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Contents

Abstract

Under the UN-FCCC, countries must submit National Inventory Reports of greenhouse gas emissions. These inventories must be prepared while applying *good practice. Good practice* in emission inventorying implies assessments of uncertainties in the inventory. The IPCC guidelines describe two methods for uncertainty analysis: the tier-1 and tier-2 method. The tier-2 method involves a probabilistic analysis that, in contrast with the tier-1 method, takes account of correlations between variables of the emission model and of non-normal probability distributions of the values for these variables.

The present study is the first tier-2 analysis of the Dutch inventory of greenhouse gases. The work required setting up an emission model that calculates emissions from the primary data and from probability density functions (pdfs) for all variables and parameters in the model. Most of the pdfs were based on expert judgments.

The uncertainties refer to emissions and to the trend in emissions (% change relative to reference year).

The uncertainty in the 1999 emission (about 230 Mtonne CO_2-eq.) is calculated at 3.6%. This is to be compared with a 4.4% uncertainty that resulted from an earlier tier-1 uncertainty analysis, i.e. neglecting correlations – in particular - and assuming only normal pdfs led to a 25% higher uncertainty.

The 1999 emission is 5.8% lower then the emission in the reference year 1990 (and 1995 for CFCs and SF_6). The range of 95% confidence in this value is 1.5% point – 8.4% point.

1. Introduction

Under the United Nations Framework Convention on Climate Change (UN-FCCC), countries must submit annually National Inventory Reports (NIR) of greenhouse gas emissions. These reports present annual accounts of a country's (net) emissions of greenhouse gases. The format of these accounts is prescribed by the UN-FCCC: so-called Common Reporting Formats (CRF). The submitted inventories must be accompanied by an explanatory National Inventory Report (NIR). For the estimation of emissions, the IPCC has developed guidelines and recommendations in the 1996 IPCC Guidelines (revised in 2000) and in the IPCC Good Practice and Uncertainty Management Report (IPCC, 2000). Countries are requested to follow these guidelines and recommendations as much as possible.

Emission inventories will be key indicators for determining compliance with the agreements under the Kyoto protocol. The protocol includes an obligation to apply *good practice* in the drafting of a NIR with reference to the work of the IPCC. *Good practice* ensures that an inventory is transparent, consistent, comparable, complete and accurate (TCCCA). *Good practice* is meant to ensure that these TCCCA criteria are being met.

Countries now are also requested to submit uncertainty estimates of the national inventories and trends, together with the annual submissions. These uncertainties should be estimated by applying methods described by the IPCC (2000). The IPCC Good Practice and Uncertainty Management (GPGAUM) report (IPC, 2000) proposes methods for uncertainty estimation and reporting. UNFCCC is in the process of accepting the IPCC guidance as mandatory for reporting under the Kyoto protocol.

In order to set up the so-called National System and to further implement *good practice* in the inventorying of greenhouse gas emission in the Netherlands, the Dutch authorities – embodied in the *Werkgroep Emissies Broeikasgassen* (Working group on emissions of greenhouse gas emissions) - initiated several activities. The Netherlands Agency for Energy and the Environment *(*NOVEM) does the actual managing of these activities. The present study, on the uncertainties in the Dutch inventory of greenhouse gases, is one of the studies commissioned by the NOVEM.

The broad objective of the present study was to investigate the viability of the tier-2 uncertainty analysis, applied to the national greenhouse gas emission inventory, as submitted to the UNFCCC, in the Netherlands. Two major activities were undertaken to meet this objective.

The first body of work constituted the collection of information with respect to the various aspects of uncertainty in inventorying. Examples of such aspects are: (*i*) the uncertainties in the quantitative sense (probability density functions for every variable of the emission model), (*ii*) the possibilities to reduce these uncertainties, (*iii*) the underlying sources of these uncertainties. This information was collected by means of literature searches and conducting a series of structured interviews among experts in the area of emission inventorying. The goal of this series of interviews went beyond merely inventorying quantitative information; a major aim was to get insight into the experts' attitudes towards uncertainty in emissions. See van Asselt *et al.* (2002) for the results.

The second objective was to perform a tier-2 uncertainty analysis of the Dutch Emission inventory as submitted in 2001 (Olivier et al., 2001). The estimate should comply with requirement as described in the IPCC GPGAUM guidelines (IPCC, 2000). Meeting this objective required the reconstruction (or modifying) of the model for current emissions (emission of 1999) and for the trend in emissions, that is the change in the 1999 emissions relative to the emissions in the base year. The structure of such model determines about what uncertainty information is required.

This report is structured as follows. Chapter 2 first summarises some methodological aspects of the study and presents definitions of concepts used throughout the report.

Then, from Chapter 3 through Chapter 14, we discuss emissions from source categories: for instance, ‘emissions from mobile sources’ and ‘emissions of F-gases’. Each of these chapters is organised in a similar manner. First, the data on emissions are presented as reported in the NIR 2001 (Olivier et al., 2001), that is the actual CRF files that are electronically submitted to the UN-FCCC. Secondly, we describe how these emissions are calculated. A fourth section describes the uncertainties and their backgrounds. This section always concludes with a table that shows the uncertainties that are assumed in the calculations. The results of these calculations are then in a fifth section. Section 6 concludes. Often, these conclusions include a discussion about the scope for reduction in uncertainty.

Chapter 15 summarises, concludes, discusses and gives recommendations.

2. Tier 1 and Tier 2 uncertainty

The IPCC's publication "Good practice guidance and uncertainty management in National greenhouse gas emission inventories" (IPCC, 2000) deals with uncertainties in inventories in Chapter 6 "Quantifying uncertainties in practice" and in its Annex 1 "Conceptual basis for uncertainty analysis".

Emission inventorying involves the construction and application of an emission model. A general emission model looks like:

$$Em = f\left(X_1, X_2, ...X_n\right)$$

Em (emission) is a function of many parameters and variables X_i. Parameters are those variables that are supposed not to change over time (*e.g.,* emission factors).

Uncertainty analysis. One may distinguish two sources of uncertainty:

- Model (or structural, or epistemic) uncertainty refers to the lack of knowledge that is needed to specify the emission model;
- Uncertainty in variables (and parameters) refers to errors in measurements or errors in otherwise assessed (*e.g.* from expert judgment) values of variables and parameters.

The present study deals with the second type of uncertainty.

This type of uncertainty is expressed in probability density functions (pdf). A pdf establishes degrees of belief in the values that can be assigned to a variable. Uncertainty analysis involves the assignment of pdfs to every variable X_i [$Pdf\left(X_i\right)$] and subsequent mapping of these pdfs to the pdf of the dependent variable [*Pdf (Em)*] according to:

$$Pdf\left(Em\right) = \int_{x_1 \in X_1} \int_{x_2 \in X_2} ..... \int_{x_n \in X_n} f\left(X_1 = x_1, X_2 = x_2, ...X_n = x_n\right) dx_1, dx_2, ...dx_n$$

Pdf (Em) can be determined analytically if the model (the mapping) is linear, the variables are mutually independent and if all pdfs follow normal distributions. If these conditions are not met, one can perform the integrations experimentally, for instance by Monte Carlo integration.

Monte Carlo uncertainty analysis refers to the experimental assessment of *Pdf (Em)* by performing a (very large) series of calculations with values for the variables X_i that are randomly[1] chosen from their associated pdfs. (If variables are mutually dependent the correlation between variables must be specified). The result is a pdf for Em[2].

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[1] The Monte Carlo technique is laborious. Therefore, other techniques have been developed (i.e. latin hypercube sampling) that give results more quickly at only a slight expense of quality.

The IPCC's "Good practice guidance and uncertainty management in National Greenhouse gas emission inventories" (IPCC, 2000) refers to the Monte Carlo analysis as the **Tier 2** uncertainty analysis. **Tier 1** uncertainty analysis refers to the analytical easy-to-apply method that is based on disregarding correlations between variables, linearisation of the emission model and assuming all pdfs to be normally distributed (and standard deviation <60%). The rationale for applying the **Tier 1** method is two fold. First, the method is relatively easy to apply. Second, since most of the greenhouse emissions are calculated with linear models (fuel consumption times emission factor), the results of a tier-1 uncertainty analysis are likely indicative for first order conclusions.

These conclusions should for instance relate to the policy question "how to manage efforts to reduce uncertainties in emissions?" In this a list of source categories emissions ranked by their contribution to overall uncertainty is very useful. Such list can be made from so-called **Standard B coefficients** for model inputs**.** Such coefficients indicate how sensitive the output (the emission or the trend) is to the value of an input of the emission model. Both inputs and outputs are normalized by their respective standard deviations. The value of such a Standard B coefficient can range between –1 and +1. For instance, for total emissions of greenhouse gases in 1999 we found that the Standard B coefficient for the input variable "Total consumption of natural gas" (with an uncertainty[3] of 1.7%) was +0.14. This means that one standard deviation increase in "Total consumption of natural gas" increases total emissions with 0.14 of its standard deviation.

These coefficients are found from the data generated by the Monte Carlo procedure by performing a multi-variate regression analysis of the sensitivity of the outcomes of the calculation to its inputs.

An alternative method to assess sensitivity is to calculate Spearman rank correlation coefficients. Such a coefficient measures correlation between output and input distributions. Ranking the inputs by these coefficients also gives insight in the significance of the uncertainties of the inputs for the output. Generally, the present report presents only

Standard B coefficients, since the differences in the rankings from both methods for sensitivity analysis are usually minor.

The appendix of this report contains a large list of variables and parameters of the emissions model together with their values and uncertainties. The uncertainty of such variables is defined as the nature of the pdf (e.g. normal distribution, uniform, triangular) and a percentage uncertainty. This percentage corresponds with twice the standard deviation of the pdf.

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[2] The actual confidence in Pdf (Em) depends on the credibility of the functional form. Monte Carlo analysis does not address this type of uncertainty. Confidence can be enhanced by estimating the emission using a methodology that is independent from the current emission model. For instance, there are initiatives to determine methane emissions from waste disposal sites by inverse dispersion modelling. This method is entirely different from a method that uses a model for the genesis and fate of methane in a 'general' landfill. Of course, next to such model validation, a supportive opinion of experts may also contribute to confidence.

[3] Throughout this report a percentage uncertainty means two times the standard deviation (2σ), unless indicated otherwise.

3. Emissions from the use of natural gas

3.1 Introduction

The NIR 2001 (Olivier et al., 2001, Table 5.1) lists potential key sources. This list distinguishes two sources within "Natural gas combustion activities": "Emissions from stationary combustion gas" and "Feedstock gas".

"Emissions from stationary combustion gas" – part of IPCC source category 1A "Fuel combustion activities" - ranks on top of the list of sources ranked by size of emissions (Olivier et al., 2001, Table 5.1; Olivier et al. 2002, Table 7.1). About 30% of all greenhouse gas emissions in 1999 were from this source. This category of emission sources is also on top of the 1999 list of source categories that are ordered by their contribution to the difference between 1999 emissions and base year emission (the 1990-1999 trend). The source category is the sixth on the list of sources ranked by contribution to the tier 1 uncertainty in total emission in 1999 (Olivier et al., 2001, p.30). In 1999, natural gas was used in stationary sources only.

The source category "Emissions from the use of gas as a feedstock" is not distinguished by the IPCC as a separate source category. For the Netherlands, however, the emissions from the use of fossil fuels as feedstocks are important. The emission of the latter source - the use of gas as a feedstock (e.g. for production of NH3 and methanol) - is about 2.5% of total emissions – CO_2-eq. - of all greenhouse gases. This relatively high share justifies to separately assess uncertainties in the emissions that relate to this type of source.

This chapter is structured as follows. The next section presents the emissions as reported in the NIR 2001 (Olivier et al., 2001). Section 3 describes the procedures to estimate emissions and the basic input data. There is a separate section on the estimation of the emission from the use of natural gas as a feedstock. Section 4 discusses the uncertainties in the emission models. The results are in Section 5. Section 6 discusses and concludes.

Section 7, an appendix, gives information on the chemical composition of natural gas, which is relevant to the emission factor for combustion of natural gas.

3.2 Reported emissions

Olivier et al. (2001) report the emissions (these include emissions allocated to feedstock consumption) that are shown by Tabel 3.1. This table gives two figures for national emissions, reflecting two methods to calculate the emissions: the reference approach (RA) and the national approach (NA). These methods are summarized in Section 3.3.

Table 3.1 CO_2 emissions (ktonne CO_2) from stationary combustion of gas.

Sector	1990	1999
CO_2 emissions from the use of gaseous fuels * (National approach) (includes emissions from feedstock)	66,919	78,965
CO_2 emissions from the use of gaseous fuels * (Reference approach)	71,693	80,591
Allocated to consumption of feedstock:	4,804	5,346

Source: RIVM CRF files 1999 and 1990, Tables 1.A(c).

Table 3.2 presents the earlier (Olivier et al., 2001) tier-1 estimates of the uncertainties in the emission. The uncertainty in emission is derived from the uncertainty in the "activity data", which is national use of natural gas for combustion, and the uncertainty in the emission factor.

Table 3.2 Tier-1 uncertainties in CO_2 emissions from stationary use of liquid fuels.

Source category	Emission 1999	Uncertainty in activity data	Uncertainty in Efactor	Uncertainty in emission
Emissions from stationary combution: gas	75,247	3%	1%	3%
Feedstock gas	6,507	5%	10%	11%

Source: Olivier et al. (2001, p. 28). Activity data: national consumption of natural gas for combustion (reference approach).

Combustion of fuels also results in emissions of N_2O and CH_4. These emissions – see Table 3.3- are small (0.05%, respectively 0.2% of all emissions). Table 3.21 and Table 3.22 present details.

Table 3.3 Emissions of nitrous oxide and methane from combustion of natural gas.

	1990	1999
Emission of N_2O (ktonne N_2O)	0.13	0.13
Emission of CH_4 (ktonne CH_4)	20.7	21.5

3.3 Emission models

This section describes the procedures to calculate emission. Uncertainties in the parameters and variables of the emission model are discussed in the next section.

There are two methods to assess emissions from the use of fuels: the Reference Approach (RA) and the National Approach (NA). These are also called the top-down method – based on national level statistical information - respectively the bottom-up – based on emission source data - method. The NA method is also called the sectoral method. The NA-method is believed to give the most accurate emission estimates.

Countries are required to apply the NA method for establishing emission figures (emissions from the use of fuels) in their inventories of greenhouse gas emissions.

The UNFCC ask, however, to apply also the RA method. Comparing the results of both methods provides a quick method to verify the inventory.

3.3.1 The National approach

The NA emission estimate relies on two main sources of statistical information:

- Firm-level information about energy use and emissions that is submitted by firms to the institutions engaged in emissions inventorying (e.g., to TNO and RIVM).
- Information of Statistics Netherlands (CBS) about energy use by sector.

These two bodies of information are used in conjunction by CBS and RIVM to estimate emissions. The firm-level information relates to large industries (e.g. refineries, power plants, chemical industries).

The firm level environmental information is collected in the context of:

- The checking of compliance with environmental permits, and the monitoring compliance of (groups of) firms with covenants with respect to environmental performance;
- Reporting of firms to the *emissieregistratie* (ER) (Pollutants Emissies register). The body of firm level information is called ER-I (I for individual) as opposed to ER-Collective, which relates to information developed with generic estimations.

The environmental information provided by individual firms usually includes information on energy use. Such information may not entirely match the information on energy use that such firms provides to Statistics Netherlands in response to energy use surveys, due to, for instance, differences in (details of) definitions of the supplied information. Also, in environmental reports, companies may report CO_2 emissions, but not the associated fuel consumption. Therefore, the fuel data of mentioned in the Table 1A of the CRF (National approach information) do not explain all CO_2 emissions from fuel combustion. The four-bullets comment on the Table 1.A(c) (the comparison of the reference approach with the national approach – See detailed CRF tables of the NIR 2001) says:

- Not all CO_2 emissions (from combustion) submitted by industry are accompanied by fuel data in the inventory;
- In industry reports some of the CO_2 emissions from combustion are allocated as process emissions and thus the corresponding fuel data are not incorporated in the totals for the fuel data;
- Industries may calculate and report actual CO_2 emissions from energy used as chemical feedstock using different overall CO_2 emission factors for the amount of energy carriers converted into products than used in the RA for estimating non-reported feedstock emissions;
- Industry firms report more heavy fuels used as chemical feedstock than the energy statistics used in the RA.

After having established the CO_2 emissions of ER-I companies (individual companies), and having identified to which sectors these companies/emissions belong, the emission estimate proceeds by, for every sector, estimating the fuel use and associated emissions from companies other than the “individual firms”. Details about this procedure – called

bijschatten -are given in the NIR 2001 (Olivier et al., 2001 p.21). The procedure uses the information about fuel consumption per sector from Statistics Netherlands, according to:

$$Emission = \sum_{i}^{j} \left\{ \left(E_i^j - E_i^{j,k} \right) * Ef_i^j + Em_i^{j,k} \right\}$$

Where:

E_i^j = Fuel consumption by sector *j*

$E_i^{j,k}$ = Fuel consumption reported by/assigned to company *k*

Ef = Emission factor

Em = CO2 emission reported by a company *k*

i = Type of fuel

j = Sector

k = Refers to individual firms which data are available

$Ef_i^j = Em_i^{j,k} / E_i^{j,k}$

3.3.2 Reference approach

Tables 1.A(b), 1.A(c) and 1.A(d) of the NIR present the calculation of CO_2 emissions according to the reference approach. This method is based on annual carbon balance sheets for a country, in other words, on a country's national energy account[4].

$$Emission(t) = \sum_i \mathrm{Pr}_i \cdot Cb_i + \sum_i \mathrm{Im}\, p_i \cdot Cb_i + \sum_i Exp_i \cdot Cb_i + \sum_i Stock_i \cdot Cb_i + \sum_i Feedstock_i \cdot Cb_i \cdot (1 - \alpha_i)$$

Emission (t) = Emission in year t

i = Type of fossil fuel

Cb_i = Carbon content (kg/MJ) of fuel *i*

Pr_i = Production (MJ) of fuel *i*

$\mathrm{Im}\, p_i$ = Import (MJ) of fuel *i*

Exp_i = Export (MJ) of fuel *i*

$Stock_i$ = Stock change (MJ) of fuel *i*

$Feedstock_i$ = Use as a feedstock (MJ) of fuel *i*

α_i = Fraction of carbon stored in products from feedstock *i*

The concept of this method is not disputed and, if the parameters and variables can de assessed sufficiently reliable, the method gives proper results. Statistics Netherlands makes energy balances from surveys among the firms that produce, import, export and trade in energy (fuels and electricity). Coverage of the survey is 100%. The figure for national gas consumption obtained from these survey are believed to be more accurate than the estimate of natural gas consumption from survey among consumers of natural gas (See Table 3.10).

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[4] These accounts are available from Statistics Netherlands (CBS).

The primary unit of measurement of amounts of natural gas is Nm^3. Its energy content and the CO_2 emission factor is calculated from the chemical composition of gas and the heats of combustion of each component (mainly methane) (See next Section 3.7).

Table 3.4 shows the calculation of the CO_2 emission from combustion of natural gas (excluding the emissions due to the use of natural gas as a feedstock).

Table 3.4 Calculation of CO_2 emissions of combustion of natural gas. Reference approach.

Year	Apparent consumption. (Combustion & feedstock) (PJ)	Feedstock consumption (PJ)	Emission factor (t CO_2/PJ)	Emission from combustion (ktonne CO_2)
1990	1290	95.31	56.0	66,903
1999	1450	106.10	56.0	75,258

Source: CRF Table 1.A(b)

The reference approach (RA) leads to an emission from the use of gas (combustion & feedstock) that is about 2% higher than the emission according to the national approach (NA). The information used in National approach is consistent with the energy balance information on which the RA approach is based. However, the National approach database incorporates more detail and insight in fuel use leading to emissions. Systemic errors in the RA approach (See Section 3.3.1) are avoided and, therefore, the NA approach is believed to be more accurate.

Table 3.22 and Table 3.23 show the sector-by-sector emissions and natural gas consumptions as submitted to the UN-FCCC in the NIR 2001. From emissions and these natural gas consumptions the co-called implied emission factors are calculated. These implied emission factors vary from 66 t/TJ to 54.3 t/TJ. The RA approach uses an average 56.0 t/TJ, which is the value for most of the gas that is used in the Netherlands. A part of the explanation of the variation is that in some manufacturing industries a type of natural gas is used that bring about somewhat lower emissions due to a deviating chemical composition. A detailed explanation of these differences would lead to a detailed analysis of the inventory on which the NA is based. This is outside the scope of the present work.

3.3.3 A practical way to assess uncertainty in NA emissions. A composite model

A tier-2 uncertainty analysis of the outcome of the NA assessment of national emissions was not feasible within the scope of this study, since there was no data on the uncertainties in the emission figures that firms submit to the inventory agencies. An uncertainty analysis of the outcome of RA emission assessment, without sector level detail, is, however, possible.

How would it still be possible to assess a tier-2 uncertainty in the outcome of the NA emission? This section proposes a (composed) method to at least estimate the CO_2 emission associated with the use gas by all sectors. The method relies on the recent estimates by Statistic Netherlands (Tinbergen, 2001) of the uncertainties in national fuel consumptions that are established by Statistics Netherlands.

Starting point is the summary information shown in Table 3.5.

Table 3.5 Outcomes of the two methods to estimate CO_2 emissions from the use(combustion & feedstock) of natural gas.

	Reference Approach		National Approach	
	Energy consumption (PJ)	CO_2 emissions (Gg)	Energy consumption (PJ)	CO_2 emissions (Gg)
Gaseous Fuels (1990)	1290	71693	1193	66920
Gaseous Fuels (1999)	1450	80592	1406	78965

Source: RIVM CRF files 1999 and 1990, Tables 1.A(c).

Note that fuel consumption according to the national approach is lower than the RA fuel consumption (which is essentially fuel consumption as measured by Statistics Netherlands).

We propose to estimate an uncertainty in the NA emission by using the following expression:

$$Em_{total}^{National} = A + Ef\ \left(E_{Total-CBS} + B\right)$$

$Em_{total}^{National}$ = CO_2 emission as assessed according to the National Approach.

Ef = The average emission factor for natural gas (56.0 kg/GJ).

$E_{total\text{-}CBS}$ = National consumption of natural gas according to Statistics Netherlands.

B = The difference in fuel consumption as measured by Statistics Netherlands with the fuel consumption observed in the national approach (See Table 3.5). This may relate for instance to natural gas that is used as a feedstock.

A = A correction factor that captures the information about emissions that is developed within the National approach and which is additional to the information used in the RA approach. A captures for instance the knowledge – available to the agencies that are engaged in establishing the inventory - that some companies use natural gas with an emission factor that deviates from the average emission factor.

Table 3.6 gives the values for the factors A and B, as found from the information in Table 3.5 and the average emission factor.

Table 3.6 Correction factors in the NA-RA relation.

Correction factors	1990	1999
A (kT)	105	203
B (PJ)	-96.88	-43.55

In the uncertainty analysis one has to assign uncertainties to these correction factors. The factors A and B capture the systemic differences between the both methods. Since there

is an *a priori* belief that national approach is accurate in the estimation of emissions in important sectors (where the estimation relies on firm information) the uncertainties in both correction factors must be rather low – say a few percent max.

3.3.4 Allocating CO_2 emissions to the use of natural gas as a feedstock.

The key source categories that are assessed in the NIR of the Netherlands comprise three types of sources in addition to the potential source categories as listed by the IPCC (IPCC, 2000). These three source categories refer to the CO_2 emissions that are associated with, respectively, the use of natural gas, liquid fuels and coal as a feedstock. Because of the distinction of these source categories – these are subcategories within the broad IPCC source categories "CO_2 emissions from the use of natural gas", "CO_2 emissions from the use of liquid fuels" or "CO_2 emissions from the use of coal" (IPCC source category 1A).

These emissions were assessed – for the 1999 inventory - as follows (Olivier et al., 2001). A first order estimate is made from statistical data of Statistics Netherlands (CBS) about the uses of fuel as a feedstock, the default emission factor for a specific fuel, and an assumption about the fraction of carbon in feedstock which is embodied in the final product (and presumed not to be emitted into the atmosphere). Table 3.7 shows the emissions from the use of natural gas as a feedstock and how these are calculated.
Emissions from Table 3.4 and Table 3.7 add up to the RA emissions shown in Table 3.1. Most of the feedstock gas is for the production of NH3[5].

Table 3.7 Emissions from the use of natural gas as a feedstock.

Year	Feedstock consumption (PJ)	Carbon content of gas	Fraction of carbon embodied in product	Carbon (CO_2-eq) embodied in product (ktonne)	Emission (ktonne CO_2)
1990	95.31	56.0 kt CO_2/PJ	0.1	534	4803
1999	106.10	56.0 kt CO_2 /PJ	0.1	594	5346

Source: CRF Table 1.A(d).

These estimates are considered as first order estimates. Detailed – firm level - insights in the origins of CO_2 emissions obtained by the inventorying agency that processes firm level information with respect to CO_2 emissions and fuel use, led to the suggestion that the (first order estimate) emissions in Table 3.7 must be underestimates. Olivier et al. (2001) assumed that the difference between the emission estimates according to the RA and NA method (See Table 3.1 and Table 3.5) is because of this underestimation in the emissions from the use of gas **and liquid fuels** (See next chapter) as feedstocks. Therefore, Olivier *et al*. (2001) heightened the first order estimates of feedstock emissions with the difference between the RA and NA emissions. This difference was allocated to "emissions from natural gas feedstock" and "emission from liquid fuels as feedstocks"

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[5] Except for the production of urea. However, urea is used as a fertiliser and, when urea is applied, CO_2 is released into the atmosphere. Natural gas is also used for the production of methanol and products of methanol. The fraction of carbon embodied in products (See Table 3.7) refers to mainly the carbon in products made from methanol.

according the proportion of total use of natural gas and total use of liquid fuels (in stationary sources). Table 3.8 gives the details of the allocation procedure.

Table 3.9 then presents the outcome of the allocation of the NA emissions to the source category "CO_2 emissions from combustion only" and "Emissions from the use of feedstock.

Table 3.8 Allocating the difference between RA and NA emissions to feedstock emissions.

	1990	1999
Difference emissions (kt CO_2) according to Reference and National approach	873.36	3,263.80
Share of gas feedstock emission in all feedstock emissions	52.5%	35.4%
Allocation of the RA-NA difference to gas feedstock emission	458.82	1,153.89
Allocation of the RA-NA difference to liquid feedstock emission	414.53	2,109.92

Table 3.9 Emissions (ktonne CO_2) from the use of natural gas in stationary source split over" combustion only" and " use as a feedstock".

	1990	1999
CO_2 emissions from stationary combustion only: gas	61657	72466
CO_2 emissions from feedstock: gas	5262	6501

The uncertainties in feedstock use and emissions are researched in a project commissioned by NOVEM to Utrecht University and ECN. The results of this study could not be used, as these are foreseen only in mid 2003.

3.3.5 Methane and N_2O emissions

CH_4 and N_2O emissions are assessed from individual information about emissions from large combustion sources, and, for the other sources, from fuel consumption by sector and appropriate emission factors (Spakman et al., 1999) Table 3.21 and Table 3.22 give the data of thes emissions of methane and nitrous oxide.

3.4 Uncertainties

3.4.1 Domestic consumption of natural gas

National domestic consumption of natural gas (*Binnenlands verbruik*) is measured by Statistics Netherlands. Statistics Netherlands establishes national consumption applying two different methods. The first method is by measuring extraction of natural gas, its import and export and its supply to the users. Since Statistics Netherlands (CBS) has a 100% response on their surveys among gas supply firms there is a relative confidence in their numbers for volumes of supplied gas. CBS (Tinbergen, 2001) indicates a 2σ value of 1.7% of 1451 PJ domestic consumption (*Binnenlands verbruik*) in 1999. The other method to establish is by measuring consumption by surveys among the users. Statistics Netherlands publishes energy consumption by sector. Table.3.10 shows the uncertainties

in gas consumption by sector. These uncertainties lead to a 2.2% uncertainty in the total. Measuring gas consumption, according to the method applied in 1999, leads to a less accurate domestic consumption than measuring production, import and export of natural gas. We will use 1.7% uncertainty in the calculations.

Note that, much of the uncertainty in the composite uncertainty in the total gas consumption is due to uncertainty in gas consumption by the sectors "households" and "other".

These estimates of the uncertainties were only recently developed by Statistics Netherlands. Earlier, Olivier et al. (2001) proposed an uncertainty of 3% in the activity data (gas consumption) for this source category (i.e. natural gas consumption) as an expert estimate (see also Van Amstel *et al*, 2000).

Table 3.10 Natural gas balance and gas consumption per sector (1999) and uncertainties as estimated by Statistics Netherlands.

Sector	Gas consumption (PJ)	Uncertainty %
Production	2269	0.5
Import	324	0.6
Export	1143	1.9
Total	1451	1.7
Gas production	34	0.5
Oil refineries	33	0.5
Large scale power & heat production	201	0.5
Small scale power & heat production	145	1.0
Waste incineration	1	1.9
Gas distribution	33	1.7
Manufacturing industry	399	1.8
Households	334	3.5
Other	272	10.4
Total	1451	2.2

Source: Tinbergen/Statistics Netherlands (2001).

3.4.2 The emission factor for natural gas

The uncertainty in the emission factor for natural gas is relatively small. However, since combustion of natural gas is the most important source category in terms of emissions, there is reason to discuss this emission factor in some more detail.

An emission factor for natural gas is derived from the average chemical composition of that gas. Table. 3.11 shows the composition of natural gas from the Slochteren reservoir, the main source of Dutch Natural gas. Using the figures in this table (and assuming Boyle's law to hold completely) the emission factor is 56.0 kt/PJ. This factor, which is developed in the eighties by Statistics Netherlands from Gasunie information (Zonneveld, 2001), is used in the NIR and other emission inventories in the Netherlands.

So uncertainty in the emission factor is due to a possible annual variability in the chemical composition of Slochteren gas and, perhaps, uncertainty in the measuring of the chemical composition of gas. There are other factors, however, that may add to the uncertainty.

Table 3.11 Composition of natural gas from Slochteren reservoir and other information required to calculate emission factor.

Component	Vol %	Net heat of combustion (MJ/kg)	Mol weight	Number of C
Methane	81.4	50.1	16	1
Ethane	2.9	47.6	30	2
Propane	0.4	46.4	44	3
Butane	0.2	45.8	58	4
CO_2	0.9	0	44	1

First, we note that there are two gas supply systems in the Netherlands, both run by the Gasunie firm (Gasunie provides the gas transport services in the Netherlands). The main net (which is the oldest) supplies natural gas of "Slochteren" quality.
The unit of indicator for Slochteren quality is the Wobbe index (TJ per Nm^3) of gas. Natural gases of origins other than Slochteren and that have Wobbe indexes different from Slochteren gas, are mixed with other gases in such way so that the Wobbe index of composite gas complies with the ^{Wobbe} index of Slochteren gas. Today about 60% of natural gas in the Netherlands is from other (small) reservoirs in the Netherlands and the North Sea, or from Norway and also from Russia. This import is on the rise.

Next to the main gas net there is a separate system for gas transport of natural gas to large industrial consumers (e.g. iron and steel industry). This net is used for transport of so-called high-calorific gas (high Wobbe-index) from other reservoirs than Slochteren. According to Gasunie information about the chemical composition of this gas (as presented by van Harmelen (2001)) the emission factor would be 56.3 kg CO_2 per GJ, about 0.5% higher than the Slochteren factor (56.0 kg CO_2 per GJ). Van Harmelen and Koch (2001) propose to use 56.1 kg CO_2 per GJ as the average emission factor[6].

In our calculations we used 56.0 kg CO_2 per GJ, with a normally distributed pdf and a 1% uncertainty. The newly proposed figure (the difference is very small) is not used in our calculations.

Chemical composition of natural gas and emission factor. Actually the Wobbe-index is not relevant to the calculation of the emission factor and CO_2 emissions. The key determinant for the emission factor is the chemical composition of natural gas. The main constituent of natural gas is methane. Of all combustible constituents of the Slochteren gas methane takes 95%. So the methane content is a main variable. The gas industry uses the methane/ethane ratio as an important indicator for gas quality (which is expressed in the Wobbe index). The emission factor for a 100% methane natural gas would be 54.9 kt/PJ. This is a minimum value. A 100% ethane natural gas would have an emission factor of 61.6 kt/PJ (See Figure 3.1). According to the Gasunie (2001), the average composition of natural gas is such that 56.0 kt/PJ also holds for average gas. For instance Norwegian gas from Ekofisk reservoir has a low content of methane (92%), but the effect of this on the average emission factor (it would enhance the factor) is cancelled out by the import of Russian gas with a high (> 95%) methane content.

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[6] The IPCC proposes also 56.1 kg CO_2 per GJ as a default emission factor (Table 1-2, Module 1, IPCC Guidelines for NGGIs, Vol 2.)

Of course, together with the methane/ethane ratio, the CO_2 content of the gas is also important (Slochteren gas contains 0.9% CO_2).

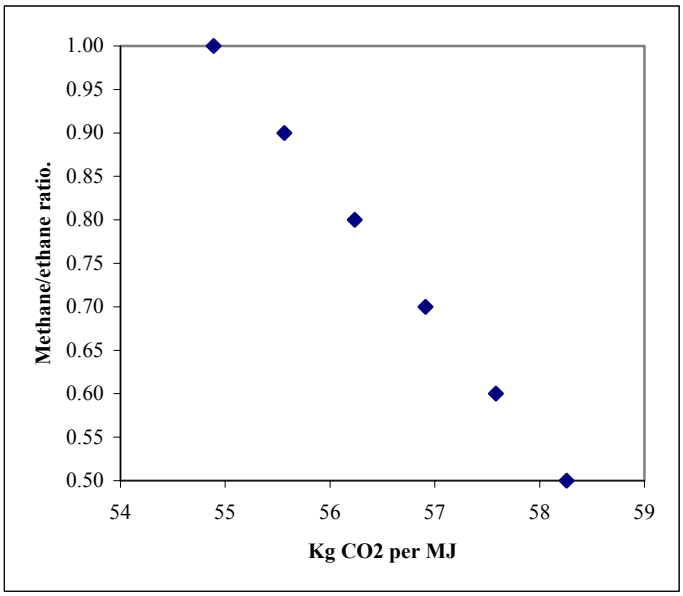

Figure 3.1 CO_2 emission factor of 'natural gas' in relation to the methane/ethane ratio.

For an assessment of the change in emissions from natural gas between the current year and the reference year 1990 and a changing composition of natural gas have implications for the treatment of uncertainty in the emission factor. The more the origins of gas change over the year the less the emission factors for the current and reference year are correlated. The uncertainty in the trend of the emission (the relative change in the emission) will increase when correlation is reduced. We performed a small sensitivity analysis of the impact of possible changes in emission factors (See under "Results Tier –2 analysis").

3.4.3 The allocation of the emission to "Combustion only" and "Use of gas as a feedstock"

The procedure (See 3.3.4) to split the CO_2 emissions from the use of natural gas in stationary sources to "emissions from combustion only" and "emissions from the use as feedstock" introduces four extra variables that uncertainties can be assigned to:

- The use of natural gas as a feedstock as given by Statistics Netherlands;
- The fraction of carbon in natural gas that is embodied in final products;
- The RA-NA emission difference;
- The share of this difference allocated to natural gas feedstock emissions.

The uncertainties that we attributed to these variables are in Table 3.16. The uncertainties are own estimates and values are selected in such way that the uncertainties are of the same magnitude as the (tier-1) uncertainties that were adopted by Olivier et al. (2001). For instance the 100% uncertainty in the share of carbon (0.1) eventually embodied in final products more or less corresponds with the 10% uncertainty in their " emission factor" for CO_2 emission from the use of natural gas as a feedstock.

3.5 Results TIER II analysis

3.5.1 Introduction

This section presents the results of the uncertainty assessments. This first assessment regards uncertainties in the emission estimates for 1999 and 1990 and the uncertainty in the change in emissions between 1990 and 1999. Then, in Section 3.5.3, we present a tier-2 uncertainty analysis of the emissions of the use of natural gas as calculated according to the reference approach. This is to compare our results with the results of the earlier tier-1 uncertainty analysis of Olivier et. al. (2001).

3.5.2 Emission in 1990, in 1999 and 1990-1999 trend

Table 3.12 gives the inputs for the calculation of uncertainties in the NA emission according to the composite model (the NA-RA model, see Section 3.3.3). Note that the uncertainties in the values for import, export and production of natural gas add up to 1.7% uncertainty in the 1999 domestic consumption.

Table 3.12 Initial uncertainties in parameters for estimating uncertainty in emissions due to the consumption (combustion & feedstock) of natural gas (NA-RA model).

Variable	Value	Pdf	Uncertainty (2σ) (%)
Average emission factor 1999 (kt/PJ)	56	Normal	1
Production of natural gas 1999 (PJ)	2269	Normal	0.5
Import of natural gas 1999 (PJ)	324	Normal	0.8
Export of natural gas 1999 (PJ)	1143	Normal	1.9
B 1999 Natural gas (PJ)	44	Normal	2
A 1999 Natural gas (ktP/J)	203	Normal	2
Average emission factor natural gas 1990 (kt/PJ)	56	Normal	1
Total consumption natural gas 1990 (PJ) (CBS)	1290	Normal	2.1
B 1990 Natural gas (PJ)	97	Normal	3
A 1990 Natural gas (ktP/J)	105	Normal	3

Figure 3.2 shows the result of the Monte Carlo analysis of the uncertainty in the emission in 1999. Table 3.13 gives the detailed outcome of the tier-2 analysis, including uncertainties in the 1990 emissions and in the 1990-1999 trend.

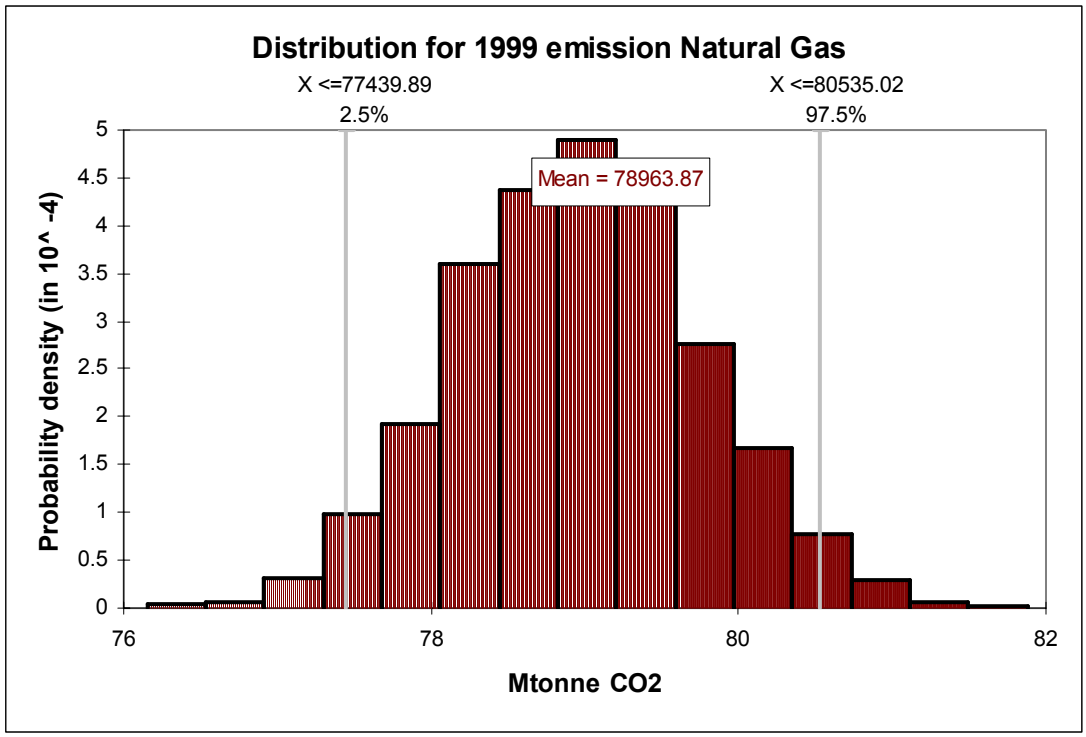

Figure 3.2 Probability density histogram for 1999 CO_2 emission from the use of natural gas

Table 3.13 Outcomes of the tier-2 uncertainty analysis of the CO_2 emission from the use of natural gas, according to the NA-RA model.

	1990 emission	1999 – emission	1990 -1999Trend
Minimum	64237.16	76132.27	11.44597
Mean	66917	78957	18.0 %
Maximum	70672.5	81950.09	25.33515
Std Dev	829.5204	798.816	1.678343
Variance	688104.1	638107	2.816834
Uncertainties	2.5%	2.0%	18.6%

To what uncertainties are these outcomes most sensitive? Next tables present the results of a sensitivity analysis (See Chapter 2 for an explanation) that answer this question. Table 3.14 gives the sensitivities of the 1999 emission to the uncertainties in the variables of the model, which is based on gas consumption derived from a gas balance (see upper part of Table 3.10). The uncertainty in the value for the export of natural gas is the most important to the value for the emission from the use of natural gas.

Table 3.14 Sensitivity of 1999 CO_2 emissions to the uncertainties in the gas balance and other variables. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Export of natural gas 1999 (PJ)	-0.759
Average emission factor 1999 (kt/PJ)	0.493
Production of natural gas 1999 (PJ)	0.404
Import of natural gas 1999 (PJ)	0.091
B 1999 Natural gas (PJ)	-0.03
A 1999 Natural gas (ktP/J)	0.002
B 1999 Natural gas (PJ)	-0.026

Trend. In the period 1990-1999, CO_2 emission of this source category rose by 18%. The uncertainty of this figure is (by accident) also 18%, given the input values. The figure for the trend is most sensitive to the uncertainty in the gas consumption in 1990 (Table 3.15). We had estimated the latter uncertainty at 2.1%, assuming that for 1990 gas production, import and export was somehow less well observed than for 1999. So, the uncertainty in total gas consumption in 1990 was set at 2.1%, while for 1999 the corresponding figure was 1.7% (this figure results from the uncertainties in the figures for the different items in the gas balance, i.e. uncertainties in production, export and import).

Table 3.15 Sensitivity of the uncertainty in the 1990-1999 trend in CO_2 emissions from combustion of natural gas to variables in emission model. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Total consumption natural gas 1990 (PJ) (CBS) Unc. 2.1%.	-0.796
Export of natural gas 1999 (PJ)	-0.537
Production of natural gas 1999 (PJ)	0.281
B 1990 Natural gas (PJ)	0.085
Import of natural gas 1999 (PJ)	0.065
B 1999 Natural gas (PJ)	-0.022
A 1999 Natural gas (ktP/J)	0.002
A 1990 Natural gas (ktP/J)	-0.002

3.5.3 Emissions allocated to “combustion only” and “use as feedstock”

Table 3.16 gives the adopted uncertainties in the allocation procedure.

To what uncertainty in what variable is this outcome most sensitive to, given the assumptions in Table 3.15?

Table 3.17 gives the result of the sensitivity analysis for the emission from feedstocks. So, given the assumed uncertainties, the confidence is most dependent on the assumption of the share of carbon (between 0.05 and 0.15) that is embodied in final products manufactured from natural gas. (See Chapter 2 for an explanation of Standard B coefficients).

Table 3.16 Initial uncertainties in allocating emissions to "Combustion only" and "Feedstocks".

Variable	Value	Pdf	Uncertainty (2σ) (%)
1999 gas consumption for feedstock (PJ)	106.1	Normal	5
Gas feedstock. Fraction of C embodied in final products	0.1	Normal	100
1990 gas consumption for feedstock	95.31	Normal	5
Difference in 1999 CO_2 emissions from NA & RA approaches	3263.8	Normal	0
1999 NA-RA diff. CO_2 emissions attributed to gas feedstock	1153.8	Normal	10

Table 3.17 Sensitivity of 1999 CO_2 emissions from natural gas as feedstock to variables in emission model. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Gas feedstock. Fraction of C embodied in carbon in final products	-0.885
1999 gas consumption for feedstock (PJ)	0.404
1999 NA-RA difference CO_2 emissions attributed to gas feedstock	0.177
Average emission factor 1999 (kt CO_2/PJ natural gas)	0.08

Table 3.18 shows for the estimation of the emission form combustion only this share is less important. Uncertainty is dominated by uncertainties in the 1999 export of natural gas, the carbon content of natural gas (i.e. the average emission factor) and the production of natural gas.

Table 3.18 Sensitivity of 1999 CO_2 emissions from combustion of natural gas to variables in emission model. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Export of natural gas 1999 (PJ)	-0.716
Average emission factor 1999 (kt CO_2/PJ natural gas)	0.427
Production of natural gas 1999 (PJ)	0.37
Gas feedstock. Fraction of C embodied in carbon	0.345
1999 gas consumption for feedstock (PJ)	-0.157
Import of natural gas 1999 (PJ)	0.085
1999 NA-RA difference CO_2 emissions attributed to gas feedstock	-0.069
B 1999 Natural gas (PJ)	-0.028
A 1999 Natural gas (ktP/J)	0.002

3.5.4 Emissions of N_2O and methane from combustion of natural gas

In addition to CO_2 emission, combustion of natural gas leads to emissions of methane and nitrous oxide. The summary emission data for 1999 are given in Table 3.19 (see also Table 3.21 and Table 3.22). Emissions of nitrous oxide and methane are minor in comparison to CO_2 emissions. These emissions were calculated according to the national approach. We did not assign uncertainties to these emissions (See Chapter 10).

Table 3.19 Emissions (ktonne) of CO_2 , CH_4 and N_2O from combustion of natural gas.

CO_2	CH_4	N_2O
72466	21.46*	0.13*

*) Source: CRF Table 1.A(a)s1

3.6 Discussion and conclusions

The earlier (tier-1) uncertainty analysis (Olivier et al., 2001) estimated the uncertainty of the emission from combustion of natural gas at 3% and the uncertainty of the emission associated with the use of gas as a feedstock at 11%. Composite (tier-1) uncertainty, from applying the law of error propagation to the sum of both emissions, would be 6.4%. Our estimate of the uncertainty of emissions from the use of natural gas is 2.1%. The difference is mostly due to correlation between the data of gas consumption for "combustion only" and "feedstock" only. Table 3.20 indicates how to compare. The upper two rows show the data on emissions and the uncertainties estimated earlier by Olivier et al. (2001) in the NIR 2001. The third row gives the composite uncertainty: 3.0%.

The middle rows (present uncertainty) give the uncertainties as identified in the present study, from new information about uncertainties in the data from Statistics Netherlands and additional assumptions on the difference in the outcomes of the RA and NA emission estimates. The present approach leads to somewhat lower uncertainties. The new uncertainties (of emission from combustion only and from feedstock) were combined to assess the uncertainty of the emission from "combustion & feedstock" according to the tier-1 methodology. The result is 2.4% (against 3.0% in the earlier tier-1 estimate). Taking account of correlation – applying the methodology of tier-2 uncertainty analysis – leads, however, to an uncertainty of 2.1%.

Table 3.14 showed that the uncertainty in CO_2 emissions (of combustion + feedstock) is most sensitive to the uncertainty in the gas balance as established by Statistics Netherlands and by the average emission factor for natural gas (See.).

We made an alternative uncertainty assessment based on domestic gas consumption from adding up sector gas consumptions. Uncertainty in the 1999 emission becomes then 2.4%, still lower than the earlier tier-1 estimate. A sensitivity analysis showed that, if uncertainty is based on figures of gas consumption by sector, uncertainty in gas consumption in the sector "other consumption" is the most important (See also Table 3.10). Uncertainty in the emission factor and uncertainty in gas consumption by households rank second and third. Statistics Netherlands plans to better measure gas consumption in these sectors.

The average emission factor is the second important factor for overall uncertainty. It is likely to become more important in the future, with increasing import of gas with a chemical composition different from the Slochteren gas. The primary source of information about this is the Gasunie. Recently Van Harmelen *et al* (2001) reviewed the emission factor for natural gas.

Table 3.20 A comparison between tier-1 uncertainty and tier-2 uncertainty in emissions from the use of natural gas.

Source category	Emission	Tier 1 uncertainties*
CO_2 emissions from stationary combustion only: gas	72463	3.2%
CO_2 emissions from feedstock: gas	6501	11.2%
CO_2 emission from combustion and feedstock (Law of error propagation)	78965	3.0%
		Tier 2 uncertainties
CO_2 emissions from stationary combustion only: gas		2.4%
CO_2 emissions from feedstock: gas		10.3%
CO_2 emission from combustion and feedstock (Law of error propagation)		2.4%
CO_2 emission from combustion and feedstock (with correlation)		2.1%

*) Tier-1 uncertainties as estimated in the NIR 2001 (Olivier et al., 2001).

The sector approach does not explicitly cover emissions from the use of natural gas as a feedstock, i.e. the IPCC CRF does not explicitly distinguish a source category "Emission from the use of fuel as a feedstock" and its counterpart "emission from the use of fuel in combustion only". Assumptions on the amount of carbon embodied in the final products of natural gas, however, must be implicit in the primary (firm level) information on CO_2 emissions. It is unknown (at least in the public domain) what these assumptions are.

3.7 Appendix

3.7.1 Chemical composition of natural gases

Table 3.21 below gives some compositions[7] of natural gas. We didn't found information on the composition of Russian gas. A spokesman of the Gasunie said that the methane content of Russian gas is very high.

3.7.2 Reported emissions by sector

Table 3.21 and Table 3.22 (extracted from CRF Table 1.A(a)) show sector-by-sector emissions and gas consumption. This information is established according to the national approach (NA) (See Section 3.3). From emissions and gas consumption data the tables show the implied emission factors. These range from 54.3 to 66.0 t CO_2 per TJ. These extreme values differ quite a bit from the 56.0 average, which is expected from the chemical composition of natural gas (see below).

[7] (http://216.92.194.138/Gasvormige_brandstoffen.htm.,www.elcomat.be/catalogus/nl/711.pdf) (July 2001).

Table 3.21 Composition (vol. %) and emission factors of natural gases by origin.

Hydrocarbon	Gross (Mj/kg)	Groningen	"Rich gas"	H-gas Ekofisk	L-gas Enriched	Algeria
Methane	55.6	81.4	88.0	88,17	83.42	89,0
Ethane	51.9	2.9	5.7	5,30	3.73	8,31
Propane	50.4	0.4	1.7	1,20	0.74	1,32
Butane	49.5	0.2	0.7	0,38	0.25	0,47
CO_2	0	0.9				
Net combustion value ($Kj.Nm^3$) (Measured)		36.74		40.77		43.74
Calculated emission factor (tCO_2 per J (net heat of combustion)		56.0	56.8	56.7	56.4	56.3

(http://216.92.194.138/Gasvormige_brandstoffen.htm.;www.elcomat.be/catalogus/nl/711.pdf., November 2001. *) Calculated assuming Boyle's law.

Table 3.212 Sectoral data on emissions from combustion of natural gas 1990.

Greenhouse gas source and sink categories 1990	Consumption (TJ)	Implied emission factors (2)			Emissions		
		CO_2 (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)
a. Public Electricity and Heat Production	244,085.40	56.55	1.41	0.10	13,803.32	0.34	0.02
b. Petroleum Refining	9,321.87	54.50	5.27	0.10	508.00	0.05	0.00
c. Manufacture of Solid Fuels and Other Energy Industries	21,625.54	55.87	21.21	0.02	1,208.31	0.46	0.00
a. Iron and Steel	1,474.50	55.93	9.12	0.11	82.47	0.01	0.00
b. Non-Ferrous Metals	0.00	0.00	0.00	0.00	0.00		
c. Chemicals	159,060.56	55.93	15.09	0.12	8,896.39	2.40	0.02
d. Pulp, Paper and Print	27,479.21	55.94	3.83	0.09	1,537.16	0.11	0.00
e. Food Processing, Beverages and Tobacco	63,803.80	55.87	7.79	0.10	3,564.63	0.50	0.01
f. Other	76,176.90	55.93	9.12	0.11	4,260.64	0.69	0.01
a. Commercial/Institutional	120,402.08	56.07	8.45	0.10	6,751.22	1.02	0.01
b. Residential	339,714.00	55.98	37.66	0.10	19,017.80	12.79	0.03
c. Agriculture/Forestry/Fisheries	129,806.00	56.08	17.87	0.10	7,279.14	2.32	0.01
1.A.5 Other (Not elsewhere specified)	170.00	63.06	2.61	0.10	10.72	0.00	0.00
Total gaseous fuel combustion	1,193,119.85	56.09	0.02	0.10	66,919.81	20.69	0.12

Table 3.23 Sectoral data on emissions from combustion of natural gas 1999.

Greenhouse gas source and sink categories 1999	Consumption (TJ)	Implied emission factors (2)			Emission		
		CO_2 (t/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)
a. Public Electricity and Heat Production	361,453.28	54.84	2.38	0.09	19,821.24	0.86	0.03
b. Petroleum Refining	19,230.26	54.30	1.06	0.10	1,044.29	0.02	0.00
c. Manufacture of Solid Fuels and Other Energy Industries	30,196.00	56.00	97.82	0.10	1,690.99	2.95	0.00
a. Iron and Steel	0.00	0.00	0.00	0.00	0.00	0.00	0.00
b. Non-Ferrous Metals	0.00	0.00	0.00	0.00	0.00	0.00	0.00
c. Chemicals	157,182.33	56.24	2.09	0.10	8,839.49	0.33	0.02
d. Pulp, Paper and Print	35,459.20	55.76	1.06	0.10	1,977.20	0.04	0.00
e. Food Processing, Beverages and Tobacco	78,038.74	56.59	3.17	0.10	4,416.48	0.25	0.01
f. Other	100,736.70	61.77	4.89	0.00	6,222.99	0.49	0.00
a. Commercial/Institutional	149,958.90	56.01	7.02	0.10	8,398.88	1.05	0.01
b. Residential	336,731.71	55.95	38.67	0.10	18,839.58	13.02	0.03
c. Agriculture/Forestry/Fisheries	137,257.14	56.10	17.83	0.10	7,699.91	2.45	0.01
1.A.5 Other (Not elsewhere specified)	207.37	66.00	0.70	0.10	13.69	0.00	0.00
Total gaseous fuel combustion (TJ)	1,406,451.63	56.14	0.02	0.09	78,964.75	21.46	0.13

4. Emissions from oil combustion and activities Stationary sources (1A)

4.1 Introduction

This chapter is on CO_2 emissions that result from non-transport use of oil and oil products. Emissions from mobile sources are dealt with in Chapter 6. The next section presents the emissions as reported in the CRF files as submitted to the UN-FCCC in the NIR 2001 (Olivier et al., 2001). Section 3, "emission models", presents the emission model as based on the ideas developed in Section 3.3.3. Section 4 presents the uncertainties as assumed in the calculation of the emission and that underlie uncertainty in the eventual emission. Section 5 presents the results of the tier-2 analysis, while Section 6 presents a discussion and conclusions.

4.2 Reported emissions

Table 4.1 summarises the reported emissions that are assigned to the use of liquid fuels. CO_2 emissions from stationary combustion (top row) are calculated according to the Reference approach (RA). The fifth row shows total CO_2 emissions from liquid fuels as estimated by the National (or sector) approach (NA) and reported in Tables 1.A. The bottom row shows CO_2 emissions identified in the National approach that were assigned the use of "other fuels", while the amount of this use is indicated as nil.

Table 4.1 CO_2 emissions (ktonne) attributed to the use of liquid fuel.

	1990	1999	Trend (%)
CO_2 emissions from stationary combustion: oil	17,787	18,148	2.0
CO_2 emissions from feedstock (oil)	3,889	3,801	-2.3
CO_2 emissions from transport	29,095	34,700	19.5
Total CO_2 emissions from liquid fuels (RA)	50,772	56,649[8]	11.6
Total CO_2 emissions from liquid & other fuels (NA)	57,718	61,195	
CO_2 emissions from chemical industry assigned to an unspecified amount of "other fuels" (NA)	8,213	11,352	

Source: From Tables 1.A(a), 1.A(b), 1.A(d), of the NIR 2001 (Olivier et al., 2001).

For 1990, emissions according to the National (sector) approach are about 16% higher than those estimated according to the Reference method. For 1999 the national approach gives an emission figure that is about 19% higher than the result of the Reference approach. However, note that in the National approach there are emissions from energy consumption that are not allocated to a specified amount of fuel use.

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[8] This number differs from the figure submitted in the NIR 2001. Table 1.A(c) says this emission is 56,388 ktonne. This since we did not use the emission factors for gasoline, diesel and LPG as shown in Table 1.A(b), but the emission factors shown in Table 1.A(a)s3. This is to preserve arithmetic consistency.

For instance, for the chemical industry (source category 1.A.2 c) there is indicated a CO_2 emissions from the use of "other fuels", without, a specified amount of consumption of "other fuels".

Table 4.2 shows the tier-1 uncertainties assigned to the RA emission estimates (Olivier et al., 2001).

Table 4.2 Tier-1 uncertainties in CO_2 emissions from stationary use of liquid fuels.

Source category	Emission 1999	Uncertainty in activity data	Uncertainty in Efactor	Uncertainty in emission
Emissions from stationary combustion: oil	17,842	3%	2%	3.6%
Feedstock oil	5,922	20%	50%	54%

Source: Olivier et al. (2001, p. 28). Activity data: national consumption of oil for combustion (reference approach).

4.3 Emission models

4.3.1 Introduction

For this source category the outcomes of the national approach and the reference approach (See Section 3.3) are quite different. The National approach leads to a substantially higher (about 20% in 1999) emission than the reference approach.

Table 4.3 Outcomes of the two methods to estimate CO_2 emissions from the use of liquid fuels in stationary sources.

	Reference Approach		National Approach	
	Energy consumption (PJ)	CO_2 emissions (Gg)	Energy consumption (PJ)	CO_2 emissions (Gg)
Liquid and other Fuels (1999)	559	21639	204	26496
Liquid and other Fuels (1990)	572	21677	266	28623

Source: RIVM CRF files 1999 and 1990, Tables 1.A(c). Adjusted for fuel consumption and emissions by mobile sources.

4.3.2 The NA-RA model

We propose the following method to estimate the uncertainty in the NA emission from relevant information of which there is insight in the uncertainty (See for explanation Section 3.3.3.):

$$Em_{total}^{National} = A + Ef\ \left(E_{Total-CBS} + B\right)$$

Table 4.4 Correction factors in the NA-RA model. Aggregate emission factor.

Correction factors	1990	1999
Aggregate emission factor (t/GJ)	73.0	73.0
A (kT)	9205	11604
B (PJ)	-306	-355

4.3.3 The allocation of the emissions to "combustion only" and "feedstocks"

Section 3.4.3 describe how Olivier et al. (2001) estimated emissions that are from the use of natural gas as a fuel, respectively as a feedstock. The same procedure is applied for allocating oil-based emissions to "use of feedstock" and "combustion only".

The emission from "use as feedstock" is based on:

- Initial emission estimate according to the reference approach (from Table 1.A(b) and Table 1.A.(d));
- Allocating a part of the difference in fuel-use CO_2 emissions as determined with the RA and NA method respectively (See Section 3.4.3).

The initial estimate is somewhat complex since the statistics distinguish seven types of liquid fuels that are used as feedstocks. For each of these fuels there is a separate emission estimate. What of the RA-NA emission difference is allocated to "use of liquid fuels as feedstock" depends entirely on what is already allocated to the emission from "natural gas as feedstock" (See Section 3.4.3). In the NIR 2001 (Olivier et al., 2001) all other is allocated to the use of liquid fuels as a feedstock.

4.4 Uncertainties

4.4.1 Use of oil and oil products

The estimate of the uncertainty of national consumption of liquid fuels is shown in Table 4.5, which table presents results of the recent analysis of Statistics Netherlands of uncertainties in their energy balances (Tinbergen, 2001). This information was not available to the earlier tier-1 uncertainty calculations by Olivier et al. (2001).

Uncertainty in the total as measured by adding consumption data is 1.90%. This number relates to emissions from stationary and mobile sources together. If one leaves out transport, the uncertainty in the consumption of oil and oil products (in "stationary equipment only") rises from 1.9% to 3.4%, since there is a relatively high confidence in the value for emissions from transport.

We selected fuel "consumption by sector" as being less uncertain than the estimate from the fuel balance (1.9% versus 7.0%). So the model becomes:

$$Em_{total}^{National} = A + Ef\left(\sum_i E_i + B\right)$$

E_i = fuel consumption

i = sector i (excluding transport)

The uncertainties shown in the table below pertain to fuel use as measured for 1999. Uncertainties of fuel consumption in earlier years is likely higher since the method that is used to assess fuel us has improved over the years. Therefore, we assume that the fuel use in 1990 is less well known. The conjecture is that the uncertainty in the aggregate 1990 figure is 25% higher than the uncertainty in the aggregate 1999 figure. So, the uncertainty in oil consumption in 1990 was estimated at 4.2%.

Table 4.5 Oil consumption statistics and uncertainties (1999) as estimated by Statistics Netherlands.

Balance sheet item	Amount (PJ)	Uncertainty (2 sigma)
Production of crude oil	111	0.5%
Import of crude oil & oil products	5924	0.6%
Export of crude oil & oil products	4442	1.4%
Bunkers	677	2.1%
Stock changes	121	0.9%
Total from balance data	1037	7.0%
Cokes manufacturing	1	0.7%
Oil refineries	149	11.2%
Large scale power & heat production	1	0.5%
Small scale power & heat production	34	1.0%
Waste incineration	0	-
Distribution of oil products	1	8.5%
Manufacturing industry	335	1.3%
Transport	451	2.0%
Households	4	3.5%
Other consumers	62	16.1%
Total from consumption data	1037	1.90%

Source: CBS/Tinbergen, 2001.

4.4.2 Emission factors

The emission factors vary with type of oil product. The emission factor for LPG is about 66 t CO_2 per TJ. For residual fuel oil one calculates with 77 t/TJ. For gasoil the value is 72.2 (Table 1.A1 (b)).
Uncertainties in these emission factors are in the range of 2% (Olivier et al., 2001, p. 28). We used 73.0 t CO_2 per TJ as the aggregate factor for oil (liquid and other fuels) used in stationary "sources", with 2% as the default uncertainty.

4.4.3 Uncertainties in the assessment of feedstock emissions

The emission model (See Section 3.3.3 and Section 3.4.3) involves many variables. This is since there are several types of liquid fuels that can be used as feedstocks. Table 4.7 summarises the uncertainties that we assigned to each of these variables. In addition, the table shows variables that are relevant to the emission model of which uncertainties are elsewhere indicated (e.g. the use of gas as a feedstock).

The uncertainties in the apparent consumptions of the various liquid fuels (see Tables 1.A(b) and Table 1.A.(d) of the CRF files) are selected in such way that the composite uncertainty (uncertainty in the sum of apparent consumption[9]) is about the uncertainty assumed in the tier-1 approach (20%). This composite uncertainty is in line with the uncertainty indicated in the earlier tier-1 uncertainty assessment (Table 5.1 of the NIR 2001, Olivier et al. 2001).

Table 4.6 shows the result of the first order calculation (the initial estimate) of the feedstock emissions (i.e. feedstock emissions as estimated by applying the reference approach).

Table 4.6 RA Feedstock emissions by type of fuel according.

	Emissions (ktonne CO_2-eq) associated with the use of feedstock .	
	1990	1999
Other Kerosene 4)	0	6
Gas / Diesel Oil	90	1
Residual Fuel Oil	39	0
LPG	934	696
Ethane	0	0
Naphtha	585	233
Lubricants	396	581
Other Oil	1846	2279
Total	3890	3796

Source: from Tables 1.A(b) and 1.A(d) of the NIR 2001 (Olivier et al. 2001).

4.5 Results of tier-2 uncertainty analysis

4.5.1 Uncertainty in the emissions of CO_2 from stationary sources. NA-RA model

Table 4.8 lists the inputs for the calculation of uncertainties in the NA emission according to the NA-RA model. This table partly reiterates Table 4.5.

[9] As determined by applying the law of propagation of (normally distributed and non-correlated) errors.

Table 4.7 Assumed uncertainties in the estimation of the uncertainties in feedstock emissions from the use of liquid fuels.

CO_2 emissions from feedstocks	Value	Type of pdf	% uncertainty
1999 gas consumption for feedstock (PJ)	106.1	Normal	5
1999 NA-RA difference CO_2 emissions attributed to gas feedstock	1153	Normal	10
Carbon emission factor (t C/TJ) Gasoline	19.71	*	
Carbon emission factor (t C/TJ) Jet Kerosene	19.9	Normal	2
Carbon emission factor (t C/TJ) Other Kerosene	19.9	Normal	2
Carbon emission factor (t C/TJ) Gas / Diesel Oil	19.99	*	
Carbon emission factor (t C/TJ) Residual Fuel Oil	21	Normal	2
Carbon emission factor (t C/TJ) LPG	18	Normal	2
Carbon emission factor (t C/TJ) Naphtha	19.9	Normal	2
Carbon emission factor (t C/TJ) Other Oil 5)	19.9	Normal	2
Consumption feedstock TJ 1999 Other Kerosene 4)	450	Normal	25
Consumption feedstock TJ 1999 Gas / Diesel Oil	70	Normal	25
Consumption feedstock TJ 1999 LPG	58600	Normal	10
Consumption feedstock TJ 1999 Naphtha	17760	Normal	10
Consumption feedstock TJ 1999 Bitumen	14990	Normal	10
Consumption feedstock TJ 1999 Lubricants	7960	Normal	10
Consumption feedstock TJ 1999 Other Oil 5)	173520	Normal	25
Fraction of carbon stored Other Kerosene 4)	0.82	Normal	20
Fraction of carbon stored Gas / Diesel Oil	0.82	Normal	20
Fraction of carbon stored LPG	0.82	Normal	20
Fraction of carbon stored Naphtha	0.82	Normal	20
Fraction of carbon stored Bitumen	1	Normal	20
Fraction of carbon stored Other Oil 5)	0.82	Normal	20

* See Chapter 6.

Table 4.8 Initial uncertainties in parameters for estimating uncertainty in emissions due to the use of oil and oil products (NA-RA model).

Variable	Value	Pdf	Uncertainty (2σ) (%)
Average emission factor 1999 (kt/PJ) liquid fuels	73	Normal	2
Average emission factor 1990 (kt/PJ) liquid fuels	73	Normal	2
Oil consumption by cokes industry (PJ) 1999	1	Normal	0.7
Consumption of oil Refineries (PJ) 1999	149	Normal	11.5
Elect & heat Central oil products 1999 (PJ)	1	Normal	0.5
Elect & heat de-centralised oil products 1999 (PJ)	34	Normal	1
Waste incineration oil products 1999 (PJ)	0	Normal	0
Distribution of oil products 1999 (PJ)	1	Normal	8.5
Industry liquid fuels 1999 (PJ)	335	Normal	1.3
Households oil consumption 1999. PJ.	4	Normal	3.5
Other consumers oil products 1999 (PJ)	62	Normal	16.1
Total domestic consumption 1990 (PJ)	572	Normal	4.2
B 1999 oil & oil products (PJ)	355	Normal	2
A 1999 Oil and oil products (ktP/J)	11,604	Normal	2
B 1990 oil & oil products (PJ)	306	Normal	3
A 1990 Oil and oil products (ktP/J)	9,205	Normal	3

Table 4.9 summarises the outcomes of the tier-2 analysis using the above-mentioned inputs.

Table 4.9 Outcomes of the tier-2 uncertainty analysis of the CO_2 emission from the use of liquid fuels, according to the NA-RA model.

	1990 emission	1999 – emission	1990 -1999Trend
Minimum	25366	23269.25	-0.22359
Mean	28622.66	26470.9	-7.42%
Maximum	32541.58	29855.07	9.47E-02
Std Dev	979.8799	855.379	0.043285
Variance	960164.8	731673.3	1.87E-03
Uncertainties	6.85%	6.46%	-116.67%

To what uncertainties are these outcomes most sensitive? Next table presents the results of an sensitivity analysis (See Chapter 2 for an explanation).

Table 4.10 Sensitivity of 1999 CO_2 emissions to the various input of the emission model. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Consumption of oil Refineries (PJ) 1999	0.725
B 1999 oil & oil products (PJ)	-0.442
Other consumers	0.431
Industry	0.186
Average emission factor 1999 (kt/PJ) liquid fuels	0.174
A 1999 Oil and oil products (ktP/J)	0.135
Elect & heat decentralized	0.015
Households	0.006
Distribution of oil/oil products 1999 (PJ)	0.004

Consumption of oil products as measured by Statistics Netherlands is most important to the uncertainty. The correction factor B (which captures the difference in oil consumption as measured by Statistics Netherlands and oil consumption as published in the CRF tables) is in second place.

Trend. In the period 1990-1999, CO_2 emission of this source category declined by 17%. The uncertainty of this figure is large: 116% (given uncertainties in the input values).

Table 4.11 shows that the uncertainty in domestic consumption in 1990, contributes most to the uncertainty in the trend. Note that, lacking specific information about uncertainties in the energy statistics for 1990, we assumed that the uncertainty in 1990 domestic consumption excluding transport (4.2%) (See Table 4.8) does not equal composite uncertainty in the figure for 1999 oil consumption (3.4%, see Table 4.5). We assumed an additional 25% uncertainty that would stem from less accurate measurement of the consumption in 1990.

Table 4.11 Sensitivity of the uncertainty in the 1990-1999 trend in CO_2 emissions from combustion of liquid fuel (stationary sources) to variables in emission model. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Domestic consumption of oil & oil products 1990 (PJ)	-0.657
Consumption of oil Refineries (PJ) 1999	0.506
B 1999 oil & oil products (PJ)	-0.307
B 1990 oil & oil products (PJ)	0.302
Other consumers oil products 1999 (PJ)	0.298
Average emission factor 1990 (kt/PJ) liquid fuels	-0.147
Industry liquid fuels 1999 (PJ)	0.13
Average emission factor 1999 (kt/PJ) liquid fuels	0.121
A 1999 Oil and oil products (ktP/J)	0.095
Elect & heat Decentral oil products 1999 (PJ)	0.009
Households oil consumption 1999. (J)	0.004
A 1990 Oil and oil products (ktP/J)	-0.003

4.5.2 Allocation of emissions to feedstock use

Table 4.12 gives the outcome of the allocation of the all oil use emissions to the source categories "combustion only (stationary)" and oil use as feedstock.

Table 4.12 A comparison between tier-1 uncertainty and tier-2 uncertainty in emissions from the use of liquid fuels.

Source category	Emission	NIR 2001 uncertainties
CO_2 emissions from stationary combustion only: oil	72463	13.9%
CO_2 emissions from feedstock: oil	6501	57.6%
CO_2 emission from combustion and feedstock (Law of error propagation)	78965	6.4%

Table 4.13 indicates the most important uncertainties that underlie the uncertainty in the overall emission from the use of oil products as a feedstock. Most important are the assumptions with respect to the feedstock "Other Oil" (see Table 4.7).

Table 4.13 Sensitivity of the CO_2 emissions from the use of feedstock (liquid fuels and stationary sources) to variables in emission model. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Fraction of carbon stored Other Oil	-0.609
Consumption feedstock TJ 1999 Other Oil 5)	0.168
Fraction of carbon stored LPG	-0.116
1999 NA-RA difference CO_2 emissions attributed to gas feedstock	-0.033
Consumption feedstock TJ 1999 LPG	0.021
Carbon emission factor (t C/TJ) Other Oil.	0.015

4.6 Discussion and conclusions

We analysed the uncertainties in the emissions of CO_2 from the use of oil & oil products (liquid fuels) in stationary sources, as reported in the NIR 2001 (Olivier et al. 2001). By lack of the detailed information that underlies the reported emissions we formulated a simple model that relates the emission estimates to sets of information (i.e. use of oil products by sector) of which the reliability is known.

The uncertainty in the 1999 emission turned out to be 6.4% (the earlier tier-1 assessment indicated 12.3% (combustion and feedstock together). This is mostly explained by the fact that the tier-2 analysis takes account of correlation (See Table 4.14 and the discussion in the preceding chapter).

Correlation – the present emission model allocates emission of "use of oil" to "oil combustion" and "oil as feedstock" - explains also why the tier-2 uncertainty in the emission from "combustion only" is substantially higher than the earlier tier-1 uncertainty (13.9% versus 3.6%), while the uncertainties in the emission from "feedstock" are, deliberately, about equal.

Table 4.14 A comparison between tier-1 uncertainty and tier-2 uncertainty in emissions from the use of liquid fuels.

Source category	Emission	NIR 2001 uncertainties
CO_2 emissions from stationary combustion only: oil	72463	3.6%
CO_2 emissions from feedstock: oil	6501	53.9%
CO_2 emission from combustion and feedstock (Law of error propagation)	78965	12.3%
		Present uncertainties
CO_2 emissions from stationary combustion only: oil		13.9%
CO_2 emissions from feedstock: oil		57.6%
CO_2 emission from combustion and feedstock (Law of error propagation)		16.8%
CO_2 emission from combustion and feedstock (with correlation)		6.4%

Sensitivity analysis. The sensitivity analysis (Table 4.10) shows that – given the set of assumptions on the uncertainties in the values of model variables – the emission estimate for 1999 is most sensitive to the uncertainty in fuel consumption by the refinery sector.

The use of oil as it is observed from the environmental information submitted to the agencies that produce the actual inventories (RIVM/CBS/TNO) differs from the use of oil as it is published in energy statistics. The agencies have insight in the background of the difference. The "emission model" that underlies our uncertainty estimate captures this difference and enables to assign an uncertainty to this difference; this uncertainty captures the quality of the insights in the differences. In the calculation we assigned a 2% uncertainty to this difference (factor B, See Section 3.3.3). This uncertainty ranks then second in the table of variables, closely followed by the uncertainty in oil consumption by "other consumers".

Reduction of uncertainty in emission estimate. The sensitivity analysis (Table 4.10) shows the uncertainty in the use of oil by refineries – as estimated by Statistics Netherlands – is most important, followed by uncertainty in the factor B, which factor embodies "difference between the energy statistics information (of CBS) and the information on actual emissions (of PER-I)". Emissions of oil refineries are part of the PER-I. So, reduction of uncertainty would require improvements in the activities of the PER-I and CBS.

Details of how both bodies (CBS/PER-I) of information are matched and made compatible are unknown to us. Information of individual companies submitted to Statistics Netherlands are legally confidential and therefore, not available for analysis by other parties than Statistics Netherlands.

Another action would focus on improving the information with respect the heat of combustion (energy content) and the carbon content of fuel. This is in particular important to the estimate of the emission, and not to the estimate of the trend. This is since we assumed that the emission factors for the 1990 and 1999 are identical, implying the assumption that there is no change in the average carbon contents of oil and oil products over the years.
The primary source of information on carbon contents of fuels is the oil industry. An evaluation of the annual variations in carbon contents would require information from these industries. Currently, TNO-MEP is performing a study of the carbon contents of fossil fuels for NOVEM/WEB (Van Harmelen and Koch, 2002).

5. CO_2 emissions from the use of coal (1A)

5.1 Introduction

Emissions from the use of coal constitute about 13% of total national emissions in 1999. The tier-1 estimate of the uncertainty in this number was 4%. This source category belongs to the top ten of source categories ranked by their contribution to tier-1 overall uncertainty in emissions and in trend (See p.30 of the NIR 2001, Olivier et al., 2001).

Section 2 presents the emissions as reported in the NIR 2001. Section 3 describes how the emissions are calculated in the emission model developed for the uncertainty estimation. Section 4 presents the uncertainties in the input variables and parameters, as assumed for the calculations. Section 5 presents the results of the tier-2 uncertainty analysis. Section 6 discusses and concludes.

5.2 Reported emissions

The two bottom rows of Table 5.1 show CO_2 emissions from the use of coal (CRF-file, Table 1.A(c)) calculated according to the Reference Approach respectively the National approach (IPCC, 1996). The emissions refer to emissions from combustion of coal and to emissions from the use of coal as a feedstock (the share of the latter in emissions from coal is about 1.2%). The apparent consumption refers to an item in the energy balance sheet, which is the basis for the reference approach in the emission estimation.

Table 5.1 Coal and coal products and derived CO_2 emissions from combustion of coal (Reference and National approaches).

	Apparent consumption (PJ)		Emission (ktonne CO_2)	
	1990	1999	1990	1999
Reference approach	374	316	35,415	30,401
National approach	292	221	33,897	30,459

Source CRF -Table 1.A(c) from the NIR 2001 (Olivier et al. 2001).

The 1999 emission total calculated with the Reference approach (RA) is only slightly different from the total NA estimate. For 1990, the Reference approach results in a figure that is about 4.6% lower than the result from the National approach.

For the trend (percentage change in emission between 1990 and 1999) the choice of method has a major effect. According to the reference approach emissions decreased with 14%, while according to the national approach emissions decreased with 10%.

The NIR 2001 (Olivier et al. 2001, Table 5.1) shows emissions from "Feedstock coal to be 400 ktonne, with a note that the table is based on preliminary CRF data. In the actually submitted figures there is no emission associated with the use coal as a feedstock (See CRF Table 1.A(d)).

Table 5.2 Tier-1 uncertainties in CO_2 emissions from use of coal and coal products.

Source category	Emission 1999	Uncertainty in activity data	Uncertainty in Efactor	Uncertainty in emission
Stationary combustion	34,934	30,001	3%	3%
Feedstock coal	481	400	5%	10%

Source: Olivier et al. (2001, p. 28). Activity data: national consumption of oil for combustion (reference approach).

5.3 Emission model

5.3.1 Introduction

For this source category the outcomes of the national approach and the reference approach (See Section 3.3) are quite different. The national approach leads to a substantially higher (about 20% in 1999) emission than the reference approach.

Table 5.3 Outcomes of the two methods to estimate CO_2 emissions from the use of Coal.

	Reference Approach		National Approach	
	Energy consumption (PJ)	CO_2 emissions (Gg)	Energy consumption (PJ)	CO_2 emissions (Gg)
1999 Solid Fuels (excluding international bunkers)	316.00	30,400.85	221.00	30,459.20
1990 Solid Fuels (excluding international bunkers)	374.00	35,414.57	292.25	33,897.97

Source: RIVM CRF files 1999 and 1990, Tables 1.A(c).

5.3.2 The NA-RA model

We propose the following method to estimate an uncertainty in the NA emission, by using the following expression (See for explanation Section 3.3.3.):

$$Em_{total}^{National} = A + Ef\ \left(E_{Total-CBS} + B\right)$$

Table 5.4 Correction factors in the NA-RA model. Aggregate emission factor.

Correction factors	1990	1999
Aggregate emission factor (t/GJ)	96.8	96.5
A (kT)	5683	9058
B (PJ)	-81.75	-95.0

5.3.3 Feedstock and combustion only

Feedstock emission is small compared to the emission from combustion of coal (about 1.5%). This emission is assessed separately by the inventorying agency.

5.4 Uncertainties

Table 5.5 shows the uncertainty in the figures for the use of coal & coal products.

Table 5.5 Coal use statistics and uncertainties (1999) as estimated by Statistics Netherlands.

Balance item	Amount (PJ)	Uncertainty (2 sigma)
Import of coal & coal products	513	0.8%
Export of coal & coal products	213	1.7%
Stock changes of coal & coal products	16	1.1%
Total		1.7%
Cokes manufacturing	13	6.6%
Large scale power & heat production	211	0.4%
Small scale power & heat production	1	1.0%
Manufacturing industry	87	1.3%
Other	3	33.3%
Total		0.8%

Source: CBS/Tinbergen, 2001.

We will use the figures of coal consumption in the uncertainty analysis. The emission factor for combustion of coal is an average. Its value changes over the years with the change in origins of the coal (all of which is imported).

Table 5.6 Carbon content factors and emission factors as used in the Reference calculation.

C content coal derivates (C eq per TJ)	C content gases from coal (C eq per TJ)	1990 C content Other Bit. coal (C eq per TJ)	1999 C content Other Bit.coal (C eq per TJ)
25.64	28.09	26.33	26.41

In terms of CO_2 kg per TJ the "Other Bit. Coal" emission factors correspond with 96.8 kg CO_2 per TJ and 96.5 CO_2 per TJ. These factors are national averages. We could not find an explicit documentation of these factors.

The allocation of the emission from the use of coal to source categories "Combustion only" and "Feedstock" is based on adopting the NIR-2001 emission assessment of feedstock emission and the earlier tier-1 uncertainty in feedstock emission (11%).

5.5 The uncertainty analysis

Table 5.7 shows the values of the parameters and variables and their assumed uncertainties.

Table 5.7 Values& uncertainties of parameters and variables in NA-RA- emission model for CO_2 emissions from the use of coal & coal product.

Variable	Value	Type pdf	(%)
Average emission factor 1999	97	Normal	1
Import coal & coal products (PJ) 1999	513	Normal	0.8
Export coal 1999 (PJ)	213	Normal	1.7
Stock change coal 1999 (PJ)	16	Normal	1.1
Cokes production PJ 1999	13	Normal	6.6
Electric production (Centraal) coal PJ 1999	211	Normal	0.4
Electric product (decentral) coal PJ 1999	1	Normal	1
Industry coal PJ 1999	87	Normal	1.3
Other 1999 coal PJ	3	Normal	33.3
B 1999 Coal	95	Normal	2
A 1999 Coal	9058	Normal	2
Average emission factor 1990	97	Normal	1
B 1990 coal	82	Normal	2
A 1990 coal	5683	Normal	2
Domestic consumption of coal & coal products 1990 (PJ)	374	Normal	1

Table 5.8 summarises the outcomes of the calculations.

Table 5.8 Outcomes of the tier-2 uncertainty analysis of the CO_2 emission from the use of coal and coal products, according to the NA-RA model.

	1990 emission	1999 – emission	1990 -1999Trend%
Minimum	33020.63	29685.5	-13.8231
Mean	33896.05	30361.16	-10.4397
Maximum	34674.71	31088.85	-7.14864
Std Dev	245.904	193.9397	0.868954
Variance	60468.77	37612.6	0.755081
Uncertainties	1.45%	1.28%	-16.65%

Table 5.9 shows that for the estimation of the 1999 emission the average emission factor is rather important. The reliability of the PER-I process – captured by the uncertainties assigned to the factors A and B – is also important.

Table 5.9 Sensitivity of 1990-1999 trend in CO_2 emissions from the use of coal to variables in emission model. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
Average emission factor 1999	0.551
B 1999 Coal	-0.472
A 1999 Coal	0.465
Industry coal PJ 1999	0.284
Other 1999 coal PJ	0.248
Cokes production PJ 1999	0.214
Electr. production (Central) coal PJ 1999	0.211
Electr. product (decentral) coal PJ 1999	0.003

5.6 Discussion and conclusions

The uncertainty in the 1999 emissions is about 1.3%, clearly less than the earlier tier-1 uncertainty assessment by Olivier et al. (2001) and described in the NIR 2001. The new information of the Netherlands Statistics with respect to uncertainty in coal use – low compared to the assumptions by Olivier et al. - explains most of the difference.

The most important factor behind the uncertainty in the emission – given that the uses of coal is precisely known - is the uncertainty in the average carbon content. Van Harmelen and Koch (2001) analysed information with respect to carbon content of coals. Over the years, the countries of origin of coal (and coal properties) that is used in the Netherlands changed. Therefore, it is likely that average carbon content is not constant over the years.

Scope for reduction in uncertainty. The average carbon content of coal is the variable that contributes most to uncertainties in emissions and the trend. Van Harmelen and Koch (2001) discussed emission factors for coal. About 75% of the coal is used in power plants. Power plants obtain coal via the *Gemeenschappelijk Kolenbureau Electriciteitsproductie bedrijven GKE)* (A coal procurement office of Dutch energy firms). GKE analyses the composition of coal, so the source of primary information on the carbon content of most coal is at GKE.

The second important uncertainty is in the net consumption of “Other bituminous coal”. Uncertainty in the figures for net consumption relate in particular to the uncertainties in the export of coal as recorded by Statistics Netherlands. So, an improvement of the reliability of the data would require additional

6. Emissions from mobile combustion (1A)

6.1 Introduction

"Emissions from mobile combustion" is a composite source category that refers to emissions of CO_2, N_2O and methane from the CRF source categories road vehicles, navigation, aircraft, railways and "Other transportation" (CRF file, Table 1.A.3.e). The sector "other transportation" comprises tractors, building equipment (e.g., compressors, cranes), lawn mowers, in sum, all kind of apparatus equipped with reciprocal engines that use petrol or diesel as a fuel. Emissions of CFCs from (air-conditioners in) vehicles are dealt with in the Chapter 14.

"Emissions from transport" is after "Emissions from combustion of natural gas" the second largest emission; in 1999 'emissions from transport" accounted for about 15% of total emissions.

"Emissions from transport" comprise various key source categories. Of these key source categories "CO_2 mobile combustion: other' and "CO_2 emission from water borne-navigation" rank among the source categories that are most important to the tier-1 uncertainty in the trend of emissions (p. 30 of the NIR 2001, (Olivier et al., 2001).

Section 2 summarises the reported data. Section 3 summarises the calculation procedure. An extensive description of the emissions model (Klein et al., 2002) is about to be published. Section 4 discusses uncertainties that are used in the calculations. The results of the latter are described in Section 5. Section 6 discusses and concludes.

6.2 Reported emissions and Emission model

Table 6.1 shows the emissions and the figures for energy consumption that have been reported to the UN-FCCC in the NIR 2001 of the Netherlands (Olivier et al., 2001).

6.3 Emission model

6.3.1 Calculation of CO_2 emissions

The CO_2 emission model (Klein et al., 2002) that is used for estimating the emissions from this source category is simple: fuel consumption times an appropriate emission factor for CO_2. So, in case of CO_2, the emission factors – derived from the chemical compositions of the fuels and their chemical and thermodynamic properties - do not depend on the type of vehicles or the use of vehicles (drive cycles).

Fuel consumption in the transport sector is measured by Statistics Netherlands from surveys among suppliers of transportation fuels (petrol, diesel fuel, LPG, jet kerosene and other gasoil (used in navigation). The so-established value for total consumption in transport is then allocated to various subsectors within the transport sector, using additional circumstantional information (e.g. fuel consumption per kilometer of passenger cars, traffic and transportation statistics).

Table 6.1 Fuel consumption in the transport sectors and reported emissions of CO_2, N_2O and CH_4 in 1999.

Source category	1990	1999	CO_2	CH_4	N_2O
	(TJ)	(TJ)	(Gg)	(Gg)	(Gg)
a. Civil Aviation (domestic)			1999	1999	1999
Jet Kerosene	6743	5747	419.51	0.05	0.03
b. Road Transportation					
Gasoline	152000	180676	13063	3.49	2.26
Diesel Oil	159100	219883	16,117	0.53	2.31
LPG	41000	29075	1930	0.17	0.69
c. Railways					
Liquid Fuels	1220	1258	92	0.00	0.02
d. Navigation (domestic)					
Gas/Diesel Oil	12020	11059	807	0.03	0.18
e. Other Transportation					
Liquid Fuels			2,270	0.29	0.50
1.A.3 Transport Total	402944	478660	34,699	4.57	5.98

Source. CRF-file, Table 1.A(a)s3 (NIR, 2001).

Table 6.2 shows the emission factors that were used. These apply to both 1990 and 1999, so the assumption is that there is no change in the ratio between carbon content of fuels and heat of combustion (Klein et al., 2002, p. 42). This is likely since for the hydrocarbons that are in transport fuels the differences in heats of combustion per unit carbon content are small. Small variations in the chemical composition, therefore, will hardly have influence on emission factors (say < 0.5%).

Table 6.2 CO_2 emission factors for transport.

Fuel	Emission factor (t/TJ)	Fuel	Emission factor (t/TJ)
Petrol	72.3	LPG (road transport)	66.4
Diesel Oil	73.3	Gas/Diesel Oil in navigation	73.0
Diesel fuel in railways	73.3	Liquid Fuels in other vehicles	73.3
Jet Kerosene (aircraft)	73.0		

6.3.2 Calculation of N_2O and methane emission

In terms of CO_2-eq the emissions of N_2O and methane are minor compared to those of CO_2. Methane emission contributes about 0.8% to all emissions from mobile combustion and N_2O about 3%.

The model that is used for the calculation of emissions of methane and nitrous oxide in the NIR and other Dutch emission inventories (i.e. PER), is more complex than the CO_2 emission model. The calculations are not based on fuel consumption but on transportation statistics, information about transport technologies and other characteristics, e.g. kilometers driven, drive cycles, trip lengths, style of car driving, and vehicle technology (Klein et al., 2002).

In view of the limited share of N_2O and methane in all emissions, we used a simplified emission model for the uncertainty analysis. This model was constructed by attributing N_2O and methane emission factors to fuel consumption. This is done by dividing N_2O and CH_4 emissions (calculated according to elaborate method and reported in the NIR 2001) by corresponding fuel consumption data. The result is a series of implied 'emission factors'. Table 6.3 summarises and shows how these implied emission factors vary across sectors and across time (See Table 6.7 and Table 6.8 show the detailed factors as derived from the CFR-files).

The Table shows that the emission factors for road transport change over time. The changes with respect to emission from gasoline vehicle are due to the advent of catalytic systems for abatement of pollution from exhaust gases. Diesel engine technology, which also changed over the years, is also influential (See below).

Tabel 6.3 Implied (lumped) emission factors for methane and nitrous oxide in mobile sources kg/TJ.

	CH_4 1990	CH_4 1999	N_2O 1990	N_2O 1999
Gasoline	38.3	19.3	10.9	12.5
Diesel oil	7.3	2.4	10.4	10.5
Diesel fuel in railways	2.50	3.0	16.2	16.2
Jet Kerosene (aircraft)	11.7	9.0	4.7	4.7
LPG (road transport)	13.0	5.7	11.5	23.6
Gas/Diesel oil in navigation	3.0	3.0	16.2	16.2
Liquid Fuels in "other vehicles"	9.4	9.4	16.2	16.2

N_2O. Olivier et al. (2001), on p. 57, summarise the estimation of the N_2O emissions in the NIR 2001. N_2O emissions were derived from NOx emissions, which in turn are based on emission factors that relate emissions to transport (g/km), for different types of vehicles and different drive cycles. Recently, this method is modified by using new emission factors that are based on actual measurements of N_2O emissions from cars (Klein et al., 2002). This new information is not used for the inventory in the NIR 2001, and, therefore, also not in the emission model of the present study.

Methane. The calculation of methane emissions is based on the model for VOC emissions from mobile sources of Statistics Netherlands. The structure of this model is similar to the corresponding model for NOx (and thus N_2O, see above). The key assumptions are in Table 6.5.

So, according to this model the lumped emission factor changes over time with changing technologies. This reflects the introduction of progressively stricter emission standards with respect to VOC emissions for gasoline-fueled cars mainly.

Tabel 6.4 Emission factors (mg/km) for N_2O.

Type of vehicle	Fuel	Emission Standard	Drive cycle		
			Urban	Rural	Motorway
Passenger cars, vans	Petrol/LPG	No catalyst	5	5	5
		EURO 1	40	20	20
		EURO 2	25	5	5
		EURO 3	10	5	5
	Diesel	Conventional	5	5	5
		EURO 1	5	5	5
		EURO 2	10	10	10
		EURO 3	10	10	10
Vans	Diesel		20	20	20
Lorries, busses, other diesel	Diesel		30	30	30

Source: Klein et al., 2002.

Table 6.5 Share of methane in total emissions of VOCs of vehicles.

Source characteristic	Share of VOC emissions
Petrol, no catalytic converter	0.05
Petrol with catalytic converter	0.12
Diesel engine	0.04
LPG fuelled engine	0.03
Petrol for mopeds	0.05
Jet fuels	0.10
All other oil products	0.20
Other	0.05

Source: Spakman et al., 1997, p.29.

6.4 Uncertainties

6.4.1 CO_2

The model 'Fuel consumption times a CO_2 emission factor' is based on a mass balance of the combustion process. There is a high confidence in this model. Uncertainty evolves from errors in the data about fuel consumption and corresponding emission factors. Table 6.6 summarises the assumptions on the uncertainties that are used in the calculations (for calculations see next section).

The uncertainty in the **emission factors** (kg CO_2 per MJ fuel) is assumed to be normally distributed and to have a range of confidence of 2% for each of fuels that are distinguished. This reflects variations in the chemical composition of fuels relative to heats of combustion. There is also a negligible possibility that not all carbon of the fuel is converted in carbon dioxide.

One may ask whether the uncertainty in the emission factor for 1990 (reference year) is correlated with the emission factor for 1999. We assume full correlation. This means that fuel of 1990 is identical (in terms of heat of combustion and carbon content) to fuel of 1999, or, in other words, the sources of possible variability in the emission factor are not time dependent. This assumption is important to trend calculations.

Table 6.6 Assumed uncertainties in variables of the emission model for CO_2 emissions from transport.

Variable	Value	Pdf	Uncertainty
Total petrol consumption (Road petrol + aviation kerosene) TJ 1999	186,422	Normal	2
Total Diesel consumption TJ 1999	263,162	Normal	2.5
Petrol consumption in road transport TJ 1999	180,675	Normal	2
Diesel fuel consumption in road transport TJ 1999	219,883	Normal	2.5
LPG consumption in road transport TJ 1999	29,075	Normal	2
Jet kerosene TJ 1999	5,747	LogNormal	100
Fuel consumption in navigation TJ 1999	12,020	Triangular*	
Fuel consumption in railways TJ 1999	1,258	Normal	5
CO_2 efactor diesel/gasoil (kt/PJ)	73.3	Normal	2
CO_2 efactor gasoline (kt/PJ)	72.3	Normal	2
Emission factor CO_2 LPG (kt/PJ)	66.4	Normal	3
Emission factor kerosene and diesel oil (kt/PJ)	73.0	Normal	2

* Min 8000, most likely 11061, max 17000.

The second uncertainty is in the **fuel consumption data** (see Table 6.1). These assumptions are based on the following considerations:

- The NIR 2001, p.28 (Olivier et al., 2001) indicates uncertainties for fuel consumption by "road vehicles" (2%), "navigation" (100%), "aviation" (50%) and "other" 50%. Experts of Statistics Netherlands indicated (Van Asselt et al., 2002) that the uncertainty for "aviation" is also 100%. They noted that the mean (*verwachtingswaarde*) of the estimate of fuel consumption is likely too high for "aviation" and too low for "navigation".
  To account for this we assumed a lognormal error distribution, respectively a triangular distribution. Note that emissions from aviation and navigation constitute only about 3% of all CO_2 emissions from transport, so the effects of these detailed uncertainty considerations on total uncertainty are minor.
  It is important to note that in our model the fuel consumption in the sector "Mobile combustion: other" is a residual (*restpost*) and treated as a balance item. So, errors in the emission estimate are determined by the error in total fuel consumption in transport and by the estimation of fuel consumption in the sectors other than "Mobile sources, other".
- Very recently Statistics Netherlands disclosed some results of their analysis of uncertainties in the energy balance for 1999 (Tinbergen, 2001). For fuel consumption in the transport sector the uncertainty is estimated at 2.0%. This uncertainty refers to fuel consumption lumped over transport fuels and transport sectors. We disaggregated the uncertainty over fuels tentatively.

Table 6.6 shows the eventually assumed uncertainties in fuel consumptions that were used in the (initial) calculations. Uncertainties in the CO_2 emission factors are all 2% (normally distributed).

Note that, in contrast with the tier-1 uncertainty analysis, we did not attribute uncertainty to fuel consumption of the sector 'Mobile combustion: other '. This sector ranks high on the Tier 1 list of source categories of which the uncertainty has a high influence on the

overall uncertainty in the trend (NIR 2001, Column "Combined uncertainty in trend" of Table 5.2, p.26). This rank is due to the Olivier *et al.*'s assumption of 50% uncertainty in the fuel consumption figure. For a Tier 2 uncertainty analysis, however, one takes account of the fact that "other" is a balance item (a residual): fuel consumption is total consumption minus consumption measured in other sectors. So this fuel consumption depends on other fuel consumptions, and in a tier 2 analysis there is no need to estimate an uncertainty for fuel consumption in this sector.

6.4.2 Nitrous oxide

We indicated that for the NIR nitrous oxide emissions are not estimated from fuel consumption statistics, but from (*i*) transportation statistics (km per year, per type of vehicle, per type of fuel, stratified by age of vehicle), (*ii*) emission factors for NOx and (*iii*) from an assumption about the relation of N_2O and NOx emissions, which in turn, depends on vehicle technology (Klein et al., 2002). The emissions factors shown by Table 6.3 are (only) implied emission factors.

There are estimations of the uncertainties of these implied emissions factors. These uncertainties are high. Olivier et. al. (2001) estimate the uncertainty in the emission factor for "road vehicles" at 50%, while for all other transport the corresponding implied emission factor is estimated at 100%. The expert of Statistics Netherlands found 100% a better estimate for the uncertainty in the (implied) emission factor for road vehicles. These high uncertainties comply with uncertainties used in other uncertainty analyses (Winiwarter and Orthofer, 2000; Rypdal and Zhang, 2000).

A rigorous Tier 2 uncertainty analysis would require attributing pdfs to all the many elements of the full model. Such analysis was not given priority within the scope of the present study, since the share of this source in total emissions is only <0.75%, while elaborating the full uncertainty model would require considerable effort.

There is, however, a benefit to apply the Tier 2 method on the simplified model. This is because of recent new information from measurements of N_2O that indicate that N_2O emissions are lower than initially assumed (TNO measurements under the ROB programme). These indications can be incorporated in the uncertainty analysis by defining a pdf that gives a relatively high probability to the lower emissions. To account for these expectations, we attributed lognormal pdfs (mean=1.000 and median=0.707) to the emission factors (See Table 6.7). Tier-1 uncertainty analysis is cannot take account of new insights in such way.

Winiwarter and Orthofer (2000) used a triangular pdf for their emission factor for "N_2O from traffic" (min 30%, max. 70%). For 1997, for highway driving and for cars equipped with catalysts, they used 35.65 g per GJ as the most likely emission factor. For urban drive cycle their emission factor was 11.16 g/GJ. These factors tend to be higher than the factors used in the Dutch inventory (as suggested by Table 6.3). They cannot, however, be directly compared since the Dutch factors are implied factors.

Table 6.7 Uncertainties in the variables in the simplified model of emissions of N_2O from transport.

Variable	Mean*	Type of pdf	Uncertainty (%)
N_2O emission factor petrol road transport (tonne per PJ) Year	10.935165	LogNormal	100
N_2O emission factor petrol road 1990	12.510224	LogNormal	100
N_2O emission factor diesel road transport (tonne per PJ) 1999	10.447172	LogNormal	100
N_2O emission factor diesel in road 1990	10.496672	LogNormal	100
N_2O emission factor LPG (tonne per PJ) 1999	11.505788	LogNormal	100
N_2O emission factor LPG 1990	23.620122	LogNormal	100
N_2O emission factor diesel Rail/navigation/Other	16.2	LogNormal	100
N_2O emission factor jet kerosene 1999/1990	4.7	LogNormal	100

* These values were calculated from emissions and corresponding fuel consumption in the CRF files submitted to the UN-FCC.

Table 6.7 shows all the assumptions that were made for the calculations.Later (Rypdal and Winiwarter, 2001) reported a triangular function between Min 70% and Max 170%. Rypdal and Zhang (2000) (p. 15) used a Beta distribution (-66% - +200%) for N_2O from oil combustion in road traffic (in their relatively simple transport emissions model). So, our estimate of the uncertainties is different in the sense that we, in contrast with these authors, assign a low probability to high values for the emission factor (from the recent indications that emissions are lower than previously thought).

Calculation of the trend. For the calculation of the 1990-1999 trend in the emission the possible correlation between the (aggregate) emission factors for 1990 and for 1999 for must be addressed. This is important since processes that led to N_2O emission in 1990 are different from processes behind the 1999 emissions. In 1990, there were hardly any vehicles equipped with three way-catalysts. Combustion processes in the engine determined N_2O emissions. In contrast, in 1999, most of the road transportation of vehicles equipped with petrol fuelled engines, was by cars equipped with three way catalysts. For those cars the chemical processes in the catalytic equipment determine N_2O emissions. The type of the exhaust control equipment is also important to N_2O emissions (see Table 6.4). So the lack of knowledge that produces the uncertainty in the emissions is different for 1990 and 1999. This uncertainty adds to the uncertainty from the experimental difficulties to measure N_2O emissions.

We don't have sufficient information to quantify correlation between emission factors for 1990 and 1999. In order to still have some idea about the impact of correlation on the result for the uncertainty in the trend we made two calculations: a trend with and a trend without correlation between the aggregate emission factors for 1990 respectively 1999 (See Table 6.11).

6.4.3 Methane

Calculation of methane emission is entirely analogous to the calculation of the emission of nitrous oxide. Methane emission, however, is thought to be less uncertain. Uncertainties in emission factors are all estimated at 50%. The pdfs are assumed to be normal.

Table 6.8 shows the variables for the emission factors as derived from the information in the CRF files and which are used in the calculations.

Table 6.8 Uncertainties in the variables in the simplified model for methane emissions from transport.

Variable	Mean	Type of pdf	Uncertainty (%)
CH_4 emission factor petrol road (g/GJ) 1990	38.2882	Normal	50
CH_4 emission factor petrol road (g/GJ) 1999	19.3278	Normal	50
CH_4 emission factor diesel in road (g/GJ) 1990	7.31194	Normal	50
CH_4 emission factor diesel in road (g/GJ) 1999	2.42139	Normal	50
CH_4 emission factor LPG (g/GJ) 1990	13.0220	Normal	50
CH_4 emission factor LPG (g/GJ) 1999	5.69227	Normal	50
CH_4 emission factor diesel fuel in railways (g/GJ) 1990	2.50172	Normal	50
CH_4 emission factor diesel fuel in railways (g/GJ) 1999	3.06510	Normal	50
CH_4 emission factor Jet Kerosene (aircraft) (g/GJ) 1990	11.7355	Normal	50
CH_4 emission factor Jet Kerosene (aircraft) (g/GJ) 1999	8.95451	Normal	50
CH_4 emission factor gas/diesel oil in navigation (g/GJ) 1999/1990	2.97628	Normal	50

6.5 Results

6.5.1 Carbon dioxide

The central estimate of total carbon dioxide emissions from transport is 34.7 Mtonne CO_2. The tier-2 uncertainty analysis results in a range of 95% confidence of 34.1 – 35.2 Mtonne, which corresponds with 1.6% uncertainty. The corresponding uncertainty from the tier-1 uncertainty analysis in the NIR 2001 would be 4.9% (for all CO_2 emission from mobile combustion). The difference is mainly due to the tier-2 uncertainty analysis taking account of the dependency of fuel consumptions in the sector “other transport” and fuel consumption in, in particular, “road transport”.

Table 6.9 shows that the outcome of the calculations of CO_2 emissions from mobile combustion is most sensitive to total diesel consumption and to total petrol consumption.

Table 6.9 Sensitivity of 1999 emission to variables in CO_2 emission model from mobile combustion.

Variable	Standard B coefficient
Total Diesel consumption TJ 1999	0.863
Total petrol consumption (Road petrol + aviation kerosene) 1999	0.484
Emission factor CO_2 LPG (kt/PJ)	0.103
LPG consumption in road transport 1999	0.069
Emission factor gas oil for navigation / CO_2	0.031
Emission factor jet kerosene / CO_2	0.015
Jet kerosene 1999	0.008
Fuel consumption in navigation 1999	-0.002
R-Squared=	0.99992

Results with respect to uncertainties in the **trend** of the emissions between 1990 and 1999 (% change) are presented in Figure 16.1 and Table 6.10. Figure 16.1 shows that emissions increased by 16% to 22% (19.2% is the mean). Table 6.10 shows that the uncertainty in the trend calculation is mostly the result from uncertainties in the figures for total fuel consumption in the transport sector (Standard B coefficients that are less then 0.01 are not shown).

The statistics on diesel fuel consumption are most important for an assessment of trend uncertainty. Uncertainties in fuel consumptions in subsectors of the transport sector (e.g. aviation, navigation) are hardly relevant for the uncertainty in the trend.

Table 6.10 Sensitivity of 1990-1999 trend (%) to variables in CO_2 emission model.

Variable	Standard B coefficient
Total Diesel consumption / 1999	0.628
Total Diesel consumption / 1990	-0.579
Total petrol consumption / 1990	-0.356
Total petrol consumption / 1999	0.352
LPG consumption in road transport / 1990	-0.064
LPG consumption in road transport / 1999	0.05
Emission factor diesel in road/railways/other / CO_2	0.047

6.5.2 Figure 1 Emissions of N_2O and methane

N_2O**.** Figure 6.2 shows the probability distribution for the 1999 N_2O emissions. The mean of the emission is 6.0 ktonne N_2O, which corresponds with 1.8 Mtonne CO_2-eq. The skewed distribution reflects the skewed probability function for N_2O emission factors (see section on uncertainty) which in turn reflects the indication that N_2O emission might be lower than previously assumed. The range of 95% confidence is 1.0 Mtonne CO_2-eq. – 3.0 Mtonne CO_2-eq. The comparable range of confidence that results from the tier-1 uncertainty analysis (Olivier et al. 2001) is 1.0 – 2.7 Mtonne CO_2-eq. This is in line with the expectation that emissions might be lower than previously (e.g. the uncertainty assessment by Olivier et al. (2001) assessed.

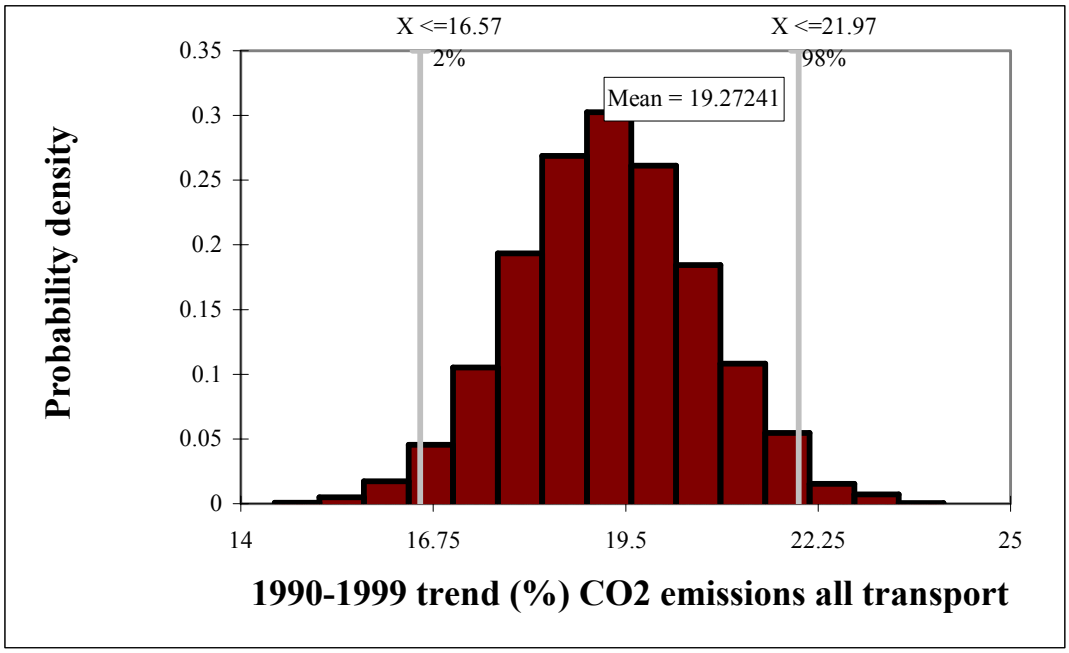

Figure 6.2 1990-1990 trend (pdf of % change) in CO_2 emissions from all transport.

The trend in N_2O emissions depends highly on the way the inter-annual dependency (correlation) between emission factors is treated. Table 6.11 shows the outcomes of two calculations with different assumptions on correlation. It shows that if the uncertainties in the emissions of petrol and LPG fuelled cars for 1990 and 1999 are completely independent the uncertainty in the trend is high. There is even a probability that emissions decreased in that period (i.e. if it turns out that N_2O emissions from cars built in the eighties are higher than now assumed, while, in addition, emissions from cars built in the nineties (with catalysts) are lower than assumed in the current model). The means are different in both calculations due to the effect of pdfs having a lognormal character.

A sensitivity analysis shows, as expected, that in the case of full correlation the uncertainties in fuel consumptions are important for the results, while in case of independency of the emission in 1990 and 1999 the uncertainty in the trend depends mainly on the uncertainties in the emission factors.

6.5.3 Methane

The range of 95% confidence in the methane emission of 1999 is 2.8 ktonne – 6.2 ktonne with a mean of 4.5 ktonne Methane. This is similar to the result of the tier-1 uncertainty analysis (Olivier et al., 2001).

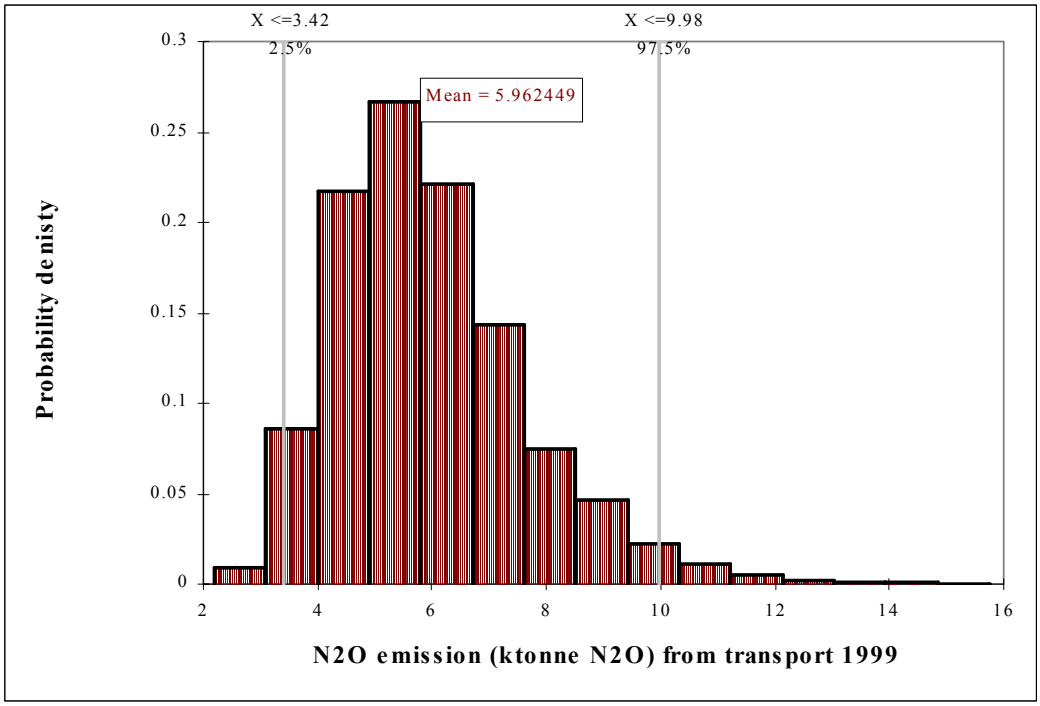

Figure 6.2 Probability density function of the 1999 N_2O emissions from transport.

Table 6.11 Trend in N_2O emissions from transport as a function of assumed dependency between 1990 and 1999 emission factors for petrol and LPG fuelled vehicles.

Correlation between emission factors 1990 and 1999	Mean	Range of 95% confidence	
No	39%	-23%	+127%
Full	31%	+22%	+37%

6.6 Discussion and conclusion

1999 emissions. The assumption and calculations describe above indicate that total emissions (CO_2, N_2O and methane) from transport in 1999 amount to 37.3 Mtonne CO_2 eq., with a range of 95% confidence of 36.1 – 39.2 Mtonne.

Table 6.12 Tier-2 uncertainty assessment of uncertainties in greenhouse gas emissions of all transport.

Greenhouse gas	1999 emission in Mtonne CO_2-eq	95% confidence range
Carbon dioxide	34.7	34.1 – 35.2
Nitrous oxide	1.8	1.0 – 3.1
Methane	0.10	0.06 – 0.13
All greenhouse gases	36.6	35.8- 37.9

A sensitivity analysis (not shown here) indicated that N_2O emission factors (for petrol, diesel and LPG) and methane emission factors (for transport with petrol fuelled engines) are most important to the overall uncertainty. This is not a new conclusion (Van Amstel et al., 2000).

The 1990-1999 trend in emissions. The emission of all greenhouse gases from transport rose with 19.5% in the period 1990-1999. For the assessment of the uncertainty in this number there is a particular issue with respect to the correlation between the emission factors for N_2O emissions from petrol fuelled road vehicles in 1990 and in 1999. In 1990 the "process" that caused N_2O emissions was combustion of petrol in the engine, while in 1999 N_2O emissions was to be associated with chemical processes in catalytic exhaust control systems. So this source of uncertainty in emissions is different for both years. This suggests that the 1990 and 1999 emission factors are not fully correlated. To assess the sensitivity of the 1990-1999 trend to this suggestion, we calculated the uncertainty of trend twice: one with and one without assuming dependencies between N_2O emission factors for petrol and LPG fuelled cars.

Table 6.13 shows the effect of these assumptions on the range of confidence in the 1990-1999 trend. Rejecting dependency between the N_2O emission factors doubles the range of confidence.

Table 6.13 The impact of inter-annual (1990-1999) dependency of N_2O emission factors (petrol road vehicles) on the uncertainty in the trend for transport related emissions.

Assumption on dependency/correlation	95% confidence range in trend
Sources of uncertainty in 1990 and 1999 N_2O emission factor are equal	18.9% - 20.1%
N_2O Emission factors for 1990 and 1999 are entirely independent	16.4% - 22.8%

The uncertainty in the N_2O emissions is also the most important item for the explanation of the uncertainty in the trend in all emissions of all transport (range of 95% confidence). The results of two sensitivity analyses in Table 6.14 and Table 6.15 show the importance of the assessment of the correlation between the N_2O emissions in 1990 and 1999 to the uncertainty in the trend in all greenhouse emissions from transport.

6.7 Scope for reduction in uncertainty

The analysis confirms earlier conclusions that lack of knowledge about N_2O emissions is most important to overall uncertainty.

Research is going on to improve knowledge with respect to N_2O. Current inventories – for the year 2000 - use already other emission factors than the ones used in this study (Klein et al., 2002). NOVEM commissioned a study "*Bepaling karakteristieke* N_2O-*emissies van personenauto's TNO Wegtransportmiddelen*" to TNO-WT. Oonk (2001) presented some first results that point at a decrease in N_2O emissions with the introduction of modern technologies (enforced by European emission limit standards) to reduce

exhaust gas emissions of vehicles. The results of this research were not incorporated in the NIR 2001.

Table 6.14 Sensitivity of 1990-1999 trend (%) of greenhouse gas emissions from transport to input variables. N_2O emission factors for petrol and LPG cars assumed to be independent for 1990 and 1999.

Variable	Standard B coefficient
N_2O emission factor petrol road (g/GJ) 1999 / N_2O	0.719
N_2O emission factor petrol road (g/GJ) 1990 / N_2O	-0.624
N_2O emission factor LPG (g/GJ) 1999 / N_2O	0.219
N_2O emission factor LPG (g/GJ) 1990 / N_2O	-0.178
N_2O emission factor diesel in road (g/GJ) 1990 / N_2O	0.1
CH_4 emission factor petrol road (g/GJ) 1990	-0.074
N_2O emission factor diesel Rail/navigation/Other (g/GJ) 1999	-0.047
CH_4 emission factor petrol road (g/GJ) 1999	0.037
Total Diesel consumption TJ 1999 / 1999	0.033
Total Diesel consumption in transport (TJ) 1990 / 1990	-0.032

Table 6.15 Sensitivity of 1990-1999 trend (%) of greenhouse gas emissions from transport to input variables. N_2O emission factors for petrol and LPG cars assumed to be dependent for 1990 and 1999.

Variable	Standard B coefficient
N_2O emission factor diesel in road (g/GJ) 1990 / N_2O	0.549
N_2O emission factor petrol road (g/GJ) 1990 / N_2O	0.472
CH_4 emission factor petrol road (g/GJ) 1990	-0.403
N_2O emission factor diesel Rail/navigation/Other (g/GJ) 1999	-0.257
N_2O emission factor LPG (g/GJ) 1990 / N_2O	0.213
CH_4 emission factor petrol road (g/GJ) 1999	0.203
Total Diesel consumption TJ 1999 / 1999	0.185
Total Diesel consumption in transport (TJ) 1990 / 1990	-0.175
Jet kerosene (TJ) 1990 / 1990	0.109
Total petrol consumption in transport(TJ) 1990 / 1990	-0.091

It is likely that these new insights - which could not be captured in our model – would change the assessments of the overall uncertainty in the emissions. Additional research, preferably based on the full emission model as used by Statistics Netherlands, will be required to assess the implications of the new insights for the uncertainties in the emissions and in the trend.

7. Other CO_2 emissions (1B2, 2, 3D, 6D)

7.1 Introduction

This short chapter is on CO_2 emissions from process other than from the combustion or chemical processing of fossil fuels. The NIR 2001 reports these emissions under the headings "Emissions from cement production", "Other industrial: CO_2" and "Misc. CO_2". The 1999 share of the emissions from these three sources in the total CO_2 emissions is 2.0%.

All these sources are mutually independent. We did not identify new information with respect to uncertainties. Because of these two circumstances the tier-2 uncertainty analysis did not give new results.

7.2 Reported emissions

Table 7.1 shows the emissions as reported in the CRF files associated with NIR 2001. The three bottom rows – in italics - show the summary data by the key sources as defined in the tier-1 uncertainty assessment in NIR 2001 (Olivier et al. 2001, p. 28).

Table 7.1 CO_2 emissions (ktonne) from industrial and other sources Reported in the NIR 2001 (CRF tables).

	1990	1999	Trend (%)
Cement production (2 A 1)		376.00	
Other mineral products (2A 7) (e.g. glass)	746.73*	699.36	
Carbide production (2 B 4)		2.29	
Other chemical production (2 B 5)		254.94	
Other metal production (2 C 5)	0.62	21.50	
Other production Food and Drink other (2 D 2/other)	209.51	124.02	
Other –Misc. (2 G Misc)	944.61	306.27	
Other waste (Total Waste 6 D. Other. Misc)	110.73	184.45	
Solvent and other use (3 D Misc)	0	10.86	
Oil refining/storage (1.B.2.a)	206.61	1299.75	
Natural gas production/processing (1.B.2.b I)	99	225.38	
Natural gas Transmission & distribution (1.B.2.b ii)	2.45	2.24	
Other fugitive emissions from oil and natural gas (1.B.2.d)	317.20		
Emission from cement production	300	376	25
Other industrial: CO_2 (2 A)	1601	1408	-12
Misc. CO_2	735	1722	134

* Of which 300 allocated to cement production in the NIR 2001.

The origin of most of these emissions is the use of limestone (CaCO3) in certain industrial processes (e.g. iron and steel, cement, glass manufacturing, flue gas desulphurisation, sugar) and the flaring and venting of fuel gases from installations for storage and handling of natural gas and oil products.

7.3 Data sources and emission model

For the recent emission estimates, information is provided by individual firms (Spakman et al 1997 (p. 50)). These relate to specific sources. Most firms disclose this information in the context of environmental reporting (mandatory under the Environmental Management Act of 1994) and in the context of covenants between associations of industries and the government. Emissions for 1990 were often estimated with generic emission factors by the PER agency. These emissions were later re-calculated on the basis of new information. The NIR 2001 (Olivier et. al., 2001) does not refer to details and literature with respect to these sources.

The information in the NIR 2001 was captured by the following simple emission model.

$$Emission_{1999} = Efact_{1990} \; Aindex \; Afactor_{1990-1999}$$

Where $Efact_{1990}$ = "Emission factor" for 1990
$Aindex$ = Activity index (=1 for base year)
$Afactor_{1990-1999}$ = Activity factor, which accounts for the change in activity between base year and 1999

The Emission factor is just 1990 emission divided by the 1990 index. The uncertainty in the Afactor is set at nil.

7.4 Uncertainties

Table 7.2 shows the assumptions about the uncertainty that were made for the earlier tier 1- uncertainty analysis in the NIR 2001.

Table 7.2 Assumptions on uncertainty (tier-1 approach).

	AD %	EF %	Emission(%)
Emission from cement production	5	10	11
Other industrial: CO_2	20	5	21
Misc. CO_2	20	50	54

Source: NIR 2001, p. 28.

We did not identify any additional information that would justify adopting other uncertainties[10]. So the uncertainties shown in Table 7.3 comply with the earlier estimated uncertainties.

[10] Although experts indicated that from the amounts of limestone that are used in some of these sources one can infer upper limits to emissions. This would lead to truncated probability distribution functions. Given the minor importance of the source and the lack of data about the use of limestone we did not elaborate this aspect.

Table 7.3 Uncertainties in the variables in the simplified model for CO_2 emissions from small CO_2 sources.

Variable	Mean	Type of pdf	Uncertainty (%)
1990 "Emission factor" from cement production (ktonne)	300	Normal	10
1990 Activity index	1	Normal	5
Activity factor cement 1990-1999	1.253333	Normal	0
1990 "Emission factor" Other industrial: CO_2 (ktonne)	1601.47	Normal	20
1990 Activity index - other industrial CO_2	1	Normal	5
Activity factor other industry -(CO_2) 1990-1999	0.8794295	Normal	0
1990 Misc. CO_2 "emission factor"	735.99	Normal	50
1990 Activity index - Misc. CO_2	1	Normal	20
Activity factor Misc. CO_2 (1990-1999)	2.340629	Normal	0

7.5 Results of tier-2 uncertainty analysis

Table 7.4 shows, as expected from Table 7.2, that uncertainty of the emissions in "Misc. CO_2" is the most important to composite uncertainty.

Table 7.4 Sensitivity of 1999 other CO_2 emissions. Sensitivity in Standard B coefficients.

Variable	Standard B coefficient
1999 Misc. CO_2	0.946
1999 Other industrial: CO_2	0.303
1999 Emission from cement production)	0.042

The 1990-1999 trend for the three source categories together is a 33% increase. The 95% confidence limits of this number are 30.5% and 35.4%. This calculation is under the assumption that none of the variables are mutually correlated i.e. uncertainty in the trend is only the result of uncertainty in activity data.

Table 7.1 shows, however, that in the energy sector major changes occurred between 1990 and 1999 with respect to CO_2 emissions (from flaring and handling of oil and natural gas). The background of these changes was not identified.

7.6 Conclusions

The source categories dealt with here contribute about 1.5% to all greenhouse gas emissions. The source of information about current emissions is the individual firms that report about emissions under either obligations from permits or by covenants with the national government. Formerly (1990) emissions were estimated with emissions factors (IPCC, 1996; SPIN, 1995). Table 7.2 suggests that the 1999 emissions are relatively well known, with exception of the emissions from "Misc. CO_2" (i.e. from storage and handling of fossil fuels).

Table 7.1 shows several changes in the format of the emission estimate (source categories), and also, with respect to "Misc. CO_2" major changes in emissions. The background of these changes was not identified. So, with respect to the trend assessment, the assumption that trend uncertainty is determined by uncertainty in activity only is questionable. Table 7.4 suggests that for reduction in uncertainty in the trend the source category "flaring and venting in the oil and gas industry" (i.e. refineries, oil trading and storage) would be the most important source to focus on.

Since no additional information on the uncertainties – these emissions are minor - was developed, the tier-2 uncertainty analysis added little to possible conclusions from the tier-1 uncertainty analysis.

7.7 Scope for uncertainty reduction

Since the source of information about these emissions is the individual firms one would turn to these firms and ask them either to provide a documented uncertainty analysis or to provide the information that allows others to assess reliabilities of emission information.

8. CH_4 emissions from enteric fermentation and manure management (4A)

8.1 Introduction

This chapter deals with methane emission from domestic livestock. Methane is produced by two processes: enteric fermentation and fermentation of manure. Fermentation is the process of organic carbon converting into carbon dioxide and methane, under anaerobic conditions (when no oxygen is present). Enteric fermentation occurs in ruminants (cattle) and pseudo-ruminants (e.g. horses). About 3% of all 1999 greenhouse gas emissions is from this source. Fermentation of manure occurs when manure is stored. The origin of the organic carbon in manure that is converted into methane is fodder for the animals. Methane from manure management accounts for about 1.5% of all greenhouse gas emissions in 1999. Usually, emission inventories treat the emissions from enteric fermentation and from manure management separately. Here, in the context of a tier-2 uncertainty analysis, they are dealt with in a single document since the emissions are correlated (by the number of animals).

Section 2 presents the emissions as reported in the NIR 2001 (Olivier et al., 2001) and background data. Section 3 summarises the emission models that were used to calculate the emissions. Uncertainties in variables and parameters of these emission models are dealt with in Section 4. Section 5 presents the results of the tier-2 calculations. Finally Section 6 discusses and concludes.

8.2 Reported emissions

CH_4 emissions from enteric fermentation in ruminants (and pseudo-ruminants) decreased from 401.9 ktonne CH_4 in 1990 to 331.8 ktonne in 1999 (Olivier et al., 2001, Table 7.15). This decrease is mainly due to a reduction in the number of cattle.

Table 5.1 in the NIR 2001 (Olivier et al., 2001) gives uncertainties for all these categories separately. From these one can calculate that the tier-1 uncertainty of methane emissions from enteric fermentation and manure management together is 20%.

8.3 Emission models

8.3.1 Enteric fermentation

Emission from enteric fermentation is calculated from numbers of animals and appropriate emission factors. Table 8.3 shows the (re)calculation. Note that the Netherlands livestock statistics have a structure and a level of detail that differs from the structure of the livestock statistics in common reporting format of the IPCC (See Table 8.1).

Table 8.1 Numbers of animals and methane emissions from enteric fermentation. Summary data reported in the CRF files (NIR 2001).

	Numbers of animals (Thousands)		Implied emission factors (kg/animal)		Emission (ktonne)	
Animal	1990	1999	1990	1999	1990	1999
Dairy Cattle	3606.7	2972.4	80.6	81.3	290.7	241.6
Non-Dairy Cattle	1319.3	1233.3	56.8	46.5	74.9	57.4
Sheep	1702.4	1400.7	8.0	8.0	13.6	11.2
Goats	60.8	152.8	8.2	8.0	0.5	1.2
Horses	69.6	115.2	18.7	0.0	1.3	0.0
Swine	13915	13566.8	1.5	1.5	20.9	20.4
Poultry	92764.1	104767	0.0	0.0	0.0	0.0
Total					401.9	331.8

Source: CRF Table 4 and Table 4A (NIR 2001, Olivier et al. 2001).

Emissions due to manure management decreased with about 10% (See Table 8.2).

Table 8.2 CH_4 emissions from manure management. Reported (NIR, 2001) emissions.

Source category	1990	1999
Cattle	42.73	36.48
1.Dairy Cattle	25.48	20.84
2 Non-Dairy Cattle	17.25	15.64
3.Sheep	0.76	0.69
4.Goats	0.00	0.33
6.Horses	0.00	0.00
8.Swine	49.21	44.04
9.Poultry	10.27	9.51
Total	102.98	91.05

Source: CRF Table 4 1 (NIR 2001, Olivier et al. 2001).

The emission factors – See Table 8.3- have been developed in the beginning of the nineties (OECD, 1991; Amstel, van , et al., 1993; Spakman et al. 1997; IPCC, 2000). These factors are calculated from the following series of input variables:

- Weight of animal (kg);
- Daily weight gain in kg (relevant young cattle);
- Milk production in kg per day (dairy cattle only);
- Activity factor (1 or 1.17) (An animal in a stable needs lees food then when in a pasture);
- Number of hours work (hr/day) (not relevant for the Netherlands);
- Energy content of feed (MJ/kg);
- DMD - Dry matter digestibility (what part of an animal's food (and potential methane) can be digested, and possibly turned into methane).

Van Amstel et al. (1993) give some details about the calculation of the emission factors, but not sufficient to be able to recalculate emission factors. These emission factors were established once and used for all years.

Table 8.3 The calculation of CH_4 emission values for different ruminants in 1990 and 1999 in the Netherlands.

Category of animal	Number of animals (thousands)	Number of animals* (thousands)	Emission by head (kg CH_4 per head)	Emission (ktonne CH_4)	Emission (ktonne CH_4)
	1990	1999		1990	1999
Dairy cattle					
Cattle dairy (< 1)	806	635	49.25	39.70	31.27
Heifers	880	633	62.8	55.26	39.75
Dairy cow	1878	1694	102.13	191.80	173.01
Steers (>yr)	43	10	93.22	4.01	0.93
Meat cattle				0.00	
Meat cattle <1y	602	753	17.65	10.63	13.29
Meat cattle >1y	598	327	87.01	52.03	28.45
Meat Adult >2y	120	152	102.13	12.26	15.52
Other livestock					
Sheep	1702	1401	8	13.62	11.21
Goats	60.8	153	8	0.49	1.22
Horses	69.6	115	18	1.25	2.07
Swine	13915	13567	1.5	20.87	20.35
Poultry	95452	108973	0.09	8.59	9.81
				410	347

c* Source: CBS Statline October 2001.

The source of the information of the number of animals is livestock (*Veestapel*) data of Statistics Netherlands.

8.3.2 Manure management

Manure that is stored under anaerobic conditions produces methane due to fermentation. Anaerobic conditions occur when manure is (temporarily) stored in tanks or storage room under stables/feedlots. The explanatory variable (the activity) for calculating the emission is the amount of manure that is produced – not the number of animals – and which is temporarily stored in tanks or other storage equipment. Spakman et al. (1997) give an example for the calculation of the emissions in 1994 (See Table 8.4).

Table 8.4 Calculation of emissions from manure management for the year 1994.

	Emission factor	Manure (Slurry) production	Methane emission
	(kg CH_4 per m3 of manure)	(million m3)	Ktonne
Dairy cows	0.698	33.09	23.1
Meat cattle	2.534	4.78	12.1
Sheep and goats	2.979	0.27	0.8
Meat cattle (young)	2.534	2.41	6.1
Swine	3.009	16.38	49.3
Poultry	4.110	2.24	9.2
Total		59.2	100,6

These emission factors were derived from the estimates of emissions per animal as calculated (IPCC Section 4.3.1.2, p. 4.34, IPCC, 2000) from:

$$Ef_i = VS_i * 365 * B_{0,i} * 0.67 * \sum_{j,k} MCF_{j,k} * MS_{i,j,k}$$

Where:

- Ef_i = annual emission factor for a defined livestock population *i* , (in kg per tonne manure);
- VS_i = Daily volatile solids (VS) excreted for an animal within defined livestock population *i,* in kg.;
- 365 number of days;
- Bo: maximum methane producing capacity for manure produced by an animal *i* (m3/kg of VS);
- 0.66 kg/m3 density of methane;
- MCF: methane conversion factors for a specific manure management system *j* in a certain climate region *k*.

A specific management system may refer to the timespan that the slurry is kept stored. For instance, for the management of manure from swine, the assumption (in Van Amstel et al, 1993, p.57) is that the slurry is stored outside the stable for more than 1 month. Cattle manure produced in pastures is assumed not to produce methane emissions.

Table 8.5 presents the parameters that were developed for the Netherlands in the early nineties. The last column shows the emission factors that are calculated from these parameters. From these figures and considering that the density of methane is 0.66 kg/m3 one calculates the emission factors shown in Table 8.4.

Tabel 8.5 Parameters used for emission factors for estimating emissions from manure management as published in the early nineties. And emission factors.

1999	VS (Volatile Solid content) (kg)	Bo Methane emission potential (m3/kg)	MCF methane conversion factor	Emission factor (kg/tonne manure)
Cattle –stable	0.124	0.17	0.05	0.697748
Cattle pasture	0.116	0.24	0	0
Fattening steers	0.116	0.33	0.1	2.534136
Fattening calves	0.116	0.33	0.1	2.534136
Sheeps & goats	0.25	0.18	0.1	2.979
Swine	0.101	0.45	0.1	3.00879
Of which breeding pigs	0.101	0.45	0.1	3.00879
Poultry dry	0.194	0.32	0.1	4.109696
Poultry slurry	0.194	0.32	0.1	4.109696

Source.: Van Amstel et al., 1993 (p. 56)

Emissions follow from these emission factors and statistics of manure production. Table 8.6 shows our recalculation of the emissions based on manure production data of Statistics Netherlands (*Transport en gebruik van mest en mineralen 1994-1999*/Statline) and the emission factors discussed above. Our results are slightly different from the reported

data (see Table 8.2). The origin of the difference is not clear. Perhaps, the statistics of manure production were not consolidated.

Table 8.6 Calculation of emissions from manure management for the year 1999 with reported information.

	Emission factor	Manure (Slurry) production	Methane emission
	(kg/tonne)	(millioMtonne)	Ktonne
Dairy cows	0.698	31.29	21.84
Meat cattle	2.534	1.64	4.17
Sheep and goats	2.979	0.34	1.02
Meat cattle (young)	2.534	2.81	7.13
Swine	3.009	14.66	44.11
Poultry	4.110	2.07	8.51
Total		59.2	86.77

In the current NIR (Olivier et al., 2001) the emissions for 1990 are different from the early estimates (Van Amstel et al., 1993). New data on manure production may explain these differences. We did not find data on manure production in 1990 that are comparable/compatible to the recent statistical data.

8.4 Uncertainties

8.4.1 Enteric fermentation

Table 8.7 selected uncertainties in the variables of the emission model that is used in the assessment of the emissions from enteric fermentation. These uncertainties are the same as assumed in the Tier 1 uncertainty analysis by Olivier et al. (2001).

8.4.2 Manure management

Manure production is clearly correlated with number of animals, so emission of manure management correlated with emissions from manure management. In order to be able to take account of this correlation we rearranged the model for emissions from manure management. Instead of relating the emissions to manure production they were related to the number of animals, by defining a parameter “manure per animal”; the emission models for enteric fermentation and for manure production were linked. Such correlation is not accounted for in the tier-1 uncertainty assessment in the NIR 2001 (Olivier et al., 2001).

Manure per animal follows from manure production (in the NIR emission model for manure management) and numbers of animals (in the NIR model for enteric fermentation emissions). This factor is assigned to an uncertainty, to account for the uncertainty that is in the measurements of manure production by Netherlands Statistics (or those institutions that perform the actual surveys).

Table 8.7 Assumed uncertainties in variable of the emission model for methane emissions from enteric fermentation.

Category of animal	Uncertainty in emission factor	Uncertainty in numbers 1990	Uncertainty in numbers 1999
Cattle dairy (< 1)	Normal, 20%	Normal, 5%	Normal, 20%
Heifers	Normal, 20%	Normal, 5%	Normal, 20%
Dairy cow	Normal, 20%	Normal, 5%	Normal, 20%
Steers (>yr)	Normal, 20%	Normal, 5%	Normal, 20%
Meat cattle <1y	Normal, 20%	Normal, 5%	Normal, 20%
Meat cattle >1y	Normal, 20%	Normal, 5%	Normal, 20%
Meat Adult >2y	Normal, 20%	Normal, 5%	Normal, 20%
Sheep	Normal, 30%	Normal, 5%	Normal, 30%
Goats	Normal, 30%	Normal, 5%	Normal, 30%
Horses	Normal, 30%	Normal, 5%	Normal, 30%
Swine	Normal, 50%	Normal, 5%	Normal, 50%
Poultry	Normal, 30%	Normal, 5%	Normal, 30%

Note: "normal" refers to the assumption that the probability is normally distributed.

Of the three factors that together make up the emission factor (emission per amount of manure), MCF (Methane Conversion Factor) is the most uncertain. The factor captures for instance assumptions on temperature (temperature is important to the rate of methane production) on technology of manure systems (e.g., sometimes methane (biogas) is collected and used) and on the actual management (e.g. whether a tank is directly cleaned after its use). The microbiology of methane formation itself is relatively well known. Most of the uncertainty is created by the assumptions about 'average' manure management.

Our initial assumption is that the probability distribution function has a lognormal character. This reflects the likely 'non-linear' impact of differences in manure management (e.g. temperature, tank cleaning frequencies) on methane production. Figure 8.1 gives, as an example, the probability density distribution for the emission factor from manure from swine.

Table 8.8 lists the assumptions that were made in the calculation of the overall uncertainty. The values of the parameter "manure per animal" were calculated from the information from Netherlands Statistics (for 1999. Data for the year 1990 estimated). The uncertainties of the Table can be compared with the Tier 1 uncertainties obtained by Olivier et al. (2001). They assumed a 100% uncertainty for the emission factors and 10% uncertainty for the activity data. Their emission factor corresponds with the "emission factor per tonne manure" times "manure per animal".

Table 8.8 Assumptions in variables in the emission model for manure management (1990 and 1999).

Parameter	Type of pdf	Uncertainty (%)
Emission factor per tonne manure (swine)	LogNormal	100
Number animals (swine) 1999	Normal	5
Manure per animal (swine) 1999	Normal	10
Ef per tonne manure (dairy cattle)	LogNormal	100
Number animals (dairy cattle) 1999	Normal	5
Manure per animal (dairy cattle) 1999	Normal	10
Ef per tonne manure (non-dairy cattle)	LogNormal	100
Number animals (non-dairy cattle) 1999	Normal	5
Manure per animal (non-dairy cattle) 1999	Normal	10
Composite Ef per tonne manure (sheep)	LogNormal	100
Number animals (sheep)	Normal	5
Manure per animal (sheep)	Normal	10
Composite Ef per tonne manure (poultry)	LogNormal	100
Number of poultry 1999	Normal	5
Manure per animal (poultry 1999)	Normal	10

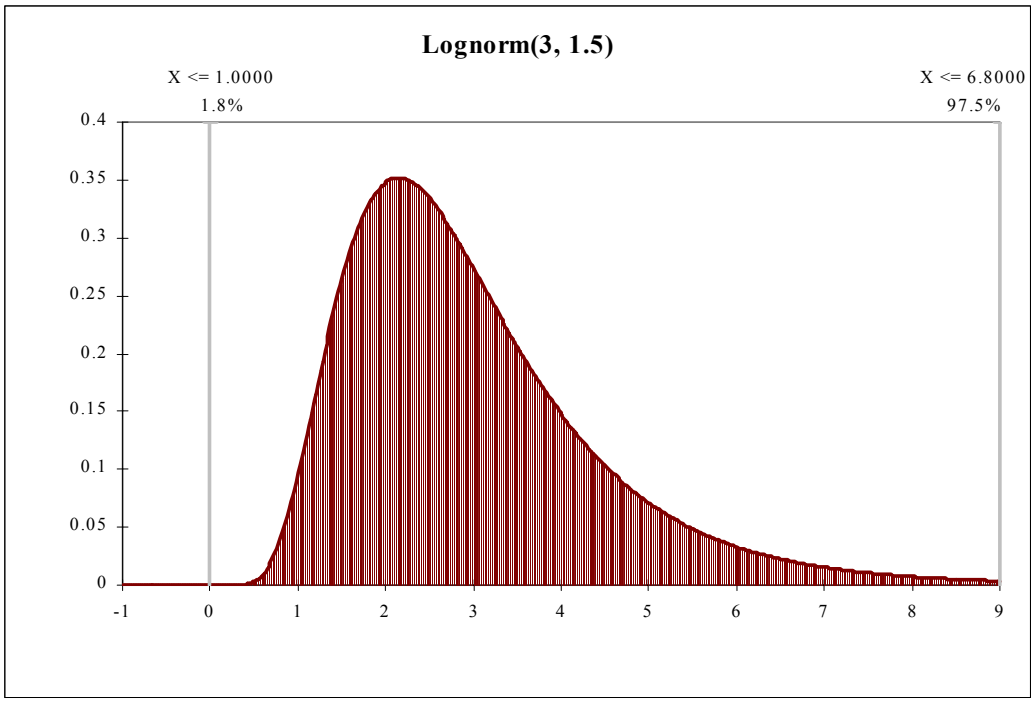

Figure 8.1 Lognormal distribution CH_4 emission for manure from swine. Mean = 3.00, Standard deviation is 1.5.

8.5 Results

8.5.1 Introduction

The sections below present the results for the analysis of enteric fermentation and manure management separately. The last section presents the result of an analysis of methane emission from "agriculture" as a whole.

8.5.2 1999 Emission from enteric fermentation

Figure 8.2 shows that the 95% range of confidence for the methane emissions from enteric fermentation is 310-386 ktonne methane. The mean is 384 ktonne[11]. The assumed uncertainty in the emission factor for dairy cows contributes most to this range of confidence (See Table 8.9).

8.5.3 1999 Emission from manure management

1999 methane emission from manure management ranges between 52 and 153 ktonne CH_4 (95% confidence), with a mean of 90.8 ktonne (To save space we don't present the graph of the density function). The uncertainty in the emission factor per swine is the most important factor to overall uncertainty, as shown by Table 8.10.

8.5.4 Enteric fermentation. 1990-1999 trend

Figure 8.3 shows the results of the Tier 2 analysis of the trend in the emissions from enteric fermentation of all different livestock based on the uncertainties given in Table 8.7. The mean of the trend is a 15% decrease of the emissions between 1990 and 1999. The reduction pf this emission is mainly due to a decrease in the number of dairy cows.

The uncertainties that most influence the uncertainty in the trend are uncertainties in the numbers of dairy cows in 1999 and in 1990 (See Table 6.10). Note that the emission factors are assumed not to change over the years.

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[11] This is higher that reported in the CRF files, since the our number includes methane emissions from poultry.

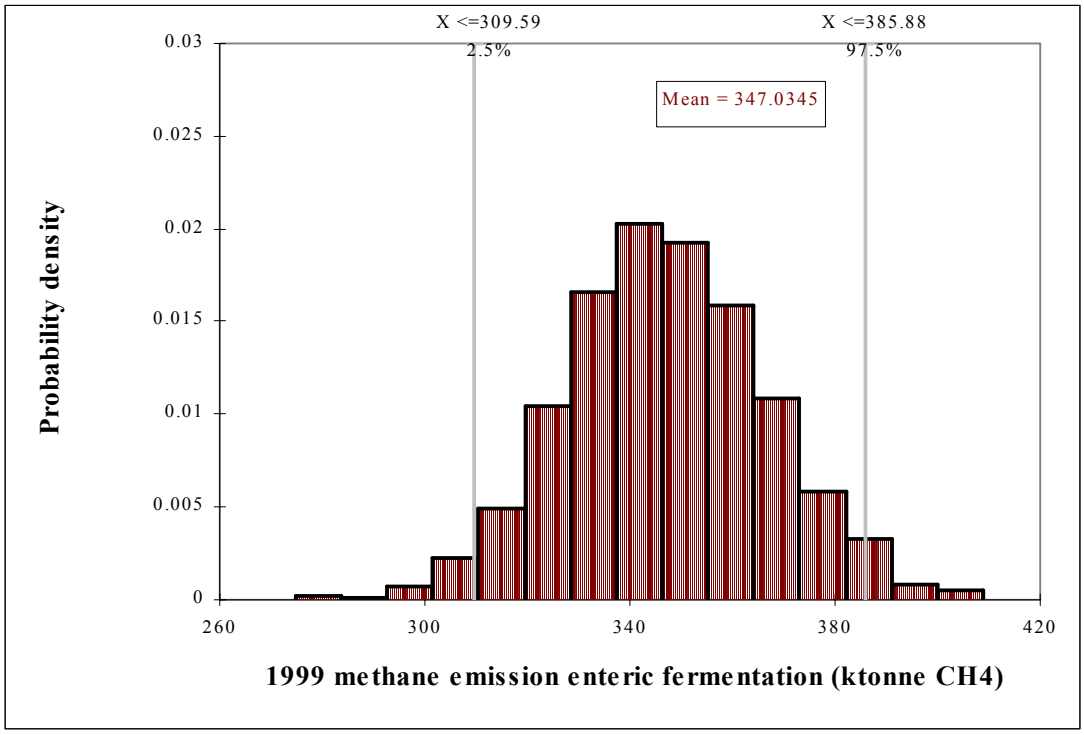

Figure 8.2 Probability density function for 1999 methane emissions from enteric fermentation.

Table 8.9 Main sensitivities of 1999 CH_4 emission from enteric fermentation to model variables and parameters.

Variable	Standard B coefficient
EF Dairy cow / Emission factor (kg/head/year)	0.877
EF Swine / Emission factor (kg/head/year)	0.262
Dairy cow (numbers 1999)	0.219
EF Heifers / Emission factor (kg/head/year)	0.202
EF Cattle dairy (< 1) / Emission factor (kg/head/year)	0.157

Table 8.10 Main sensitivities of 1999 CH_4 emission from manure management to model variables and parameters.

Variable	Standard B coefficient
Emission factor per tonne manure (swine) / Emiss factor	0.846
Ef per tonne manure (dairy cattle) / Emiss factor	0.389
Ef per tonne manure (non-dairy cattle) / Emiss factor	0.305
Composite Ef per tonne manure (poultry) / Emiss factor	0.19
Manure per animal (swine) 1999 / Emiss factor	0.103

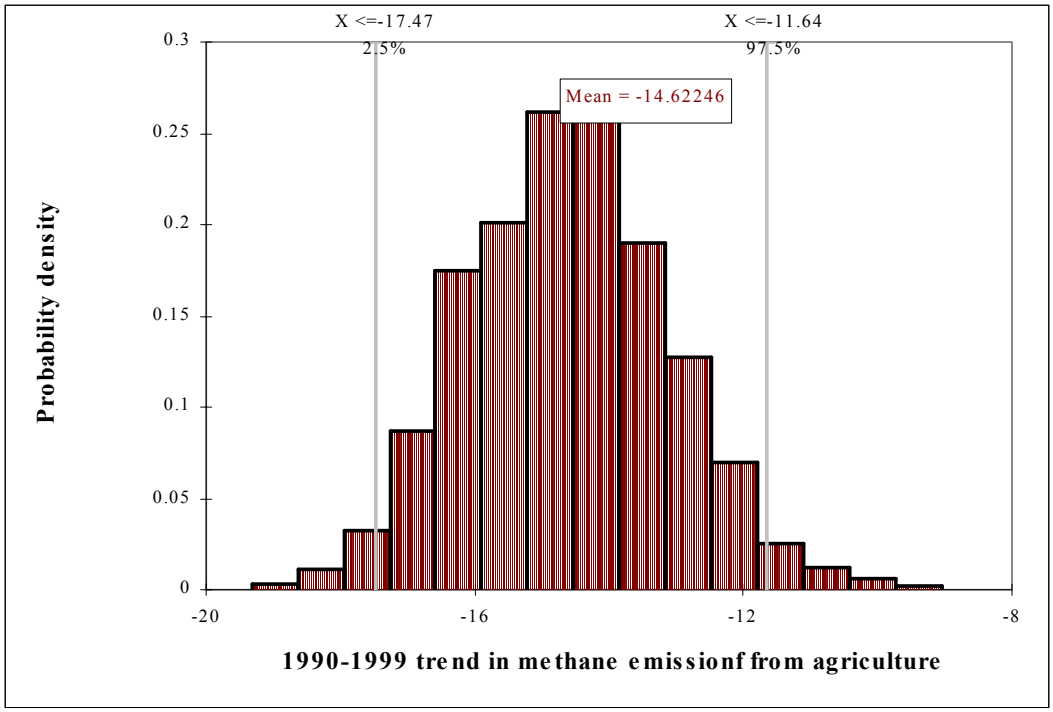

Figure 8.3 Uncertainty (pdf) in the decrease (%) of methane emissions in the period 1990-1999.

Table 8.13 shows, not surprisingly, that the number of dairy cows and the associated emission factors are most important to the trend.

Table 8.11 Sensitivity of 1990-1999 trend (%) to variables in enteric fermentation emission model.

Variable	Standard B coefficient
Dairy cow (numbers)	0.646
Dairy cow / Emission factor (kg/head/year)	-0.619
EF Meat cattle >1y / Emission factor (kg/head/year)	-0.232
Heifers / Emission factor (kg/head/year)	-0.178
EF Dairy cow / Emission factor (kg/head/year)	0.163
Heifers (numbers)	0.147
Cattle dairy (< 1) / Emission factor (kg/head/year)	-0.124
Cattle dairy (< 1) (numbers)	0.115
EF Heifers / Emission factor (kg/head/year)	-0.106
EF Swine / Emission factor (kg/head/year)	0.105

8.5.5 1990-1999 Trend in CH_4 emission from manure management

Table 8.8 suggests that for the calculation of the annual emissions the main uncertainties are in the emission factors. The Tier 2 calculations, see Table 8.9 and Table 8.10, confirm this observation.

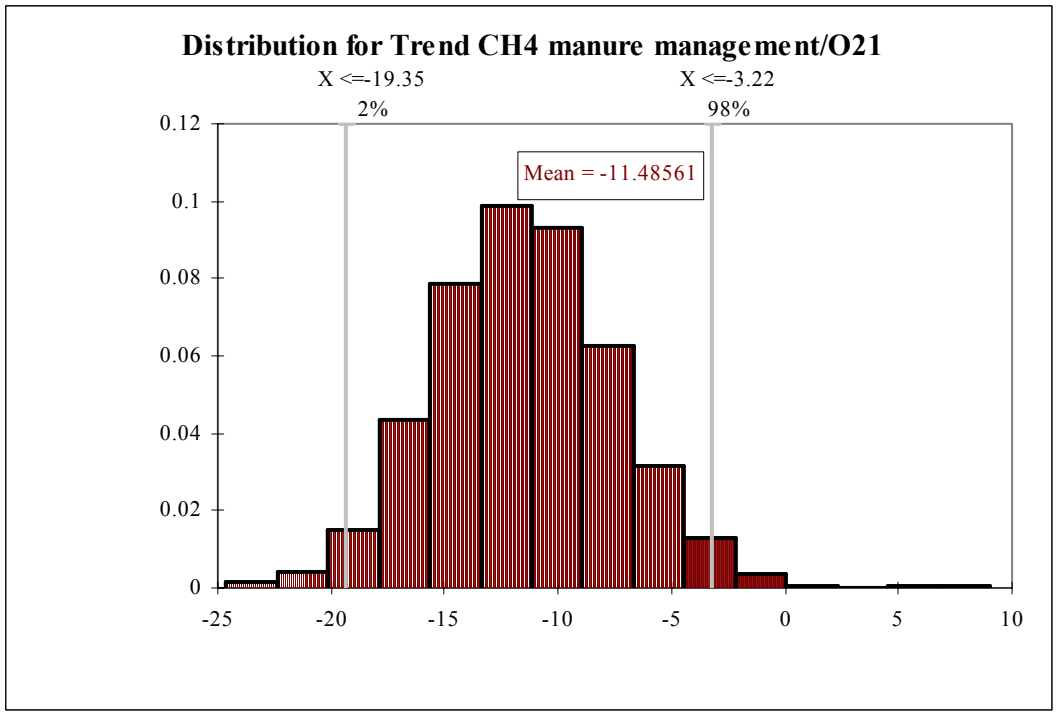

Figure 8.4 Uncertainty (pdf) in the decrease (%) of methane emissions from manure management.

Somewhat less obvious is the assessment of the variables to which the trend (-11.5%, See Figure 8.4) is most sensitive. Table 8.12 shows that the uncertainties in manure production from swine in 1990 respectively 1999 are the most important factors behind the uncertainty in the 1990-1999 trend. Note that we assumed that errors in the amounts of manure per animal for 1990 respectively 1999 are not correlated.

Table 8.12 Sensitivity of 1990-1999 trend (%) to variables in methane emissions from manure management.

Variable	Standard B coefficient
Manure per animal (swine) 1999 / Emiss factor	0.59
Manure per animal (swine) 1990 / Emiss factor	-0.576
Number animals (swine) 1999 / Emiss factor	0.343
Number animals (swine) 1990 / Emiss factor	-0.335
Manure per animal (dairy cattle) 1990 / Emiss factor	-0.319
Manure per animal (dairy cattle) 1999 / Emiss factor	0.316
Manure per animal (non-dairy cattle) 1990 / Emiss factor	-0.236
Ef per tonne manure (dairy cattle) / Emiss factor	-0.233
Manure per animal (non-dairy cattle) 1999 / Emiss factor	0.227
R-Squared=	0.789158

8.5.6 1990-1999 Trend in all CH_4 emission from agriculture

The trend is that methane emission from agriculture decreased with 14.6% in the period 1990 – 1999. The range of 95% confidence in this value is –17.5% to –11.6%.

What uncertainties contribute most to the overall uncertainty in the trend? Table shows the result of the regression analysis that gives an answer to this question. The table shows only those variables and parameters that figure in the top of the ranked list. On this list the number of dairy cows – of which the uncertainty was put at 5% - ranks on top. The numbers of swine rank also in the top. Manure per swine – the parameter that 'links' emissions from enteric fermentation with emissions from manure management – ranks second. One may interpret this uncertainty as the composite uncertainty in the numbers of animals and manure production. This conclusion needs possibly reconsideration. Surprisingly, the large uncertainties in the emission factors seem to be less important to the overall uncertainty than the numbers. Note, however, that the assumption is that the nature of the uncertainty in the emission factor did not change over the years, in other words the uncertainties in the emission factors for 1990 and 1999 are considered to be fully correlated.

Table 8.13 Sensitivity of 1990-1999 trend (%) to variables in the model for methane emission from agriculture (enteric fermentation and manure management).

Variable	Standard B coefficient
Dairy cow (number, 1990)	0.557
Dairy cow (number, 1999)	-0.498
Manure per animal (swine) 1999	0.33
Manure per animal (swine) 1990	-0.306
Number animals (swine) 1999	0.231
Number animals (swine) 1990	-0.222
Ent. Ferm. Meat cattle >1y / Emission factor (kg/head/year)	-0.197
Manure per animal (dairy cattle) 1999	0.155
Manure per animal (dairy cattle) 1990	-0.154
Ent. Ferm. Heifers / Emission factor (kg/head/year)	-0.141
Emission factor per tonne manure (swine) / Emiss factor	0.125
Ent. Ferm. Dairy cow / Emission factor (kg/head/year)	0.121
R-Squared=	0.925477

It should be noted that the present analysis does not take account of a series of developments in agriculture that influence emission factors. For instance dairy cows in 1999 are different from dairy cows in 1990, with respect to weight, milk production of composition of feed. These changes are not taken into account in the current methodology to calculate emissions from enteric fermentation. With respect to emissions from manure management, we also did not take account of changes in the practice of manure management (for management of manure other than from swine). This is because of lack of information about the actual emission factors (for 1990 and 1999) and the underlying assumptions.

8.5.7 Correlation

There is a correlation between CH_4 and N_2O emissions (Chapter 11) from manure management, since the numbers of animals is correlates with manure production, which is the emission explanatory factor in that source category.

8.6 Conclusion and discussion

Methane emissions from enteric fermentation and from manure management for 1999 add up to 438 ktonne methane, with a range of 95% confidence between 382 ktonne and 509 ktonne. This uncertainty is mainly the result of the uncertainties in the various emission factors; information with respect to the numbers of animals is relatively well known. The exception is the number of dairy cows, which is among the 10 variables that contribute most to the broad range of confidence in the 1999 emission (from a sensitivity analysis of which the result is not shown here).

The range of 95% confidence for the 1990-1999 trend (%) is –17.5% to – 11.6%. Table shows that, in contrast with the uncertainty in the emission, also the uncertainties in numbers of animals are important.

The emission models that are used are simple mass balance models. For enteric fermentation there exist more elaborate models (IPCC, 2000; Van Amstel, 1994). According to Van Amstel at al. (1994) these models had been used to calculate the CH_4 emission factors for enteric fermentation. We attempted to use these underlying models for the uncertainty analysis. However, we were unable to identify all the required input information that was used at that time. Similarly, we were not able to completely reconstruct the model for estimating the CH_4 emissions from manure management.

8.7 Scope for uncertainty reduction

The "CH_4 from enteric fermentation" emission model that is applied for the NIR 2001 is a simple model derived from the more elaborate model described by the IPCC in its guidelines for emission inventorying. This simple model was established in the beginning of the nineties. Since then the situation in particularly dairy farming changed. In this context the question was raised whether the model that is applied requires revision. Within NOVEM's ROB-Agro programme there is currently a discussion about the feasibility of updating the model or even the feasibility of applying an elaborate model for the NIRs to come. It could be the model as suggested by the IPCC (2000), or it could be a model based on information specific to the situation in the Netherlands (Veen, 2000).

Since the estimation of 1990 emission is important for reliable trend assessment, the availability of time series of the required information for these emission models is an important issue to address in the developments of these updated emission models.

The tier-2 uncertainty analysis proper does not add to this discussion of the adequacy of models. Once, improved model are available, and assessment of uncertainties in parameters and variables, the tier-2 uncertainty analysis can be applied. With respect to the annual emission it is not quite possible to say whether the outcome of such analysis will reduce uncertainty.

With respect the trend, however, improved models might only give slightly improved reliabilities since the number of animals is the most important variable for the assessment of the trend (see table). Confirmation of this tentative conclusion, however, requires the availability of a detailed emission model.

9. CH_4 emissions from solid waste disposal sites (6A)

9.1 Introduction

This chapter is on methane emissions of solid waste disposal sites. The source of this methane is organic carbon in waste. Through fermentation processes this carbon is partly converted into methane. In 1999 methane emissions were about 4% of total greenhouse gas emissions. Initial uncertainty assessments (NIR 2001, Olivier et al. 2001) indicated that this source category ranked third in the list of source categories ordered by their contribution to uncertainty in national emission.

This chapter is structured as follows. The next section presents reported data. Section 3 describes the emission model. Then, in Section 4, the uncertainties are discussed and uncertainties are proposes. Section 5 presents the results of the calculation of uncertainty in the 1999 emission and in the 1990-1999 trend in emission. Section 6 and Section 7 discuss.

9.2 Reported emissions

Table 9.1 shows the reported emissions for "Managed Waste Disposal on Land".

Table 9.1 CH_4 emissions from "Managed Waste Disposal on Land" as reported in the NIR 2001.

1990	1999	Unit
562	428	Ktonne (Gg) CH_4
11804	8994	Ktonne CO_2 eq

Source: Table 6.A,C of CRF-nld-2001-99.xls and CRF-nld-2001-90.xls (NIR 2001, Olivier et al. 2001).

There seems to be a small error[12] in the emission model that is used to calculate these emissions (See next section). Recalculation leads to the data in Table 9.2.

Table 9.2 Recalculated CH_4 emissions.

1990	1999	Unit
571	408	Ktonne (Gg) CH_4

CH_4 emissions from solid waste disposal sites decreased from 1990 to 1999 because of:

- A decrease in the volume of waste that is landfilled;

[12] The rate constant for the formation of methane depends on the carbon content of the waste. Since the carbon content changes in the period 1990 – 1995 (the advent of separate collection of green waste) the rate constant changes accordingly for that waste of that year. So to each vintage of waste there is a single rate constant. In the model that is used for NIR, however, all rate constants change after 1990. So, for waste from say 1980, the associate rate constant changes by 1990. It should not. Table 9.1 and Table 9.2 show the effect of this error.

- An increase in the recovery of methane waste gas;
- A decrease in the content of organic carbon in waste (due to the increase of recycling of organic household waste).

The amount of municipal solid waste (MSW) that is landfilled was 13,900 Gg in 1990 and in 1999 5,000 Gg. The corresponding figures for methane (biogas) recovery from landfills are 27.30 Gg methane and 76.03 Gg methane respectively.

9.3 Emission model

Waste disposal sites produce methane (biogas), which is formed by fermentation processes that convert 'organic carbon' in waste into methane (Coops *et al*., 1995; Hoeks, 1983). The biochemistry of biogas formation is well known, under laboratory conditions. For the calculation, however, of methane formation from actual sites one needs a range of different types information on the precise structure of the site and on the chemical composition of the waste, since factors such as transport of methane (and air/oxygen) in the landfill are important to the eventual methane emission as well. Much of this information is not available; therefore, one needs many assumptions.

Emission of CH_4 from waste disposal sites is calculated with a vintage model (Spakman et al., 1997; Van Amstel et al., 1993; Scharff et al., 2000). The key assumption is that emissions arise from single waste disposal site in the Netherlands where land filling started in 1945. So once disposed off waste contributes each year to the total methane production (but, as shown below, each year less). The model is shown below.

$$E(T) = (1-\delta) * \left[\left(\beta * \chi * \varepsilon * \sum_{t=t_0}^{t=T-1} W(t) * \alpha_t * k_t * e^{-k_t * (T-t)} \right) - \left(\chi * \lambda * R(T) \right) \right].$$

Where

$E(T)$ = CH4 emission (ktonne) in the present year T.

$W(t)$ =Amount of solid waste disposal (ktonne) in year t.

$R(T)$ = Recovery of landfill gas (ktonne) in the present year T.

t_0 = The starting year of waste disposal at solid waste disposal sites (1945).

α_t = Fraction of biodegradable carbon in waste
(0.132 and 0.12 C per tonne waste before 1990 and after 1999 respectively).

β = Fraction of organic C actually reacting to gaseous material (0.58).

χ = Fraction of gaseous material being methane (0.60) (the rest is mainly CO2).

δ = Fraction of methane that is oxidised within the disposal tip (in top layer) (0.10).

ε = Conversion factor for mass C to mass CH4 (16/12).

λ = Conversion factor for volume C to mass CH4 (16/22.4).

k = Rate constant k = 0.094 before 1990,
decreasing to k = 0.0693 in 1995 and constant after 1995
because of a decrease in the share of biodegradable waste.

The model takes explicitly account of the following characteristics of the biogas formation and variables:

- Waste (that contains organic carbon) that is disposed of will produce methane in all years after its disposal. The production decreases by the year following an first order process;

- A part of the methane that is produced within the tip is, on its way out of the tip, oxidized to CO_2 in the (aerobic) top layer of the site;
- The organic carbon content of solid waste;
- The rate constant of biogas formation;
- The content of methane in the biogas (about 60%);
- The recovery of biogas.

There are three parameters that are constant over the years:

- The fraction of organic carbon that converts into biogas;
- The fraction of carbon in biogas that is present as methane;
- The fraction of methane in biogas that is oxidised into CO_2 (in the top layer of the waste tip):

Since 1990, the fraction of degradable carbon and the rate constant (which depends on this fraction) decrease, due to the separate collection of 'green' waste. The model assumes that the values of these parameters (k and α_t) decrease with fixed factors (of which the uncertainty is set at 0%.). Through this analytical form one avoids co-variance in the time series for both variables (See below).

It is interesting to identify what each vintage of waste (what waste from what year) contributes most to the emissions. Figure 9.1 shows this information. This figure plots methane emission in 1990 respectively in 1999, by year of disposal. The curve for 1990 shows that most important to total emissions is the waste that is disposed off the preceding year. For the emission in 1999, it is the waste from 1991 that contributes most. After 1990, the amount of waste that is landfilled tapers of, while, in addition, the organic carbon content decreases. The net effect of these developments is a sharp decrease of the contribution of recent waste landfill to total emissions. The figure also shows that waste that is landfilled before 1970 is hardly relevant to total emissions, according to the model. In 1999 the contribution of early (< 1970) landfill to the total 1999 emission is 3% and in 1990 this contribution is 5.5%.

9.4 Uncertainties

9.4.1 Probability density distributions

So the model for calculating CH_4 emissions from waste disposal sites includes several variables with different uncertainties. For the tier-2 uncertainty analysis these uncertainties have to be quantified. Table 9.3 shows the initial assessments. The figures are partly based on the results of the interviews (Van Asselt et al, 2002).

Most notable is the assumption on the fraction of methane that is oxidized in the top layer of a waste tip. The assumed probability density function is uniform. It says that the amount of oxidized methane is somewhere between zero and 0.2. The mean is, per definition, 0.1, which is the number used in the NIR calculations.

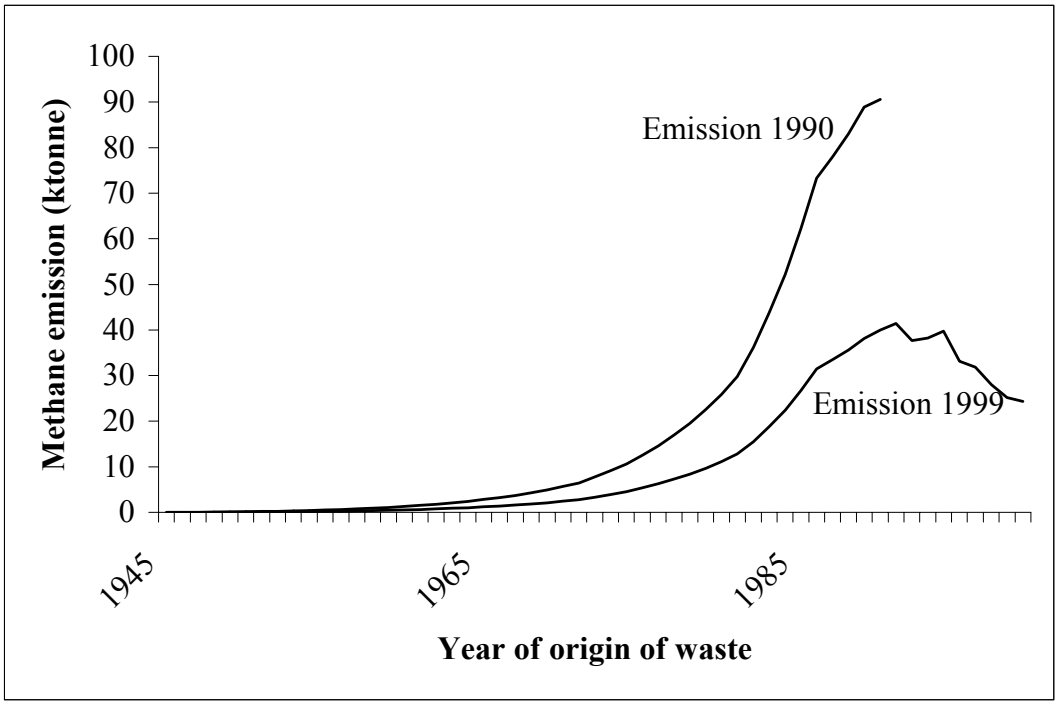

Figure 9.1 Methane emissions in 1990 respectively 1999 by year of origin of waste disposed off in landfills.

This value was proposed by Coops et al. (1995). Coops *et al*. (1995) mention that estimates of this oxidation factor have varied from 10 to 50%. The high uncertainty with respect to this factor was confirmed in the series of expert interviews (Van Asselt et al., 2002).

Eventually, uncertainties were established in such way that the eventual uncertainty in the emission would be of similar magnitude as the earlier estimate of the uncertainty.

We assumed that the uncertainty in the amounts of waste that is landfilled is constant over the years. Van Amstel et al. (2000) (p. 136) state that the uncertainties in the amounts of waste disposed off in recent years have become less.

Likely, the uncertainty in amounts of waste landfilled before say 1980 is higher than 10%. Figure 9.1 and also the results of calculations, indicate that the reliability in the numbers for amounts of waste are less important to the final result. For practical reasons, we assumed this uncertainty to be constant over the years.

Table 9.3 Probability distributions for variables in the model for methane emissions from waste disposal.

Variable	Mean	Pdf	Uncer-tainty (%)
Fraction of organic carbon reacting to gaseous material	0.58	Normal	20
Organic C content of waste which is landfilled (kg/tonne) <1991	132	Normal	20
Uncertainty in amounts (tonnes) of annually disposed waste	10	Normal	10
Fraction of carbon reacting to methane (instead of to CO_2)	0.6	Normal	10
Fraction of methane oxidised in top layer	0.1	Min 0	Max 0.2
Rate constant <1990	0.094	Normal	10
Rate of annual decrease of rate constant 1990-1995	0.737234	Normal	0
1990 Recovered landfill gas (Million m3)	63.7	Normal	5
1999 Recovered landfill gas (million m3)	177.4	Normal	5

9.4.2 Dependencies and correlations

The emission in the year T is the result of emissions due to solid waste disposed off in previous years. In the uncertainty analysis the question is then raised to what extend the (time series) variables are mutually independent. We made the following assumptions.

The first assumption is that the fraction of organic carbon that is degradable (58%) is not time dependent.

The organic carbon content of waste decreases in the period 1990 – 1999. See Table 9.4. In the model we defined the organic carbon content for the years after 1990 as a fraction of a (time independent) carbon content. The uncertainty was assigned to the latter. This way co-variance between the carbon content in the different years was avoided. This is important for the calculation of trend in the emission (percentage emission change between 1990 and 1999).

Table 9.4 The decrease in carbon content of waste, which is landfilled.

Year	Organic carbon content	Year	Organic carbon content
1989	132	1995	128.2
1990	130.83	1996	127.5
1991	129.67	1997	126.2
1992	128.5	1998	124
1993	128.4	1999	120
1994	128.3	2000	110

The numbers of the annual amounts of waste that is landfilled are considered mutually independent, under the assumption that there is no systematic bias in these data. This information is developed from surveys among waste treatment firms by Afvalzorg BV and

its predecessor (*Stichting Verwijdering Afvalstoffen,* SVA). We also assumed that the time series values for the amounts of biogas that is combusted are not correlated.

The fraction of methane in the tip gas (*stortgas*) (60%) and the fraction of methane oxidized in the top layer are both assumed to be invariable over time (See for a discussion Coops et al., 1995).

There is a correlation with data beyond the "methane emissions from waste disposal". The error in the amount of CH_4 that is recovered from the biogas (and combusted) correlated with the error in CO_2 emissions from this combustion. However, this is assumed to be of minor importance to the overall uncertainty analysis of greenhouse gas emissions since this CO_2 emission is minute.

9.5 Results

9.5.1 Emissions and sensitivities

Figure 9.2 shows the histogram of the results of the Monte-Carlo analysis while using the uncertainties indicated in Table 9.3. The confidence limits for the emissions are 316 – 510 ktonne, while the mean is 408 ktonne.

We made a few alternative calculations that differ in the assumption for the oxidation factor, since it appears that this factor is the most uncertain. The results of these calculations are shown in Table 9.5. These results include the central estimate of the emission and the sensitivity of each outcome to the uncertainty in the input parameters expressed in standard B coefficients (See Chapter 2). Sensitivities to the error in the amounts of waste disposed of are not shown. They are an order of magnitude smaller than the coefficients shown in the table. So the first column refers to the calculation of which the probability function is displayed in Figure 9.2.

9.5.2 Trend 1990-1999

Emissions decreased by 29% point. The range of 95% confidence is between 22% point and 34% point. See Figure 9.3.

Table 9.5 1999 methane emission and its' sensitivities (Standard B coefficients) to input parameters by assumptions on the oxidation factor and uncertainties.

Type of pdf and uncertainty	Uniform 100%	Lognormal 75%	Lognormal 75%	Uniform 100%
Mean in oxidation factor (% oxidation)	10%	10%	20%	30%
Fraction of organic carbon reacting to gaseous material	0.698	0.747	0.622	0.317
Fraction of methane oxidised in top layer	-0.533	-0.346	-0.638	-0.931
Fraction of carbon reacting to methane (instead of to CO_2)	0.412	0.403	0.348	0.188
Organic C content of waste which is landfilled (kg/tonne) <1991	0.381	0.389	0.332	0.153
Emission 1999 (ktonne methane)	408	410	363	312

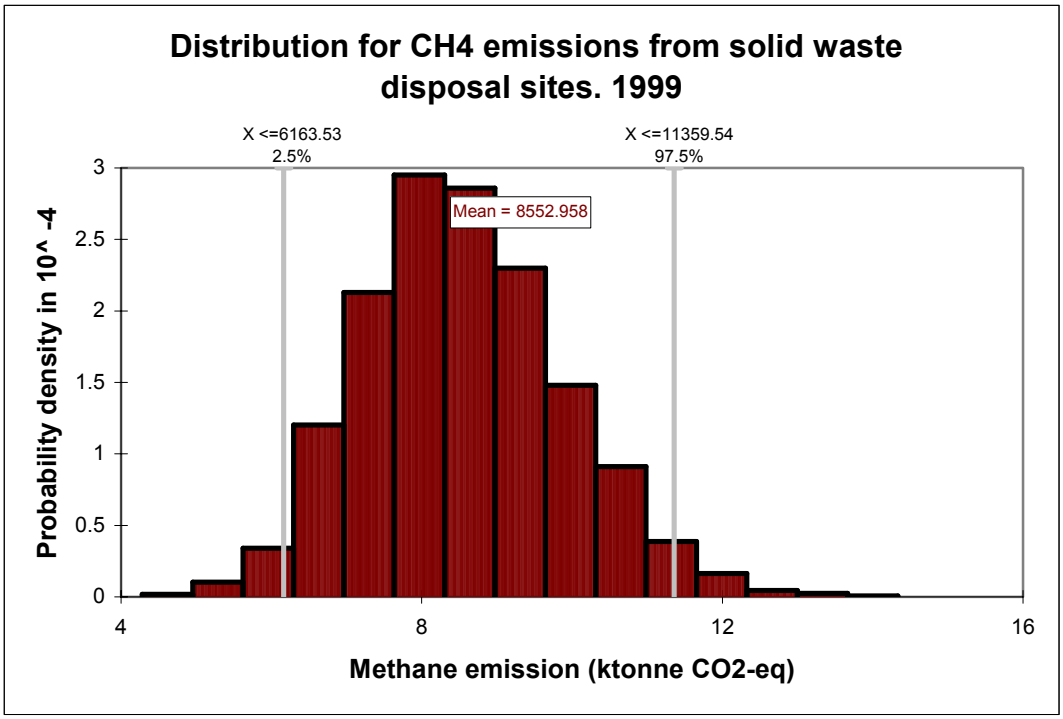

Figure 9.2 Probability distribution of the methane emission of landfills for 1999

For the trend the ranking of variables according to sensitivity is quite different. The uncertainty in the organic carbon content of waste has become the most important to the trend. The assumption on the amount of methane oxidised in the top layer has disappeared from list, while for the trend the uncertainty in rate constant of the model is relatively important. It strikes also that the uncertainties in the amounts of waste are relatively important.

Table 9.6 Sensitivity of 1990-1999 trend (%) to the 7 most important variables in methane emission model for waste disposal.

Variable	Standard B coefficient
Organic carbon content	-0.922
Fraction organic carbon/degradable	0.228
Rate constant	-0.203
Waste disposal (Mtonne) in 1992	0.086
Waste disposal (Mtonne) in 1991	0.085
Waste disposal (Mtonne) in 1990	0.082
Waste disposal (Mtonne) in 1993	0.078

9.6 Discussion

Tier-1 and tier-2 uncertainty analysis. Tier 1 uncertainty analysis assumes the emission model to be in the form of emission factor times activity. In case of the source category "CH_4 emissions from waste disposal sites" activity is the amount of waste that is

tipped yearly. The emission model that is actually used is much more complex.

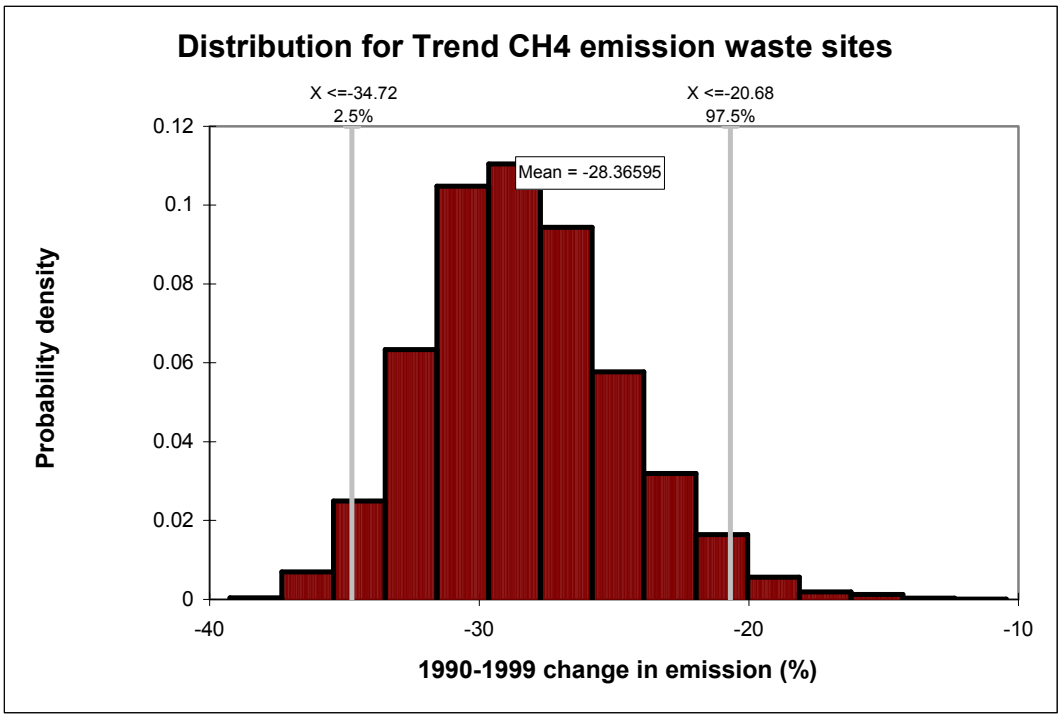

Figure 9.3 Probability distribution of the decrease in methane emission of landfills between 1990 and 1999.

The implied emission factor (methane emissions as calculated according to the model described above divided by the amount of waste) is clearly very much lumped. (Olivier et. al. (2001), p. 28) assume 30% uncertainty in this emission factor, and 15% uncertainty in the activity. Which leads to a 32% overall uncertainty in this emission. We made a number of calculations that differ in the assumption about the fraction of formed methane that is oxidized in the waste tip. The assumption that reflects a large uncertainty in the oxidation factor (0% to 60%, uniform) leads to an uncertainty in the emission of about 65% (confidence range 162 – 485, mean 312 ktonne). The assumption with a 'small' uncertainty (0% - 20%, uniform), which is more in line with the model used in the NIR 20001, results in a 50% uncertainty (317 – 506, mean 408 ktonne).

Note that tier-2 uncertainty analysis does not address uncertainty that is from the choice of model.

9.7 Scope for uncertainty reduction

Methane emissions from landfills depend on many factors. Specific circumstances of a landfill are among those factors. The model which is used to calculate methane emission is, compared with an actual disposal site, a very stylised description of the actual bacteriological, chemical and physical processes that result in emissions of methane.
The model that is used for the estimates of the national emissions was established in 1995 (Coops et al., 1995).

Tier-2 uncertainty analysis is confined to the analysis of the impact of uncertainties in parameters and variables of a given model. The credibility of recommendations with respect to address uncertainties in parameters or variables of a model depend on the trustworthiness of that model. Trustworthiness can be enhanced by validation of the model. Validation of the methane-from-waste-tips emission model would require actual measuring of emissions, the composition of waste (current waste but also waste in the past) and processes within landfills (e.g. to get assess the oxidation of methane in the aerobic zones of a landfill).

The approach for estimating methane emissions from landfill is currently discussed. One of the issues is the possibility to actually measure emissions. Under NOVEM's ROB programme there is an initiative to start such an endeavor. The emission measurement method (by inverse dispersion modeling) is being considered with respect to its feasibility (Scharff et al. 2000). Results can be used to improve the national emission model. To what extent emission estimates can be made more reliable depends on the performance of the dispersion model, in particular on the (inverse) modeling of meteorology.

Early research of methane emission from waste landfills (Van Amstel et al, 1994) suggested the use of a stratified model, distinguishing different rate constants for the formation of methane. Interviewees indicated that this approach is still discussed. Our sensitivity analysis, however, (See Table 6.10) suggest that for the uncertainty in the outcome of the present model uncertainty in the rate constants are not decisive. The most important uncertainties are "fraction of methane oxidised", the fraction of organic carbon that is degradable, the composition of landfill gas and the organic C content of waste. It is less important to have very precise figures on the current amounts of waste that are landfilled.

Costs to halve uncertainty in the emission estimate would be in the order of magnitude of up to k€ 150 according to one of the experts that were interviewed (Van Asselt, 2002).

The discussion above refers to estimating the current emission. For an assessment of **the trend** (percentage change in emissions with reference to 1990), conclusions are different. For instance the fraction of carbon that is oxidized is less important. Table 9.6 says the assessment of the organic carbon content of waste becomes most important. This assessment should also focus on the organic carbon content of waste, which was landfilled in the eighties, since this waste determines the emission in 1990 (the reference year for the trend). In addition the sensitivity analysis showed that the rate constant is important.

The weight of these conclusions depends on the credibility of the emission model. Research under the ROB-programme, mentioned above, can contribute to the evaluation of the model.

9.8 Appendix to Chapter 9

Table 9.7 shows the time series of waste disposal in the Netherlands, as used in the model.

Table 9.7 Time series of waste disposed of in landfills.

Year	Waste (Mtonne)	Year	Waste (Mtonne)	Year	Waste (Mtonne)
1945	0.1	1964	4.5	1983	14
1946	0.2	1965	4.7	1984	15.2
1947	0.5	1966	4.9	1985	16.3
1948	0.7	1967	5.2	1986	15.8
1949	1	1968	5.4	1987	15.3
1950	1.2	1969	5.7	1988	14.9
1951	1.4	1970	5.9	1989	14.4
1952	1.6	1971	6.4	1990	13.9
1953	1.8	1972	6.9	1991	11.9
1954	2.1	1973	7.3	1992	11.4
1955	2.3	1974	7.8	1993	11.3
1956	2.5	1975	8.3	1994	9.1
1957	2.8	1976	8.8	1995	8.2
1958	3	1977	9.2	1996	6.8
1959	3.3	1978	9.7	1997	5.8
1960	3.5	1979	10.1	1998	5.4
1961	3.7	1980	10.6	1999	5.4
1962	4	1981	11.7	2000	5.2
1963	4.2	1982	12.9		
1948	0.7	1967	5.2		

Recovery of waste tip gas: in 1990 63.7 mln m3 and in 1999 177.4 mln m3.

10. Other CH_4 and N_2O emissions

10.1 Introduction

This chapter covers all emissions that are not elsewhere discussed. Of these emissions methane from production, storage and handling of fossil fuels is the most important.

10.2 Reported emissions

Table 10.1 and Table 10.2 give the source categories and emission data as found in the detailed CRF tables of the NIR 2001 and which are not covered by the other chapters.

Table 10.1 Methane emissions (ktonne CH_4) not covered elsewhere.

Source category	1990	1999
Fuel combustion activities (Sectoral approach) non-transport	27.05	25.32
Fugitive emissions from oil: (refining and storage)	0.28	0.27
Production of oil (Table 1B2)	14.34	IE
Production /processing natural gas	85.2	81.78
Transmission of natural gas	6.3	3.51
Distribution of natural gas	72.6	58.67
Industrial processes	3.4	2.48
Waste water handling	6.3	3.78
Waste incineration	IE	0.0171
Other energy	0.31	
Total Methane emissions	216	176

Source: CRF-tables 1.A(a), 1.B.2, 2(I) and 6 (entry B, D).

Total methane emissions from these categories add up to 3,037 ktonne CO_2-eq. in 1990 (1.4% of all emissions) and to 3,692 ktonne CO_2-eq in 1999 (1.6% of total).

Table 10.2 Nitrous oxide emissions (tonne N_2O) not covered elsewhere.

Source category	1990	1999
Misc. N_2O	500	606
Emissions from stationary combustion: non-CO_2	700	467

We have not assigned uncertainties to the emissions shown in italics. The share of these sources to total greenhouse gas emission was 0.17% and 0.14% in 1990, respectively 1999.

10.3 Emission model

The emission data in the tables are from the Pollutant Emission Register (*Emissie Registratie).* For methane the two most important sources are the emissions.

- Production and transmission of natural gas by the oil and gas industry (venting and flaring mainly;
- The distribution of natural gas in gas distribution firms (distribution by gas networks).

Information about the emissions of the first category is from the oil and gas industry (as published in annual environmental reports (*Milieujaarverslagen (MJV)*).

Emission from the distribution of natural gas to the small consumers (e.g. households) is estimated with emission factors (or leakage rates). Old gas piping systems (pre 1960 piping systems) have high leakage records. The estimation of the share of these old systems in the total gas distribution infrastructure is important to the overall emission (IPCC, 1996).

The emissions from nitrous oxide and methane from combustion of fuels are estimated sector by sector with generic emissions factors, unless specific information of specific sources is available. The emission model that is used in our calculations assumes emissions to be proportional with activities (production, transmission and distribution of fossil fuel (mainly natural gas) as indicated in the CRF files of the NIR 2001.

For "other industrial CH_4" the model was adopted that is described in Section 7.3.

10.4 Uncertainties

Table 10.3 shows the uncertainties as assigned to the various elements of the emission model.

Table 10.5 shows the sensitivity of the emission to the model inputs. Note that we conceptualised emissions factors for 1999 as the product of the 1990 emission factor with a change variable, which captures the changes in the emission factor.

The trend is that methane emissions decreased with 18% in the period 1990-1999. The range of 95% confidence in this number is –23% point to –14% point.

Table 10.6 shows the corresponding sensitivities. The uncertainties in the 'change factors' prove to be important. The change factors capture technological change between 1990-and 1999. Their uncertainties are an indication of magnitude of correlation between the emission factors in 1990 and in 1999. They assume that 1990 emissions are estimated from (relatively well known) 1999 emissions by considering the technical change that occurred in the period 1990-1999 (e.g. other piping systems, improved flaring techniques) and estimating the implications for emissions.

Table 10.3 Uncertainties assigned to variables and parameters in emission model of "other CH_4 emissions".

Variable	Value	Pdf	Un certainty (%)
Distribution of natural gas (PJ) 1990	675	Normal	5
Methane emission factor (1990) distribution of natural gas kt/PJ	0.10755556	Normal	50
Distribution of natural gas (PJ) 1999	724	Normal	5
1990-1999 change in CH_4 emission factor distribution of natural gas	0.75343306	Normal	5
Transmission of natural gas 1990 (PJ)	2292	Normal	1
Transmission of natural gas 1999 (PJ)	2385	Normal	1
Emission factor transmission of nat gas kt/PJ (1990)	0.00274869	Normal	25
1990-1999 change in CH_4 emission factor transmission of natural gas	0.53541779	Normal	5
Methane emission factor production and processing of natural gas 1990	0.03717277	Normal	25
Production/processing of natural gas (PJ) 1990	2292	Normal	1
Production/processing of natural gas (PJ) 1990	2280	Normal	1
1990-1999 change in CH_4 emission factor production/processing of natural gas	0.96491105	Normal	5
Fuel combustion activities (Sectoral approach) non-transport emissions 1990 ktonne CH_4	27.05	Normal	50
1990 -1999 composite factor for change in fuel combustion activities	0.93604436	Normal	5
1990 Methane "Em. Fact." from industrial processes (Other industrial: CH_4)	3.4	Normal	50
1990 Activity index. (Other industrial: CH_4)	1	Normal	10
Activity factor 1990-1999 (Other industrial: CH_4)	0.72941176	Normal	0
1990 Methane "Em. Fact." from Waste water handling (kt CH_4 eq/activity)	6.3	Normal	25
1990 Activity index. CH_4 from Waste water handling	1	Normal	20
Activity factor (1990-1999) Waste water handling	0.6031746	Normal	0
1990 Methane "Em. Fact." Misc. CH_4	2	Normal	25
1990 Activity index. Misc. CH_4	1	Normal	20
Activity factor (1990-1999) Misc. CH_4	0.97	Normal	0

Table 10.4 Uncertainties assigned to variables and parameters in emission model of N_2O from isc. sources.

Variable	Value	Pdf	Uncertainty (%)
"Emission factor" Solvent use/Misc. N_2O (ktonne N_2O)	0.5	Normal	50
1990 Activity index. N_2O Solvent use	1	Normal	50
Activity factor solvent use 1990-1999	1	Normal	0

10.5 Results

Figure 10.1 shows the result of the analysis for methane emissions.

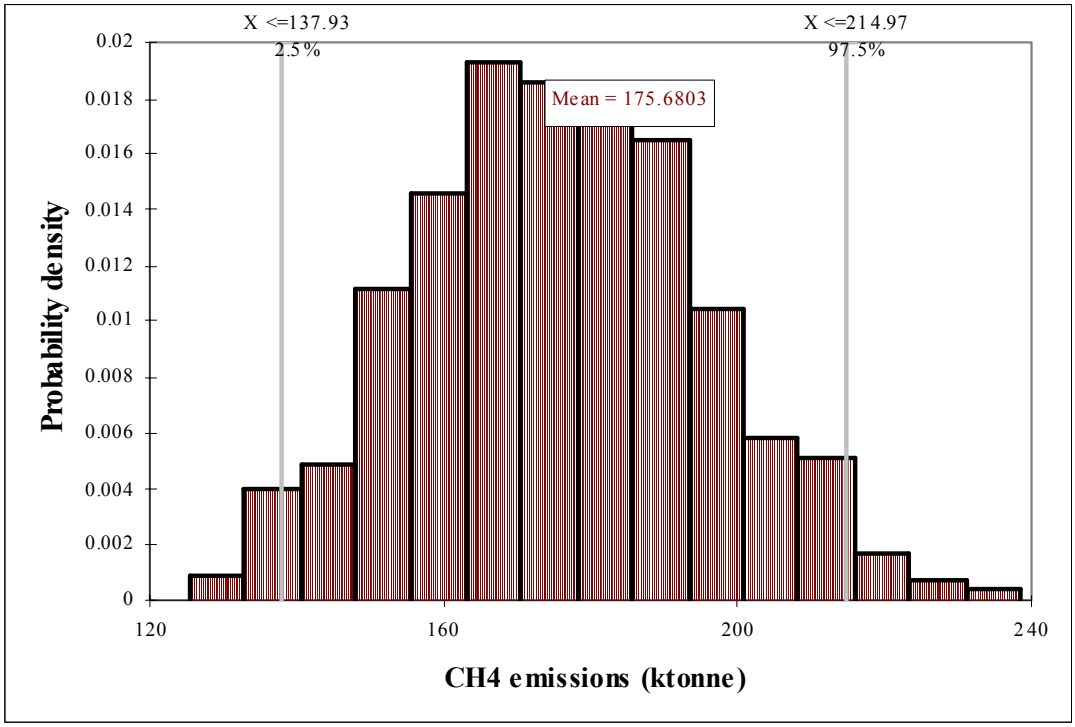

Figure 10.1 Probability density function for "other methane emissions" in 1999.

Table 10.5 Sensitivity of 1999 emission to model inputs.

Variable	B coefficient
Methane emission factor (1990) distribution of natural gas (kt/PJ)	0.75
Methane emission factor production and processing of natural gas (kt/PJ)	0.52
Fuel combustion activities (Sectoral approach) non-transport	0.333
1990-1999 change in CH_4 emission factor production/processing	0.204
1990-1999 change in CH_4 emission factor distribution of natural gas	0.075
Emission factor transmission of nat gas kt/PJ (1990) / IE	0.046
1990 –1999 composite factor for change in fuel combustion a	0.032
Production/processing of natural gas (PJ) 1990 / IE	0.022
Distribution of natural gas (PJ) 1999 / IE	0.014
1990-1999 change in CH_4 emission factor transmission of natural gas	0.004

Table 10.6 Sensitivity of 1990-1999 trend uncertainty to uncertainties in variables.

Variable	B coefficient
1990-1999 change in CH_4 emission factor production/processing of natural gas	0.83
Methane emission factor production and processing of natural gas	0.32
1990-1999 change in CH_4 emission factor distribution of natural gas	0.298
Fuel combustion activities (Sectoral approach) non-transport	0.172
1990 -1999 composite factor for change in fuel combustion in non-transport sectors	0.137

10.6 Conclusion and scope for reduction in uncertainties

Production, processing and the distribution of natural gas are the most important source categories. The gas industries (e.g. the Gasunie) are the main source of information for emissions from production and handling of natural gas. How this information is developed (method of measurements) is not transparent to the emission inventory agencies according to the expert interviewee (Van Asselt, 2002). The costs of a programme, within the industry, to reduce uncertainty was estimated at k€ 25-50.

There is little scope for reduction in the uncertainty in emissions from distribution of natural gas (to households). Costs would be very high.

11. N_2O emissions from agriculture (4B and 4D)

11.1 Introduction

Within the source category "N_2O emissions from agriculture", IPCC makes a distinction between three major source categories: "emissions from manure management" (4B), "direct N_2O emissions from agricultural soils" (4D) and "indirect emissions from nitrogen used in agriculture" (4D). The latter category refers to emissions that are attributed to the use of fertiliser in the past and to the effects of water management (e.g. water table management) on chemical processes in soils that result in N_2O emission.

Section 2 presents the emissions of N_2O in 1999 and 1990 as reported in the NIR 2001 (Olivier et al. 2001). Section 3 summarises how these emissions were assessed. The uncertainties are discussed in Section 4 and a set of uncertainties for the calculations is proposed. The results of the tier-2 uncertainty analyses are in Section 5 Finally, Section 6 discusses and concludes.

11.2 Reported emissions

Table 11.1 presents the figures that were reported to the UN-FCCC in the NIR 2001, except for indirect background emissions. The NIR 2001 inventory presents these N_2O emissions as 4.71 ktonne N_2O in Table 4.D under the heading "Other". Section 3.5 indicates that an error might have occurred and this number should be 5.5 ktonne.

Table 11.1 Nitrous oxide emissions (ktonne N_2O) from agriculture.

Source category	1990	1999
Manure. From excretion of N in meadow and paddock	3.8	2.7
Emission from the use of synthetic fertiliser	7.0	6.8
Emissions from animal wastes applied to soils	5.7	10.5
From dry pulses and soybeans	0.2	0.2
Indirect (background) emissions due to agriculture*	5.5	5.5
Total emissions from soils	22.2	25.7
N_2O manure management emission (Stable & storage)	0.7	0.7

*Recalculated. The NIR 2001 says this emission is 4.7 ktonne (See below).

The 1999 emissions accounted for about 3.5% of all greenhouse gas emissions in that year.

11.3 Emission model

Spakman et al. (1997) summarise the calculation procedures. Calculations are based on a substance flow analysis of nitrogen in agriculture[13].

[13] Very recently, nitrogen substance flow analysis and uncertainties in nitrogen fluxes for the Netherlands were reviewed (Kroeze et al., 2002; De Vries et al. 2002). The information could not be used timely.

Calculations start with the input of nitrogen into agriculture (via fertiliser or manure) and then the model tracks the fate of nitrogen.

11.3.1 Direct emissions from the use of fertiliser

A fraction of the nitrogen in N-fertilisers is not taken up by crops, but volatilizes to NH3 and denitrifies into N_2O (and N2 and NH3). In the emission estimates one uses the results from field studies (measurements of N_2O emissions under controlled conditions) to estimate this fraction. It appears that there are many variables - e.g., types of soil, weather, water table, conditions of application of fertiliser - that highly influence the rate of denitrification. Models than accurately describe emissions as a function of these variables are yet to be constructed. A second hurdle to get a reliable insight in these emissions is that the variability of all these conditions across the Netherlands is not accurately known.

N_2O emissions from the application of synthetic N-fertilisers are calculated with a simple model (Spakman et al. (1997); Kroeze (1994, p. 40):

$$N_2O = 44/28 * F(N) * \alpha * (Soil_{(Mineral)} * Ef_{(Mineral)} + Soil_{(Organic)} * Ef_{(Organic)}),$$

where

N_2O = N_2O emission (ktonne).

F(N) = Amount of fertiliser (ktonne N) applied.

α = Share of N that is not volatised as NH_3 and that can potentially be converted into N_2O (0.98).

$Soil_{(Mineral)}$ = Share of agricultural soil that is "mineral" (0.90).

$Soil_{(Organic)}$ = Share of agricultural soil that is "organic" (1 - $Soil_{(Mineral)}$).

$Ef_{(Mineral)}$ = Fraction of N converted into N_2O if the soil is "mineral" (0.01).

$Ef_{Organic}$ = Fraction of N converted into N_2O if the soil is "organic" (0.02).

The expression implies the assumption that application rates (kg N per ha) are the same for mineral and organic (i.e. peat) soils.

From this expression one can construct an emission factor that relates emission to the national use of fertiliser. This emission factor (which actually lumps four independent variables) says that, on average, 1.1% of the applied nitrogen is emitted as nitrous oxide. This is the upper limit of the range (0.1%-1.1%) for the emission factor that was presented by the initial IPCC guidelines. The 1996 revised IPCC guidelines recommend 1.25% +/- 1% as the appropriate emission factor (IPCC, 1996, revised, Vol III, Table 4-18).

Table 11.2 Consumption of fertiliser and associated N_2O emissions in different units.

	Unit	1990	1999
Consumption of fertilizer (applied nitrogen)	ktonne (Gg) N	403.8	392.42
Emission	ktonne (Gg) N20	6.98	6.78
Emission	ktonne (Gg) N	4.44	4.31
Emission	ktonne CO_2 eq.	2121	2061

Source: Tables 4.D of the CRF files.

Table 11.2 shows that in 1990 and 1999 farmers applied 403.80 ktonne N fertiliser respectively 392.42 ktonne N-fertiliser (measured as N) (Olivier et al. 2001). See also Table C5.6 of www.rivm.nl/milieucompendium. The corresponding emission is 6.98 and 6.78 Gg N_2O, or 1.1% of the applied nitrogen.

11.3.2 Animal wastes applied to soils

This source category refers to N_2O emissions from manure (from stables) that is applied on agricultural soils. How slurry is applied is important for the eventual emissions. Until the nineties livestock slurry was just spread over the fields, nowadays manure is incorporated in the topsoil, supposedly leading to higher N_2O emissions. The background of this change in practice of manure application is the policy to reduce emissions of NH3 from manure.

Spakman et al. (1997), p. 42 describe the emission model. Input variables are:

- The amount of manure collected and stored, measured in terms of N;
- Import and export (or stock changes) of manure (in N);
- The amount of manure that is biologically treated (aerobic treatment);
- The emission of NH3 when the manure is applied.

Currently, the import and export of manure and biological treatment of manure have only a limited significance compared to the other variables.

Key parameters are:

- The share of manure that is incorporated in the soils and not just spread over the fields (note: this is an important parameter in the calculation of the change in emission between 1990 and 1999);
- The ratio between organic and mineral soils;
- Emission factors for mineral soil and for organic soils.

We could not identify the source of the information about values for the input variables. It is likely that the values for manure production (ktonne N) and emissions of ammonia are taken from nitrogen mass balance models that are used by the RIVM in its information system (info for Milieubalans).

11.3.3 N-fixing crops

This emission is minor. It decreased from 0.24 ktonne in 1990 to 0.20 ktonne in 1999. This emission is not analysed with respect to uncertainty.

11.3.4 Animal production. Emission from manure produced in meadow and paddock

Spakman et al. (1997) (p. 40) describe the emission model. This model is also based on a mass balance, starting from total production of manure by cattle, in terms of nitrogen.

$$N_2O = \alpha * \beta * A * (Ef_{Urine} * F_{urine} + Ef_{Faeces} * F_{Faeces})$$

Where

N_2O = Emission (ktonne N)

A = Annual production of manure (ktonne N)

α = Factor indicating the share of manure produced in pasture (as opposed to held instock) (0.25)

β = Share of N not relased as ammonia (0.92)

Ef_{Urine} = Share of N in urine emitted as N2O (0.02)

F_{urine} = Share of N excreted in urine as opposed to in faeces (0.6)

Ef_{Faeces} = Share of N in faeces emitted as N2O (0.01)

F_{Faeces} = Share of N excreted in faeces (1 - F_{urine})

For 1999 the emission was 3.35 Gg N20, while the amount of manure applied (N excretion on pasture range and paddock was 133.4 ktonne N in that year.

11.3.5 Indirect background emissions

Indirect (agricultural) background emissions are those N_2O emissions that are the result of the use of fertiliser in the past and the result of the lowering of water tables for agricultural purposes. The emission estimate is based on Kroeze (1994,p.47), who, in turn, based the calculations on Bouwman and Van der Hoek (1991), Bouwman (1994) and Velthof and Oenema (1994). The emission model says that the emission is the difference between current emissions from agricultural soils with emissions that would occur when there would not have been any agricultural activities. The establishment of the natural background emissions is based on assumptions. Table 11.3 shows the data that are used in the emission model. Actually, the background – natural – emissions from forests and other lands are not relevant to the emission inventory.

Table 11.3 Key data for the estimation of indirect N_2O emissions (4D other).

Soil type	Aera (1000ha)	Background (kg N_2O $ha^{-1}yr^{-1}$)	Measured (1) (kg N_2O $ha^{-1}yr^{-1}$)	Anthropogenic (1) (Gg N_2O yr^{-1})
Arable land	931	0.8	1.6	0.7
Grassland mineral soils	820	0.8	1.6	0.7
Grassland organic soils	275	0.8	15.7	4.1
Forests	300	0.7		
Other lands	1080	0.5		
Total				5.5

Note: Area data may be somewhat outdated here, however, this does not influence the result. (1) Data from Kroeze (199, p. 47).

So the outcome is different from Kroeze's in 1994. She calculated 4.7 ktonne N_2O[14]. In her Table 4-8 (p. 47) she subtracts a natural emission of 1.5 Gg N_2O as N from a total emission 4.5 Gg N_2O as N. However this 1.5 includes emissions from forests and other lands that don't have anthropogenic emissions. There should be subtracted 1.0 Gg N_2O as N, leading to 3.5 Gg N_2O as N, which equals 5.5 Gg N_2O as N_2O.

11.3.6 Manure management (emissions from animal houses)

The Emission model is summarised by Spakmant et al. (1997) (p. 41).

$$N_2O = (\alpha * \beta * \chi * A - F) * \delta + \varepsilon * F$$

Where

N_2O = Emission (ktonne N)

A = Annual production of manure (ktonne N)

α = Factor indicating the share of manure produced in stables (and held in stock/manure basins). This is factor is 0.75 (see also 4D 2)

β = Share of N released (volatised) as ammonia from stables (0.144)

χ = Share of N not released (volatised) as ammonia from manure basins (0.988)

F = Amount of manure held in stock and biologically treated

δ = Emission factor of N_2O from basins (0.001) (as N)

ε = Emission factor of N_2O from biological treatment plants (0.02)

Table 11.4. summarises the calculation. It is described by Spakman et al. 1997 p. 41.

Table 11.4 Summary of calculation of emissions from manure management.

Variables and parameters	1990	1999
Excretion of manure in stable (ktonne N)	492.7	441.7
NH3 losses in stable (%)	14	14
Left in stable (ktonne N)	423.8	379.8
NH3 losses from storage (%N)	1.00	1.00
Net N content manure (ktonne N)	419.5	376.0
Manure (N) biologically treated (ktonne N)	0	2
Emission factor biological treatment (%)	2	2
Emission from biological treatment	0	0.04
Manure (N) stored anaerobically	419.5	374.0
Emission factor anearobic storage (%)	0.1	0.1
Total emissions (ktonne N)	0.42	0.41
Total emissions (ktonne N_2O)	0.66	0.65

11.4 Uncertainties

A few years ago Van Aardenne et al. (1998) studied the uncertainties in IPCC default method applied for the Netherlands for 1990. They concluded the direct emissions from the use of fertilizer are the most important to N_2O emissions (of 1990). Excretion of N in

[14] Kroeze (1994) probably subtracted natural background emissions of forests and other land from total indirect emissions.

manure was also am important factor (the input uncertainty was about 60%). As will be shown the situation in 1999 is quite different from the situation in 1990, mainly due to the current practice of incorporating slurry into soils instead of spreading. Van Aardenne et al. (1998) included in their analysis the N_2O emissions from nitrate in water that must be attributed to leaching and run-off of nitrogen in fertilizer and manure. In the NIR 2001, however, this emission – N_2O from surface water - is not attributed to agriculture.

The calculations of the probability density functions of the emissions and the trend require values for a large number of variables and parameters. summarises the uncertainties that eventually are adopted for the tier-2 uncertainty analysis. In the sections below they are briefly discussed separately.

11.4.1 Emission from the use of fertilisers

Olivier et al. (2001) assume (Tier-1 approach) uncertainties of 10% for the yearly consumption of N-fertiliser, while the uncertainty in the aggregate emission factor is assumed to be 60%. The composite uncertainty is 61%.

The emission model (See Section 3.1) has six variables, each of which is assigned an uncertainty.

Information on the use of fertiliser is collected by Statistics Netherlands from surveys among farmers. By law (MINAS-regulation), farmers have to produce annual “mineral accounts” that include information on the use of fertiliser. Following Olivier et al. (2001) we assign an uncertainty of 10% with a normal distribution to the use of fertiliser.

The shares of areas of mineral and organic soil respectively are derived from national information on areas of arable land, grassland on mineral soils and grassland on organic soils that are input data to the calculation of indirect N_2O emissions. So, indirect and direct N_2O emissions are dependent. Each of these areas is assigned an uncertainty of 10%.

Most of the uncertainty refers to the amount of N-fertiliser that is turned into N_2O. The emission factors used in the NIR are proposed by Kroeze (1994) and comply with the IPCC values (1996). The assessment of the loss of N-fertiliser as NH3 (less important) and as N_2O are derived from earlier field studies. There are recent field studies that report N_2O emissions per ha of ground. Hellebrand an Scholtz (2000) reports emission factors at the low end of the IPCC range (0.25% - 2.25%). Velthof (1997,p. 136), also based on field studies, proposes an emission factor of 0.6% (10 g N_2O per kg fertiliser N) for mineral soils and 1.8% for peat soils (organic soils). So, this could indicate that the IPCC recommendations overestimate these emissions. We draw no conclusions from this work.

We assume an uncertainty of 60% for the N_2O emission factor, in line with the assessment of Olivier et al. (2001). Earlier studies (Winiwarter and Rypdal, 2001; Rypdal and Zhang; 2000; Winiwarter and Orthofer, 2000) indicated that the probability distribution for this emission factor is not normal. They used lognormal (Rypdal and Zhang, 2000; Winiwarter and Orthofer, 2000) and triangular distributions (Winiwarter and Rypdal; 2001). We use a lognormal distribution. This choice is supported by the expert interviews (Van Asselt et al, 2002).

Table 11.5 gives the uncertainties that are used in the uncertainty calculations for emissions from agriculture.

Table 11.5 Uncertainties for the initial tier-2 uncertainty analysis.

Variable/parameter	Pdf	Uncertainty (%)
Use of synthetic fertiliser 1990 (ktonne N)	Normal	10
Use of synthetic fertiliser 1999 (ktonne N)	Normal	10
Emission factor (as N) from use of fertiliser	LogNormal	60

11.4.2 N-fixing crops

No uncertainty is assigned.

11.4.3 Animal production. Emission from manure produced in meadow and paddock

Table 11.6 shows the uncertainties that were selected. These are based on the Tier-1 uncertainties as mentioned by Spakman et al (2001) and on the interviews among experts (Van Asselt et al., 2002).

Table 11.6 Uncertainties in the emission model for N_2O emissions of manure production in meadows.

Variable/parameter	Pdf	Uncert. (%)
Manure 1999. Total excretion N	Normal	10
Manure 1990. Total excretion N	Normal	10
1999 Share of excretion in meadow	Normal	10
1990 Share of excretion in meadow	Normal	10
N-losses from NH3 formation %	Normal	50
Share N in urine	Normal	5
EF N in urine	Normal	60
EF N in faeces	Normal	60

11.4.4 Indirect background emissions

The emission model that was used in the Dutch NIRs has been developed in the early nineties. The outcome was 4.7 ktonne N_2O, and this value was not assumed to change.

Since then, some new information came available (Velthof, 1997 (p.137)). If one uses this new information emissions are lower: 3.1 Gg (See Table 11.7)

Table 11.7 The estimation of indirect background N_2O emissions (4D other) based on more recent data.

Soil type	Aera (1000 ha)	Background (kg N_2O $ha^{-1}yr^{-1}$)	Measured (2) (kg N_2O $ha^{-1}yr^{-1}$)	Anthropogenic (2) (Gg N_2O yr^{-1})
Arable land	931	0.8	1.4 (+/- 0.4)	0.6
Grassland mineral soils	820	0.8	1.4 (+/- 0.4)	0.5
Grassland organic soils	275	0.8	8.3 (+/- 8.1)	2.1
Forests	300	0.7		
Other lands	1080	0.5		
Total				3.1

Note: Area data may be somewhat outdated here, however, this does not influence the result. (2) Data from Velthof (1997, p. 136).

Both 1990 and 1999 emission estimates would be lower if the new calculation as mentioned in Table 11.7 would be accepted. We did not use this new information.

The uncertainties in the amounts of different types of soil were each put at 10% with a normal distribution. Note that this assumption affects also direct emissions of N_2O (See below).

11.4.5 Emissions from animal wastes

The crucial assumption here is on the amount of nitrogen in slurry that is turned into N_2O when the slurry is applied in the fields. The estimate in the NIR is that 1 to 2 % of the nitrogen volatises as N_2O; 1% if the manure is just spread over the fields, and 2% if the slurry is incorporated into the soil. Both factors were assigned to a lognormal pdf with an uncertainty of 100%. They were assumed mutually independent. This is an assumption with important implications for the uncertainty in the change in emissions between 1990 and 1999.

Table 11.8 Uncertainties for the initial tier-2 uncertainty analysis of indirect background emissions.

Variable/parameter	Pdf	Uncertainty (%)
Background emission factor arable land (kg N ha-yr-1)	LogNormal	100
Background emission factor grassland (mineral soil) (kg N ha-yr-1)	LogNormal	100
Background emission grassland (organic soil) (kg N ha-yr-1)	LogNormal	100
Background emission factor forests land (kg N ha-yr-1)	LogNormal	100
Background emission factor other land (kg N ha-yr-1)	LogNormal	100
Measured gross emission arable land (kg N ha-1yr-1)	Normal	100
Measured gross emission grassland (organic) (kg N ha-1yr-1)	Normal	100
Measured gross emission grassland (mineral) (kg N ha-1yr-1)	Normal	100

11.4.6 Manure management (emissions from animal houses)

See Table 11.9.

11.4.7 Uncertainties in summary

The series of emission models (except the model for emissions of soybeans) that are used for calculating the emissions comprise about 40 variables and parameters that uncertainties must be assigned to. The list and the initially assumed uncertainties are in Table 11.9.

11.5 Results

11.5.1 N_2O emissions in 1999

Figure 11.1 shows the result of the uncertainty analysis. The figure for the emissions includes the emission from manure management. The range of 95% confidence is 16 ktonne – 41 ktonne, while the mean is 26 ktonne

The 95% range of confidence from the earlier tier-1 analysis (Olivier et al., 2001) is 12.8 – 30.8 ktonne. So, in our calculations uncertainty is higher. Although, the methodological difference between the tier-1 and the tier-2 uncertainty analysis hinder comparison of results, we may think of a number of reasons behind this difference. First, we think we corrected an error in the calculation of indirect N_2O emission, since this emission is highly uncertainty, the overall uncertainty increased as well. Second, the difference reflects the lognormal uncertainties that were assumed for several emission factors. Apparently, these effects more than compensates for the uncertainty reducing effect of taking into account of dependencies (correlation) between the different variables and parameters in the emission models.

Table 11.10 presents what variables and parameters (their uncertainties) contribute most to the uncertainty in total emissions. The uncertainty in the emission factor for N_2O emissions from manure that is incorporated in the soil is most important.

11.5.2 Uncertainty in the 1990-1999 trend

Table 11.11 and Figure 11.2 summarise the results of the calculations of the trend (percentage change in emissions between 1990 and 1999). According to our calculation emissions have increased by 18%. However, the large uncertainties implies that the "true" value of the 1990-1999 trend is somewhere between –21% point and +88% point (95% confidence level). Again the uncertainty in the emissions associated with the incorporation of manure in the top soils of fields is the most important factor in the uncertainty around the trend.

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Table 11.9 Variables and parameters for the calculation of uncertainties in N_2O emissions from agriculture.

Variable	Type of Pdf	Uncer-tainty (%)	Variable	Type of Pdf	Uncer-tainty (%)
Manure 1999. Total excretion N	Normal	10	Spreaded over mineral soils (%)	Normal	10
Manure 1990. Total excretion N	Normal	10	Emission factor injected/incorporated manure (%)	LogNormal	100
1999 Share of excretion in meadow	Normal	10	Emission factor mineral soils (%), if spreaded	LogNormal	100
1990 Share of excretion in meadow	Normal	10	Emission factor organic soils(%), if spreaded	LogNormal	100
N-losses from NH3 formation %	Normal	50	Use of synthetic fertiliser 1990 (ktonne N)	Normal	10
Share N in urine	Normal	5	Use of synthetic fertiliser 1999 (ktonne N)	Normal	10
EF N in urine	Normal	60	Emission factor (as N) from use of fertiliser	LogNormal	60
EF N in faeces	Normal	60	Background emission factor arable land (kg N ha-yr-1)	LogNormal	100
NH3 losses in stable (%)	Normal	50	Background emission factor grassland (mineral soil) (kg N ha-yr-1)	LogNormal	100
NH3 losses from storage (%N)	Normal	50	Background emission grassland (organic soil) (kg N ha-yr-1)	LogNormal	100
Manure 1999 (N) biologically treated (ktonne)	Normal	25	Background emission factor forests land (kg N ha-yr-1)	LogNormal	100
Manure 1990 (N) biologically treated (ktonne)	Normal	0	Background emission factor other land (kg N ha-yr-1)	LogNormal	100
Emission factor biological treatment (%)	Normal	100	Measured gross emission arable land (kg N ha-1yr-1)	Normal	100
Emission factor anearobic storage (%)	Normal	75	Measured gross emission grassland (organic) (kg N ha-1yr-1)	Normal	100
1990 Stock changes & import/export	Normal	0	Measured gross emission grassland (mineral) (kg N ha-1yr-1)	Normal	100
1999 Stock changes & import/export	Normal	10	Arable land (1000 ha)	Normal	10
1990 NH3 emissions at application of manure	Normal	25	Grassland mineral soils (1000 ha)	Normal	10
1999 NH3 emissions at application of manure	Normal	25	Grassland organic soils (1000 ha)	Normal	10
1999 Percentage of manure injected/incorporated	Normal	5	Forests (1000 ha)	Normal	10
1990 Percentage of manure injected/incorporated	Normal	10	Other lands (1000 ha)	Normal	10

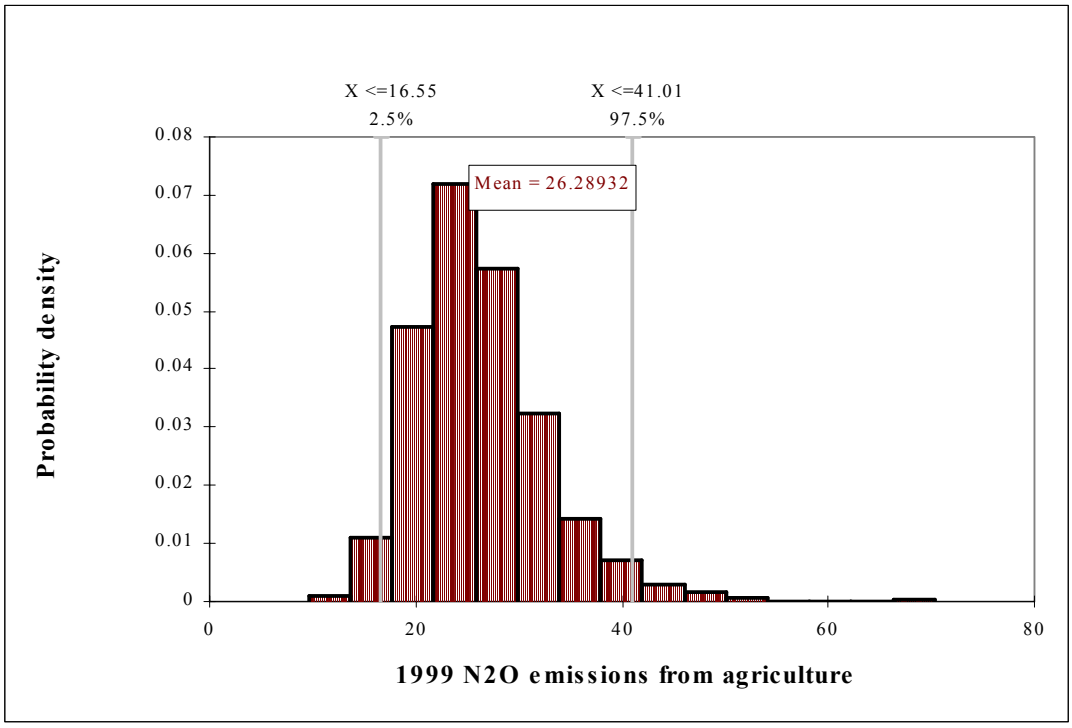

Figure 11.1 Pdf for the emissions of N_2O from agriculture (including manure management).

Table 11.10 The top five factors that determine the uncertainty in N_2O emissions of agriculture for 1999.

Variable	Standard B coefficient
Emission factor injected/incorporated manure (%)	0.854
Measured gross emission grassland (mineral) (kg N ha-1yr-1)	0.346
Emission factor (as N) from use of fertiliser	0.336
Measured gross emission arable land (kg N ha-1yr-1)	0.118
Measured gross emission grassland (organic) (kg N ha-1yr-1)	0.103
R-Squared=	0.997071

The possibility that the emissions decreased in the period 1990-1999 follows from the reduction in the amount of manure that was produced and applied on the fields (about 10% less in 1999) and the circumstance that in 1990 manure was not incorporated into the soil, while for 1999 it was assumed that all manure is incorporated. Emission factors associated with both methods differ. The possibility of a negative trend arises from the probabilities that the emission factor of “incorporating manure” more or less equals or is less that the emission factor for “spreading of manure”.

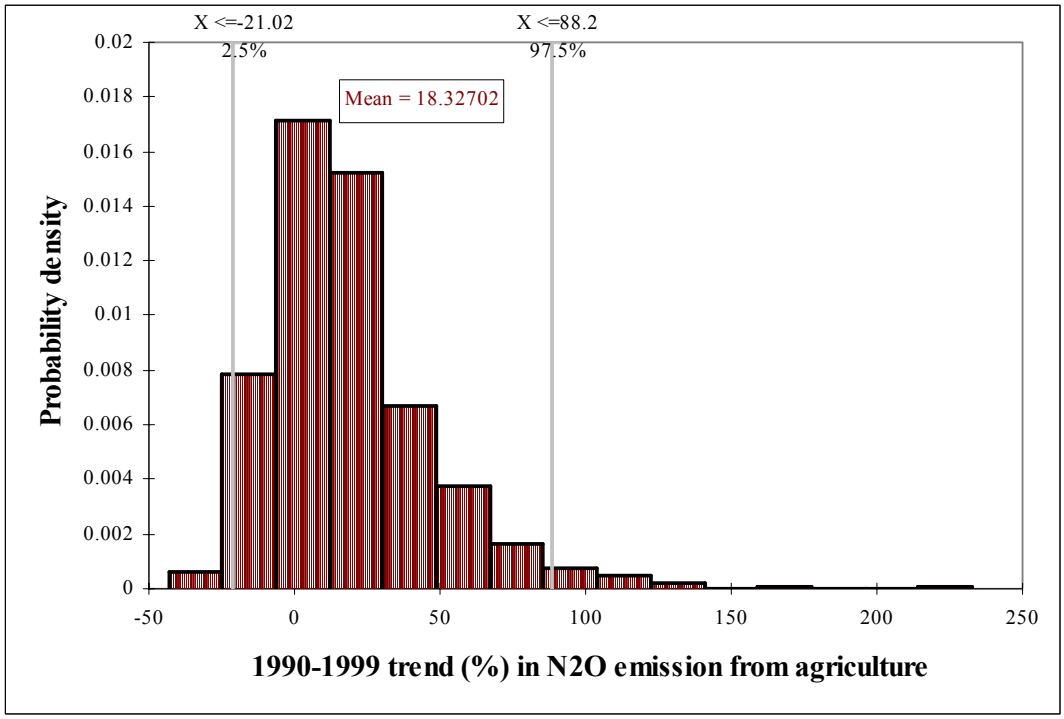

Figure 11.2 Uncertainty in the 1990-1990 emission trend of N_2O from agriculture (including manure management).

Table 11.11 The top five important factors that determine the uncertainty in the 1990-1999 trend of N_2O emissions of agriculture.

Variable	Standard B coefficient
Emission factor injected/incorporated manure (%)	0.877
Emission factor manure in mineral soils (%), if spreaded	-0.372
Emission factor manure on organic soils (%), if spreaded	-0.115
Measured gross emission grassland (mineral) (kg N ha-1yr-1)	-0.068
Emission factor (as N) from use of fertiliser	-0.068
Use of synthetic fertiliser 1990 (ktonne N)	-0.067
EF N in urine	-0.06
Use of synthetic fertiliser 1999 (ktonne N)	0.058
Spreaded over mineral soils (%)	0.04
R-Squared=	0.96327

Correlation. N_2O emissions from manure (of swine mainly) are correlated – this is not modelled - with the methane emissions from swine and cattle, through the numbers of these animals. Uncertainties in the numbers of animals, however, are small compared with uncertainties in emission factors. Therefore, this correlation will have little effect on the uncertainties in the sum (N_2O and CH_4) of the emissions from agriculture.

11.6 Discussion and conclusions

The emissions that are dealt with in this chapter constitute about 3.5% of total green-house gas emissions in 1999. The tier-1 uncertainty analysis (NIR 2001) indicated a 95%

range of confidence of 12.8 – 30.8 ktonne for this group of emissions. The corresponding tier-2 analysis resulted in a 95% range of confidence of 16 ktonne – 41 ktonne (mean 26 ktonne).

Most of the uncertainty arises from a lack of knowledge in soil processes that produce N_2O. Unknown spatial variability of factors that are expected to influence emissions (e.g. water table levels) is likely a further barrier to develop accurate emission estimates. The emission factors are used in the current inventorying, are based on field measurements that date back to before the nineties.

For the assessment of the annual emissions the uncertainty in emissions from direct and indirect application of fertilisers is the most important.

The most important uncertainty that contribute to the size of the range of confidence in the emission trend relates to the emission factors for N_2O emission from applying slurry on the fields.

Scope for reduction in uncertainties. Table 11.10 and Table 11.11 imply priorities for reduction in uncertainties within the category N_2O emissions from agriculture. For both the emission estimate and the trend (1990-1999) calculation it appears that uncertainty in emission factors are the most important.

Much of the uncertainty relates to lack in scientific knowledge and can be resolved by science type of work. The main barriers to develop the required knowledge are probably resources and, possibly, a lack of scientific capacity in the Netherlands.

Uncertainty with respect to current statistical information (i.e. manure production, use of fertiliser) is relatively small. For trend assessments, it is necessary to develop consistent time series of statistical data (e.g. of manure production). Such development could run against institutional problems that relate to obtaining and processing data from different authorities and administrative agencies.

Work to improve emission factors is going on under the ROB programme. The ROB-agri programme aims primarily at the improvement of the management and control of emissions from agricultural activities. Under this emphasis, it might be that the assessment of the N_2O emissions from spreading of manure in 1990 – which nowadays hardly occurs – is not given much priority within the programme. Uncertainty in the 1990-1999 trend in the N_2O emissions might only be partly resolved.

12. N_2O emissions from polluted surface water (7)

12.1 Introduction

Nitrates in water are converted (denitrified) into other nitrogen compounds, including nitrous oxide. Nitrous oxide is insoluble in water and is air borne. Nitrate in water of anthropogenic origin is, therefore, a source of nitrous oxide emissions. This source is part of the IPCC source category 7 "Other".

12.2 Reported emissions

The reported N_2O emission is 3.80 ktonne N_2O. (CRF table Summary 1.As2). This figure holds for 1990 and all subsequent years. This emission contributed 0.5% to the total of 1999 greenhouse gas emissions.

The overall emission uncertainty (2σ) was estimated as 206%, as the result of a 50% error in the 'activity' and 200% uncertainty in the 'emission factor' (Tier-1 estimate by Olivier et al., 2001, p.29).

12.3 Emission model

The calculation is based on the assumption that 1% of all nitrogen that is leached or washed (run-off) from soils and reaches surface water is converted into nitrous oxide (Spakman et al., 1997).

12.4 Uncertainties

Activity data. Water management models used by the State Water Management Authority (*Rijkswaterstaat)* and RIVM calculated that 240 ktonne N per year leached towards surface water. So, N_2O emission is 2.4 ktonne N, which corresponds with 3.8 ktonne N_2O as used in this analysis. The origins of the assessments of N leaching and run-off that are used for this emission estimate is not clear. Spakman et al. (1997) refer to the PROMISE model as the source of the estimate for N leaching to water, but the current status of this model is unknown (to us). Van der Most et al. (1998) refer to a report of Boers et al. (1997) (RIZA, DLO Staring. Waterloopkundig lab).

More recent sources (Milieucompendium, 1999 (Table C5.5)) of information of leaching and run-off give lower input figures, i.e. indigenous sources were assumed to have emitted 139 ktonne N to surface water in 1997. For the emission of N to surface water, Olivier et al. (2001) assume an uncertainty of 50%.

Emission factor. Spakman et al. (1997) refer to Kroeze (1994) who refers to a high and a low estimate for the emission factor (p 52) and settles on a figure at 1 %. Olivier et al. (2001) assume an TIER I uncertainty of 200%.

Tier-2 calculations. The tier-2 uncertainty analysis of all N_2O emissions and of all greenhouse gas emissions we adopted the assumptions of the tier-1 uncertainty analysis.

This implies a 200% uncertainty in the emissions (normal pdf) and a zero percent uncertainty in the trend.

Table 12.1 Uncertainties assigned to variables and parameters in emission model of "other CH_4 emissions".

Variable	Value	Pdf	Uncertainty (%)
Nitrogen (kt N) input to surface water 1990.	240	Normal	50
Nitrogen input to surface water relative to input in 1990	1	Normal	0
Polluted surface water. Efactor (kg N_2O per kg N)	0.01571429	Normal	200

12.4.1 Correlations

About 60% of the nitrogen input to water is from agriculture. This, in turn, is due to nitrogen input to soils during agricultural activities. The two main activities are the use of N-fertiliser and the application of manure. The amounts are about equal (Milieucompendium 1999, Table C5.6) for 1997.

Another source for water borne nitrogen is through deposition, accounting for about 5% to 8% of the nitrogen input to water. Since air borne nitrogen is partly due to ammonia emissions from agriculture the emissions from polluted surface water are correlated with N_2O emissions from agriculture. And with methane emission from manure management through the production of manure. These correlations were not accounted for.

12.5 Scope for uncertainty reduction in emission data

The leaching of nitrogen into surface water has decreased over the recent years. The effect of this is not accounted for in recent emission estimates. Accounting for this development will have impact on the trend assessment and its uncertainty.

Linking this emission to the annual nitrogen input to water seems not to require a great effort. A practical problem, however, might be to find or construct consistent time series for N-leaching and run-off to surface water from 1990 onwards.

13. N_2O emissions of nitric acid production and other chemical processes (2)

13.1 Introduction

N_2O emissions from the chemical industry ranks on top of the list of source categories ordered by their contribution to overall uncertainty in emission inventories (NIR 2001, Olivier et al. 2001, p. 30). Over 80% of the emissions from chemical industry are from the production of Nitric acid.

Below we first present some detailed information on the emissions from nitric acid production and the emissions reported in the NIR 2001. Section 3 discusses uncertainties, while Section 4 presents the result of the calculations. Section 5 discusses and concludes.

13.2 N_2O emissions from chemical industry

Nitric acid production is a two-step process. The first step is the combustion of ammonia with pure oxygen over a platinum catalyst in the form of a grid or net. Combustion results in a mixture of NO_2, NO and N_2O, where NO_2 is the desired product. In a subsequent step in the production process, NO_2 reacts with water to give nitric acid. The catalyst must be changed a few times a year since its performance decreases when in use.

The chemistry and physics of N_2O formation in nitric acid production is not well documented (IPCC, 1996, revised; Schwefer et al., 2000). About 95% to 98% of the ammonia - depending on the technology – is converted into nitric acid. The tail gases – before emission abatement - contain about equal amounts of NO_x and N_2O (EFMA, 2001).

There were several nitric acid plants at various locations in 1990, i.e. IJmuiden, Rozenburg Pernis, Geleen and Sluiskil. Montfoort (1995) gave a summary of environmental data for nitric acid production and emissions in The Netherlands. Continental Engineering (2000) presents detailed data that apply mostly to the years 1996/1997 (See Table 13.1). The plants in Pernis and Rozenburg were closed in 2000 and 2001.

The technologies (process, emission reduction equipment (SCR/NSCR for reduction in emissions of NOx) for the plants in IJmuiden, Pernis and Rozenburg did not change between 1990 and 1999 (Bakker, 2001; DCMR, 2001).

Table 13.1 shows a clear variation in its implicit emission factors (emission by production capacity). The low emission factor of the Rozenburg plant is due to a NSCR (Non Selective Catalytic Reduction) unit that reduces nitrogen oxides (measured as NO_2) emissions. Emissions of NOx by other plants are kept within permit limits by other means. DSM reports (DSM, 2001) that the 1999 nitrous oxide emissions were 16.9 ktonne. The report does not say from what sources, however DSM is the sole plant in the Netherlands that produces caprolactam and acrylonitril. So the difference – about 5-6 ktonne – can be attributed to DSM manufacturing caprolactam (Montfoort, 1995).

Table 13.1 Nitric acid production in The Netherlands and emissions of nitrous oxide.

Firm	Site	Reference	Capacity (ktonne per year)	N_2O emission (ktonne per year)
DSM Agro BV	Geleen	SZF4	210	6-8 (estimated)
	Geleen	SZF5	500	
	IJmuiden	SZF4	255	3.7 (estimated[15])
	IJmuiden	SZF5	245	
Hydro Agri	Sluiskil	6	584	4.4 (measured)
Sluiskil BV	Sluiskil	7	730	5.4 (measured)
Kemira Agro BV	Pernis	Closed down.	mid 2000	
	Rozenburg	To be closed by 2001.	400	0.084 measured
Total			2924	20.5

Source: VROM as cited by Continental engineering (2000).

The 1990 emissions were estimated from total Dutch nitric acid production using a single emission factor (Montfoort, 1995). Measurements of N_2O emissions in the tail gases of some nitric acid plants started in the nineties. Information on emissions becoming available from these measurements likely allows to better estimate the 1990 emissions. Section 2.9 of volume III of the IPCC guidelines (1996, revised) recommends the use of data that are based on measurements.

Detailed data (RIVM file CRF-nld-2001-99.xls) do not present activity data and emission factors for 1999, probably for reasons of confidentiality (presently, there are only two firms in the Netherlands that produce nitric acid). There are no official statistics of production.

Reported emissions

Olivier et al (2001) report 11,206 CO_2-eq. (36.15 ktonne N_2O, or 23.0 ktonne N_2O measured in N) as the amount of N_2O emissions from chemical industry in the Dutch inventory in 1999. Production of nitric acid is the main emission source. The figure includes an estimated emission of about 5 ktonne N_2O from the production of caprolactam and acrylonitril. This is not reported separately for reasons of confidentiality. The corresponding 1990 emission is 31.53 ktonne N_2O.

13.3 Uncertainties

The emission in the inventory report (Olivier et al., 2001) of 36.1 ktonne N_2O in 1999 is not explained in terms of an emission factor and activity (production of nitric acid). Olivier et al. (2001) indicate an uncertainty of 50% in the emission factor and an uncertainty of 10% in the 'activity'. The composite (TIER I) uncertainty is 51%.

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[15] The Environmental Management Plan (BPM) of DSM-IJmuiden says that this number is derived from measurements of N_2O concentrations in the vent gases. No details are given. It also says that the number also applies for the year 1990. According to the environmental authorities (Bakker, 2001), sample-wise (as opposed to continuous) measuring started in 1992 in IJmuiden.

There is some additional information. Emissions of the Nitric acid plants in IJmuiden have been measured, sample-wise. An environmental civil servant of the Province of North-Holland estimates the uncertainty of the emission of these plants at 60-80% (Bakker, 2001). We will use the N_2O emissions and accompanying probability density functions (pdf's) ase presented in Table 13.2. So, we assign an uncertainty to the emissions and we do not distinguish uncertainties in an emission factor and in activity (nitric acid production).

Table 13.2 Emissions and pdf's with parameter values for N_2O emissions from chemical industry (production of nitric acid and caprolactam).

Year	Reported emission (ktonne N_2O)	Proposed pdf
1999	36.15	Normally distributed. 50%
1990	31.53	Normally distributed. 50%

For estimating the trend the question is raised to what extent the emission estimates for both years are correlated[16]. If the plants were not changed (technology, mode of operation) between 1990 and 1999, one may assume that emissions are fully correlated.

13.4 Results

With respect to the uncertainty in the **annual** emission the result of tier-2 analysis does not give information other than the tier-1 analysis.

With respect to the **trend** we did a little analysis with the following emission model.

$$Emission(1999) = Emission_{Caprolactam} + Act_{1990-1999} \cdot Emission_{Nitric\cdot acid}(1990)$$

$Act_{1990\text{-}1999}$ represents the development in production. Emission from caprolactam was set at 5000 ktonne. We assigned a pdf (probability density function) to $Act_{1990\text{-}1999}$ and to the 1990 emission from Nitric acid production. Both pdfs were normal, while the uncertainty in $Act_{1990\text{-}1999}$ was 10% and the uncertainty in the 1990 emission 50% (according to the assumptions in the tier-1 analysis, Olivier et al., 2001). The result is shown in Figure 13.1. Emission increased by 16% (range of 95% confidence 6% - 25%). A sensitivity analysis showed that the uncertainty in $Act_{1990\text{-}1999}$ contributes most to the uncertainty in the trend.

In an alternative analysis, we assumed emissions in 1990 and 1999 not to be correlated. In such case (50% uncertainty in emissions for both years) the range of 95% confidence in the trend becomes wide: -38% + 115%.

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[16] There is another correlation issue. Nitric acid is produced from NH3, which is produced from hydrogen. Hydrogen, in turn, is produced from natural gas. Hydrogen production leads to CO_2 emissions. The CO_2 emission from ammonia production is about 0.5 tonne CO_2 per tonne NH3 (EFMA, 2000). Then the emission of 1 tonne N_2O involves stoichiometrically only 0.33 tonne CO_2 emission. However, N_2O is a 310 times more potent greenhouse gas than CO_2 and, therefore, the effect is negligible.

Since, however, at least some of the plants were altered between 1990 and 1999, correlation must exist and the range of confidence must be smaller.

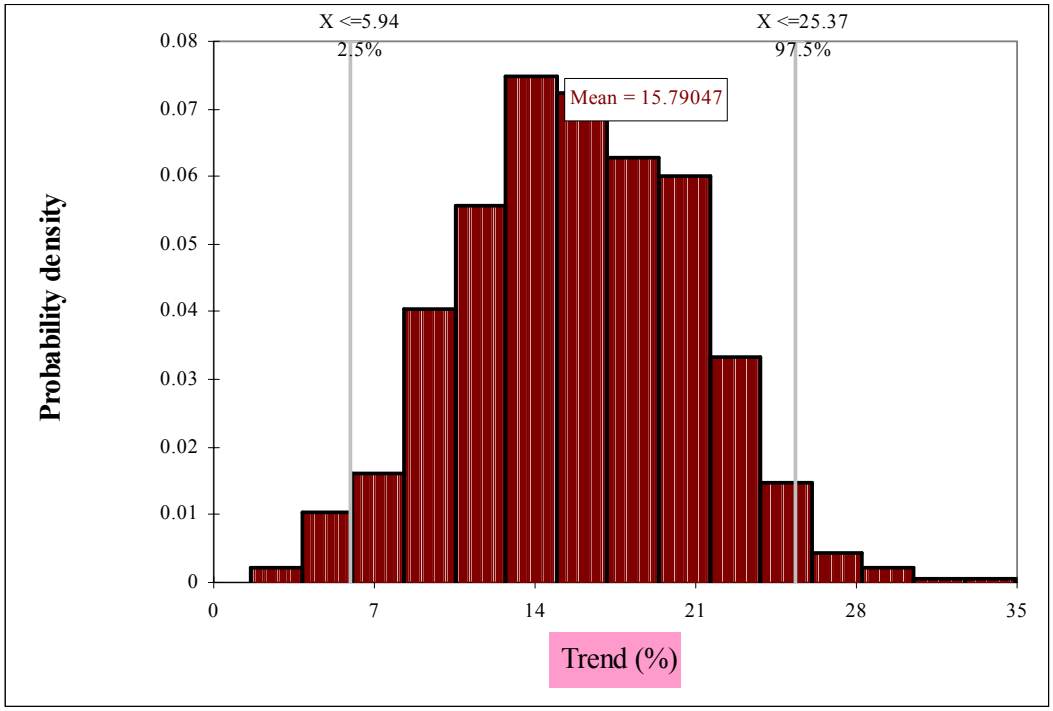

Figure 13.1 Probability density function for the1990-1999 trend (%) in N_2O emissions from chemical industry.

13.5 Discussion

The tier-2 analysis of the current (1999) emissions does not give new information with respect to uncertainty. Wit respect to the results for the trend the question is raised about the correlation between the 1990 emission (reference year) and the current emission. This question concerns the nature of the uncertainty in the emissions, the key question whether uncertainty reflects actual annual variability in the emissions or whether it reflects a lack of appropriate measurements or calculations. We have assumed the latter. This includes the assumption that between 1990 and 1999 the actual technology (e.g. catalysts) did not change. Under these assumptions, the uncertainty in the trend depends most on the uncertainty in the production of nitric acid. In other words: annual production is the only variable that explains annual variation in emissions.

Scope for uncertainty reduction in emission data. There is a ROB-working group "*Salpeterzuurindustrie*" (Nitric acid producers) which develops a protocol for monitoring N_2O emissions. The monitoring will involve measurements of N_2O in the vent gases of nitric acid production. Obviously, direct continuous measurements will give more .reliable emission data (assuming good measurement practice is applied).

The quantitative assessment of the actual reliability (or uncertainty) requires an analysis of the actual measurements. Questions are "what is actually measured?" and "how are the measurements used to establish annual emissions?" Under the programme for QA/QC in greenhouse gas emission inventorying the ROB working group and the

chemical industry are developing protocols for the assessment of the emissions. The questions could be addressed in such protocol.

In order to reduce uncertainty in the trend of the emissions it is recommended that this protocol also address the emission of 1990 and the amount of correlation in the errors of annual emission assessments.

13.6 Appendix

Table 13.3 summarises recent literature information on N_2O emissions from nitric acid production in the Netherlands.

Table 13.3 Literature on N_2O emissions from Nitric acid production in the Netherlands.

Reference	Emission	Comment
IPCC guide-lines (Revised 1996)	Vol III, Table 2-7 reports 2-9 g N_2O/kg HNO3.	IPCC recommends to use 9 g N_2O/kg HNO3 produced if N_2O emissions have not been measured.
ER-37 (1997)	8-9.5 g N_2O/kg HNO3. Point estimate of 9 (g N_2O/kg HNO3). HNO3 production of 3.0 Mtonne per year	These values are partly based on emission measurements for a part of Nitric acid plants.
Montfoort (1995)	Emissions in 1990 and 1993 16.7 respectively 17.0 ktonne (N-N_2O) at five firms. Same emission factor (as reported in ER-37 (1997)).	Based on Kroeze (1994).
Brink et al. (2000)	N_2O concentrations: 0.2 vol.%, or 1,500 ppm, or 2.9 g/Nm3*	Table B-2 says this is the concentration averaged over Dutch Nitric acid plants.
Olivier et al. (2001)	11,206 CO_2-eq.	This relates to 36.1 ktonne N_2O. (conversion factor 310) Quite different from the industry's estimate (see Continental, 2000)
Continental Engineering (2000)	N_2O emission 20.5 ktonne (2000)	Based on VROM information. Partly measured.

*Corresponds with an emission factor of 9.3 kg N_2O/kg HNO3 which, in turn, means that 2.5% of the NH3 feedstock is converted into N_2O instead of the desired NO_2 (Schwefer et al., 2000).

14. Emissions of F gases (2II)

14.1 Introduction

Emissions of F-gases are attributed to IPCC source category 2 – industrial sources. We deal only with the emissions and sources as reported in the NIR 2001 (Olivier et al., 2001). The share of F-gases in total national greenhouse gas emissions was 5% in 1999.

Next section presents the data as used in the NIR 2001 (Olivier et al., 2001). Section 3 describes the origins of the information, the 'emission models' and associated uncertainties. Section 4 presents the results of calculation, while Section 5 discusses and concludes.

14.2 Reported emissions

Table 14.1 gives the data on emissions of F-gases as reported to the UN-FCCC in the NIR 2001 (Olivier et al., 2001). The table shows also the GWPs for the various F-gases that must be used to quantify the emissions in CO_2-equivalents. Table 14.2 shows the emissions by IPCC source category and in terms of ktonne CO_2-equivalents.

The origin of emission of unspecified PFCs is chip manufacturing. This activity is also a source of SF6 emissions, together with the use of SF6 in high-power switches (*vermogensschakelaars)*.

14.3 Origins of information, Emission model and uncertainties

14.3.1 Introduction

This section summarises the methodologies to assess the emissions for each of the source categories mentioned in Table 11.1. Also the uncertainties are indicated that are used in the calculation. The general emission model is (See also Section 7.3):

The information in the NIR 2001 was captured by the following simple emission model.

$$Emission_{1999} = Efact_{1995} \;\; Aindex \;\; Afactor_{1995-1999}$$

Where $Efact_{1995}$ = "Emission factor" for 1995

$Aindex$ = Activity index (=1 for base year)

$Afactor_{1995-1999}$ = Activity factor, which accounts for the change in activity between base year and 1999

The Emission factor is just 1995 emission divided by the 1995 index. The uncertainty in the Afactor is set at nil.

Table 14.1 Emissions (tonne) of F-gases by type of F-gas and source in 1995 and 1999.

	GWP values used		Alumin-ium pro-duction	HCF-22 produc-tion	Other from produc-tion	Indus-trial refrige ration	Mobile Air-condi-tioning	Foam blowing (hard foam only)	Other sources
HFC-23	11700	1995		536.0					
		1999		631.4					
HFC-125	2800	1995			19.7	4.3			
		1999			16.0	44.5			
HFC-134a	1300	1995			85.0	43.6	26.2	107.0	
		1999			14.2	108.8	116.4	532.0	
HFC-152a	140	1995			24.0				
		1999			0.0				
HFC-143a	3800	1995			6.2	3.1			
		1999			18.0	42.0			
Unspecified HCF	3000	1995				2.0			
		1999				16.2			
CF_4	6500	1995	223.0						
		1999	308.0						
C_2F_6	9200	1995	38.0						
		1999	51.0						
Unspecified PFC	8400	1995							8.1
		1999							14.1
SF_6	23900	1995							7.3
		1999							5.7

Table 14.2 Emission of F-gases in CO_2-eq and by source categories. From CRF files.

Source category	1995	1999
HFC-23 emissions from HCFC-22 manufacturing	6,464	7,387
Other CFC emissions from manufacturing	193	132
Emissions from substitutes for ODS: HFCs	260	1,317
PFC emissions from aluminium production	1,799	2,471
PFC emissions from PFC use	68	118
SF6 emissions from SF6 use	174	137
Total	8,765	11,562

We assign uncertainties to each 1995 emission and to each Act_factor (See Table 14.3). For the emissions in 1995 we adopt the tier-1 uncertainties in the EF as proposed by Olivier et al. (2001) in the NIR 2001, while the uncertainty in Act_factor is the corresponding uncertainty in AD (See Table 5.1 in the NIR 2001). The exception is the 1995 emission for SF6 gases where we adopted a triangular distribution. Below we discuss these assumptions.

The model implies that the structure of the uncertainties in the emissions for 1995 and 1999 are the same. In other words, the emissions in both years are fully correlated.

14.3.2 HFC-23 gases from HFC-22 manufacturing

This source refers to HFC-22 manufacturing (HFC-22 is a refrigerant and feedstock for the production of Teflon plastics) in the plant of DuPont in the city of Dordrecht. The information with respect to the emissions is from DuPont. The emissions are assessed from mass balances (Van Asselt et al., 2002). There is no information from DuPont about the uncertainty in the emission estimate. DuPont is the single manufacturer in the Netherlands and information on production volumes is confidential.

In their tier-1 uncertainty assessment Olivier et al. (2001) assumed a 15% uncertainty in the activity and a 25% uncertainty in the emission factor. This adds to an overall 29% uncertainty for the emission itself (for 1999). We note that the 1999 workshop on uncertainties in emission inventorying (Van Amstel et al., 2000, p.107) concluded that the HFC emissions "can be given with a margin of error of 5%".

Olivier et al. (2001) (p. 59) mention that in the period between 1995 and 1999 DuPont installed equipment for emission control[17].
So, one must assume that the increase in the emissions is not proportional to an increase in the production. Details, however, are unknown to us. In the calculation - next section - we assume that the uncertainty for both 1995 and 1999 emissions is 30% and normally distributed.

14.3.3 HFC-emissions from manufacturing of HFC-23

These emissions are recorded in the CRF Tabels under the heading "HFC emissions from manufacturing". For these emissions we assume the same uncertainties as for the emission of HFC-23 (above). 1999 emissions are a factor 0.684 more than 1995 emissions.

14.3.4 Aluminium production

There are two aluminium manufacturers in the Netherlands, Aldel in Delfzijl and Pechiney near Vlissingen. The precise annual total volumes of aluminium production are not available for reasons of confidentiality. The firms report PFC emissions within the framework of environmental accounts (at least Aldel). Formerly, the emissions were estimated with default emission factors, which were developed by the IPCC.

According to the conclusions of the 1999 workshop "emissions are well known and can be given with a margin of error of 5%" (Van Amstel, et al., 2000. p. 107). In the NIR 2001 Olivier et al. (2001) assume an uncertainty of 5% for the activity, while they assigned an uncertainty of 20% to the emission factor. The composite tier-1 uncertainty – in the emission – is then 21%.

In our Tier-2 uncertainty analysis we assumed also 20% uncertainty, normally distributed. This assumption is according to the estimates of the experts that were interviewed (Van Asselt, 2002). For the trend we assume that the uncertainties in the emissions for 1995 and 1999 have the same origin. In other words, the trend (difference in 1995 and 1999 emissions) is completely due to changes in production volumes.

14.3.5 PFC emissions from PFC use

There are various uses of PFCs (e.g. cleaning purposes) that result in emissions (in contrast with the origin of PFCs from the aluminium industry where PFCs are formed in the aluminium manufacturing process). Details about the use of PFC (for etching and cleaning) are not known. Chip manufacturing - Philips Semiconductors - is one of the sources of emissions. Emission from the manufacturing of semiconductor occurs at disturbances of the production process. So, emissions depend on the quality of the control of the production process.

The figure for this emission is based on information from KPMG and from the semiconductor industry. KPMG is the office that administers import and export of CFCs, and the sales of CFCs under the CFC action programme. KPMG cannot account for 10% of the net import. The share of the emission from semiconductor manufacturing in the total emission is not known (for reasons of confidentiality).

An alternative assumption for the uncertainty in the emission would be a lognormal (or skewed triangular) distribution. Such distribution would account for the possibility that the 10% unexplained consumption must be associated with emissions.

14.3.6 HFC emissions from ODS substitutes

Since the ban on the use of ozone depleting substances (ODS) under the Montreal protocol (1990), several substitutes for these chemicals (e.g. refrigerants, foaming agents, cleaning agents) have become available. These substance are also emitted are subject to control under the Kyoto protocol. These emissions are attributed to an aggregate source category called “HFC emissions from the use of ODS substitutes”.

The use and supply of HFCs is monitored by KPMG under the CFC covenant. KPMG collects information on the imports, exports and domestic sales of these substances. KPMG then provides data of annual supply of the different substances in stationary equipment to the *Emissie-registratie* (Pollutants emission Register). The KPMG information refers also to the supply of refrigerants[18]. Emissions of refrigerants are due to leaking from refrigeration equipment and losses during the handling of the refrigerant. Emissions are calculated with a vintage model from assumptions about the current stocks of refrigerants and leakage rates. Leakage rates may be assumed to depend on the year of construction and on the age of the equipment. This way, such emissions model can account for modern equipment being more tight and leaking less then older equipment.

Similar models are used for estimation of the leakage of HFC-134a from air-conditioning equipment in cars and to estimate emissions due to the use of HFCs in foam (PUR-foam) that is used in the construction industry.

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17 In 2000 additional efforts did reduce the emissions with about 50%.

18 Apparently it is not monitored to what extent supplied refrigerants are used to add to existing stocks that were depleted due to leakages. This would be a direct way to measure emissions from leakage.

Olivier at al. (2001) assess the tier-1 uncertainty in the emissions for this composite source category at 51%. This is the result of an assumed 10% in the 'activity' and 50% uncertainty in the "emission factor". Note that "activity" is actually a pseudo-activity.

A tier-2 uncertainty analysis would require assumptions on the uncertainties in the following parameters and variables (that would constitute a vintage emission model):

- Amounts of refrigerants (and foaming agents) each year put into new equipment by class of equipment;
- Leakage rates of these substance by class of equipment while, if relevant to leakage rates, taking account of age of the equipment (or type of foam);
- Assumptions of the lifetime of equipment;
- Assumptions on the fate of the ODS substitutes (recovery or release in the atmosphere) when the equipment is scrapped;
- An estimate of the initial stocks and leakage rates for those stocks.

According to the interview with the RIVM expert (Van Asselt et al., 2002), the uncertainty in leakage rates (or leakage rate) would be the most important factor to the overall uncertainty of the emission estimate.

We did not obtain the model and the data that underlie the model (KPMG information is confidential) and have to rely on the expert's opinion for an uncertainty assessment. Following the RIVM we assume a 50% uncertainty in the emission data (for 1995).

What about the uncertainty in the trend (percentage change in emission between the base year 1995 and the present year) according to the tier-2 uncertainty analysis? Without knowing the model and its parameters it is difficult to indicate the main factors.
Likely candidates would be:

- The leakage rates from earlier vintages and from the 'initial' stock. This depends heavily on the extent of correlation between leakage rates from 'old' and 'modern' stocks. An assessment would require insight in the arguing behind establishing leakage rates;
- The uncertainty in the initial stock (the assumption about the magnitude of the stock that was formed before KPMG started monitoring supply of refrigerants and foaming agents. However the supply of CFC134a started only in 1994. So is unlikely that its uncertainty will contribute much to the uncertainty in the trend.

In the period 1995-1999 emission increased by about 506%. In our model for the emission (See Section 14.3.1) the activity factor (1995-1999) has a value of 5,06.

14.3.7 SF6 emissions

High-voltage power switches are filled with SF6. This gas is emitted at filling, testing and scrapping of this equipment. Olivier et al. (2001) say that, because of there is evidence that not all sources are accounted for[19], the range of confidence in the emissions is –10% to +100% (they used 100% in their tier-1 uncertainty analysis – which not allows

[19] One of the sources not accounted for is from the use of SF6 in double glazing. A recent estimate (de Groot, 2000) is 161 ktonne CO_2-eq. This is of a similar order of magnitude as the emissions from power switches.

to account for asymmetric uncertainties). Following this notion we assume a triangular probability density function (pdf) with min-max of –10% and +100% for the emission in 1995. The emission in 1999 is 0.787 (uncertainty 100%) times the emissions of 1995.

14.3.8 Summary

Table 11.9 lists the assumptions about the pdfs for the 1995 emissions of F-gases and developments. Note that the "activity factors" have all been assigned a zero uncertainty (in order to avoid that the uncertainties in the 1999 emissions are higher than the uncertainties in the 1995 emissions).

Table 14.3 Variables and parameters for the calculation of uncertainties in 1999 emissions of F-gases.

Parameter		Pdf	Uncertainty (%)
"Emission factor" HFC-23 emissions from HCFC-22 manufacturing 1995 (ktonne CO_2-eq)	6464	Normal	25
1995 Activity index. HFC-23	1.00	Normal	15
Activity factor HCFC-22 production 1995-1999	1.14	Normal	0
"Emission factor" Other CFC emissions from manufacturing 1995 (ktonne CO_2-eq)	193	Normal	25
1995 Activity index. Other CFC manufacturing	1.00	Normal	15
Activity factor manufacturing other CFCs 1990-1999	0.68	Normal	0
"Emission factor" from the use of substitutes for ODS: HFCs 1995 (ktonne CO_2-eq)	260	Normal	50
1995 Activity index for use of OPS substitutes.	1.00	Normal	10
Activity factor ODS use 1995-1999	5.07	Normal	0
"Emission factor" PFC emissions from aluminium production 1995 (ktonne CO_2-eq)	1799	Normal	20
1995 activity index aluminium production	1.00	Normal	5
1995-1999 development in Al production	1.37	Normal	0
"Emission factor" PFC emissions from PFC use 1995 (ktonne CO_2-eq)	68	Normal	25
1995 activity index PFC use	1.00	Normal	5
1995-1999 developments in PFC use	1.74	Normal	0
"Emission factor" SF6 emissions from SF6 use 1995 (ktonne CO_2-eq)	225	Triangular	Min 124, Most likely 137, Max 2700
1995 activity index SF6 use	1.00	Normal	50
1995-1999 developments in SF6 use	0.79	Normal	0

14.4 Results

14.4.1 Emission in 1999

Figure 14.1 shows what the pdf the total 1999 emission looks like from the assumptions in Table 11.9. Total emissions is somewhere between 9.4 Mtonne CO_2-eq and 13.8 tonne CO_2-eq (95% confidence), with a mean of 11.6 Mtonne CO_2-eq.

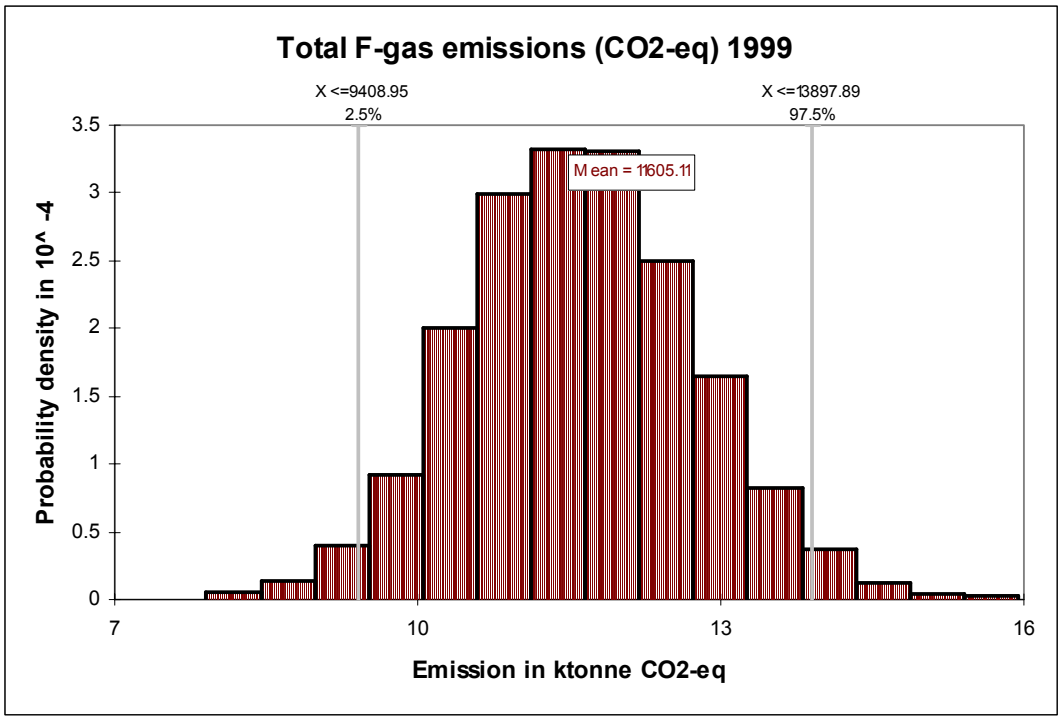

Figure 14.1 Probability density function (pdf) for the emissions of F-gases measured in CO_2-eq.

Table 14.4 shows that, not surprisingly - See Table 11.6 - the uncertainty in the HFC-23 emissions from HCF-22 manufacturing contributes most to overall uncertainty.

Table 14.4 The main factors that determine the uncertainties in the 1999 CFC emissions.

Variable	Standard B coefficient
Emission factor HFC-23 emissions from HCFC-22 manufacturing 1990	0.800
1995 Activity index. HFC-23	0.475
Emission factor from the use of substitutes for ODS: HFCs 1990	0.291
Emission factor PFC emissions from aluminium production 1990	0.214
1995 Activity index for use of OPS substitutes.	0.058
1995 activity index aluminium production	0.053
1995 activity index SF6 use	0.037
Emission factor SF6 emissions from SF6 use 1995 (ktonne C	0.032
Emission factor Other CFC emissions from manufacturing 199	0.016

14.4.2 Trend in emissions

The mean in the 1995-1999 trend is that emissions increased by 17%. Given the uncertainties as presented in Table 11.9 the range of confidence would be 3%-30%. The uncertainty in the developments with respect to emissions from HCH-22 manufacturing are most influential to this range of confidence (See Table 14.5).

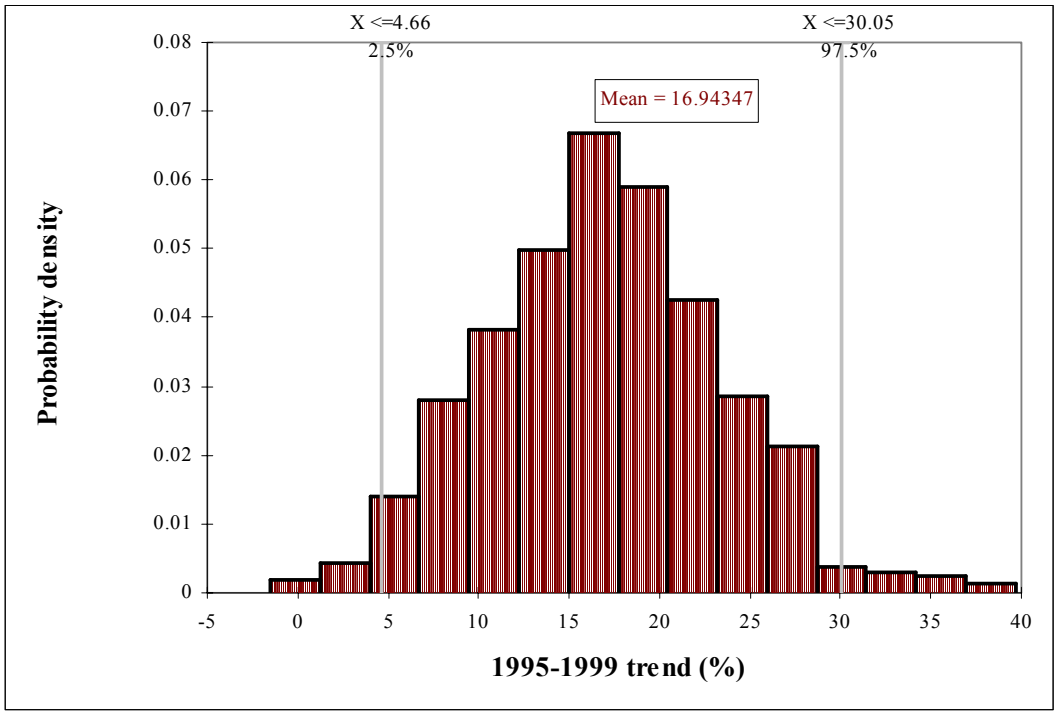

Figure 14.2 Pdf for the trend in the emissions of F-gases.

Table 14.5 The main factors that determine the uncertainty in the trend in 1999 CFC emissions.

Variable	Standard B coefficient
1995 Activity index. HFC-23	0.869
Emission factor from the use of substitutes for ODS: HFCs	0.4
Emission factor HFC-23 emissions from HCFC-22 manufacturing	-0.19
1995 Activity index for use of OPS substitutes.	0.105
1995 activity index aluminium production	0.098
1995 activity index SF6 use	0.071
Emission factor SF6 emissions from SF6 use 1995	-0.035
Emission factor PFC emissions from aluminium production 1995	0.023
Emission factor Other CFC emissions from manufacturing 1995	-0.023
1995 Activity index. Other CFC manufacturing	0.016
Emission factor PFC emissions from PFC use 1995	0.005

14.5 Discussion and conclusion

The uncertainty in the 1999 estimate of the emissions of F-gases (11.6 Mtonne CO_2-eq) is about 40%. The emissions constitute about 4%-6% of all greenhouse gas emissions (in 1999). The uncertainty is fairly high.

There is some additional uncertainty from the fact the emissions in NIR-2001 do not cover all sources. There is a study that identifies the magnitude of these underestimates (Groot, 200). This study identifies an SF6 emission of about 310 ktonne CO_2-eq., which is 3% of all emissions from this source category. Neglecting these emissions has little influence on overall uncertainty.

For the source category "F-gases" there is confidence in nature of the models that are use to assess the emissions. Uncertainty (among emission analysts) arises mostly from the lack of available measurements that are required to assess the values for variables (e.g. export of foaming agents) and parameters (e.g. rate of CFC leaking from refrigerating equipment). Measurements may not be available for two reasons. It could be that certain information (physical measurements or accounting data) is never measured, or it might be that the information is not available to the emission assessors for institutional reasons, for instance for reasons of confidentiality.

The uncertainty identified in the present study does not deviate significantly from results that would be derived with a tier-1 approach. This is since the structure of the 'emission model', the lack of correlations, and the estimates of the probability density functions make the outcome of the tier-2 analysis not different from a result of a tier-1 method.

14.6 Scope for reduction in uncertainty

Most influential to the uncertainty in the emissions is the HFC-23 emissions at the DuPont plant in Dordrecht (given the assumptions in Table 14.3). The primary sources for the emission data of this source are the environmental accounting reports (*Milieujaarverslagen MJV*). There is no requirement that reporting firms should present an uncertainty analysis.

Under NOVEM's programme to reduce other-than-CO_2 greenhouse gas emissions (*ROBklimaat programma)* there are activities to actually reduce the emissions of the DuPont plant by installing an incinerator. It might be that within the framework of this activity more information is developed that would be appropriate to allow better estimate uncertainties.

For an improvement of the estimate of the trend the focus would be on the reduction in uncertainty in the 1995 emission from the DuPont plant and on the emissions from new refrigerants. In both sectors there are major changes. HFC-23 emission will decrease since DuPont has installed emission abatement equipment after 1999. In contrast emissions from ODS-substitutes are on the rise.

Further reduction in uncertainties would require to contact the industries, or representative of the industry (e.g. KPMG), and ask for more information and for the possibilities to have more appropriate information available (See also Van Asselt et al., 2002).

Work to reduce uncertainty in emissions from source categories not covered by the NIR-2001 estimates is carried out. The first assessment (Groot, 2000) indicates that the emissions are small compared to the uncertainties in the emissions described above.

15. Discussion and conclusions

15.1 Introduction

Under the United Nations Framework Convention on Climate Change (UN-FCCC) countries must submit annually National Inventory Reports (NIR) of greenhouse gas emissions. These reports present annual accounts of a country's (net) emissions of greenhouse gases. The format of these accounts is prescribed by the UNFCCC: so-called Common Reporting Formats (CRF).

Emission inventories will be key indicators for determining compliance with the agreements under the Kyoto protocol. The protocol includes an obligation to apply *good practice* in the drafting of a NIR with reference to the work of the IPCC. *Good practice* ensures that an inventory is transparent, consistent, comparable, complete and accurate (TCCCA). *Good practice* is meant to ensure that these TCCCA criteria are being met.

The broad objective of the present study was to investigate the viability of a tier-2 uncertainty analysis, applied to the national greenhouse gas emission inventory, as submitted to the UNFCCC, in the Netherlands. Two major activities were undertaken to meet this objective.

The first body of work constituted the collection of information with respect to the various aspects of uncertainty in inventorying. Examples of such aspects are: (*i*) the uncertainties in the quantitative sense (probability density functions for every variable of the emission model), (*ii*) the possibilities to reduce these uncertainties, (*iii*) the underlying sources of these uncertainties. This information was collected by means of literature searches and conducting a series of structured interviews among experts in the area of emission inventorying. The goal of this series of interviews went beyond merely inventorying quantitative information; a major aim was to get insight into the experts' attitudes towards uncertainty in emissions. See van Asselt et al. (2002) for the results.

The second objective was to perform a tier-2 uncertainty analysis of the Dutch 1999 Emission inventory as submitted in the NIR 2001 (Olivier et al., 2001). The uncertainty estimate should comply with requirement as described in the IPCC GPGAUM guidelines (IPCC, 2000). Meeting this objective required the reconstruction (or modifying) of the model for current emissions (emission of 1999) and for the trend in emissions, that is the change in the 1999 emissions relative to the emissions in the base year. The structure of such model determines about what uncertainty information is required.

Part of the context of the work was the study of the quality management (QM) and quality control (QC) of the emission inventorying, which, in turn, is part of *good practice* in preparing National Inventory reports. Within this context the question was raised what the tier-2 uncertainty analysis can add to QA and QC, and, in a wider view, what the results of the analysis mean for the development of policies to reduce emissions of greenhouse gases in the Netherlands. Obviously, it makes sense to investigate whether information on uncertainties can help to further develop the current research programme on the reduction in climate change emissions (e.g. NOVEM's ROB (*Reductieplan Overige Broeikasgassen)*.

This concluding chapter has the following structure. First, we briefly summarise the results of the earlier tier-1 uncertainty analysis that was performed by Olivier et al. (2001) and to which the results of the present work is to be compared. Section 3 summarises the methodology, in particular the way the uncertainties of in CO_2 emissions from source category 1A are dealt with. Results of the calculation as they apply to total emissions are presented in Section 4. Section 5 provides a discussion of the results and compares with the results of the tier-1 uncertainty analysis. Section 6 presents recommendations.

Appended to this chapter is the list of references and finally an exhaustive list of all model variables (about 300) with their values and assigned uncertainties as used in the calculations of the uncertainties in the emissions.

15.2 The earlier tier-1 uncertainty analysis

Before discussing the results of the tier-2 uncertainty analysis, we summarise the earlier tier-1 uncertainty analysis of the emission inventory for 1999 and 1990 in Olivier et al. (2001). This analysis is summarised in Table 15.1, Table 15.2, Table 15.3 and Table 15.4. Table 15.1 summarises the emissions as presented in the NIR 2001 (hard copy, distributed in the summer of 2001). The last column gives the uncertainties for the 1999 emissions.

Table 15.1 Summary uncertainties of 1999 emissions according to the earlier tier-1 uncertainty analysis (NIR 2001, Olivier et al. 2001).

Greenhouse gas	Emission (kt CO_2-eq) 1990	Emission (kt CO_2-eq) 1999	Uncertainty* (%)
CO_2	161,169	174,124	3%
CH_4	27,134	21,705	25%
N_2O	19,997	22,690	33%*
F-gases	8,765	11,562	22%*
Total CO_2-eq.	217,065	230,082	4.4%

* Underestimates according to the authors.

In the period 1990-1999 total emissions increased by 6.0%. According to the tier-1 uncertainty analysis the uncertainty (in absolute terms) in the trend is 2.7% point (which corresponds with a relative uncertainty of about 60%).

Table 15.2 Summary uncertainties of 1990-1999 trend according to the earlier tier-1 uncertainty analysis (NIR 2001, Olivier et al. 2001).

Greenhouse gas emission in ktonne CO_2-eq.	Difference 1990 – 1999 (kt CO_2-eq)	1990-1999 trend* (%)	Uncertainty* (%)
CO_2	12,955	8.0%	2.9%
CH_4	-5,429	-20.0%	7.3%
N_2O	2,693	13.5%	11.7%
F-gases	2,797	32.9%	19.6%
Total CO_2-eq.	13,016	6.0%	2.7%

* Values are not rounded for reasons of arithmetic consistency; so, the number of digits does not reflect reliability.

Sensitivities. Table 15.3 and Table 15.4– See NIR 2001 - present source categories ranked by their contribution to the total uncertainty in the annual emissions and the trend (i.e. the relative change in emissions from 1990 to 1999). Such ranking may constitute core programmes to reduce uncertainties.

Comparison of Table 15.3 with Table 15.4 indicates that such programmes will be different, i.e. a programme that focuses on reduction in uncertainty in the reporting of annual emission data will be different from a programme that aims at a reduction in uncertainty in the emissions trend. For instance, according to this tier-1 analysis the uncertainties in the emissions from the source categories "CO_2 from Mobile combustion. Other" and "Emissions from stationary combustion: coal" are important to the trend, but they do not rank in the top ten of sectors that contribute to the uncertainty in the annual emission.

Table 15.3 Uncertainty in 1999 (as % of total national emissions in 1999) (NIR 2001, Olivier et al. 2001.)

IPCC	Source category		(%)
2	Emissions from nitric acid production	N_2O	2.5%
4D	Direct N_2O emissions from agricultural soils	N_2O	1.7%
6A	CH_4 emissions from solid waste disposal sites	CH_4	1.3%
4D	Indirect N_2O emissions from nitrogen used in agriculture	N_2O	1.3%
7	Polluted surface water	N_2O	1.1%
1A	Emissions from stationary combustion: gas	CO_2	1.0%
2	HFC-23 emissions from HCFC-22 manufacture	HFC	1.0%
7	Misc. CO_2	CO_2	0.9%
1A	Feedstock oil	CO_2	0.8%

Source: NIR 2001 (Olivier et al., 2001). The numbers in the last column give the absolute standard deviation in the emission of the source category divided by total emissions.

Table 15.4 Uncertainty as % into 1990-1999 trend in total national emissions (NIR 2001, Olivier et al. 2001).

IPCC	Source category		(%)
1A	Emissions from stationary combustion: gas	CO_2	1.5%
6A	CH_4 emissions from solid waste disposal sites	CH_4	1.0%
7	Misc. CO_2	CO_2	0.9%
1A	Mobile combustion: other	CO_2	0.8%
2	Emissions from nitric acid production	N_2O	0.8%
2	HFC-23 emissions from HCFC-22 manufacture	HFC	0.7%
1A	Emissions from stationary combustion: coal	CO_2	0.6%

Source: NIR 2001

Tier-1 uncertainty analysis is based on a number of assumptions. First, the method assumes that emissions are calculated with simple linear emission model:

$$Emission(t) = \sum_{i}^{k} Ef_i^k \cdot Act_i^k(t)$$

Where:

i = source category

k = greenhouse gas

Ef = emission factor

Act = activity factor

The second assumption is the different parameters and variables are not correlated. The third assumption is that (assumed) errors in the variables are normally distributed (i.e. the probability density functions that are assigned to emission factors and activities are normally distributed). As also remarked by Olivier et al (2001), these simplifications limit the robustness of conclusions with respect to uncertainty in emissions, in trends and in guidance for further research. Tier-2 uncertainty analysis allows treating less simple emission models that take into account correlations and probability density functions that are not normally distributed.

15.3 Tier-2 uncertainty analysis

15.3.1 Methodology

The first step in the approach was to specify the emission model as completely as possible within the framework of the study. The emission model –actually a series of independent models - should be understood as the set of primary data (variables and parameters that are mutually independent) and the calculation procedures that give the emissions from these data. We use the term primary data for the information that is used by the persons/institutions that actually produce the emission inventory[20].

The model was built from the information submitted to the UN-FCCC in the NIR 2001. In addition, we obtained underlying data, models and other information from institutions such as RIVM, CBS, TNO and Wageningen University.

The trend (base year – 1999) in the emissions is calculated as follows:

$$Trend = 100 * \frac{Emission(t) - Emission\left(t_{Base-year}\right)}{Emission\left(t_{Base-year}\right)}$$

Essential to the construction of the model is to avoid dependencies (or correlations) among variables and parameters. For instance, the sub-models that describe emissions from agriculture should take into account that the emissions of methane from enteric fermentation and from manure management are correlated via the number of animals. This correlation is not relevant for the calculation of the point values for the emissions. An uncertainty analysis of the trend that does not take account of this correlation gives too high uncertainties. Treatment of dependencies (or correlation) over time is especially

[20] These persons rely, in turn, on primary data from others (e.g., persons that develop information within firms), etcetera.

important for the trend analysis, due to questions with respect to correlations between emission factors for different years. For most model parameters (as opposed to model variables- See Chapter 2), it was assumed that the 1990 and 1999 values (e.g. of emission factors) were fully correlated (in other words, the ground for variability that underlies a probability density function (pdf) is not time dependent).

After establishing a correct emission model, the uncertainties must be assessed; in other words, pdfs have to be assigned to variables and parameters. Very few, if any, of these pdfs are based on actual measurements, nearly all are constructions from expert judgements. The pdfs were obtained from literature, from interviewing experts and a discussion on uncertainties in a workshop with experts (see Van Asselt et al, 2002). We relied also on our own judgement with respect to some uncertainties.

In general, the uncertainties of the input variables are in line with the uncertainties selected for the earlier tier-1 uncertainty analysis (Olivier et al. 2001). Only when new specific information was available (e.g. estimates of uncertainties in fuel use data from Statistics Netherlands) uncertainties deviate significantly from the earlier assumptions on uncertainties.

Eventually, the emission models comprised about 300 variables, for each of which uncertainties (pdfs) were established.

Given an appropriate emission model and pdfs for the variables and parameters of the model one can perform the calculations (i.e. simulations) with the help of appropriate software. We used @RISK software.

15.3.2 Construction of an emission model for source category 1A

The UN-FCCC asks for emission inventories in a specific format (Common Reporting Formats). This format, developed by the IPCC, distinguishes 7 headline source categories: Energy (1); Industrial processes (2); Solvent and Other Product use (3); Agriculture (4); Land Use change and forestry (5); Waste (6); and "Other" (7). Except for source category "Fuel Combustion Activities" (1A), it was possible to emulate the emission models. This source accounts for about 70% of all emissions. The approach taken to assess the uncertainty in these emissions is discussed below:

The emission attributed to source category "Fuel Combustion Activities" (1A) is assessed - in a concerted way - from two bodies of information:

- Emissions of individual companies as reported by these firms in the context of the Dutch Pollutants Emissions Register (PER-I) or in the context of covenants about environmental policies between the Dutch Governments and industry associations. This information relates to large sources only;
- The second body of information is the energy statistics for the Netherlands of published by the Statistics Netherlands.

The CO_2 emissions of PER-I companies account for about 40% of the CO_2 emissions of source category 1A (Van Amstel et al., 2000).

Within the present study, it was not possible to carry out an uncertainty analysis that takes account of uncertainties in the primary information underlying the emission inven-

tory (source category 1A, stationary sources). Such information is not available. Nevertheless, there are possibilities to approximate uncertainty in the total CO_2 emissions from source category 1A. These alternative uncertainty estimates are based on two observations: first, total CO_2 emissions correlates strongly with total fuel use, and, second, uncertainty in total fuel uses is relatively well known.

The first methodology is to assess the uncertainty in the CO_2 emissions, by type of fuel, as estimated by the reference approach. This is the approach taken in the earlier tier-1 uncertainty estimates (Olivier et al., 2001; Olivier et al., 2002). The present study uses a short-cut method to estimate the uncertainty in the outcome of national approach (which is the actual figure about the 1A emissions submitted to the UN FCCC). The emissions of source category 1A (but for transport emissions) is associated with national consumption of fuel as follows:

$$Em_{total}^{National} = A + Ef\left(\sum_i E_i + B\right)$$

$Em_{total}^{National}$	CO_2 emission as assessed according to the National Approach.
Ef	An average emission factor for fossil fuel (natural gas, "oil" or coal)
E_i	Consumption of fossil fuel by sector i according to Statistics Netherlands
A	The difference in fuel consumption as measured by Statistics Netherlands with the fuel consumption observed in the national approach. Some firms do report CO_2 emissions to the PER-I, but not the associated fuel use. In the CRF-tables (1A), such emissions are assigned to the fuel category "Other".
B	A correction factor that captures the information about emissions that is developed within the National approach and which is additional to the information used in the Reference approach. A captures for instance the knowledge – available to the agencies that are engaged in establishing the inventory - that some companies use natural gas with an emission factor that deviates from the average emission factor.

The factors A and B (which actually are assessed sector by sector) capture the information of the PER-I that is additional to the information in the energy statistics of Statistics Netherlands. Now, for 1999, the difference between $Em_{total}^{National}$ and $Em_{total}^{Reference}$ (where $Em_{total}^{Reference} = Ef\left(\sum_i E_i\right)$) is only a few percent (for gas and coal) and about 24% for liquid fuels (or 8%, if liquid fuels and "other fuels" are taken together; See Table 15.5). So the uncertainty in $Em_{total}^{National}$ is to a large extent determined by the uncertainty in $Em_{total}^{Reference}$, of which the uncertainty depends in turn on uncertainties in energy use and average emission factors. If the information submitted to the PER-I is reliable, the uncertainties in A and B must be low, say a few percent. In the present calculations these uncertainties were assumed to be 2%, except for oil and gas consumption in 1990.

Uncertainties in these emissions were assumed to be 3%. This difference (see Table 3.12and Table 4.8) reflects improvements in procedures for emission estimations in the period 1990-2000[21].

Table 15.5 Table 1A(c) of the NIR 2001 (Olivier et al., 2001).

Fuel types	Reference approach		National approach		Difference	
	Energy consumption (PJ)	CO_2 emissions (Gg)	Energy consumption (PJ)	CO_2 emissions (Gg)	Energy consumption (%)	CO_2 emissions (%)
Liquid Fuels (excluding international bunkers)	1,038.00	56,338.04	651.80	45,265.29	59.25	24.46
Solid Fuels (excluding international bunkers)	316.00	30,400.85	221.00	30,459.20	42.99	-0.19
Gaseous Fuels	1,450.00	80,591.65	1,406.45	78,964.75	3.10	2.06
Other			31.36	15,929.35		
Total	2,804.00	167,330.53	2,310.61	170,618.58	21.35	-1.93

15.3.3 IPCC source category 1A and feedstock emissions

The 1A key source categories that are assessed in the NIR of the Netherlands differ from the potential source categories that are distinguished by the IPCC (IPCC, 2000) and that are part of the Common Reporting Format (CRF). While the CRF refers to source categories "CO_2 emissions from stationary use of fuels", the NIR makes a distinction between "use for combustion" and " use as feedstocks". The latter source category, for each type of fuel, refers to the CO_2 emissions that are associated with, respectively, the use of natural gas, liquid fuels and coal as feedstocks.

These emissions were assessed - for the 1999 inventory - as follows (Olivier et al., 2001). (See Section 3.3 for an example). A first order estimate is made from statistical data of Statistics Netherlands (CBS) about the uses of fuel as a feedstock, the default emission factor for a specific fuel, and an assumption about the fraction of carbon in feedstock which is embodied in the final product (and presumed not to be emitted into the atmosphere). These estimates (from information in Table 1A(c) and Table 1A(d) of the CRF tables) are considered as first order estimates.

Detailed – firm level - insights in the origins of CO_2 emissions obtained by the inventorying agency that processes firm level information with respect to CO_2 emissions and fuel use, led to the suggestion that the first order estimate emissions are underestimates of feedstock associated emissions. Olivier et al. (2001) assumed that the difference between the emission estimates according to the RA and NA method (See Table 3.1 and Table 3.5) is because of this underestimation in the emissions from the use of gas and liquid fuels as feedstocks. Therefore, Olivier *et al*. (2001) heightened the first order estimates of feedstock emissions with the difference between the RA and NA emissions.

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[21] An important change in the data collection process occurred in the period 1998-2000. In 1998, the PER-I comprised emission data of 550 firms, while for 1999 the corresponding number was 192. For 2000, the number is 316.

This difference was allocated to "emissions from natural gas feedstock" and "emission from liquid fuels as feedstocks" according the proportion of total use of natural gas and total use of liquid fuels (in stationary sources). Table 15.9 gives, as an example, the details of the allocation procedure.

Table 15.6 Allocating the difference between RA and NA emissions to feedstock emissions.

	1990	1999
Difference emissions (kt CO_2) according to Reference and National approach	873.36	3,263.80
Share of gas feedstock emission in all feedstock emissions	52.5%	35.4%
Allocation of the RA-NA difference to gas feedstock emission	458.82	1,153.89
Allocation of the RA-NA difference to liquid feedstock emission	414.53	2,109.92

So, in the present tier-2 uncertainty analysis the emissions from feedstocks and combustion are determined by allocating total emission – from the use of fuel – over source categories "feedstock" and "combustion". As a result the uncertainties in these emissions are correlated.

15.3.4 Methodology of sensitivity analysis

An important question is: "how can the uncertainty be reduced?" An analysis of the sensitivity of total uncertainty to the uncertainties in the variables and parameters gives a first clue of the answer. Such analysis is also performed by the software. The sensitivity analysis produces a list of variables and parameters ranked by their so-called **Standard B coefficients.** Such a coefficient reflects the sensitivity of the output to a change of the input, normalised by their respective standard deviations. For instance, a Standard B coefficient of 0.35 assigned to a certain emission factor says that one standard deviation unit increase in this factor increases the emission by 0.35 standard deviation units. These coefficients are found with multi-variate regression analysis.

We note that tier-2 uncertainty analysis does not address model (or systemic) uncertainty. Tier- 2 analysis might only give some circumstantial evidence about model uncertainty. For most of the emission inventory (CO_2 emissions, F-gas emissions[22], i.e. for about 80% of all emissions), however, there is confidence in the emission models. Model uncertainty is probably most important in the area of N_2O emissions from agriculture and methane from waste.

[22] Model uncertainty implies that sources somehow have been identified and incorporated in the emission inventory. Recently, new, sources of emission of F-gases were identified (*e.g.* SF6 from glazing). These emissions, however, are small (Groot et al., 2000).

15.4 The tier-2 uncertainty analysis. Overall results

15.4.1 Introduction

This section gives the result of the tier-2 uncertainty analysis as applied to the sum of all emissions and on the trend in total emissions. Results at the detailed level (by source category) are in the separate chapters.
We present the result of the analysis of the 1999 emission estimate and the uncertainty in the trend of the emission. For the trend, we also made a calculation with alternative assumptions on some key uncertainties (sensitivity analysis). Section 15.5 compares the outcomes with the results of the earlier tier-1 uncertainty analysis (Olivier et al. 2001). The appendix of this report gives an exhaustive list of all the assumptions on the uncertainties that are behind the calculations. Alternative suggestions for uncertainties are welcome.

15.4.2 Total greenhouse gas emissions and uncertainties by key source category.

Table 15.7 gives an overview of the 1999 emissions and their uncertainties according to the present analysis by key source categories as these were identified by Olivier et al. (2001). Table 15.8 presents the summary outcomes in the analysis of the uncertainty in total emission of greenhouse gas emissions for 1990 and 1999.

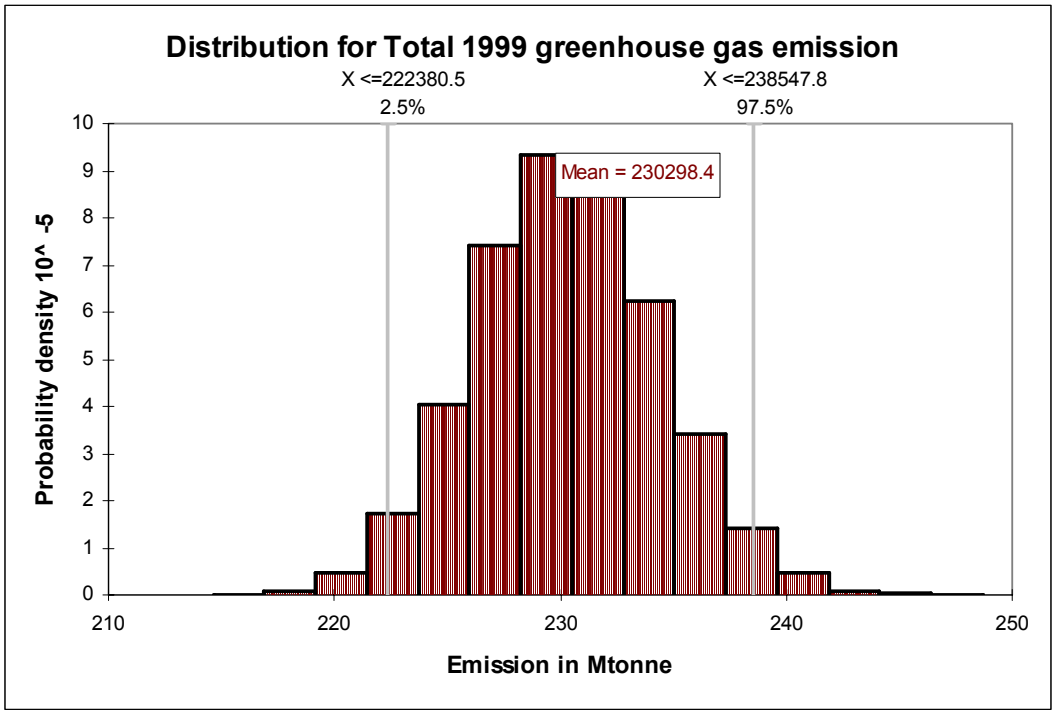

Figure 15.1 Probability density of greenhouse gas emissions 1999.

Figure 15.1 shows the graph of the resulting probability density function of the total of greenhouse gas emission for 1999. For the assumptions on the pdfs of all input variables we refer to the preceding chapters.

For 1999, the uncertainty in total emissions (230 Mtonne) is **3.6%**; the range of 95% confidence is from 222 Mtonne to 238 Mtonne. This uncertainty is lower than the earlier (tier-1) uncertainty estimate (4.4%) by Olivier et al (2001) in the NIR 20001. Section 15.5 discusses the difference.

Table 15.7 1999 emission and tier-2 uncertainties.

		Gas	Tier-2 EM. Unc.	Emission (Gg CO_2 eq.)
1A	CO_2	Emissions from stationary combustion: gas	2.4%	72463
1A	CO_2	Emissions from stationary combustion: oil	13.9%	20560
1A	CO_2	Emissions from stationary combustion: coal	1.3%	29962
1A	CO_2	Mobile combustion: road vehicles	2.1%	31111
1A	CO_2	Mobile combustion: water-borne navigation	31.0%	877
1A	CO_2	Mobile combustion: aircraft	100.3%	420
1A	CO_2	Mobile combustion: other	29.6%	2291
1A	CO_2	Feedstock gas	10.3%	6501
1A	CO_2	Feedstock oil	57.6%	5911
1A	CO_2	Feedstock coal	11.1%	400
2	CO_2	Emissions from cement production	10.9%	376
2	CO_2	Other industrial: CO_2	20.9%	1408
7	CO_2	Misc. CO_2	53.3%	1723
		Total CO_2 emission (CO_2-eq.)	**1.6%**	**174017**
1A	CH_4	Emissions from stationary combustion: non-CO_2	50.3%	532
1A	CH_4	Mobile combustion	38.9%	96
1B	CH_4	Fugitive emissions from oil and gas: gas production	24.9%	1723
1B	CH_4	Fugitive emissions from oil and gas: gas distribution	47.4%	1306
2	CH_4	Other industrial: CH4	50.6%	52
4A	CH_4	CH4 emissions from enteric fermentation: cattle	12.7%	6347
4A	CH_4	CH4 emissions from enteric fermentation: swine	50.8%	427
4A	CH_4	CH4 emissions from enteric fermentation: sheep	30.5%	235
4A	CH_4	CH4 emissions from enteric fermentation: other	22.5%	275
4B	CH_4	Emissions from manure management: cattle	72.4%	766
4B	CH_4	Emissions from manure management: swine	102.1%	926
4B	CH_4	Emissions from manure management: poultry	103.7%	200
4B	CH_4	Emissions from manure management: other	97.8%	14
6A	CH_4	CH4 emissions from solid waste disposal sites	31.9%	8562
6B	CH_4	Emissions from wastewater handling	31.5%	80
7	CH_4	Misc. CH4	31.9%	41
		Total CH4 emission (CO_2-eq.)	**14.6%**	**21578**
1A	N_2O	Emissions from stationary combustion: non-CO_2	n.a.	145
1A	N_2O	Mobile combustion: road vehicles	62.6%	1629
1A	N_2O	Mobile combustion: other	97.9%	226
2	N_2O	Emissions from nitric acid production	43.0%	11324
4B	N_2O	Emissions from manure management	69.3%	202
4D	N_2O	Direct N_2O emissions from agricultural soils	57.2%	6263
4D	N_2O	Indirect N_2O emissions from nitrogen used in agriculture	90.6%	1690
6B	N_2O	Emissions from wastewater handling	54.1%	164
7	N_2O	Polluted surface water	216.0%	1169
3	N_2O	Solvent use/ Misc. N_2O	72.4%	155
		Total N_2O emission (CO_2-eq.)	**29.3%**	**22933**
2	HFC	HFC-23 emissions from HCFC-22 manufacture	28.9%	7519

2	HFC	Emissions from substitutes for ODS substitutes: HFC	52.5%	1317
2	PFC	PFC emissions form aluminium production	20.8%	2471
2	PFC	PFC emissions from PFC use	25.4%	118
2	SF6	SF6 emissions from SF6 use	65.0%	177
		Total F-gas emission (CO_2-eq.)	**20.0%**	**11602**

Table 15.8 Outcomes of the tier-2 uncertainty analysis of the all greenhouse gas emission.

	1990 emission (ktonne)	1999 – emission (ktonne)	1990 -1999Trend (%)
Minimum	204425.8	214627.6	1.083714
Mean	**217587.7**	**230298.4**	**5.848684**
Maximum	232764.7	248670	12.81653
Std Dev	3718.989	4097.156	1.303093
Variance	1.38E+07	1.68E+07	1.698052
Uncertainty*	**3.42%**	**3.56%**	**44.56%**

* The numbers are given in detail. This is for reasons of arithmetic consistency only, and not to suggest quantitatively preciseness.

Which of the assumed uncertainties in the input variables of the emission model contributes most to the uncertainty in the total emission? Table 15.9 gives an indication. Uncertainties in N_2O emissions are most important to the total. Nearly half of the variables in the table refer to N_2O emissions.

Important to the emissions of Source category 1A are the CO_2 emissions from the use of oil products, (as incorporated in the factor B), and the final use of oil and oil products by refineries. The latter uncertainty is estimated by Statistics Netherlands. It might be that within the PER-I scheme there is information that would warrant to attach a lower uncertainty to the value for use of fuels. The uncertainty in the export of Natural gas ranks also high. Although the relative uncertainty in the export of Natural gas is low, (0.5%) the absolute uncertainty is high because of the high volume of gas export.

It strikes that uncertainty in the 1990 emissions (3.4%) is less than the uncertainty in the 1999 emission (3.6%). This is mainly due to the contribution of high uncertainty in the 1999 N_2O emission from manure management. The uncertainty in this emission ranks second in the outcome of the sensitivity analysis. For the 1990 emission, this source category is less important. So, this uncertainty compensates more than for the higher uncertainties in fuel use that were assumed for 1990.

Table 15.9 Sensitivity of the 1999 greenhouse gas emissions to inputs of the emission model. Sensitivity in Standard B coefficients (if >0.050).

Variable	Standard B coefficient
1990 Emission Nitric acid production (ktonne N_2O)	0.592
Emission factor manure/slurry injected/incorporated on the fields (N_2O)	0.409
Polluted surface water. Efactor (kg N_2O per kg N)	0.286
HFC-23 emissions from HCFC-22 manufacturing 1995 (ktonne CO_2eq)	0.225
Fraction of organic carbon reacting to gaseous material / Methane landfills	0.183
Measured gross emission grassland (mineral) (kg N ha-1yr-1) (N_2O)	0.161
Emission factor (as N) from use of fertiliser (N_2O)	0.157
Consumption of oil Refineries (PJ) 1999	0.147
Export of natural gas 1999 (PJ)	-0.145
B 1999 oil & oil products (PJ)	-0.14
Activity HCFC-22 manufacturing relative to 1995	0.137
Fraction of methane oxidised in top layer (Methane from landfills)	-0.133
Emission factor per tonne manure (swine) / Methane	0.115
Fraction of carbon reacting to methane (instead of to CO_2). Landfills	0.105
Organic C content of waste which is landfilled (kg/tonne) <1990	0.1
1990 Misc. CO_2 emission (ktonne)	0.098
Average emission factor 1999 (kt/PJ) (CO_2 natural gas)	0.098
Other consumers oil products 1999 (PJ)	0.089
N_2O emission factor diesel in road (g/GJ) 1990 / N_2O	0.088
Methane EF Dairy cow / Emission factor (kg/head/year)	0.086
N_2O emission factor petrol road (g/GJ) 1999 / N_2O	0.085
Emissions from substitutes for ODS: HFCs 1995 (ktonne CO_2-eq)	0.083
Methane emission factor (1990) distribution of natural gas	0.076
Production of natural gas 1999 (PJ)	0.075
PFC emissions from aluminium production 1995 (ktonne CO_2-eq)	0.059
Ef per tonne manure (dairy cattle) / methane	0.056

Table 15.10 Sensitivity of the 1990 greenhouse gas emissions to inputs of the emission model. Sensitivity in Standard B coefficients (if >0.050).

Variable	Standard B coefficient
1990 Emission Nitric acid production (ktonne N_2O)	0.554
Polluted surface water. Efactor (kg N_2O per kg N)	0.317
Fraction of organic carbon reacting to gaseous material / Methane landfills	0.257
Organic C content of waste which is landfilled (kg/tonne) <1990	0.251
Domestic consumption of oil & oil products 1990 (PJ) / CO_2	0.234
HFC-23 emissions from HCFC-22 manufacturing 1995 (ktonne CO_2-eq)	0.218
Total consumption natural gas 1990 (PJ) (CBS) Based on 1999 uncertainty	0.205
Fraction of methane oxidised in top layer landfills	-0.204
Emission factor manure/slurry on mineral soils (%N), if spread. N_2O	0.182
Measured gross emission grassland (mineral) (kg N ha-1yr-1). N_2O	0.179
Emission factor (as N) from use of fertiliser. N_2O	0.176
Fraction of carbon reacting to methane (instead of to CO_2) (landfill)	0.16
Emission factor per tonne manure (swine) / Methane Emission factor	0.142
B 1990 oil & oil products (PJ) CO_2	-0.136
Methane EF Dairy cow / Emission factor (kg/head/year)	0.104
Methane emission factor (1990) distribution of natural gas (kt/PJ)	0.104
Average emission factor 1999 (kt/PJ) CO_2 Natural gas	0.09
Emission factor in urine (share of N turned into N_2O) / 1990	0.07
Ef per tonne manure (dairy cattle) / Methane	0.07
N_2O emission factor diesel in road (g/GJ) 1990 / N_2O	0.068
N_2O emission factor petrol road (g/GJ) 1990 / N_2O	0.068
Measured gross emission arable land (kg N ha-1yr-1) / Background (N_2O)	0.062
Methane emission factor production and processing of natural gas	0.059
Emission factor manure/slurry on organic soils(%N), if spreaded (N_2O)	0.056
Average emission factor 1990 (kt/PJ) liquid fuels (CO_2)	0.054
PFC emissions from aluminium production 1995 (ktonne CO_2-eq)	0.053

15.4.3 The trend in greenhouse gas emissions

Figure 15.2 shows the probability density function of the trend in the emissions (the percentage change of 1999 emissions relative to the emissions in the base year(s).

Total emission increased with **5.8%**, with 90% confidence bounds of 3.5%- 8.6%. In other words, the relative uncertainty in the trend itself is **45%**. This range of confidence is similar to the trend uncertainty found in the comparable studies for the UK, Norway and Austria (Rypdal and Winiwarter, 2001). This uncertainty in the trend is similar to the uncertainty in the trend (i.e 2.6% point) according to the tier-1 uncertainty analysis of Olivier et al. 2001.

Table 15.11 shows to what uncertainties in the input variables the uncertainty in the trend is most sensitive. On top of the list, rank the emission factors for N_2O emissions from the use of manure. Although the emission from this activity (Emissions from animal wastes applied to soils) is only minor (0.8% and 1.4% of all emissions in 1990 respectively 1999), it is important to the trend for two reasons.

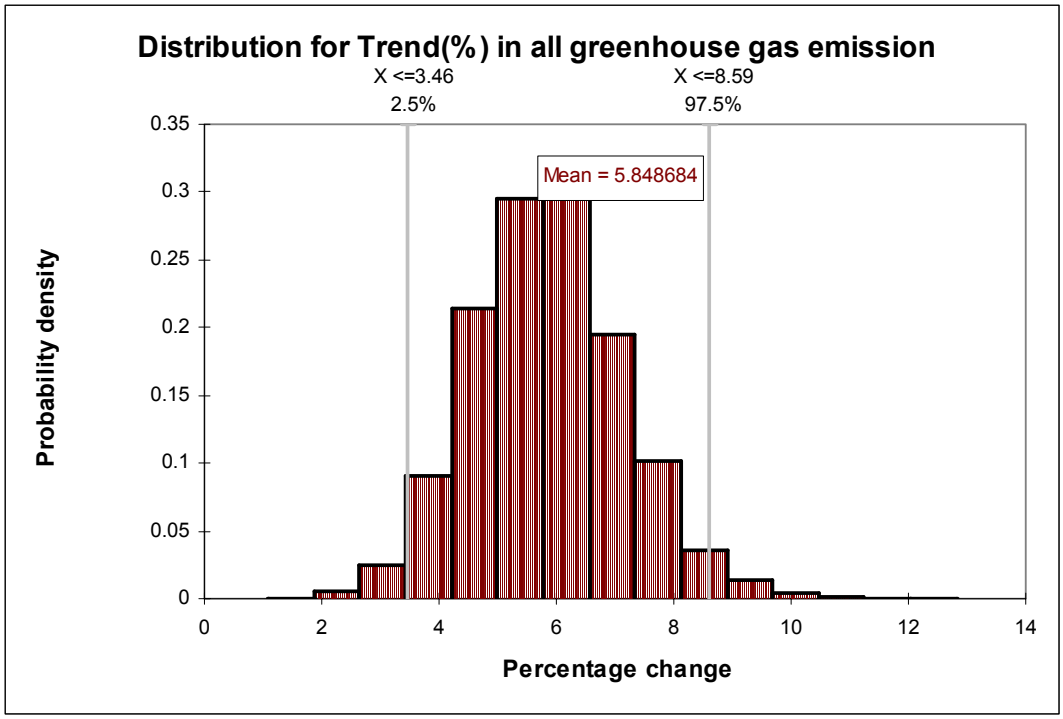

Figure 15.2 Probability density function of the 1990/1995-1999 trend (%) in greenhouse gas emissions.

First, the uncertainty in the emissions factors are high, second, we have assumed that the uncertainties in both factors are not correlated.

Energy consumption in 1990 ranks also high on the list. This is because of the high uncertainty (in the absolute sense) in energy consumption, which has a significant impact on overall uncertainty. The uncertainties in fuel use were also assumed not to correlate over time.

15.5 Discussion

15.5.1 Total emissions and trend. Comparison with NIR 2001 data

Total 1999 emissions as reported to the UN-FCCC in the CRF files (Table 10) of the NIR 2001 is 230 Mtonne CO_2 eq. The outcome of the present calculation is also 230 Mtonne CO_2-eq. There are three minor differences though that, however, nearly compensate.

- Our 1999 methane emissions from waste disposal are slight lower. The emissions for 1990 are the same;
- Our indirect N_2O emissions from agriculture are higher;
- Emissions from poultry are included in the present model.

The small differences explain that the trend according to the present model is 5.8% instead of the 6.1%[23] increase as is reported in the NIR 2001 (Olivier et al., 2001).

Table 15.11 Sensitivity of the 1999 trend in greenhouse gas emissions to inputs of emission model. Sensitivity in Standard B coefficients (if >0.05).

Variable	Standard B coefficient
N_2O Emission factor manure/slurry injected/incorporated on the field	0.584
Domestic consumption of oil & oil products 1990 (PJ)	-0.328
Total consumption natural gas 1990 (PJ) (CBS) Unc. based on 1999 unc.	-0.284
N_2O Emission factor manure/slurry on mineral soils (%N), if spreaded	-0.246
Consumption of oil Refineries (PJ) 1999 /	0.221
Export of natural gas 1999 (PJ) / (Gg)	-0.21
Organic C content of waste which is landfilled (kg/tonne)	-0.208
B 1999 oil & oil products (PJ)	-0.207
Activity HCFC-22 manufacturing relative to 1995	0.19
B 1990 oil & oil products (PJ)	0.167
Other consumers oil products 1999 (PJ)	0.129
N_2O emission factor petrol road (g/GJ) 1999	0.124
Production of natural gas 1999 (PJ) / (Gg)	0.114
N_2O emission factor petrol road (g/GJ) 1990	-0.103
Emissions from substitutes for ODS: HFCs 1995 (ktonne CO_2-eq)	0.095
Fraction of methane oxidised in top layer of landfill	0.094
1990 Emission Nitric acid production (ktonne N_2O)	0.089
Fraction of organic carbon reacting to gaseous material	-0.088
1990 Misc. CO_2 emission (ktonne)	0.083
N_2O Emission factor manure/slurry on organic soils (%N), if spreaded	-0.079
Average emission factor 1990 (kt/PJ) liquid fuels CO_2	-0.071
Fraction of carbon in waste reacting to methane (instead of to CO_2)	-0.069
Total Diesel consumption in transport (TJ) 1990 / 1990	-0.067
Domestic consumption of coal & coal products 1990 (PJ)	-0.066
Industry liquid fuels 1999 (PJ)	0.061
Activity factor Misc. CO_2 (1990-1999)	0.061

15.5.2 Tier-1 and tier-2 uncertainty in emissions

Table 15.12 compares our uncertainties in emissions with the earlier estimates by type of greenhouse gas. The table shows that the uncertainty in the total of the emissions is different: 3.6% according to the present analysis versus 4.4 % to the earlier tier-1 uncertainty analysis. These differences are the composite result of:

- The availability of more detailed figures for the uncertainties in energy consumption;
- Differences in the models (the tier-1 uncertainty analysis of the 1A emissions relates to CO_2 emissions according to the reference approach);

[23] Table 10s5 (NIR 2001) says greenhouse gas emissions (without CO_2 from LUCF) increased from 216842 Gg CO_2-eq in the "base year" to 230081 Gg CO_2-eq in 1999 (6.1%).
Our numbers are: 217588 Gg and 230298 Gg CO_2-eq.

- Taking account of dependencies (correlations) in the tier-2 method;
- Other than normal distributions (pdfs) being incorporated in the tier-2 uncertainties;
- Some difference in the uncertainties assigned to some variables (when comparable).

Table 15.12 Comparison of uncertainties (2σ) according to the earlier tier-1 and the present tier-2 analysis. Emissions for 1999.

Greenhouse gas	Tier 1 uncertainty*	Tier 2-uncertainty
Carbon dioxide	2.7%	1.6%
Methane	17%	14.6%
Nitrous oxide	35%	29.3%
F-gases	20%	20.0%
Total	4.4%	3.6%

Recalculated from Table 5.1 of the NIR 2001. The NIR 2001 itself presents the rounded figures.

A question is to what extent differences are due to new and additional numerical information or due to the simplifying assumptions that underlie the tier-1 uncertainty analysis (*i.e.* neglecting correlation/dependencies and assuming all error normally distributed). In order to identify the impact of the methodological simplifications we performed the following analysis. For each of the source categories the activities (activity in the tier-1 emission model) were identified and their uncertainties (percentages). Then, for each of the source categories, (implied) emission factors were calculated and their uncertainties assessed (applying the Monte Carlo method). In this way a series of uncertainties (percentages) were obtained for "activity data" and (implied) emission factors, in the format that is used in the tier-1 uncertainty analysis. These data can be used to reassess tier-1 uncertainties of "emission factors" and "activity data". In a few cases it is not possible to identify "activity data" (e.g., indirect N_2O emissions from agriculture).

The effects of taking account of correlations and non-normally distributed emissions on the uncertainty of total emissions follows from comparing tier-2 uncertainties of totals, with uncertainties of totals calculated from uncertainties in key source emissions applying the tier-1 methodology to assess uncertainties in totals (law of error propagation).

Table 15.13 gives an example for the emissions of CO_2 only. Applying the tier-1 methodology results in an uncertainty for total CO_2 emissions of 2.7%. The tier-2 approach, however, gives 1.6% uncertainty. So, the tier-1 method gives a substantially higher uncertainty, for CO_2 emissions. Since almost all error in the CO_2 emissions – see for exception Table 6.6. - are assumed to be normally distributed, this difference must mainly be due to the correlation between the emissions from stationary combustion and feedstock emissions, which is neglected in the tier-1 approach.

For the other gases - See Table 15.12 - the differences are less striking. Differences are due to correlation (e.g. emissions from enteric fermentation and manure management are correlated) and to the use of other than normal probability density functions (e.g. log-normal distributions for some N_2O emissions).

Table 15.13 Emulation of a tier-1 uncertainties based on tier-2 uncertainty analysis. CO_2 emissions (See Table 15.5 for the other greenhouse gases).

Source category	Activity unc.	Implied emission factor unc.	Tier-2Emission unc.	Emission (ktonne)
Emissions from stationary combustion: gas	2.4%	3.3%	2.4%	72463
Emissions from stationary combustion: oil	17.0%	20.0%	13.9%	20560
Emissions from stationary combustion: coal	0.6%	1.1%	1.3%	29962
Mobile combustion: road vehicles	2.0%	0.2%	2.1%	31111
Mobile combustion: water-borne navigation	31.0%	2.0%	31.0%	877
Mobile combustion: aircraft	100.4%	2.0%	100.3%	420
Mobile combustion: other	30.9%	1.4%	29.6%	2291
Feedstock gas	5.0%	9.5%	10.3%	6501
Feedstock oil	57.8%	77.9%	57.6%	5911
Feedstock coal			11.1%	400
Emissions from cement production	5.0%	9.9%	10.9%	376
Other industrial: CO_2	5.0%	20.1%	20.9%	1408
Misc. CO_2	19.5%	49.5%	53.3%	1723
Tier-1 total uncertainty			2.7%	174005
Tier-2 total uncertainty			1.6%	174005

For total emission one can say that applying the tier-1 uncertainty analysis would result in a total uncertainty that is overestimated by 20% (4.4% versus 3.6%).

Table 15.15 presents the data with respect to the other greenhouse gases.

15.5.3 Tier-1 and tier-2 uncertainties in the trend

The difference between 1990 and 1999 emissions corresponds with an increase in emissions (the trend) of 5.8% The NIR-2001 reports (p. 29 of Olivier et al. 2001) an increase in emissions of 6.1%. The differences in these trends are due to slight differences in the emission estimates for the emissions in the base year and 1999.

The 95% confidence range in the trend is 1.5% - 8.4%. This range is found while taking account of correlation between the parameter values for 1990/1995 and for 1999.
The distribution is apparently skewed; otherwise the trend (median of pdf) would have been 5.1%. Skewness is likely mainly due to the presence of lognormal pdfs for N_2O source categories (of which the errors are assumed not to be correlated).

Table 15.14 Emulation of a tier-1 uncertainties based on tier-2 uncertainty analysis. Other then CO_2 emissions.

		AD unc.	Implied Ef. Unc.	Tier-2 EM. Unc.	Emission (ktonne CO_2 eq.)
CH_4	Emissions from stationary combustion: non-CO_2	1.9%	50.3%	50.3%	532
CH_4	Mobile combustion: road vehicles	1.6%	38.8%	38.9%	96
CH_4	Fugitive emissions from oil and gas: gas production	1.0%	24.9%	24.9%	1723
CH_4	Fugitive emissions from oil and gas: gas distribution	5.0%	47.7%	47.4%	1306
CH_4	Other industrial: CH_4	10.1%	49.4%	50.6%	52
CH_4	CH_4 emissions from enteric fermentation: cattle	2.7%	12.3%	12.7%	6347
CH_4	CH_4 emissions from enteric fermentation: swine	5.0%	50.5%	50.8%	427
CH_4	CH_4 emissions from enteric fermentation: sheep	5.1%	30.1%	30.5%	235
CH_4	CH_4emissions from enteric fermentation: other	5.1%	22.2%	22.5%	275
CH_4	Emissions from manure management: cattle	2.7%	72.4%	72.4%	766
CH_4	Emissions from manure management: swine	5.0%	102.5%	102.1%	926
CH_4	Emissions from manure management: poultry	5.1%	103.8%	103.7%	200
CH_4	Emissions from manure management: other	4.3%	97.9%	97.8%	14
CH_4	CH_4 emissions from solid waste disposal sites	10.2%	33.8%	31.9%	8562
CH_4	Emissions from wastewater handling	20.0%	24.7%	31.5%	80
CH_4	Misc. CH_4	20.0%	24.6%	31.9%	41
	All CH_4			14.6%	21578
N_2O	Emissions from stationary combustion: non-CO_2			0.0%*	145
N_2O	Mobile combustion: road vehicles	2.0%	62.6%	62.6%	1629
N_2O	Mobile combustion: other	20.8%	95.4%	97.9%	226
N_2O	Emissions from nitric acid production	10.0%	40.0%	43.0%	11324
N_2O	Emissions from manure management	10.1%	68.4%	69.3%	202
N_2O	Direct N_2O emissions from agricultural soils	7.2%	56.4%	57.2%	6263
N_2O	Indirect N_2O emissions from nitrogen used in agriculture			90.6%	1690
N_2O	Emissions from wastewater handling			54.1%	164
N_2O	Polluted surface water	49.5%	205.9%	216.0%	1169
N_2O	Solvent use/ Misc. N_2O	49.7%	50.8%	72.4%	155
	All N_2O			29.3%	22933
HFC	HFC-23 emissions from HCFC-22 manufacture	15.0%	24.6%	28.9%	7519
HFC	Emissions from substitutes for ODS substitutes: HFC	10.0%	51.2%	52.5%	1317
PFC	PFC emissions form aluminium production	5.1%	20.1%	20.8%	2471
PFC	PFC emissions from PFC use	5.1%	25.9%	25.4%	118
SF6	SF6 emissions from SF6 use	4.9%	65.1%	65.0%	177
	All F-gases			20.0%	11602

* Not assessed.

Table 15.11 shows that the trend is sensitive to the estimates of the emissions from these source categories.

A calculation that did not take account of correlation and assumed that the pdfs for the base year emissions and the 1999 emissions were normally distributed resulted in a range of confidence of 0.8% - 12.5%.

15.5.4 Comparison with other studies

Rypdal and Winiwarter (2001) summarise and compare the few studies about uncertainties that have been performed (Winiwarter and Orthofer, 2000; Rypdal and Zhang, 2000; Charles et. al. 1998, Van Amstel et al. 1999). Of these, the studies of the emissions in Austria (Winiwarter and Orthofer, 2000) and Norway (Rypdal and Zhang, 2000) seem most comparable with our study. Their conclusions with respect the emissions are similar to ours: emissions of methane, NO_2 and F-gases are more uncertain than emissions of CO_2. Like us they also indicate that uncertainties in the trend are high. Rypdal et. al. (2001) report a tier-2 uncertainty (4-5 percentage points) in the trend in the emissions from Norway and Austria (although for 1990-2010 trend).

In addition, they conclude that large efforts are required to reduce the uncertainty in the trend. They also mention that reductions of these uncertainties in trends are necessary when compliance with the Kyoto protocol becomes a practical issue. For instance, problems may arise when new scientific insights in emissions would result in substantial changes in trend figures.

Rypdal and Winiwarter (ibid.) point at the emissions of N_2O, CH_4 and F-gases as the most uncertain ones, the ones to which research efforts should be directed. Our conclusion is also that emissions of these gases are most uncertain. However, we also conclude that reduction in these emissions will not greatly reduce uncertainty. For the Netherlands the bottleneck is the uncertainty in CO_2 emissions.

15.6 Recommendations

Having performed the tier-2 uncertainty analysis, the present research should draw conclusions with respect to the possibilities to improve the inventorying of greenhouse gases in the Netherlands.

15.6.1 Targeting the reduction in uncertainties

A major result of the tier-2 uncertainty analyses that have been performed are the calculations of the "Standard B coefficients" for the variables and parameters of the emission models as shown in Table 15.9 and Table 15.8. These lists can be seen as an additional justification and guidance for current research programmes that include research to better assess emissions (e.g. NOVEM's ROB programme).

The result of the present analysis points at a large uncertainty in the assessment of the changes in emissions.
This uncertainty is partly due to certain emission processes that have changed over the years (e.g., emissions from the application of manure). In order to reduce uncertainty in the trend of emissions research should also specifically pay attention to this type of base year emissions.

15.6.2 Who can reduce uncertainty?

The concepts that are used in uncertainty analysis rare taken from the fields of probability analysis, risk assessment and simulation modeling.

Researchers in these fields commonly distinguish three areas of uncertainty:

- Model uncertainty (or structural, or epistemic uncertainty);
- Parameter uncertainty (uncertainty in model parameters[24]);
- Uncertainties in variables (stochastic or aleatoric uncertainty, or 'natural' variability).

The "emission model" that is used for the inventorying is actually a series of independent models (e.g., the reference approach model, the model for enteric fermentation, models based on accounting information only (refrigerant CFCs)). Tier-2 and tier-1 uncertainty analyses do not address model uncertainty. Confidence in the models results not from (tier-2 type) uncertainty analysis but from, for instance, validation of models.

The model for the CO_2 emissions from combustion of fuel (simply carbon content of fuel times fuel consumption) is not disputed. For the emissions of methane and of N_2O, however, there is uncertainty in the models.

Reduction in model uncertainty. For the emission inventorying, model uncertainty is important in the assessment of N_2O emissions and, to a lesser extent, in the assessment of emissions of methane (e.g. from waste disposal sites) (See Van Asselt et al., 2002).

Model uncertainty can be reduced by scientific research. Such research is going on or is planned. NOVEM's ROB programme is an important framework for these activities. The areas of research are N_2O from vehicles[25], from agricultural activities and from nitrification processes in water and methane from waste disposal sites. The problems encountered in this scientific research relate mainly to financial resources and to scientific capacity to perform studies in these areas.

Since the same issues are relevant for other countries than the Netherlands, one might consider to seek international cooperation in this research.

Reduction in uncertainty in variables. The second type of uncertainty relates to mainly the statistical data that are fed into the models. The reduction in uncertainty in values for variables (and parameters) may also be hindered by resources, however, institutional hurdles are at least as important.

Much of these institutional hurdles refer to the legal context of annually collecting the statistical information. Of high importance is the information on energy production, demand and supply developed by Statistics Netherlands. This information is collected under the Economic Statistics Act (*Wet op de economische statistieken*) and the act on the implementation of the International Energy Programme (*Wet uitvoering Internationaal Energie Programma*). For the energy industries and for manufacturing industries Statistics Netherlands has a reasonable confidence in the results of the surveys, however, for non-manufacturing sectors (e.g. services sector) it is difficult to measure fuel consumption, and reliability is lower. Figures on trade in fuels are important for implementing the Reference approach of assessing the CO_2 emissions from fuel combustion. Uncertainty in import and export figures have a large impact on the uncertainties of net domestic

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[24] Parameters are variables that are invariant under for instance integration over time and space.

[25] The recent research referred to in the NIR 2002 (Olivier et al., 2002) was not timely available to the present study.

consumption. This is relevant to the Netherlands, since in this country there is a large import and export of oil and oil products.

As well as the legal framework related to energy statistics, there is the legal context within which industries report environmental data: the Environmental Management Act (*Wet Milieubeheer*). Under this fairly recent (1994) law about 300 firm[26]s – the most environmentally important ones – are required to prepare annual environmental reports[27]. Essentially, these firms must report only on their emissions of greenhouse gases. They are not obliged to report on fuel consumption, and also not on the uncertainties in their reported numbers. These reports are used to evaluate the environmental performance of these firms and to check compliance with environmental law and covenants. Content and format of these reports do not in general meet requirements (e.g., unambiguous definitions of survey items) for statistical processing of numerical information. This poses difficulties to the agencies engaged in emission inventorying (i.e. TNO, CBS and RIVM) since definitions and accounting schemes that are used in the different reports differ. In addition, formats and definitions may change over the years. This results in problems for the construction of time series data and the assessment of emissions in the base year (1990).

Related to this framework are the covenants between the government and groups of firms united in industry associations. In the implementation of these covenants there is often a role for an independent accountancy consultants to monitor and check compliance. For instance, under the CFC covenant, KPMG collects and processes information on the sales of CFCs. The emission inventory of CFCs draws partly from the information provided by KPMG.

A third legal framework refers to the statistical information on agriculture (e.g., number of livestock, manure production). Assessment of the emissions (N_2O, CH_4) from agriculture requires the number of animals and the production of manure. This statistical data is reliable compared to the information on emission factors. Good quality statistical data, however, is also required for 1990 in order to best estimate the trend in emission. The construction of relevant activity time series data back to 1990 may pose a problem. This is noted in the discussions for the preparation of the ROB-Agri programme.

Much of the information on which the emission inventory is based, is developed in a legal context and for specific administrative purposes, mostly in connection with environmental and energy policies. The format and content of the information that is submitted by firms to executive bodies is prescribed and geared towards specific needs stemming from these policies and not to the requirements of the NIRs. For instance, in these environmental accounts (MVJ) firms must report on emissions, but not on fuel consumption. To process this firms' information into the required information the inventorying agency has to use additional information. So there are two sources of uncertainty: uncertainty in the information that is submitted by firms, and uncertainty that stems from the processing of this information into formats required in the NIR.

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[26] The 1999 inventory covered 192 firms. This number rose to 381 for the 2001 inventory.

[27] MvT 17/11/1998 says that the costs of such report ranges from Dfl 50,000 for a semi-large company to DFl 200,000 for a large company. Total costs were estimated at Dfl 30-40 million.

Two different routes to reduce uncertainty are: (*i)* to increase the capacity to annually process the information from firms as it is produced and (*ii)* to call for, or legally require, firms to report in prescribed formats (for instance asking for uncertainties in the submitted information). The first route presumes that firms' information has much more content than is currently extracted by the inventorying agencies. This is not very likely, given the experience and expertise of these agencies. Therefore, most of the burden of action to reduce uncertainty will be on firms.

Reduction in uncertainty of parameters. Information on annual energy consumption is essential for inventorying of CO_2 emissions, but not sufficient. It is equally essential to have accurate information on the carbon content of fuels (i.e. the CO_2 emission factors). The energy firms likely have more precise information about this (heat of combustion and carbon contents) than available to the PER. A research effort is currently underway to improve the information in this area (Van Harmelen et al., 2002). The success of this research depends on the co-operation of the firms. There is no formal institutional (i.e. legal) framework for firms to provide this information on a regular basis. In the future, when more and more gas will be imported from different origins (Russia, Turkmenistan, North-Africa), knowledge on the different emission factors will become more and more important.

15.6.3 Annual tier-2 uncertainty analysis?

Uncertainty analysis is part of good practice in greenhouse gas inventorying. The IPCC guidelines state that "Uncertainty information is (..) intended (..) to help prioritise efforts to improve the accuracy of inventories in the future and guide decisions on methodological choice" (IPCC, 2000, Section 6.1). Methodological choice refers to the methods to establish emission inventories, to the identification of key source categories and to ensure that trends in national emissions are consistently estimated (IPCC, 2000, (Section 7.1).

It is unlikely that uncertainties will change quickly over the years. Ultimately, the uncertainty is based on expert opinions and these expert opinions are in turn based on long-term experience, on the availability of the results of scientific research or on established statistical surveys. It is possible that in some year such research and surveys will give new useful results. In fact, Statistics Netherlands did so recently with respect to the uncertainties in their energy statistics. In general, however, the development of new information is a task that takes years.

So, since the information on uncertainties improves only slowly, there seems no reason to repeat calculations of uncertainties every year (IPCC, 2000, p.8.5), since it is unlikely that conclusions of such repeated study will be substantially different from a preceding study.

15.6.4 Tier-1 or tier-2 uncertainty analysis. Costs

The TOR of the project asked "to assess which method would be preferable for the Netherlands and why". An answer requires an analysis of the costs of applying tier-1 and tier-2 uncertainty analysis and the associated benefits. First we discuss the costs.

The tier-1 uncertainty analysis was already once applied – preliminary - as described in the NIR 2001. The present study performed the tier-2 uncertainty analysis. These analyses are the same with respect to the inventory data. Both are also equal in using an emission model in line with the reference approach. Both methods draw from the information given in the CRF data files (for 1999) submitted to the UNFCC. The tier-1 uncertainty analysis summarises and re-arranges the emission information in these files into 44 source categories and assigns to every emission two uncertainties, one for an activity and one for the emission factor. These uncertainties are assumed to be standard deviations and are expressed as percentages of the mean. Given this information a series of calculations are made as prescribed in the IPCC good practice guidance.

The present tier-2 uncertainty analysis is based on a more accurate emission model based on the information present in the CRF files. In addition, we used background models that are used to complete the CRF files (e.g. the model for methane emission from waste disposal, model for N_2O emissions from manure management). This information is brought together in the 'emission model'. It is important that through this model the dependencies between the different elements are accounted for. The second step was to assign uncertainties – probability density functions (pdf) - to every variable and parameter of the emission model. This model is embodied in a series of spreadsheets. Calculations were performed with commercially available software (@RISK).

Given the CRF files being available, the tier-1 uncertainty analysis can readily be repeated for other years. It is not very likely that each year there are developments in the information position that warrant a change in assessment of uncertainties. The application of the tier-2 uncertainty requires, as well as the data in the CRF files, the information that is used to run the national models for assessment of specific emissions (e.g. waste disposal, emissions from agriculture). If calculation procedures to produce the NIR have not changed, a repetition of the tier-2 analysis reduces to copying these data and only checking whether uncertainties would have to be changed.

Performing a tier-2 uncertainty analysis requires more effort than the tier-1 analysis. If the format of the basic data does not change too much, a tier-2 uncertainty analysis for next year can be performed in 10 - 20 days extra (say € 10,000 - € 20,000). It is, however, not required by the IPCC to perform uncertainty analysis every year (IPCC Guidelines, (2000) p. 8.5).

15.6.5 Tier-2 uncertainty analysis of 2001 emissions

The present study was part of a programme to further implement *good practice* in emission inventorying in the Netherlands.
Through this programme the knowledge of emissions has improved. For instance, the PER-I of 2001 comprises emission data from 381 firms, while the 1999 PER-I covered 192 firms. Of some emissions, for instance, N_2O emissions from nitric acid production, more reliable information is available. In addition, in the recent period, "uncertainty in emissions" rose on the agenda of emission inventorying community.

The present study resulted in a list of factors to which total emission and the change in emission is most sensitive (See Table 15.9 and Table 15.11). Given the recently acquired information discussions might lead to re-assessments of the uncertainties in various ele-

ments of the emission model. Given that the framework for the emission-uncertainty calculation is available from the present study, this improved situation with respect to uncertainties might warrant to perform a tier-2 calculation of the uncertainty in the most recent (2001) inventory.

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16. List of all assumptions

Variables / parameters	Point value	Type	Uncer-tainty
CO_2 factors transport			
CO_2 Efactor diesel/gasoil (kt/PJ)	73.3	Normal	2
CO_2 Efactor gasoline (kt/PJ)	72.3	Normal	2
Emission factor CO_2 LPG (kt/PJ)	66.4	Normal	3
Natural gas & CO_2			
Average emission factor 1999 (kt CO_2/PJ natural gas)	56	Normal	1
Production of natural gas 1999 (PJ)	2269	Normal	0.5
Import of natural gas 1999 (PJ)	324	Normal	0.8
Export of natural gas 1999 (PJ)	1143	Normal	1.9
B 1999 Natural gas (PJ)	43.5483687	Normal	2
A 1999 Natural gas (ktP/J)	203.45397	Normal	2
Consumption of NG by gas industry (PJ) 1999	34	Normal	0.5
Consumption of NG by Refineries (PJ) 1999	33	Normal	0.5
Elect & heat Central. Cons. nat. gas 1999 (PJ)	201	Normal	0.5
Elect & heat Decentral Cons. nat. gas 1999 (PJ)	145	Normal	1
Waste incineration Cons. nat. gas 1999 (PJ)	1	Normal	1.9
Gas distribution Cons. nat. gas 1999 (PJ)	33	Normal	1.7
Industry Cons. nat. gas 1999 (PJ)	399	Normal	1.8
Households Cons. Nat. gas 1999 (PJ)	334	Normal	3.5
Other consumers Cons. nat. gas 1999 (PJ)	272	Normal	10.4
1990 average emission factor natural gas (kt/PJ)	56	Normal	1
Total consumption natural gas 1990 (PJ) (CBS)	1290	Normal	2.1
Unc. based on ref. Unc. 1999			
B 1990 Natural gas (PJ)	96.8801525	Normal	3
A 1990 Natural gas (ktP/J)	105.095225	Normal	3
Total consumption natural gas 1990 (PJ) (CBS)	1290	Normal	2.5
Unc. based on sect. unc. 1999/alternative			
Coal & CO_2			
Average CO_2 emission factor 1999 coal (kt/PJ)	96.8366667	Normal	1
Import coal & coal poducts (PJ) 1999	513	Normal	0.8
Export coal 1999 (PJ)	213	Normal	1.7
Stock change coal 1999 (PJ)	16	Normal	1.1
Cokes production PJ 1999	13	Normal	6.6
Electri production (Centraal) coal PJ 1999	211	Normal	0.4
Electr product (decentral) coal PJ 1999	1	Normal	1
Industry coal PJ 1999	87	Normal	1.3
Other 1999 coal PJ	3	Normal	33.3
B 1999 Coal	94.9978191	Normal	2
A 1999 Coal	9058.08613	Normal	2
Average CO_2 emission factor 1990 coal (kt/PJ)	96.54	Normal	1
B 1990 coal	81.753071	Normal	2
A 1990 coal	5683.47556	Normal	2
Domestic consumption of coal & coal products 1990 (PJ)	374	Normal	1
Oil and oil products & CO_2			
Average CO_2 emission factor 1999 (kt/PJ) liquid fuels	73	Normal	2
Average CO_2 emission factor 1990 (kt/PJ) liquid fuels	73	Normal	2
Oil consumpt by cokes industry (PJ) 1999	1	Normal	0.7
Consumption of oil Refineries (PJ) 1999	149	Normal	11.5

Elect & heat Central oil products 1999 (PJ)	1	Normal	0.5
Elect & heat Decentral oil products 1999 (PJ)	34	Normal	1
Waste incineration oil products 1999 (PJ)	0	Normal	0
Distribution of oil products 1999 (PJ)	1	Normal	8.5
Industry liquid fuels 1999 (PJ)	335	Normal	1.3
Households oil consumption 1999. PJ.	4	Normal	3.5
Other consumers oil products 1999 (PJ)	62	Normal	16.1
Domestic consumption of oil & oil products 1990 (PJ)	572.055763	Normal	4.2
B 1999 oil & oil products (PJ)	355.3396	Normal	2
A 1999 Oil and oil products (ktP/J)	11604	Normal	2
B 1990 oil & oil products (PJ)	306.055763	Normal	3
A 1990 Oil and oil products (ktP/J)	9205	Normal	3
Fuel consumption in transport			
Total petrol consumption in transport(TJ) 1990	158742.5	Normal	2
Total Diesel consumption in transport (TJ) 1990	203201.737	Normal	2.5
Petrol consumption in road transport (TJ) 1990	152000	Normal	2
Diesel fuel consumption in road transport (TJ) 1990	159100	Normal	2.5
LPG consumption in road transport (PJ) 1990	41000	Normal	1.5
Jet kerosene (TJ) 1990	6742.5	Log-Normal	100
Fuel consumption in navigation (TJ) 1990	12673.3333	Triangular	100
Fuel consumption in railways (TJ) 1990	1220	Normal	5
Total petrol consumption (Road petrol + aviation kerosene) TJ 1999	186422.598	Normal	2
Total Diesel consumption TJ 1999	263162.502	Normal	2.5
Petrol consumption in road transport 1999	180675.9	0	0
Diesel fuel consumption in road transport 1999	219883.1	Normal	2.5
LPG consumption in road transport 1999	29075.3	Normal	2
Jet kerosene 1999	5746.698	Log-Normal	100
Fuel consumption in navigation 1999	12019.7667	Triangular	100
Fuel consumption in railways 1999	1257.92663	Normal	5
Other CO_2			
1990 "Emission factor" from cement production (ktonne)	300	Normal	10
1990 Activity index	1	Normal	5
Activity factor cement 1990-1999	1.25333333	Normal	0
1990 "Emission factor" Other industrial: CO_2 (ktonne)	1601.47	Normal	20
1990 Activity index - other industrial CO_2	1	Normal	5
Activity factor other industry -(CO_2) 1990-1999	0.87942952	Normal	0
1990 Misc. CO_2 "emission factor"	735.99	Normal	50
1990 Activity index - Misc. CO_2	1	Normal	20
Activity factor Misc. CO_2 (1990-1999)	2.34062963	Normal	0
Methane emissions from waste landfills			
Fraction of organic carbon reacting to gaseous material	0.58	Normal	20
Organic C content of waste which is landfilled (kg/tonne) <1991	132	Normal	20
Uncertainty in amounts (tonnes) of annually disposed waste	10	Normal	10
Fraction of carbon reacting to methane (instead of to CO_2)	0.6	Normal	10
Fraction of methane oxidised in top layer	0.1	Uniform	0
Rate constant <1990	0.094	Normal	10
Rate of annual decrease of rate constant 1990-1995	0.73723404	Normal	0
1990 Recovered landfill gas (Million m3)	63.7	Normal	5
1999 Recovered landfill gas (million m3)	177.4	Normal	5
Emissions from manure management			

Emission factor per tonne manure (swine)	3.00879	Log-Normal	100
Number animals (swine) 1999	13567	Normal	5
Manure per animal (swine) 1999	0.00108056	Normal	10
EF per tonne manure (swine)	3.00879	Log-Normal	0
Number animals (swine) 1990	13915	Normal	5
Manure per animal (swine) 1990	0.00117722	Normal	10
Ef per tonne manure (dairy cattle)	0.666	Log-Normal	100
Number animals (dairy cattle) 1999	2972	Normal	5
Manure per animal (dairy cattle) 1999	0.01052826	Normal	10
Ef per tonne manure (dairy)	0.666	Log-Normal	0
Number animals (dairy cattle) 1990	3607	Normal	5
Manure per animal (dairy cattle) 1990	0.01019999	Normal	10
Ef per tonne manure (non-dairy cattle)	3.5146	Log-Normal	100
Number animals (non-dairy cattle) 1999	1232	Normal	5
Manure per animal (non-dairy cattle) 1999	0.00361201	Normal	10
Composite Ef per tonne manure	3.5146	Log-Normal	0
Number animals (non-dairy cattle) 1990	1702	Normal	5
Manure per animal (non-dairy cattle) 1990	0.00293247	Normal	10
Composite Ef per tonne manure (sheep)	2.02941176	Log-Normal	100
Number animals (sheep)	1401	Normal	5
Manure per animal (sheep)	0.00024268	Normal	10
Composite Ef per tonne manure (sheep)	2.02941176	Log-Normal	0
Number animals (sheep 1990)	1702	Normal	5
Manure per animal (sheep, 1990))	0.00022003	Normal	10
Composite Ef per tonne manure (poultry)	4.55	Log-Normal	100
CH_4 emissions from enteric fermentation			
Cattle dairy (< 1) (thousands) Numbers 1990	806	Normal	5
Heifers (thousands) Numbers 1990	880	Normal	5
Dairy cow (numbers) Numbers 1990	1878	Normal	5
Steers (>yr) Numbers 1990	43	Normal	5
Meat cattle <1y Numbers 1990	602	Normal	5
Meat cattle >1y Numbers 1990	598	Normal	5
Meat Adult >2y Numbers 1990	120	Normal	5
Sheep Numbers 1990	1702	Normal	5
Goats Numbers 1990	60.8	Normal	5
Horses Numbers 1990	69.6	Normal	5
Swine Numbers 1990	13915	Normal	5
Poultry Numbers 1990	95452	Normal	5
Cattle dairy (< 1) (thousands) Numbers 1999	633	Normal	5
Heifers (thousands) Numbers 1999	1694	Normal	5
Dairy cow (numbers) Numbers 1999	10	Normal	5
Steers (>yr) Numbers 1999	2972	Normal	5
Meat cattle <1y Numbers 1999	327	Normal	5
Meat cattle >1y Numbers 1999	152	Normal	5
Meat Adult >2y Numbers 1999	1232	Normal	5
Sheep Numbers 1999	153	Normal	5
Goats Numbers 1999	115	Normal	5

Horses Numbers 1999	13567	Normal	5
Swine Numbers 1999	108973	Normal	5
Poultry Numbers 1999	0	Normal	5
Emission factors			
Methane EF Cattle dairy (< 1) (kg/head/year)	49.25	Normal	20
Methane EF Heifers	62.8	Normal	20
Methane EF Dairy cow	102.13	Normal	20
Methane EF Steers (>yr)	93.22	Normal	20
methane EF Meat cattle <1y	17.65	Normal	20
Methane EF Meat cattle >1y	87.01	Normal	20
Methane EF Meat Adult >2y	102.13	Normal	20
EF Sheep	8	Normal	30
Methane emission factor Goats	8	Normal	30
Methane emission factor horses	18	Normal	30
Methane emission factor swine	1.5	Normal	50
Methane emission factor poultry	0.09	Normal	30
CH_4 emissions from mobile sources			
CH_4 emission factor petrol road (g/GJ) 1990	38.28825	Normal	50
CH_4 emission factor diesel in road (g/GJ) 1990	7.311938	Normal	50
CH_4 emission factor LPG (g/GJ) 1990	13.02205	Normal	50
CH_4 emission factor diesel fuel in railways (g/GJ) 1990	2.501722	Normal	50
CH_4 emission factor Jet Kerosene (aircraft) (g/GJ) 1990	11.73559	Normal	50
CH_4 emission factor gas/diesel oil in navigation (g/GJ) 1999/1990	2.976289	Normal	50
CH_4 emission factor Liquid Fuels in “other vehicles” (g/GJ) 1999/1990	9.367681	Normal	50
Gasoline. Change in EF (1999-1990) from change in average vehicle technology	0.504798	Normal	0
Diesel road. Change (1990-11999) in EF from change in average vehicle technology	0.331157	Normal	0
LPG. Change (1990-1999) in emission factor from change average vehicle technology.	0.437126	Normal	0
Change (1990-1999) in EF Diesel fuel in railways	1.225198	Normal	0
Change (1990-1999) EF Jet Kerosene (aircraft)	0.763022	Normal	0
See for Fuel consumption under CO_2 emissions			
Other CH_4 emissions			
Distribution of natural gas (PJ) 1990	675	Normal	5
Methane emission factor (1990) distribution of natural gas kt/PJ	0.10755556	Normal	50
Distribution of natural gas (PJ) 1999	724	Normal	5
1990-1999 change in CH_4 emission factor distribution of natural gas	0.75343306	Normal	5
Transmission of natural gas 1990 (PJ)	2292	Normal	1
Transmission of natural gas 1999 (PJ)	2385	Normal	1
Emission factor transmission of nat gas kt/PJ (1990)	0.00274869	Normal	25
1990-1999 change in CH_4 emission factor transmission of natural gas	0.53541779	Normal	5
Methane emission factor production and processing of natural gas 1990	0.03717277	Normal	25
Production/processing of natural gas (PJ) 1990	2292	Normal	1
Production/processing of natural gas (PJ) 1990	2280	Normal	1
1990-1999 change in CH_4 emission factor production/processing of natural gas	0.96491105	Normal	5
Fuel combustion activities (Sectoral approach) non-transport emissions 1990 ktonne CH_4	27.05	Normal	50
1990 -1999 composite factor for change in fuel combustion activities	0.93604436	Normal	5

1990 Methane "Em. Fact." from industrial processes (Other industrial: CH_4)	3.4	Normal	50
1990 Activity index. (Other industrial: CH_4)	1	Normal	10
Activity factor 1990-1999 (Other industrial: CH_4)	0.72941176	Normal	0
1990 Methane "Em. Fact." from Waste water handling (kt CH_4 eq/activity)	6.3	Normal	25
1990 Activity index. CH_4 from Waste water handling	1	Normal	20
Activity factor (1990-1999) Waste water handling	0.6031746	Normal	0
1990 Methane "Em. Fact." Misc. CH_4	2	Normal	25
1990 Activity index. Misc. CH_4	1	Normal	20
Activity factor (1990-1999) Misc. CH_4	0.97	Normal	0
N_2O **emissions from nitric acid production & other chemical manufacturing**			
N_2O emission (kt N_2O) from other than HNO3 production 1990-1999	5	Normal	20
"Emission factor" Nitric acid production (N_2O/activity index)	26.53	Normal	50
1990 activity index nitric acid production	1	Normal	10
Production of HNO3 relative to 1990	1.18846589	Normal	0
N_2O **Emissions from manure mangement**			
Manure 1999. Total N excretion (ktonne N)	559.1	Normal	10
Manure 1990. Total N excretion (ktonne N)	657	Normal	10
1999 Share of excretion in meadow	21	Normal	10
1990 Share of excretion in meadow	25	Normal	10
N-losses from NH3 formation %	8	Normal	50
Share of N excreted in urine	0.6	Normal	5
Emission factor in urine (share of N turned into N_2O)	0.02	Normal	60
Emission factor in faeces (share of N turned into N_2O)	0.01	Normal	60
NH3 losses in stable (%N)	14	Normal	50
NH3 losses from storage (%N)	1	Normal	50
Manure/slurry 1999 (N) biologically treated (ktonne)	2	Normal	25
Emission factor biological treatment (%N)	2	Normal	100
Emission factor anearobic storage (%N)	0.1	Normal	75
1990 Stock changes & import/export of manure/slurry	-0.9	Normal	0
1999 Stock changes & import/export of manure/slurry	6.4	Normal	10
1990 NH3 emissions at application of manure	104.9	Normal	25
1999 NH3 emissions at application of manure	50.6	Normal	25
1999 Percentage of manure that is injected/incorporated	100	Normal	5
1990 Percentage of manure that is injected/incorporated	0	Normal	10
Manure/slurry spreaded over mineral soils (%)	87	Normal	10
Emission factor manure/slurry injected/incorporated on the fields (%N)	2	Log-Normal	100
Emission factor manure/slurry on mineral soils (%N) , if spreaded	1	Log-Normal	100
Emission factor manure/slurry on organic soils(%N) , if spreaded	2	Log-Normal	100
Emission from the use of synthetic fertiliser			
Use of synthetic fertiliser 1990 (ktonne N)	403.8	Normal	10
Use of synthetic fertiliser 1999 relative to 1990	0.9717682	Normal	2
Emission factor (as N) from use of fertiliser	0.011	Log-Normal	60
Polluted surface water			
Nitrogen (kt N) input to surface water 1990.	240	Normal	50
Nitrogen input to surface water relative to input in 1990	1	Normal	0
Polluted surface water. Efactor (kg N_2O per kg N)	0.01571429	Normal	200
Mobile combustion:road vehicles			

N_2O emission factor petrol road (g/GJ) 1990	10.9351648	Log-Normal	100
N_2O emission factor petrol road (g/GJ) 1999	12.510224	Log-Normal	100
N_2O emission factor diesel in road (g/GJ) 1990	10.4471719	Log-Normal	100
N_2O emission factor diesel in road (g/GJ) 1999	10.5	Log-Normal	100
N_2O emission factor LPG (g/GJ) 1990	11.5057881	Log-Normal	100
N_2O emission factor LPG (g/GJ) 1999	23.62	Log-Normal	100
N_2O emission factor diesel Rail/navigation/Other (g/GJ) 1999/1990	16.2	Log-Normal	100
N_2O emission factor jet kerosene (g/GJ) 1999/1990	4.7	Log-Normal	100
Gasoline. Effect of change (1999-1990) average vehicle technology on tranport fleet N_2O emission factor	1.14403616	Normal	0
Diesel road. Effect of change (1999-1990) average vehicle technology on transport fleet N_2O emission factor	1.00473817	Normal	0
LPG. Effect of change (1999-1990) average vehicle technology on transport flee N_2O emission factor	2.05289038	Normal	0
Solvent use/Misc. N_2O			
"Emission factor" Solvent use/Misc. N_2O (ktonne N_2O)	0.5	Normal	50
1990 Activity index. N_2O Solvent use	1	Normal	50
Activity factor solvent use 1990-1999	1	Normal	0
N_2O **from waste water handling**			
"Emission factor" N_2O from Wastewater handling	0.5	Normal	50
1990 Activity index. Waster water handling	1	Normal	20
Activity factor waste water handling 1990-1999	1.06	Normal	0
Mobile combustion:road vehicles			
N_2O emission factor petrol road (g/GJ) 1990	10.9351648	Log-Normal	100
N_2O emission factor petrol road (g/GJ) 1999	12.510224	Log-Normal	100
N_2O emission factor diesel in road (g/GJ) 1990	10.4471719	Log-Normal	100
N_2O emission factor diesel in road (g/GJ) 1999	10.5	Log-Normal	100
N_2O emission factor LPG (g/GJ) 1990	11.5057881	Log-Normal	100
N_2O emission factor LPG (g/GJ) 1999	23.62	Log-Normal	100
N_2O emission factor diesel Rail/navigation/Other (g/GJ) 1999/1990	16.2	Log-Normal	100
N_2O emission factor jet kerosene (g/GJ) 1999/1990	4.7	Log-Normal	100
Gasoline. Effect of change (1999-1990) average vehicle technology on tranport fleet N_2O emission factor	1.14403616	Normal	0
Diesel road. Effect of change (1999-1990) average vehicle technology on transport fleet N_2O emission factor	1.00473817	Normal	0
LPG. Effect of change (1999-1990) average vehicle technology on transport flee N_2O emission factor	2.05289038	Normal	0
Indirect N_2O **emissions from agriculture**			
Background emission factor arable land (kg N ha-yr-1)	0.52	Log-Normal	100
Background emission factor grassland (mineral soil) (kg N ha-yr-1)	0.5	Log-Normal	100

Background emission grassland (organic soil) (kg N ha-yr-1)	0.5	Log-Normal	100
Background emission factor forests land (kg N ha-yr-1)	0.42	Log-Normal	100
Background emission factor other land (kg N ha-yr-1)	0.3	Log-Normal	100
Measured gross emission arable land (kg N ha-1yr-1)	1	Normal	100
Measured gross emission grassland (organic) (kg N ha-1yr-1)	1	Normal	100
Measured gross emission grassland (mineral) (kg N ha-1yr-1)	10	Normal	100
Arable land (1000 ha)	931	Normal	10
Grassland mineral soils (1000 ha)	820	Normal	10
Grassland organic soils (1000 ha)	275	Normal	10
Forests (1000 ha)	1080	Normal	10
Other lands (1000 ha)	1080	Normal	10
Emissions of F-gases (in ktonne CO_2-eq)			
"Emission factor" HFC-23 emissions from HCFC-22 manufacturing 1995 (ktonne CO_2-eq)	6464	Normal	25
1995 Activity index. HFC-23	1.00	Normal	15
Activity factor HCFC-22 production 1995-1999	1.14	Normal	0
"Emission factor" Other CFC emissions from manufacturing 1995 (ktonne CO_2-eq)	193	Normal	25
1995 Activity index. Other CFC manufacturing	1.00	Normal	15
Activity factor manufacturing other CFCs 1990-1999	0.68	Normal	0
"Emission factor" from the use of substitutes for ODS: HFCs 1995 (ktonne CO_2-eq)	260	Normal	50
1995 Activity index for use of OPS substitues.	1.00	Normal	10
Activity factor ODS use 1995-1999	5.07	Normal	0
"Emission factor" PFC emissions from aluminium production 1995 (ktonne CO_2-eq)	1799	Normal	20
1995 activity index aluminium production	1.00	Normal	5
1995-1999 development in Al production	1.37	Normal	0
"Emission factor" PFC emissions from PFC use 1995 (ktonne CO_2-eq)	68	Normal	25
1995 activity index PFC use	1.00	Normal	5
1995-1999 developments in PFC use	1.74	Normal	0
"Emission factor" SF6 emissions from SF6 use 1995 (ktonne CO_2-eq)	225	Triangu-lar	0
1995 activity index SF6 use	1.00	Normal	50
1995-1999 developments in SF6 use	0.79	Normal	0
CO_2 emissions from feedstocks			
1999 gas consumption for feedstock (PJ)	106.1	Normal	5
Gas feedstock. Fraction of C embodied in carbon	0.1	Normal	100
1990 gas consumption for feedstock	95.31	Normal	5
1990 CO_2 emission (kt) coal feedstock	481	Normal	11
1999 CO_2 (kt) emission coal feedstock	400	Normal	11
Difference in 1999 CO_2 emissions from NA & RA approaches	3263.80375	Normal	0
1999 NA-RA difference CO_2 emissions attributed to gas feedstock	1153.88825	Normal	10
Difference in 1990 CO_2 emissions from NA & RA approaches	873.35529	Normal	0
1990 NA-RA difference CO_2 emissions attributed to gas feedstock	458.82321	Normal	10
Carbon emission factor (t C/TJ) Crude Oil	19.9	Normal	2
Carbon emission factor (t C/TJ) Orimulsion	0	Normal	2
Carbon emission factor (t C/TJ) Natural Gas Liquids	18	Normal	2
Carbon emission factor (t C/TJ) Gasoline 3)	19.7181818	See elsewhere!	
Carbon emission factor (t C/TJ) Jet Kerosene	19.9	Normal	2
Carbon emission factor (t C/TJ) Other Kerosene 4)	19.9	Normal	2
Carbon emission factor (t C/TJ) Shale Oil	0	Normal	2

Carbon emission factor (t C/TJ) Gas / Diesel Oil	19.9909091	See elsewhere!!!	
Carbon emission factor (t C/TJ) Residual Fuel Oil	21	Normal	2
Carbon emission factor (t C/TJ) LPG	18	Normal	2
Carbon emission factor (t C/TJ) Ethane	0	Normal	2
Carbon emission factor (t C/TJ) Naphtha	19.9	Normal	2
Carbon emission factor (t C/TJ) Bitumen	21	Normal	2
Carbon emission factor (t C/TJ) Lubricants	19.9	Normal	2
Carbon emission factor (t C/TJ) Petroleum Coke	0	Normal	2
Carbon emission factor (t C/TJ) Refinery Feedstocks	0	Normal	2
Carbon emission factor (t C/TJ) Other Oil 5)	19.9	Normal	2
Consumption feedstock TJ 1999 Other Kerosene 4)	450	Normal	25
Consumption feedstock TJ 1999 Shale Oil	0	Normal	3
Consumption feedstock TJ 1999 Gas / Diesel Oil	70	Normal	25
Consumption feedstock TJ 1999 Residual Fuel Oil	0	Normal	3
Consumption feedstock TJ 1999 LPG	58600	Normal	10
Consumption feedstock TJ 1999 Ethane	0	Normal	3
Consumption feedstock TJ 1999 Naphtha	17760	Normal	10
Consumption feedstock TJ 1999 Bitumen	14990	Normal	10
Consumption feedstock TJ 1999 Lubricants	7960	Normal	10
Consumption feedstock TJ 1999 Petroleum Coke	0	Normal	3
Consumption feedstock TJ 1999 Refinery Feedstocks	0	Normal	3
Consumption feedstock TJ 1999 Other Oil 5)	173520	Normal	25
Consumption feedstock TJ 1990 Other Kerosene 4)	30	Normal	25
Consumption feedstock TJ 1990 Shale Oil	0	Normal	3
Consumption feedstock TJ 1990 Gas / Diesel Oil	6880	Normal	25
Consumption feedstock TJ 1990 Residual Fuel Oil	500	Normal	3
Consumption feedstock TJ 1990 LPG	78620	Normal	10
Consumption feedstock TJ 1990 Ethane	0	Normal	3
Consumption feedstock TJ 1990 Naphtha	44520	Normal	10
Consumption feedstock TJ 1990 Bitumen	19860	Normal	3
Consumption feedstock TJ 1990 Lubricants	5430	Normal	3
Consumption feedstock TJ 1990 Petroleum Coke	0	Normal	3
Consumption feedstock TJ 1990 Refinery Feedstocks	0	Normal	3
Consumption feedstock TJ 1990 Other Oil 5)	140530	Normal	25
Fraction of carbon stored Other Kerosene 4)	0.82	Normal	20
Fraction of carbon stored Shale Oil	0	Normal	20
Fraction of carbon stored Gas / Diesel Oil	0.82	Normal	20
Fraction of carbon stored Residual Fuel Oil	0	Normal	20
Fraction of carbon stored LPG	0.82	Normal	20
Fraction of carbon stored Ethane	0	Normal	20
Fraction of carbon stored Naphtha	0.82	Normal	20
Fraction of carbon stored Bitumen	1	Normal	20
Fraction of carbon stored Lubricants	0	Normal	20
Fraction of carbon stored Petroleum Coke	0	Normal	20
Fraction of carbon stored Refinery Feedstocks	0	Normal	20
Fraction of carbon stored Other Oil 5)	0.82	Normal	20