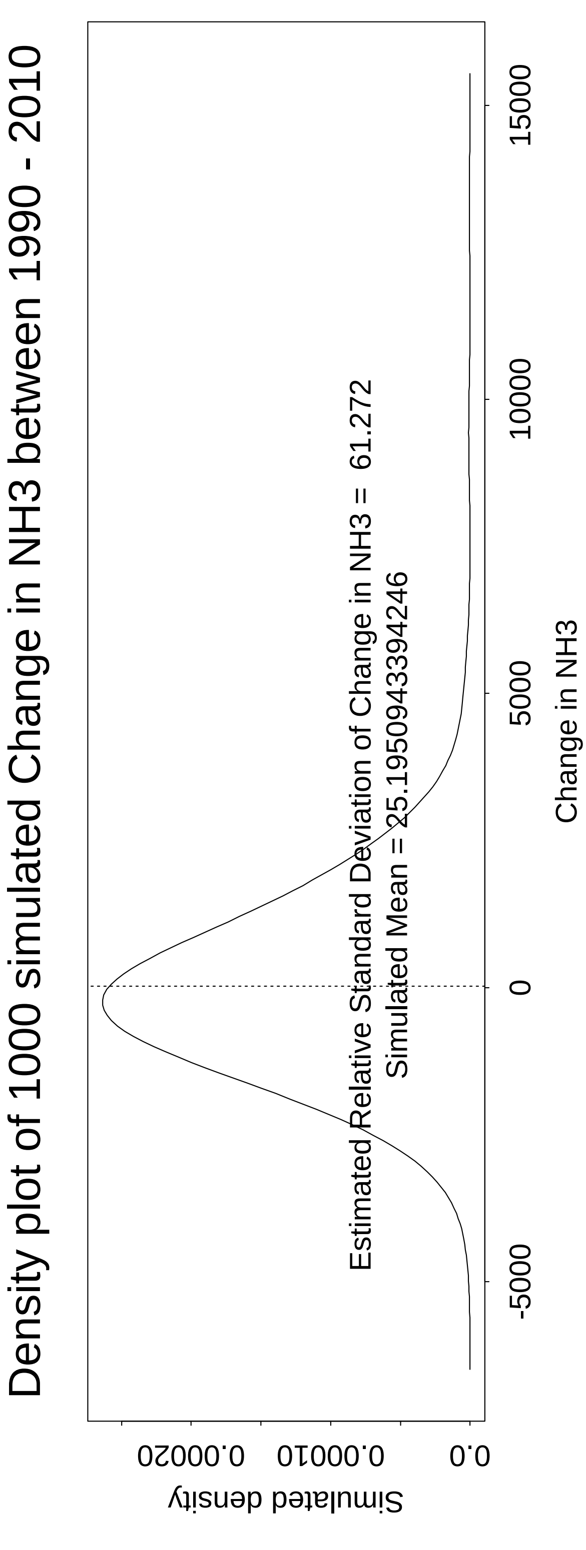

Density plot of 1000 simulated Change in NMVOC between 1990 - 1998
Estimated Relative Standard Deviation in Change in NMVOC = 0.397
Simulated Mean = 43836.0405128957
Change in NMVOC
-2*10^4
0
2*10^4
4*10^4
6*10^4
8*10^4
10^5
Simulated density
0
5*10^-6
1.5*10^-5


Density plot of 1000 simulated Change in NH3 between 1990 - 1998
Estimated Relative Standard Deviation in Change in NH3 = 0.221
Simulated Mean = 4133.1769122687
Change in NH3
2000
4000
6000
8000
Simulated density
0.0
0.0001
0.0003


Density plot of 1000 simulated Change in SO2 between 1990 - 2010
Estimated Relative Standard Deviation of Change in SO2 = -0.029
Simulated Mean = -30675.3883356329
Change in SO2
Simulated density
-34000
-32000
-30000
-28000
0.0
0.0001
0.0003


Density plot of 1000 simulated Change in NOx between 1990 - 2010
Estimated Relative Standard Deviation of Change in NOx = -0.214
Simulated Mean = -62757.2139608251
Change in NOx
Simulated density
-1.2*10^5
-10^5
-8*10^4
-6*10^4
-4*10^4
-2*10^4
0
10^-5
2*10^-5
3*10^-5


Density plot of 1000 simulated Change in NMVOC between 1990 - 2010
Estimated Relative Standard Deviation of Change in NMVOC = -0.179
Simulated Mean = -104869.62455294
Simulated density
0
5*10^-6
1.5*10^-5
-1.5*10^5
-10^5
-5*10^4
Change in NMVOC


Density plot of 1000 simulated Change in NH3 between 1990 - 2010
Estimated Relative Standard Deviation of Change in NH3 = 61.272
Simulated Mean = 25.1950943394246
Simulated density
0.0
0.00010
0.00020
-5000
0
5000
10000
15000
Change in NH3

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