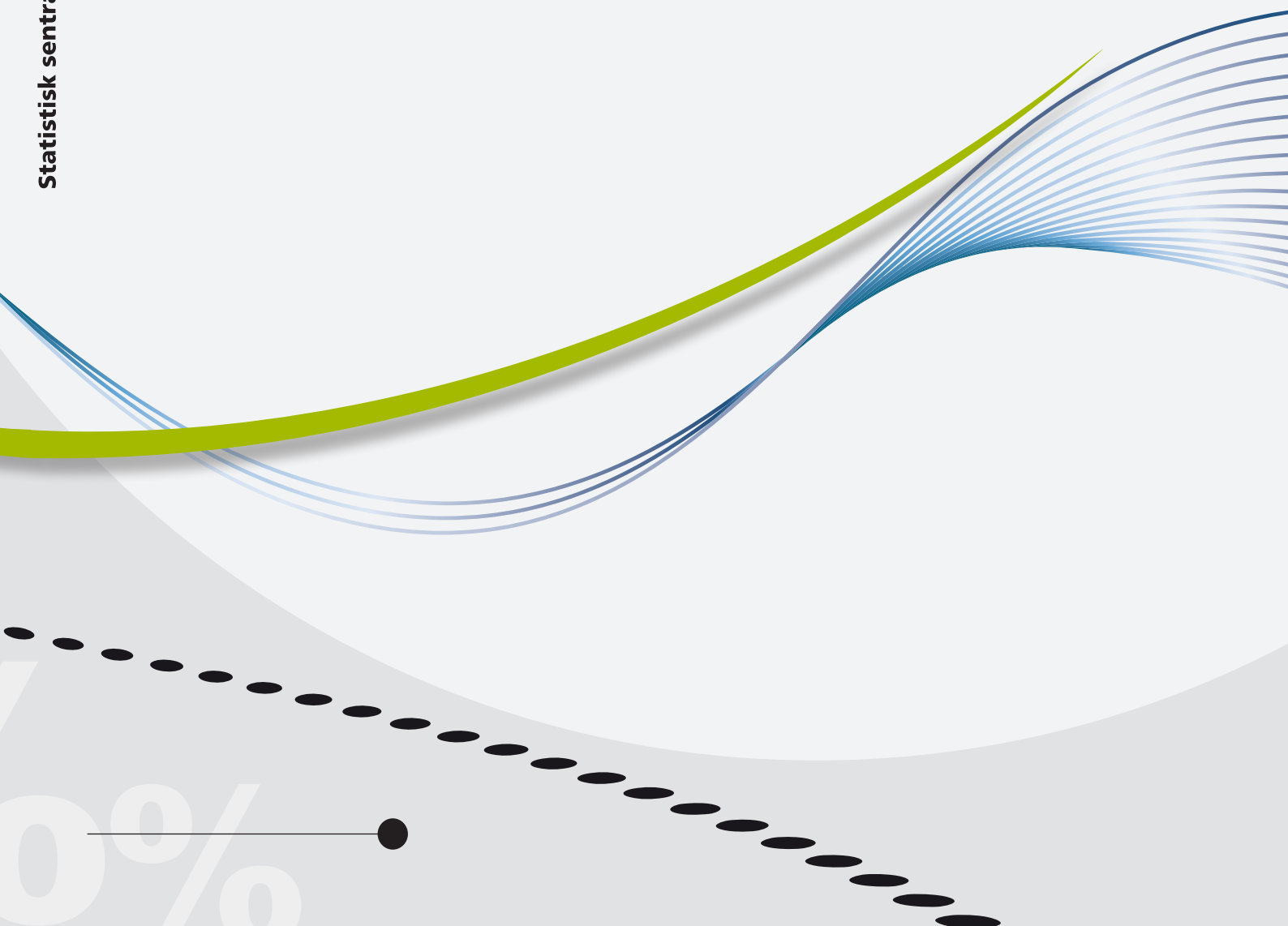


*Trond Sandmo (ed.)*

## **The Norwegian Emission Inventory 2014**

Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants





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	Category not applicable	.
	Data not available	..
	Data not yet available	...
	Not for publication	:
	Nil	-
ISBN 978-82-537-8999-6 (electronic)	Less than 0.5 of unit employed	0
ISSN 1891-5906	Less than 0.05 of unit employed	0.0
Subject: Nature and environment	Provisional or preliminary figure	*
	Break in the homogeneity of a vertical series	—
	Break in the homogeneity of a horizontal series	
	Decimal punctuation mark	.

## Preface

This report documents the methodologies used in the Norwegian inventory of emissions to air. The present report is the latest in a series of annually updated versions of a report originally published in 2005.

The Norwegian emission inventory reported to UNFCCC and ECE is a joint undertaking between the Norwegian Environment Agency and Statistics Norway. Emission data are used for a range of national applications and for international reporting.

The emissions covered in this report are those embraced by the conventions for emissions of greenhouse gases and long-range transboundary pollutants, i.e. they are defined with a territorial delimitation. The calculation methods used and the documentation of these, are, as far as possible, in accordance with the strict demands formulated in the emission conventions.

The report has been prepared by Statistics Norway's Division for energy and environmental statistics, and has been edited by Trond Sandmo, with contributions from Ketil Flugsrud, Henning Høie, Marte O. Kittilsen, Håkon Skullerud and Kristin Aasestad. The Norwegian Environment Agency has also contributed to the report.

The emission statistics are available at  
[http://www.ssb.no/english/subjects/01/klima\\_luft\\_en/](http://www.ssb.no/english/subjects/01/klima_luft_en/).

Statistics Norway, 28 August 2014

Hans Henrik Scheel

## Abstract

The Norwegian emission inventory is a joint undertaking between the Norwegian Environment Agency<sup>1</sup> and Statistics Norway. Statistics Norway is responsible for the collection and development of activity data, and emission figures are derived from models operated by Statistics Norway. The Norwegian Environment Agency is responsible for the emission factors, for providing data from specific industries and sources and for considering the quality, and assuring necessary updating, of emission models like, e.g., the road traffic model and calculation of methane emissions from landfills. Emission data are used for a range of national applications and for international reporting. The Norwegian Environment Agency is responsible for the Norwegian reporting to United Nations Framework Convention on Climate Change (UNFCCC) and to United Nations Economic Commission Europe (UN-ECE). The Norwegian Environment annually publishes reports prepared as a part of these reportings: National Inventory Report (NIR) for UNFCCC and Informative Inventory Report (IIR) for UN-ECE (Norwegian Environment Agency 2014b and 2014a).

This report documents the methodologies used in the Norwegian emission inventory of greenhouse gases (GHG), acidifying pollutants, heavy metals (HM) and persistent organic pollutants (POPs). The documentation will also serve as a part of the National Inventory Report submitted by Norway to the United Nations Framework Convention on Climate Change (UNFCCC), and as documentation of the reported emissions to UNECE for the pollutants restricted by CLRTAP (Convention on Long-Range Transboundary Air Pollution). LULUCF (land use, land-use change and forestry) is not considered in this report, see the National Inventory Report (Norwegian Environment Agency 2014b) for documentation on this topic.

This report is the latest annually updated version. The most important changes since last year's documentation are:

- Emissions of N<sub>2</sub>O and NH<sub>3</sub> from use of sewage sludge applied on parks and green spaces, cover on landfills, used as fertiliser and other use have been included for all years since 1990
- Emissions of NMVOC and particles from handling of coal at Spitsbergen are included for the first time
- The method for calculating NO<sub>x</sub> emissions from diesel engines at offshore installations has been revised

Previous editions of this report included a detailed description of recalculations in the most recent emission figures. These recalculation descriptions can now only be found in the Informative Inventory Report (Norwegian Environment Agency 2014a) and the National Inventory Report (Norwegian Environment Agency 2014b).

*The Norwegian Emission Inventory 2014; Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants* is available at <http://www.ssb.no>.

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<sup>1</sup> From 1 July 2013, the Climate and Pollution Agency, which has cooperated with Statistics Norway in the preparation of the emission inventories, and the Directorate for Nature Management were merged into the Norwegian Environment Agency. The Climate and Pollution Agency was up to 2010 called The Norwegian Pollution Control Authority, abbreviated SFT. In this publication, the previous names and abbreviation are used in some contexts, mainly in connection with references to publications.

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# 1. Introduction

## 1.1. Inventory documentation: Needs and plans

Emission data are used in many contexts nationally, and also reported internationally. There is widespread interest for the emission figures and for the methods used to perform the calculations. The emission data are based on a mix of measurements and calculations. The purpose of this report is to document the methodologies used in the Norwegian emission inventory of greenhouse gases (GHG), acidifying pollutants, heavy metals (HM) and persistent organic pollutants (POPs). The documentation has also served as a part of the National Inventory Report (Norwegian Environment Agency 2014b) submitted by Norway to the United Nations Framework Convention on Climate Change (UNFCCC), and as documentation of the reported emissions to UNECE for the pollutants restricted by CLRTAP (Convention on Long-Range Transboundary Air Pollution) (Norwegian Environment Agency 2014a).

The emissions covered in this report are those embraced by the conventions for emissions of greenhouse gases and long-range transboundary pollutants, i.e. they are defined with a territorial delimitation. The calculation methods used and the documentation of these, are, as far as possible, in accordance with the strict demands formulated in the emission conventions.

The structure of this report follows, as does the National Inventory Report (Norwegian Environment Agency 2014b), guidelines given by UNFCCC. However, the National Inventory Report discusses only greenhouse gases, and also includes LULUCF emissions. As the latter emissions not are included in the emission figures estimated and presented by Statistics Norway, they are not discussed in this report.

This documentation report is prepared annually by The Division for energy and environmental statistics at Statistics Norway. The 2014 edition has been edited by Trond Sandmo, with contributions from Ketil Flugsrud, Henning Høie, Marte O. Kittilsen, Håkon Skullerud and Kristin Aasestad at Statistics Norway. The Norwegian Environment Agency has also contributed to the report. The report is the latest in a series of updated versions of a report originally edited by Britta Hoem in 2005.

The most important changes in this edition are:

- Emissions of N<sub>2</sub>O and NH<sub>3</sub> from use of sewage sludge applied on parks and green spaces, cover on landfills, used as fertiliser and other use have been included for all years since 1990
- Emissions of NMVOC and particles from handling of coal at Spitsbergen are included for the first time
- The method for calculating NO<sub>x</sub> emissions from diesel engines at offshore installations has been revised

Previous editions of this report included a detailed description of recalculations in the most recent emission figures. These recalculation descriptions can now only be found in the Informative Inventory Report and National Inventory Report (Norwegian Environment Agency 2014a and 2014b).

## 1.2. Institutional arrangements

### 1.2.1. Responsibilities for emission calculations

The Norwegian emissions inventories have been produced for more than two decades as a collaboration between Statistics Norway (SSB) and the Norwegian Environment Agency.

Statistics Norway is responsible for the official statistics on emissions to air. This includes:

- collection of activity data
- operation and further development of models for emission estimation
- emission calculations
- filling in most of the tables for international reporting to UNFCCC and UNECE
- publishing national official statistics on emissions to air.

The Norwegian Environment Agency is responsible for:

- overall responsibility for international reporting to UNFCCC and UNECE
- emission factors for all sources
- measured emission data from large industrial plants based on individual reports submitted to the Norwegian Environment Agency on a regular basis
- considering the quality and assuring necessary updating, of emission models like, e.g., the road traffic model and calculation of methane emissions from landfills

Activity data<sup>2</sup> are collected either internally at Statistics Norway (e.g. data on energy use, industrial production, number of animals, etc.) or reported to Statistics Norway, and in some cases to the Norwegian Environment Agency, from external sources such as the Norwegian Petroleum Directorate (OD) and the Norwegian Public Roads Administration (VD). Emission figures are derived from models operated by Statistics Norway. In the modelling activities Statistics Norway makes use of the data collected by the Norwegian Environment Agency on emission factors and emissions from industrial plants.

The Norwegian Environment Agency is responsible for quality control of the data they deliver to the emission model operated by Statistics Norway, but Statistics Norway makes an additional consistency check (see chapter 1.5). Statistics Norway is responsible for quality control of the activity data and the emission figures from the model, but the Norwegian Environment Agency also participates in this quality control.

### 1.2.2. National entity under the Kyoto protocol

The Norwegian Environment Agency has been appointed by the Ministry of the Environment as the national entity for greenhouse gas inventories as defined by Article 5.1 of the Kyoto Protocol through the budget proposition to the Storting (Norwegian parliament) for 2006, which states that *"The Norwegian system will build on an existing cooperation between the Climate and Pollution Agency and i.a. Statistics Norway. On this background the Climate and Pollution Agency is appointed as a national entity with overall responsibility for the inventory and reporting"*. (St. prop. No. 1 (2005-2006)). The Ministry of the Environment proposes building the national system around well-established institutional cooperation. The data collection and data management is secured through three main acts, the Pollution Control Act (forurensningsloven), the Greenhouse Gas Emission Trading Act (klimakvoteloven) and the Statistical Act (statistikkloven).

---

<sup>2</sup>Data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time.

The Norwegian national system for production of greenhouse gas inventories is based on an extensive institutional cooperation. The Norwegian Environment Agency, Statistics Norway and the Norwegian Forest and Landscape Institute are the core institutions in the national system. The Norwegian Forest and Landscape Institute is responsible for calculations of emissions and removals from IPCC sector 5, Land Use and Land Use Change and Forestry - LULUCF (until 2006 the Norwegian Institute of Land Inventory (NIJOS)) and Article 3.3 and 3.4 under the Kyoto Protocol. Sector 5 is not included in this report since sinks and sources of greenhouse gases from LULUCF are not included in the national emission data presented by Statistics Norway each year.

### **1.3. The process of inventory preparation**

The Norwegian emission inventory is based on a general emission model and a series of more detailed satellite models, which cover specific emission sources and pollutants (e.g. road traffic, air traffic, landfills, solvents, HFCs, SF<sub>6</sub>, PFCs). These models are operated by Statistics Norway.

Data and information on point sources are recorded at the Norwegian Environment Agency in the database *Forurensning* and published in *Norske utslipp* (<http://www.norskeutslipp.no>). This is the Norwegian Pollutant Release and Transfer Register (PRTR). *Forurensning* is a further development of the old register Inkosys, which was introduced in 1978 as an internal tool for the authorities. The database was upgraded in 1992, and has later been under continuous development in order to harmonise with the PRTR adopted by the OECD in 1996. Each polluting industrial installation or plant is subjected to licensing and is obliged to produce an annual report to the pollution control authorities. The report should provide activity data, emission figures and information about the particular source, and it should address compliance with current environmental standards. The Norwegian Environment Agency supplies Statistics Norway with data from the Norwegian PRTR which are relevant for the preparation of the national emission inventory.

#### **1.3.1. Pollutants included, data collection, processing and archiving**

Statistics Norway collects the majority of data necessary to run the Norwegian emission model. These are as follows: activity levels, emission factors, aggregated results from the satellite models and emission figures for point sources. Table 1.1 gives an overview of the pollutants included in the emission inventory.

**Table 1.1. Definition of pollutants in the Norwegian emission inventory**

Class	Pollutant	Symbol	Definition
Greenhouse gases	Carbon dioxide	CO <sub>2</sub>	
	Methane	CH <sub>4</sub>	
	Nitrous oxide	N <sub>2</sub> O	
	Perfluorocarbons	PFCs	CF <sub>4</sub> + C <sub>2</sub> F <sub>6</sub> + C <sub>3</sub> F <sub>8</sub>
	Hydrofluorocarbons	HFCs	HFC-23, HFC-32, HFC-125, HFC-134, HFC-134a, HFC-143, HFC-143a, HFC-152a, HFC-227ea
	Sulphur hexafluoride	SF <sub>6</sub>	
Acidifying gases	Sulphur dioxide	SO <sub>2</sub>	
	Nitrogen oxides	NO <sub>x</sub>	NO + NO <sub>2</sub>
	Ammonia	NH <sub>3</sub>	
Heavy metals (HM)	Lead	Pb	
	Cadmium	Cd	
	Mercury	Hg	
	Arsenic	As	
	Chromium	Cr	
	Copper	Cu	
Persistent organic pollutants (POPs)	Polycyclic Aromatic Hydrocarbons	PAH	Emissions are calculated for PAH-total, PAH-6 and PAH-4. PAH-total includes 16 components according to Norwegian Standard (NS9815). PAH-6 is OSPARs Borneff-6 and include 6 components. PAH-4 is consisting of four components used as an indicator for PAH emissions required for reporting to CLRTAP.
	Dioxins	-	Dioxin emissions are given in the unit I-TEQ, which is required for reporting to CLRTAP. I-TEQ is based on the international model ("Nato-modell") and is the sum of PCDD/PCDF multiplied by the components toxicity equivalency factor (I-TEF). TEQ = sum (PCDD <sub>i</sub> * TEF <sub>i</sub> ) + sum (PCDD <sub>j</sub> * TEF <sub>j</sub> ).
Particulates	Total suspended particulates	TSP	
	-	PM <sub>10</sub>	Particulate matter with diameter less than 10µm
	-	PM <sub>2.5</sub>	Particulate matter with diameter less than 2.5µm
Other pollutants	Carbon monoxide	CO	
	Non-methane volatile organic compounds	NMVOC	

The collected data are subjected to the Quality Assurance and Quality Control (QA/QC) routines described in section 1.5 as well as source specific routines as described under each source chapter. They are subsequently processed by Statistics Norway into a format appropriate to enter the emission models. The models are designed in a manner that accommodates both the estimation methodologies reflecting Norwegian conditions and those recommended internationally.

Input data used and the model output are all stored at Statistics Norway. Relevant information including dates and procedures followed are also recorded.

#### 1.4. Definitions and structure

The structure of this documentation follows the nomenclature used for reporting to UNFCCC in the Common Reporting Format (CRF) and to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) as Nomenclature For Reporting (NFR).

The main sectors here are:

- 1A. Energy combustion
- 1B. Energy production
2. Industrial processes
3. Solvent and other product use
4. Agriculture
5. Land use change and forestry
6. Waste

The description of the pollutants included is given in table 1.1.

Emissions of heavy metals, POPs and particulates are further described in the reports Finstad *et al.* (2001), Finstad *et al.* (2002b), Finstad and Rypdal (2003) and Finstad *et al.* (2003).

## 1.5. Quality Assurance and Quality Control (QA/QC)

This chapter describes general QA/QC procedures. For source specific QA/QC, see each source sector for detailed descriptions.

The QA/QC work has several dimensions. In addition to accuracy, also timeliness is essential. As these two aspects may be in conflict, the QA/QC improvements in recent years have been focused on how to implement an effective QA/QC procedure and how to obtain a more efficient dataflow in the inventory system.

During the past years several quality assurance and quality control procedures for the preparation of the national emission inventory have been established in Norway. Statistics Norway made its first emission inventory for some gases in 1983 for the calculation year 1973. The emission estimation methodologies and the QA/QC procedures have been developed continuously since then. Norway has implemented a formal quality assurance/quality control or verification plan. A detailed description of this is presented in Annex V in the National Inventory Report 2014.

The established QA/QC procedures include the following:

- The Norwegian Environment Agency is the national entity designated to be responsible for the reporting of the national inventory of greenhouse gases to the UNFCCC. This includes coordination of the QA/QC procedures. Reported greenhouse gas emissions from many plants are covered by the EU ETS (see 3.2.1.1.3) and the emissions are verified annually.
- Statistics Norway is responsible for the quality control system with regard to technical activities of the inventory preparation.
- A Tier 1 general inventory level QC procedures, as listed in table 8.1 of the IPCC Good Practice Guidance is performed every year.
- Source category-specific QC procedures are performed for all key categories and some non-key categories; with regard to emission factors, activity data and uncertainty estimates (Tier 2).

### 1.5.1. QA Procedures

According to the IPCC Good practice guidance, good practice for QA procedures requires an objective review to assess the quality of the inventory and to identify areas where improvements could be made. Furthermore, it is good practice to use QA reviewers that have not been involved in preparing the inventory. In Norway, the Norwegian Environment Agency is responsible for reviewing the inventory with regard to quality and areas for improvement. For most sources it is a person within the Norwegian Environment Agency who has not been involved in the calculations and the quality controls who performs the QA for the particular source.

Norway has performed several studies comparing inventories from different countries (Haakonsen *et al.* 2000). Verification of emission data is another element to be assessed during the elaboration of a QA/QC and verification plan.

All three core institutions are responsible for archiving the data they collect and the estimates they calculate with associated methodology documentation and internal documentation on QA/QC. Due to the differences in the character of data collected, Norway has chosen to keep archiving systems in the three core institutions, which means that not all information is archived at a single location. These archiving systems are, however, consistent, and operate under the same rules. Although the data are archived separately, all can be accessed efficiently during a review.

### 1.5.2. General QC procedures

The Norwegian emission inventory is produced in several steps. Preliminary estimates are first produced 4-5 months after the end of the inventory year. These data are based on preliminary statistics and indicators and data that have been subjected to a less thorough quality control. The "final" update takes place about one year after the inventory year. At this stage, final statistics are available for all sources. Until 2011, also emission data at municipality level were calculated. Due to quality problems, the production of these statistics was stopped. Statistics at county level for the components CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> were published in September 2014. Recalculations of the inventory are performed annually, as methodological changes and refinements are implemented. In itself, this stepwise procedure is a part of the QA/QC-procedure since all differences in data are recorded and verified by the Norwegian Environment Agency before publication of the emission figures (see section 1.2).

For each of the steps described above, general quality control procedures are performed, but with different levels of detail and thoroughness as mentioned. The national emission model was revised in 2002 in order to facilitate the QC of the input data rather than the emission data only. Input data include emissions reported from large plants, activity data, emission factors and other estimation parameters.

In the following, the procedures listed in table 8.1 of the Good Practice Guidance (IPCC 2000), the Tier 1 General Inventory Level QC Procedures, are gone through, and it is described how these checks are performed for the Norwegian greenhouse gas emission inventory.

#### *Check that assumptions and criteria for the selection of activity data and emissions factors are documented*

Thorough checks of emission factors and activity data and their documentation have been performed for existing emission sources. When new sources appear (for example a new industrial plant) or existing sources for the first time are recognised as a source, the Norwegian Environment Agency delivers all relevant information to Statistics Norway. This information is then thoroughly checked by the inventory team at Statistics Norway. All changes in methodologies or data are documented and kept up to date.

#### *Check for transcription errors in data input and references*

Activity data are often statistical data. Official statistical data undergo a systematic revision process, which may be manual or, increasingly frequently, computerised. The revision significantly reduces the number of errors in the statistics used as input to the inventory. Furthermore, all input data (reported emissions, emission factors and activity data) for the latest inventory year are routinely compared to those of the previous inventory year, using automated procedures. Large changes are automatically flagged for further, manual QC. In addition, implied emission factors are calculated for emissions from stationary combustion at point sources. The IEFs are subjected to the same comparison between the years *t* and *t-1*. The

most thorough checks are made for the gases and categories with the largest contribution to total emissions.

*Check that emissions are calculated correctly*

When possible, estimates based on different methodologies are compared. An important example is the metal production sector where CO<sub>2</sub> estimates reported by the plants are compared with estimates based on the Good Practice methodology corrected for national circumstances. In this case, both production based and reducing agent based calculations are occasionally performed to verify the reported value. The Norwegian Environment Agency and Statistics Norway control and verify emission data reported to the Norwegian Environment Agency by industrial enterprises, registered in the database *Forurensning*. First, the Norwegian Environment Agency checks the data received from these plants, and if errors are discovered, they may then ask the plants' responsible to submit new data. Subsequently, Statistics Norway makes, where possible, occasional comparable emission calculations based on activity data sampled in official statistics, and deviations are explained through contact with the plants. Regarding more detailed information about the QC of data reported by industrial plants, see section 1.5.3.

*Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used*

All parameter values are compared with values used in previous years and with any preliminary figures available. Whenever large deviations are detected, the value of the parameter in question is first checked for typing errors or unit errors. Changes in emissions from large plants are compared with changes in activity level. If necessary, the primary data suppliers (e.g. the Norwegian Forest and Landscape Institute, The Norwegian Petroleum Directorate, Norwegian Public Roads Administration, various plants etc.) are contacted for explanations and possible corrections.

*Check the integrity of database files*

Control checks of whether appropriate data processing steps and data relationships are correctly represented are made for each step of the process. Furthermore, it is verified that data fields are properly labelled and have correct design specifications and that adequate documentation of database and model structure and operation are archived.

*Check for consistency in data between source categories*

Emission data for the last year are compared with data for the previous year, in order to check the consistency and explain any changes in the data behaviour. For example, in 2010 Statistics Norway and the Norwegian Environment Agency calculated emission data for 2009 for the first time. These data were compared with the 2008 figures for detection of any considerable deviations. There may be large deviations that are correct, caused for instance by the shutdown of large industrial plants or the launch of new ones.

*Check that the movement for inventory data among processing steps is correct*

Statistics Norway has established automated procedures to check that inventory data fed into the model not deviate too much from the figures for earlier years, and that the calculations within the model are correctly made. Checks are also made that emissions data are correctly transcribed between different intermediate products. The model is constructed so that it gives error messages if factors are lacking, which makes it quite robust to miscalculations.

*Check that uncertainties in emissions and removals are estimated correctly*

A new uncertainty analysis for greenhouse gases was undertaken in 2011, see further information in section 1.6.1 and Appendix D. For long-range transboundary air pollutants, the last uncertainty analysis was undertaken in 2001.

*Undertake review of internal documentation*

For some sources expert judgements dating some years back are employed with regard to activity data/emission factors. In most of the cases these judgements have not been reviewed since then, and may not be properly documented, which may be a weakness of the inventory. The procedures have improved the last few years, and the requirements for internal documentation to support estimates are now quite strict; all expert judgements and assumptions made by the Statistics Norway staff should be documented. This should increase reproducibility of emissions and uncertainty estimates. In 2011, work was begun to go through all emission factors, register digitally those that have sufficiently documentation and flag those that do not, for future revision. The new model at Statistics Norway has improved the process of archiving inventory data, supporting data and inventory records, which does facilitate review. The model runs are stored and may be reconstructed, and all input data from the Norwegian Environment Agency as well as notes with explanations on changes in emissions are stored. This is a continuous process of improvement at Statistics Norway.

*Check of changes due to recalculations*

Emission time series are recalculated every year to ensure time series consistency. The recalculated emission data for a year is compared with the corresponding figures estimated the year before. For example, CO<sub>2</sub> data calculated for 1990 in 2010 are compared with the 1990 CO<sub>2</sub> data calculated in 2009. The intention is to explain all major differences as far as possible. Changes may be due to revisions in energy data, new plants, correction of former errors and new emission methodologies.

*Undertake completeness checks*

Estimates are reported for all source categories and for all years as far as we know, apart from a few known data gaps, which are listed in section 1.8 Completeness. There may, of course, exist sources of greenhouse gases which are not covered. However, we are quite certain that emissions from potentially additional sources are very small or negligible.

*Compare estimates to previous estimates*

Internal checks of time series for all emission sources are performed every year when an emission calculation for a new year is done. It is then examined whether any detected inconsistencies are due to data or/and methodology changes. For example, in 2010 Statistics Norway/the Norwegian Environment Agency calculated emission data for 2009 for the first time. These data were compared with the 2008 figures for detection of any considerable deviations. There may be large deviations that are correct, caused for instance by the shutdown of large industrial plants or the launch of new ones.

**1.5.3. Source category-specific QC procedures**

Statistics Norway and the Norwegian Environment Agency have carried out several studies on specific emission sources, e.g. emissions from road, sea, and air transport, emissions from landfills as well as emissions of HFCs and SF<sub>6</sub>. These projects are repeated in regular intervals when new information is available. During the studies, emission factors have been assessed and amended in order to represent the best estimates for national circumstances, and a rationale for the choice of emission factor is provided. The emission factors are often compared with factors from literature. Furthermore, activity data have been closely examined and quality controlled and so has the uncertainty estimates.

The QC procedures with regard to emission data, activity data and uncertainty estimates for the different emission sources are described in the QA/QC-chapters of the relevant source-categories. The source category-specific analyses have primarily been performed for key categories on a case-by-case basis, which is described as being good practice. The QA/QC process for many of the sources



could be improved. The QC procedures is described in the report on the National System which was submitted by 1 January 2007.

The ERT requested in 2005 further information regarding the verification of quality of data reported by companies. The general checks performed are described under section 1.5.2. In the following is a more detailed description of QC of emission data reported from plants:

Plant emission data that are used in the emission trading system will undergo annual QC checks. The source-specific QC checks for other plants are performed less frequently (every 3 years) for emission estimates used in key categories, which account for 25-30 per cent of the total of that category. The frequency of checking of non-key plants which are not included in the emission trading scheme is every 5 years. Statistics Norway is responsible for reporting the results of the key category analysis to the Norwegian Environment Agency, while the Norwegian Environment Agency will perform the assessment of the “key plants” within a category.

The QC checks include:

- An assessment of the internal QA/QC of the plants reporting data to the Norwegian Environment Agency
  - Their QA/QC system including archiving
  - Any changes to the QA/QC system
- An assessment and documentation of measurements and sampling
  - Measurement frequency
  - Sampling
  - Use of standards (e.g. ISO)
  - Documentation for archiving
- An assessment and explanation of changes in emissions over time (e.g. changes in technology, production level or fuels) (annual check)
- An assessment of time-series consistency back to 1990 in cooperation with the Norwegian Environment Agency (if plant emission data are missing for some years and estimates are made using aggregate activity data and emission factors)
- A comparison of plant emissions to production ratios with those of other plants, including explanations of differences
- A comparison of the production level and/or fuel consumption with independent statistics
- An assessment of reported uncertainties (including statistical and non-statistical errors) to the extent this has been included in the reporting

The QC checks are made in close cooperation with the emission reporting plants.

For more details of QA/QC of specific source categories, see “source specific QA/QC” in relevant chapters.

#### **1.5.4. Verification studies**

In general, the final inventory data provided by Statistics Norway are checked and verified by the Norwegian Environment Agency.

In the following, some verification studies which have been performed are briefly described. Emission estimates for a source are often compared with estimates performed with a different methodology. In particular, Norway has conducted a study on verification of the Norwegian emission inventory (Haakonsen *et al.* 2000). The main goals of that work were to investigate the possibility of using statistical data as indicators for comparing emission figures between countries on a general basis, and to test the method on the Norwegian national emission estimates. In the report, Norwegian emission data were compared with national data for Canada, Sweden and New Zealand. It was concluded that no large errors in the Norwegian emission inventory were detected. The process of verification did,

however, reveal several smaller reporting errors; emissions that had been reported in other categories than they should have been. These errors have been corrected in later reports to the UNFCCC. We do realise that this method of verification only considers consistency compared with what other countries report. It is not a verification of the scientific value of the inventory data themselves.

In 2002, a project initiated by the Nordic Council of Ministers was completed, where the results for emissions of greenhouse gases from the agricultural sector in the national emission inventories were compared with the results using the IPCC default methodology and the IPCC default factors. The results for the Nordic countries were collected in a report (Petersen and Olesen 2002).

In 2004, the Nordic Council of Ministers initiated a new project that was finalised in 2006. This project focused on NMVOC, heavy metals and POPs. An unpublished, final report has been worked out, containing the following elements:

- comparisons of the emission estimation methodologies and emission factors used in each country (review)
- identification of gaps in knowledge
- identification of possible "burden sharings" with respect to research areas (research taking place in one country, but used in all countries)
- discussions of the particular Nordic aspects influencing the emissions
- discussions of the possible contributions from research in the Nordic countries
- proposals for research areas

In 2006, the Nordic Council of Ministers initiated a new project that was finalised in 2010. This project focused on emission of particulate matter. The final report contains the following elements:

- comparisons of the emission estimation methodologies and emission factors used in each country (review)
- identification of gaps in knowledge
- discussions of the particular Nordic aspects influencing the emissions
- discussions of the possible contributions from research in the Nordic countries
- proposals for research areas
- recommendations for further work

### **1.5.5. Archiving**

The national emissions inventory is a part of Statistics Norway's data archiving system. All input data to, and results from, the general Norwegian emission model from every publication cycle are stored and documented in this system.

Several input data are used in preliminary calculations before entering into the general Norwegian emission model. This includes satellite models such as road traffic and air traffic, as well as a number of simpler calculations that do not fit into the framework of the general model. The preliminary calculations are not included in the central archiving system, which is not suited for such a diverse collection of data. For some satellite models there is an established archiving routine where all input data and results from every calculation cycle are stored.

## **1.6. Uncertainties in total emissions**

The uncertainty in the Norwegian greenhouse gas emission inventory has been investigated by a tier 2 analysis in 2011 (Flugsrud and Hoem 2011) and the results are described in section 1.6.1 and in Appendix D. A tier 2 analysis for the greenhouse gases was also performed in 2006, and the results from that analysis is given in (Sandmo 2010). The uncertainty in the Norwegian emission inventory has also earlier been investigated systematically in three reports (Rypdal 1999; Rypdal and Zhang 2000; Rypdal and Zhang 2001). The first two reports focused on the

uncertainty in the greenhouse gas emissions, and the last report investigated the uncertainty in the emission estimates of long-range air pollutants.

### **1.6.1. Greenhouse gases**

The uncertainty analysis performed in 2011 (Flugsrud and Hoem 2011) was an update of the uncertainty analyses performed for the greenhouse gas inventory in 2006 and 2000. The report *Uncertainties in the Norwegian Greenhouse Gas Emission Inventory* (Rypdal and Zhang 2000) includes more detailed documentation of the analysis method used in all analyses.

The national greenhouse gas (GHG) emission inventory is compiled from estimates based on emission factors and activity data and direct measurements by plants. All these data and parameters will contribute to the overall inventory uncertainty. The uncertainties and probability distributions of the inventory input parameters have been assessed based on available data and expert judgements. Finally, the level and trend uncertainties of the national GHG emission inventory have been estimated using Monte Carlo simulation. The methods used in the analysis correspond to an IPCC Tier 2 method, as described in (IPCC 2000). Analyses have been made both excluding and including the sector LULUCF (land use, land-use change and forestry).

#### ***1.6.1.1. Uncertainty in emission levels***

The estimated uncertainties of the levels of total emissions and in each gas are shown in table 1.2 and table 1.3.

**Table 1.2. Uncertainties in emission levels. Each gas and total GWP weighted emissions. Excluding the LULUCF sector**

1990	$\mu$ (mean)	Fraction of total emissions	Uncertainty $2\sigma$ (per cent of mean)
Total .....	50 mill. Tonnes	1	5
CO <sub>2</sub> .....	35 mill. Tonnes	0.70	3
CH <sub>4</sub> .....	4.7 mill. Tonnes	0.09	17
N <sub>2</sub> O .....	4.7 mill. Tonnes	0.10	40
HFC .....	18 tonnes	0.00	50
PFC .....	3.4 mill. Tonnes	0.07	21
SF <sub>6</sub> .....	2.2 mill. Tonnes	0.04	2
2009	$\mu$ (mean)	Fraction of total emissions	Uncertainty $2\sigma$ (per cent of mean)
Total .....	51 mill. Tonnes	1	4
CO <sub>2</sub> .....	43 mill. Tonnes	0.84	2
CH <sub>4</sub> .....	4.3 mill. Tonnes	0.08	14
N <sub>2</sub> O .....	3.0 mill. Tonnes	0.06	58
HFC .....	708 ktonnes	0.01	48
PFC .....	379 ktonnes	0.01	20
SF <sub>6</sub> .....	64 ktonnes	0.00	56

**Table 1.3. Uncertainties in emission levels. Each gas and total GWP weighted emissions. Including the LULUCF sector**

1990	$\mu$ (mean)	Fraction of total emissions	Uncertainty $2\sigma$ (per cent of mean)
Total .....	41 mill. tonnes	1	7
CO <sub>2</sub> .....	26 mill. tonnes	0.64	9
CH <sub>4</sub> .....	4.7 mill. tonnes	0.11	16
N <sub>2</sub> O .....	4.7 mill. tonnes	0.12	38
HFC .....	18 tonnes	0.00	50
PFC .....	3.4 mill. tonnes	0.08	21
SF <sub>6</sub> .....	2.2 mill. tonnes	0.05	1
2009	$\mu$ (mean)	Fraction of total emissions	Uncertainty $2\sigma$ (per cent of mean)
Total .....	26 mill. tonnes	1	17
CO <sub>2</sub> .....	17 mill. tonnes	0.67	23
CH <sub>4</sub> .....	4.3 mill. tonnes	0.16	14
N <sub>2</sub> O .....	3.1 mill. tonnes	0.12	55
HFC .....	708 ktonnes	0.03	48
PFC .....	379 ktonnes	0.01	20
SF <sub>6</sub> .....	64 ktonnes	0.00	63

The total national emissions of GHG (LULUCF sector excluded) in 1990 are estimated with an uncertainty of 5 per cent of the mean. The main emission component CO<sub>2</sub> is known with an uncertainty of 3 per cent of the mean. The total uncertainty level was 4 per cent of the mean in 2009. There have been major changes in uncertainty level for the different emission components between the two years. The highest uncertainty change between 1990 and 2009 is in the uncertainty estimates for the SF<sub>6</sub> emissions, which has increased from 2 to 56 per cent of the mean. However, the SF<sub>6</sub> emissions are strongly reduced because magnesium production was closed down. The figures for the emission of SF<sub>6</sub> from magnesium production was quite well known, but now a larger part of the SF<sub>6</sub> emissions comes from sources with higher uncertainty. For N<sub>2</sub>O there is also a considerable increase in the uncertainty between the years. One reason for the change can be found in that N<sub>2</sub>O from the production of synthetic fertiliser with a quite low uncertainty contributes to a smaller part of the total N<sub>2</sub>O emissions in 2009 than in 1990. For the other gases there are only smaller changes in the uncertainty.

By including the LULUCF sector the results from the analysis show a total uncertainty of 7 per cent of the mean in 1990 and 17 per cent in 2009. This is due to the fact that the uncertainty in the LULUCF sector in general is higher than in most other sectors.

In the tier 2 uncertainty analysis carried out in the year 2006 (Sandmo 2010), the uncertainty for the total national emissions of GHG (LULUCF sector excluded) in 1990 was estimated to be 7 per cent of the mean. In the new analysis the uncertainty estimate is reduced with two percentage points. There are several reasons for the new lower estimate. One reason is that Statistics Norway and the Norwegian Environment Agency have increased the inventory quality by using improved methodologies for important sources, as for example emissions from road traffic and from plants that participate in the emission trading system. But the main reason for the reduced uncertainty is that Statistics Norway has collected new and lower uncertainty estimates for some activity data and emission factors that contributed substantially to the total uncertainty in the emission estimate. This means that much of the reduction in the total uncertainty of the inventory is not due to improved inventory methods, since the lower uncertainty partly is an effect of improved uncertainty estimates for some source categories which earlier were overestimated. A source category with important reductions in uncertainty since the analysis in 2006 is the uncertainty in emissions of direct N<sub>2</sub>O from other agricultural soil sources. This category includes emissions from crop residues, and the uncertainty reduction is mainly a result of lower crop production. Since the uncertainty estimates for agricultural soils are very dominating, changes in these source categories have large impact on the total uncertainty for the inventory.

In the 2006 analysis, the uncertainty in the N<sub>2</sub>O estimate was estimated to 57 per cent of the mean. In the 2011 analysis the uncertainty estimate is reduced to 40 per cent of the mean. The other emission components show just minor changes in the uncertainty estimates for 1990 in the new analysis compared to the analysis from 2006.

For the last year in the two analyses (2004 in the 2006 analysis, 2009 in the present work), the reduction in total uncertainty from 6 to 4 per cent may simply reflect changes in the relative importance of the gases. The share of CO<sub>2</sub> is increased, while the share of N<sub>2</sub>O is reduced.

As mentioned above, another reason for the reduced uncertainty is that in the years between the two analyses important inventory improvement work has been carried through. New emission sources have also been included to make the greenhouse gas inventory for Norway more complete.

**1.6.1.2. Uncertainty in emission trend**

The estimated uncertainties of the trends of total emissions and each gas are shown in table 1.4 and table 1.5.

**Table 1.4. Uncertainty of emission trends. 1990-2009. Excluding the LULUCF sector**

	Per cent change (( $\mu$ 2009- $\mu$ 1990)*100/ $\mu$ 1990)	Uncertainty (2* $\sigma$ *100/ $\mu$ 1990)
Total .....	3	3
CO <sub>2</sub> .....	23	3
CH <sub>4</sub> .....	-9	10
N <sub>2</sub> O .....	-36	11
HFC .....	-	-
PFC .....	-89	17
SF <sub>6</sub> .....	-97	0

**Table 1.5. Uncertainty of emission trends. 1990-2009. Including the LULUCF sector**

	Per cent change (( $\mu$ 2009- $\mu$ 1990)*100/ $\mu$ 1990)	Uncertainty (2* $\sigma$ *100/ $\mu$ 1990)
Total .....	-37	7
CO <sub>2</sub> .....	-33	10
CH <sub>4</sub> .....	-9	10
N <sub>2</sub> O .....	-36	12
HFC .....	-	-
PFC .....	-89	19
SF <sub>6</sub> .....	-97	0

The result shows that the increase in the total GHG emissions from 1990 to 2009 is 3 per cent, with an uncertainty in the trend on  $\pm 3$  percentage points, when the LULUCF sector is not included. This means that the 2009 emissions are likely between 0 and 6 per cent above the 1990 emissions (a 95 per cent confidence interval). Norway is by the ratification of the Kyoto Protocol obliged to limit the emissions of greenhouse gases in the period 2008-2012 to 1 per cent over the emissions in 1990 after trading with CO<sub>2</sub> quotas and the other Kyoto mechanisms is taken into account. It is important to keep in mind that the emission figures reported to the Kyoto Protocol has an uncertainty connected to the reported values.

With the sector LULUCF included in the calculations there has been a decrease in the total emissions figures on -37 per cent, with a trend uncertainty on  $\pm 7$  percentage points.

**1.6.2. Acidifying substances and NMVOC**

The emission estimates for long-range air pollutants in the Norwegian emission model may be ranked roughly in order of increasing uncertainty as follows:



The sources of uncertainty in the emission estimates include sampling errors, poor relevance of emission factors or activity data, and gross errors.

Evaluation of the uncertainty in the long-range air pollutants is given in the report Rypdal and Zhang (2001). Summary tables with the results are given in Appendix D.

**1.6.3. Heavy metals and POPs**

The uncertainty is generally higher for HM and POPs than for other components in the Norwegian emission model except for N<sub>2</sub>O. There are various reasons for this high uncertainty. The most important reason is that there is limited information about emission factors, and it is not clear how usable the emission factors found in

international literature are for Norwegian conditions. Emission factors for some HM and POPs components are insufficient for some sources, so emission factors for similar sources have then been used. In addition it is not certain that all emission sources are known or sufficiently mapped. The industrial reporting to the Norwegian Environment Agency has improved in recent years. The reported figures can, however, vary a great deal from one year to another. For earlier years they can be insufficient, and since HM and POPs are to be calculated from 1990, recalculations are necessary. These recalculations are based on a combination of assumptions and knowledge of the plants. Emission figures from the early 1990s are therefore more uncertain than figures produced today.

## **1.7. Key category analyses**

For the greenhouse gases key category analyses were performed, following the IPCC Good Practice Guidance (IPCC 2000).

No systematic key category analyses have been made for other emissions.

### **1.7.1. Greenhouse gases**

According to the IPCC definition, key categories are those that add up to 90 per cent of the total uncertainty in level and/or trend. In the Norwegian greenhouse gas emission inventory key categories are primarily identified by means of a Tier 2 methodology. A description of the methodology as well as background tables and the results from the analyses is presented in Appendix E. In this chapter a summary of the analyses and the results are described.

According to the IPCC Good Practice Guidance (IPCC 2000) it is good practice to give the results at the Tier 2 level if available. The advantage of using a Tier 2 methodology is that uncertainties are taken into account and the ranking shows where uncertainties can be reduced. However, in the 2006 IPCC guidelines it is suggested that good practice reporting should include key categories from both the Tier 1 and Tier 2.

The Tier 2 and Tier 1 analyses was performed at the level of IPCC source categories and each greenhouse gas from each source category was considered separately with respect to total GWP weighted emissions, except land-use, land-use change and forestry.

The results from the key category analyses are summarized in table 1.6. The categories identified in the Tier 2 are arranged according to the last year level analysis. In addition we have also included in table 1.6 those source categories that according to Tier 1 key category analysis or qualitative criteria in the NIR are defined as key categories.

Fugitive emissions from coal mining and handling is included as a key category due to change in trend in the coal production and the fact that the national emission factors used is an order of magnitude less than IPCC's default factors. The last identified key category is CO<sub>2</sub> capture and storage. This removal category is considered key since there is presently no methodology as such defined in the IPCC guidelines and because these operations are unique internationally.

**Table 1.6. Summary of identified key categories for the greenhouse gases except LULUCF. Per cent contribution to the total uncertainty in level and/or trend. Bold numbers are key**

Source category		Gas	Level assessment Tier 2 1990	Level assessment Tier 2 2012	Trend assessment Tier 2 1990-2012	Method (Tier) 2012
<i>Tier 2 key categories (large contribution to the total inventory uncertainty)</i>						
4D1	Direct soil emissions	N <sub>2</sub> O	<b>28.96</b>	<b>25.13</b>	<b>9.84</b>	Tier 1a
1A	Stationary Fuel Combustion (1A1-1A2-1A4), Gaseous Fuels	CO <sub>2</sub>	<b>4.14</b>	<b>8.82</b>	<b>12.29</b>	Tier 2
4D3	Indirect emissions	N <sub>2</sub> O	<b>7.44</b>	<b>6.71</b>	<b>1.65</b>	Tier 2
1A3b	Road Transportation	CO <sub>2</sub>	<b>4.41</b>	<b>5.46</b>	<b>2.88</b>	Tier 1a
4A	Enteric Fermentation	CH <sub>4</sub>	<b>5.94</b>	<b>4.86</b>	<b>2.61</b>	Tier 1/2*
1B2a	Oil (incl. oil refineries, gasoline distribution)	CO <sub>2</sub>	<b>4.55</b>	<b>4.69</b>	0.51	Tier 2
2F	Consumption of Halocarbons and Sulphur Hexafluoride	HFCs	0.00	<b>4.54</b>	<b>11.80</b>	Tier 2
1A3d	Navigation	CO <sub>2</sub>	<b>3.40</b>	<b>3.57</b>	0.57	Tier 2
6A	Solid Waste Disposal on Land	CH <sub>4</sub>	<b>6.15</b>	<b>3.48</b>	<b>6.73</b>	Tier 2
1A3e	Other (snow scooters, boats, motorized equipment)	CO <sub>2</sub>	<b>1.52</b>	<b>3.02</b>	<b>3.94</b>	Tier 2
1A	Stationary Fuel Combustion (1A1-1A2-1A4), Other Fuels	CO <sub>2</sub>	0.69	<b>2.39</b>	<b>4.44</b>	Tier 2
1A3a	Civil Aviation	CO <sub>2</sub>	<b>1.36</b>	<b>2.32</b>	<b>2.54</b>	Tier 2
1B2c	Venting and Flaring	CH <sub>4</sub>	<b>1.08</b>	<b>2.18</b>	<b>2.89</b>	Tier 2
1A	Stationary Fuel Combustion (1A1-1A2-1A4), Liquid Fuels	CO <sub>2</sub>	<b>2.70</b>	<b>1.92</b>	<b>1.95</b>	Tier 2
1A4	Other sectors - Mobile Fuel Combustion	CO <sub>2</sub>	<b>1.89</b>	<b>1.89</b>	0.05	Tier 2
1A3e	Other (snow scooters, boats, motorized equipment)	N <sub>2</sub> O	0.70	<b>1.66</b>	<b>2.52</b>	Tier 1a
2C3	Aluminium Production	CO <sub>2</sub>	<b>1.47</b>	<b>1.65</b>	0.52	Tier 2
4D2	Animal production	N <sub>2</sub> O	<b>1.83</b>	<b>1.52</b>	<b>0.76</b>	Tier 2
1B2c	Venting and Flaring	CO <sub>2</sub>	<b>1.62</b>	<b>1.49</b>	0.28	Tier 2
4B	Manure Management	N <sub>2</sub> O	<b>1.24</b>	<b>1.18</b>	0.11	Tier 2
1A	Stationary Fuel Combustion (1A1-1A2-1A4), Biomass	CH <sub>4</sub>	<b>0.92</b>	<b>1.15</b>	0.62	Tier 1
6B	Wastewater Handling	N <sub>2</sub> O	<b>0.86</b>	<b>0.99</b>	0.36	Tier 1
2C2	Ferroalloys Production	CO <sub>2</sub>	<b>0.76</b>	0.65	0.26	Tier 2
1A3d	Navigation	CH <sub>4</sub>	0.03	0.63	<b>1.56</b>	Tier 2
1A	Stationary Fuel Combustion (1A1-1A2-1A4), Gaseous Fuels	CH <sub>4</sub>	0.29	0.57	<b>0.72</b>	CS, Tier 2,3
2C3	Aluminium Production	PFCs	<b>6.75</b>	0.33	<b>16.47</b>	Tier 2
1B2b	Natural Gas	CH <sub>4</sub>	0.02	0.26	<b>0.63</b>	Tier 2
2B2	Nitric Acid Production	N <sub>2</sub> O	<b>1.23</b>	0.16	<b>2.75</b>	Tier 2
1A3b	Road Transportation	CH <sub>4</sub>	0.32	0.06	<b>0.66</b>	Tier 3
2B4	Carbide Production	CO <sub>2</sub>	0.41	0.04	<b>0.95</b>	Tier 2
<i>Tier 1 key categories (large contribution to the total emissions)</i>						
1A	Stationary Fuel Combustion (1A1-1A2-1A4), Solid Fuels	CO <sub>2</sub>	0.73	0.55	0.43	Tier 2
2B5	Other Chemical Industry	CO <sub>2</sub>	0.26	0.34	0.23	Tier 2
2B1	Ammonia Production	CO <sub>2</sub>	0.38	0.26	0.30	Tier 2
1A5b	Military - Mobile	CO <sub>2</sub>	0.28	0.16	0.30	Tier 2
2A1	Cement Production	CO <sub>2</sub>	0.05	0.05	0.01	Tier 2
2A2	Lime Production	CO <sub>2</sub>	0.00	0.01	0.03	Tier 2
2C4	SF <sub>6</sub> Used in Aluminium and Magnesium Foundries	SF <sub>6</sub>	0.05	.	.	Tier 2
<i>Qualitative key categories</i>						
1B1a	Coal Mining and Handling	CH <sub>4</sub>	0.43	0.19	0.55	Tier 2
	Capture and storage	CO <sub>2</sub>				CS (Tier 2)

Bold figures indicate whether the source category is a key.

## 1.8. Completeness

An assessment of the completeness of the emission inventory should, according to the IPCC Good Practice Guidance (IPCC 2000), address the issues of spatial, temporal and sectoral coverage along with all underlying source categories and activities. Confidentiality is an additional element of relevance.



### 1.8.1. Greenhouse gases

In terms of spatial coverage, the GHG emissions calculated cover all activities within Norway's jurisdiction. In the case of temporal coverage, complete sets of emission figures are produced and updated every year for the years 1980, 1987 and for all years from 1989.

With regard to sectoral coverage, emissions from the IPCC sector 5 LULUCF (Land Use, Land Use Change and Forestry) are not included in this documentation. The reason for this exclusion is that this sector is not part of the calculations in the Norwegian emission model operated by Statistics Norway, and it is not included in the national emission data presented by Statistics Norway each year. Norway reports emissions and removals from this sector to the UNFCCC, though. A further description of the calculations of the data Norway report for LULUCF to the UNFCCC, is given in the National Inventory Report 2013 (Climate and Pollution Agency 2014)

Otherwise, the Norwegian GHG emission inventory includes estimates from all known relevant sources or sinks. There are, however, a few exceptions of minor sources/sinks, which are not covered. These are:

- Emissions of CH<sub>4</sub> from agricultural waste, after it is applied to soils. In the IPCC Guidelines it is written that "Agricultural soils may also emit CH<sub>4</sub>", but no calculation methodology is proposed.
- Carbon stock change of harvested wood products. The IPCC default method is used, where harvested wood is counted as emissions the year the harvest takes places.

The reason for not including the above activities is lack of data and/or exclusion from the list of priorities in the national inventory work because of the source's insignificant contribution to the national total.

Emissions from the use of feedstock are in accordance with Good Practice Guidance, and they are generally accounted for in the industrial processes sector in the Norwegian inventory. By-products from processes like CO gas that is sold and combusted are accounted for and reported under the energy sector.

### 1.8.2. Other pollutants

Norway is requested to report emissions to UNECE for the pollutants restricted by CLRTAP (Convention on Long-Range Transboundary Air Pollution). Minimum reporting request each year includes the acidifying pollutants (NO<sub>x</sub>, SO<sub>2</sub>, NH<sub>3</sub>) and NMVOC, the heavy metals Pb, Cd and Hg, particulate matter (TSP, PM<sub>10</sub> and PM<sub>2.5</sub>) and CO. Norway also reports, under the section "additional reporting", the heavy metals As, Cr and Cu, and the POPs dioxins and PAH.

In terms of spatial coverage, the calculated air emissions cover all activities within Norway's jurisdiction.

In the case of temporal coverage, emission figures for CO, SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub> and NMVOC are produced and updated every year for the years 1980, 1987 and for all years from 1989. For HM, POPs and particles, emission figures are produced for all years from 1990.

With regard to sectoral coverage, the following sources with relevant emission amounts are not covered in the inventory even if emissions can be expected:

Energy sector:

- NH<sub>3</sub> emissions from Civil aviation, domestic cruise (1A3aii (ii))
- Emissions of particulate matters from clutch wear (1A3b)
- Emissions of particulate matters from use of unpaved roads (1A3b)
- Emissions of particulate matters from sand strewing (1A3b)

- Fugitive emissions of HM from solid fuel transformation (1B1b)
- Fugitive emissions of NO<sub>x</sub> from natural gas (by land-based desulphurisation) (1B2b)

Industry sector:

- Emissions of NMVOC from asphalt roofing (2A5) and NMVOC and PAH from road paving with asphalt (2A6)
- Emissions of NO<sub>x</sub>, NMVOC and NH<sub>3</sub> from ammonia production (2B1)
- Emissions of NMVOC from Nitric acid production (2B2)
- Emissions of NO<sub>x</sub> from production of NPK-fertilisers (2B5) and emissions of Cd from production of Phosphate fertilisers (2B5)
- Emissions of NMVOC from the pulp and paper industry (2D1)
- Emissions of NH<sub>3</sub> from refrigeration and air conditioning equipments using other products than halocarbons (2G)

Agricultural sector:

- Emissions of NMVOC from manure management (4B)
- Emissions of NMVOC from agricultural soils (4D)
- Emissions of NMVOC from field burning of agricultural wastes (4F)

Waste sector:

- Emissions of NO<sub>x</sub>, NMVOC, NH<sub>3</sub> and CO from solid waste disposal on land (6A)
- Emissions of NMVOC and NH<sub>3</sub> from waste-water handling (6B)
- Emissions of particulate matters and POPs from burning of bonfire, emissions of POPs from burning of garden waste, and emissions of particulate matters, POPs and HM from burning of animal carcasses and burning of waste in household stoves (6C)
- Emissions of HM and POPs in connection with fires and open burning at landfills (6C)
- Evaporation of Hg from landfills and emission of Pb by detonation of explosives (6C)
- Emissions of dioxins by smoking processes for preservation of meat and fish (6C)

The reasons for not including these emission sources are mainly lack of activity data, emission factors or known calculation methodology.

### 1.9. Indirect CO<sub>2</sub> emissions from CH<sub>4</sub> and NMVOC

According to the reporting guidelines to the Climate Convention, all emissions of carbon from fossil compounds are to be included in the national emission inventory. When methane or NMVOC are oxidised in the atmosphere, indirect CO<sub>2</sub> emissions are formed. The emissions of CH<sub>4</sub> and NMVOC from some sources will partly be of fossil origin and should therefore be included. Fossil carbon in fuels combusted are automatically included in the emission inventory due to the fact that the guidelines for calculating the emissions take into account the fossil carbon in the fuel. These indirect CO<sub>2</sub> emissions are included in the Norwegian emission inventory. However, indirect CO<sub>2</sub> emissions from non-combustion sources originating from the fossil part of CH<sub>4</sub> and NMVOC are taken into account separately, calculated on the basis of average carbon content.

Fossil carbon in the emissions of CH<sub>4</sub> and NMVOC from the following non-combustion sources are included in the Norwegian emission inventory:

- Coal Mining and Handling – 1B1a
- Gas terminals – 1B2b
- Oil terminals – 1B2a

- Refineries – 1B2a
- Oil gas extraction activity – especially from loading of crude oil – 1B2a and 2B2c
- Distribution of oil products – 1B2a
- Silicon carbide - 2B4.1
- Calcium carbide - 2B4.2
- Methanol - 2B5.5
- Plastic - 2B.5
- Ferroalloys - 2C.2
- Solvent and other product use - 3

The indirect CO<sub>2</sub> emissions from oxidised CH<sub>4</sub> and NMVOC are calculated from the content of fossil carbon in the compounds. The average amount of carbon is estimated to be 75 per cent in methane and 82 per cent in NMVOC. This leads to the emission factors 2.74 kg CO<sub>2</sub>/kg CH<sub>4</sub> and 3 kg CO<sub>2</sub>/kg NMVOC, calculated on basis of mass of molecules.

## 2. The Norwegian emission model; general description

This chapter describes the general structure of the Norwegian emission model. The model was developed by Statistics Norway (Daasvatn *et al.* 1992; Daasvatn *et al.* 1994). It was redesigned in 2003 in order to improve reporting to the UNFCCC and UNECE, and to improve QA/QC procedures.

The Norwegian emission model is organised around a general emission model called “Kuben” (“the Cube”). Several emission sources, e.g. road traffic, air traffic and solvents are covered by more detailed satellite models. Aggregated results from the side models are used as input to the general model. The satellite models are presented in the appropriate sections of chapters 3-7. This chapter describes the general emission model.

### 2.1. Structure of the general emission model

The general emission model is based on equation (2.1).

$$(2.1) \quad \text{Emissions } (E) = \text{Activity level } (A) \cdot \text{Emission Factor } (EF)$$

For emissions from *combustion*, the activity data concern energy use. In the Norwegian energy accounts, the use of different forms of energy is allocated to industries (economic sectors). In order to calculate emissions to air, energy use must also be allocated to technical sources (e.g. equipment). After energy use has been allocated in this way, the energy accounts may be viewed as a cube in which the three axes are fuels, industries, and sources.

The energy use data are combined with a corresponding matrix of emission factors. In principle, there should be one emission factor for each combination of fuel, industry, source, and pollutant. Thus, the factors may be viewed as a four-dimensional cube with pollutants as the additional dimension. However, in a matrix with a cell for each combination, most of the cells would be empty (no consumption). In addition, the same emission factor would apply to many cells.

Emissions of some pollutants from major manufacturing plants (point sources) are available from measurements or other plant-specific calculations. When such measured data are available it is possible to replace the estimated values by the measured ones:

$$(2.2) \quad \text{Emissions } (E) = [(A - A_{PS}) \cdot EF] + E_{PS}$$

where  $A_{PS}$  and  $E_{PS}$  are the activity and the measured emissions at the point sources, respectively. Emissions from activity for which no point source estimate is available ( $A - A_{PS}$ ) are still estimated with the regular emission factor.

*Non-combustion* emissions are generally calculated in the same way, by combining appropriate activity data with emission factors. Some emissions may be obtained from current reports and investigations, and some are measured directly as described in chapters 3-7. The emissions are fitted into the general model using the parameters industry, source, and pollutant. The fuel parameter is not relevant here. The source sector categories are based on EMEP/NFR and UNFCCC/CRF categories, with further subdivisions where more detailed methods are available. An overview of the source sector categories used is given in Appendix G.

## 2.2. The four axes: Pollutants, industries, fuels, and sources

The *pollutants* currently included in the model are listed in table 1.1, see section 1.3.

The model uses approximately 130 *industries* (economic sectors). The classification is common with the basis data in the energy balance/accounts, and is almost identical to that used in the national accounts, which is aggregated from the European NACE (rev. 2) classification. The allocation of energy use and emissions to industries is the basis for combining inventory results with economic data in economic/environmental accounts (Erlandsen *et al.* 2002) and with economic models. The large number of sectors is an advantage in dealing with important emissions from manufacturing industries. The disadvantage is an unnecessary disaggregation of sectors with very small emissions. To make the standard sectors more appropriate for calculation of emissions, a few changes have been made, e.g. "Private households" is defined as a sector. The list of sectors is shown in Appendix F.

The *fuels* and technical *sources* used for combustion with energy use (NFR source sector 1A) are shown in tables 2.1-2.3.

**Table 2.1. Energy commodities in the Norwegian emission inventory**

Energy commodity	Aggregate fuel category in CRF and NFR
Coal	Solid Fuels
Coke	Solid Fuels
Petrol coke	Liquid Fuels
Wood	Biomass
Wood waste	Biomass
Black liquor	Biomass
Wood pellets	Biomass
Wood briquettes	Biomass
Charcoal	Biomass
Natural gas	Gaseous Fuels
Refinery gas	Liquid Fuels
Blast furnace gas	Solid Fuels
Landfill gas	Biomass
Biogas	Biomass
Fuel gas	Liquid Fuels
LPG	Liquid Fuels
Gasoline (road transport)	Liquid Fuels
Aviation gasoline	Liquid Fuels
Kerosene (heating)	Liquid Fuels
Jet kerosene	Liquid Fuels
Autodiesel	Liquid Fuels
Marine gas oil	Liquid Fuels
Light fuel oils	Liquid Fuels
Heavy distillate	Liquid Fuels
Heavy fuel oil	Liquid Fuels
Municipal waste	Other Fuels
Special waste*	Other Fuels

\* Special waste was moved from *Liquid* to *Other* fuels in 2014.

**Table 2.2. Sources for energy combustion in the Norwegian emission inventory**

Source	CRF/NFR
<i>Stationary combustion</i>	
Direct fired furnaces	1A1, 1A2
Gas turbines	1A1c, 1A3e, 1A4a
Boilers	1A1, 1A2, 1A4, 1A5
Small stoves	1A2, 1A4, 1A5
Flaring	1B2C, 6C
<i>Mobile combustion*</i>	
Passenger car	1A3b i, 1A5b
Light duty vehicles	1A3b ii, 1A5b
Heavy duty vehicles	1A3b iii, 1A5b
Motorcycle	1A3b iv
Moped	1A3b iv
Snowscooter	1A4b, c
Railway	1A3c
Aviation jet/turboprop (0-100 m)	1A3a ii (i), 1A5b
Aviation jet/turboprop (100-1000m)	1A3a ii (i), 1A5b
Aviation jet/turboprop (cruise)	1A3a ii (ii), 1A5b
Aviation helicopter (0-100 m)	1A3a ii (i)
Aviation helicopter (100-1000m)	1A3a ii (i)
Aviation helicopter (cruise)	1A3a ii (ii)
Aviation small craft (0-100 m)	1A3a ii (i)
Aviation small craft (100-1000m)	1A3a ii (i)
Aviation small craft (cruise)	1A3a ii (ii)
Ships	1A3d, 1A4c, 1A5b
Small boats 2 stroke	1A4b
Small boats 4 stroke	1A4b, c
Equipment 2 stroke	1A3e, 1A4c
Equipment 4 stroke, tractor	1A3e, 1A4b, c, 1A5b

\* For road transport the source split is more detailed in the sub-model. See section 3.2.4.2.

Table 2.3. Combinations of fuels and sources in use

	Direct fired furnaces	Gas turbines	Boilers	Small stoves	Flaring	Passenger car	Light duty vehicles	Heavy duty vehicles	Motorcycle	Moped	Snowscooter	Railway	Aviation jet/turboprop	Aviation helicopter	Aviation small craft	Ships	Small boats 2 stroke	Small boats 4 stroke	Equipment 2 stroke	Equipment 4 stroke, tractor
Coal	x	.	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Coke	x	.	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Petrol coke	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Fuel wood	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Wood waste	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Black liquor	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Wood pellets	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Wood briquettes	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Charcoal	.	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Natural gas	x	x	x	.	x	x	.	x	.	.	.	.	.	.	.	x	.	.	.	.
Refinery gas	x	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Blast furnace gas	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Landfill gas	.	.	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Biogas	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Fuel gas	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
LPG	.	.	x	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Motor gasoline	.	.	.	.	.	x	x	x	x	x	x	.	.	.	.	.	x	x	x	x
Aviation gasoline	.	.	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.
Kerosene (heating)	.	.	x	x	.	.	.	.	.	.	.	.	.	x	.	.	.	.	.	.
Jet kerosene	.	.	.	.	.	.	.	.	.	.	.	.	x	x	.	.	.	.	.	.
Auto diesel	.	.	x	.	.	x	x	x	.	.	.	x	.	.	.	.	.	x	.	x
Marine gas oil/diesel	x	x	x	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.
Light fuel oils	.	.	x	x	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	x
Heavy distillate	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.
Heavy fuel oil	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	x	.	.	.	.
Municipal waste	.	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Special waste	x	.	x	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

The sources for non-combustion emissions and for combustion without energy use are based on EMEP/NFR and UNFCCC/CRF categories, with further subdivisions where more detailed methods are available (Appendix G).

## 2.3. Regions: a fifth axis

Information about the geographical distribution of emissions is useful for modelling and control purposes. The spatial distribution of emissions introduces another dimension (axis) to the general model. In 2011 the production of regional emission statistics was stopped, due to quality problems. Statistics at county level for the components CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> were published in September 2014.

### 2.3.1. Municipalities

The municipalities, of which there are 428 on the mainland (in 2014), have been chosen as the smallest unit for regionalisation. In addition we have included the regions Svalbard, sea areas north and south of 62 °N, and air space 100-1000 m and more than 1000 m above ground level.

Emissions are allocated to geographical units *after* the national totals have been calculated. Emissions are allocated in one of three ways:

- Emissions from *point sources* are allocated directly to municipalities.

- When figures for the activity used to calculate emissions are available *directly* at municipal level, these figures are used. Examples are fuel combustion in manufacturing industries and emissions from animals.
- When the activity at the municipal level is unknown, the national emissions are allocated *indirectly* using surrogate statistical data. For example, fuel combustion in service industries is allocated using employment figures. In a number of cases the activity is known directly at the intermediate level (county), but allocation within counties uses surrogate data.

Data from several important sources, e.g. industrial statistics, are not available at the municipal level until one and a half years after the year of emissions.

### 2.3.2. EMEP grid squares

Emissions by EMEP 50 km x 50 km grid square are reported to the UNECE and used in models of long-range air pollution. The emissions are allocated to grid squares as follows:

- Emissions from large point sources are allocated directly to the appropriate squares. From 2000, this also includes emissions from offshore petroleum activities.
- Emissions at sea from national sea traffic and offshore petroleum activities (before 2000) are allocated to squares on the basis of a detailed analysis of 1993 activity data (Flugsrud and Rypdal 1996). The 1993 emissions are projected using national emission trends for each of the categories fishing, other sea traffic, flaring, other combustion, and other emissions in the petroleum sector.
- The remaining emissions in each municipality are allocated to squares according to the proportion of the area of the municipality in each square.

The method assumes that emissions are evenly distributed within municipalities. In reality, emissions often occur only in small parts of a municipality. If a municipality is large relative to the grid squares, the emissions may be allocated wrongly. However, few municipalities measure more than 50 km across and the larger municipalities are usually sparsely populated, with small emissions. It is therefore assumed that the level of error due to the method is acceptable. The direct allocation of large point sources also reduces the potential error.



## 3. Energy

### 3.1. Overview

This chapter provides descriptions of methodologies employed to calculate emissions from the energy sector. The disposition of the chapter is following the IPCC and NFR classifications of the emission sources. In section 3.2 emission estimations from energy combustion are described. This includes combustion emissions from energy industries, manufacturing industries and construction, transport and other combustion sources. Section 3.2 also includes memo items about international bunker fuels and CO<sub>2</sub> emissions from biomass.

In section 3.3 a description is given for fugitive emissions from fuels. This includes fugitive emissions from coal mining and handling, and from oil and natural gas. Section 3.3 also includes a description of the CO<sub>2</sub> capture and storage at the oil and gas production fields Sleipner West and Snøhvit.

### 3.2. Energy combustion

*IPCC IA*

*NFR IA*

*Last update: 14.04.2014*

#### 3.2.1. Overview

Combustion of fossil fuels and biomass leads to emissions of greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, fluorinated gases), SO<sub>2</sub>, NO<sub>x</sub>, NMVOC, CO, particulate matter, heavy metals, PAH and dioxins. Small amounts of NH<sub>3</sub> can also be emitted.

Emissions from energy combustion include contributions from all sources addressed in the IPCC/UNECE Guidelines. Emissions from waste incineration at district heating plants are accounted for under the energy sector, as the energy is utilised. Methane from landfills used for energy purposes is also accounted for in this sector. Emissions from flaring in the energy sectors are described in section 3.3 *Energy production*. Coal and coke used as reducing agents and gas used for production of ammonia (non-energy part) are accounted for under industrial processes. Flaring of natural gas and fuel gas in chemical industry is recorded in section 4.3.3. Other flaring outside the energy sectors is described in chapter 7 *Waste*. The same applies to emissions from accidental fires etc. Emissions from burning of crop residues and agricultural waste are accounted for in chapter 6 *Agriculture*. Emissions from tobacco are described in chapter 5 *Solvents and other product use*.

The main source for calculation of emissions from energy combustion is the energy balance, which annually is prepared by Statistics Norway. The data used in the emission calculations are at a much more disaggregated level than the published energy balance. Many different sources are utilised in the preparation of the energy balance. E.g., energy use in extraction of oil and gas, which constitutes an important part of Norwegian energy use, is reported from the Norwegian Petroleum Directorate. Other energy producers, such as oil refineries and district heating plants, also report their own energy use to Statistics Norway.

For different oil products, the total frame for annual use is given by Statistics Norway's statistics on deliveries of petroleum products. These statistics are also used in the estimation of use in different economic sectors, together with other available information. The distribution between sectors is of varying quality – e.g., in some cases projections of previous surveys are used in this process. For manufacturing industries, however, Statistics Norway's annual survey on all types of energy use, based on reports from plants responsible for approximately 96 per cent of the energy use in these sectors, combined with estimations for the remaining plants, provides figures of high quality.

### 3.2.1.1. Method

#### 3.2.1.1.1. General

Emissions from energy combustion are estimated at the sectoral level in accordance with the IPCC sectoral approach Tier 2/Tier 3. Often total fuel consumption is better known than the sectoral consumption.

The general method to estimate emissions from fuel combustion is multiplication of fuel consumption by source and sector by an appropriate emission factor. Exceptions are road and air transport where more detailed estimation models are used, involving additional activity data (see section 3.2.4.2 and 3.2.4.1 respectively). Fuel consumption figures are taken from the Norwegian energy balance. The mean theoretical energy content of fuels and their density are listed in table 3.1.

**Table 3.1. Average energy content and density of fuels**

Energy commodity	Theoretical energy content <sup>1</sup>	Density
Coal	28.1 GJ/tonne	..
Coal coke	28.5 GJ/tonne	..
Petrol coke	35.0 GJ/tonne	..
Crude oil	42.3 GJ/tonne = 36.0 GJ/m <sup>3</sup>	0.85 tonne/m <sup>3</sup>
Refinery gas	48.6 GJ/tonne	..
Natural gas (dry gas) <sup>2</sup>	35.5 GJ/1000 Sm <sup>3</sup>	0.74 kg/Sm <sup>3</sup> (domestic use)
Natural gas (rich gas) <sup>2</sup>	40.3 GJ/1000 Sm <sup>3</sup>	0.85 kg/Sm <sup>3</sup> (continental shelf)
Liquefied propane and butane (LPG)	46.1 GJ/tonne = 24.4 GJ/m <sup>3</sup>	0.53 tonne/m <sup>3</sup>
Fuel gas <sup>3</sup>	50.0 GJ/tonne	..
Petrol	43.9 GJ/tonne = 32.5 GJ/m <sup>3</sup>	0.74 tonne/m <sup>3</sup>
Kerosene	43.1 GJ/tonne = 34.9 GJ/m <sup>3</sup>	0.81 tonne/m <sup>3</sup>
Diesel oil, gas oil and light fuel oil	43.1 GJ/tonne = 36.2 GJ/m <sup>3</sup>	0.84 tonne/m <sup>3</sup>
Heavy distillate	43.1 GJ/tonne = 37.9 GJ/m <sup>3</sup>	0.88 tonne/m <sup>3</sup>
Heavy fuel oil	40.6 GJ/tonne = 39.8 GJ/m <sup>3</sup>	0.98 tonne/m <sup>3</sup>
Methane <sup>4</sup>	50.2 GJ/tonne	..
Wood	16.8 GJ/tonne = 8.4 GJ/solid m <sup>3</sup>	0.5 tonne/solid m <sup>3</sup>
Wood waste (dry wt)	16.25-18 GJ/tonne	..
Black liquor (dry wt)	7.2-9.2 GJ/tonne	..
Waste	10.5 GJ/tonne	..

<sup>1</sup> The theoretical energy content of a particular energy commodity may vary; Figures indicate mean values. All data are net calorific value (NCV).

<sup>3</sup> Sm<sup>3</sup> = standard cubic metre (at 15 °C and 1 atmospheric pressure).

<sup>4</sup> In this inventory, *fuel gas* is a hydrogen-rich excess gas from petrochemical industry.

Landfill gas and other types of biogas are reported as methane content in the energy balance.

Source: Energy statistics, Statistics Norway.

Four documentation reports have been published describing the methodologies used for road traffic (Bang *et al.* 1999), aviation (Finstad *et al.* 2002a) and navigation (Tornsjø 2001) and (Flugsrud *et al.* 2010).

#### 3.2.1.1.2. Delimitation towards industrial processes etc.

The energy combustion sector borders to several other source categories. This section presents the demarcation with other sectors used in the inventory.

Energy consumption reported as activity data in the emission inventories is generally delimited in the same way as emissions. In cases where different substances are handled differently, the delimitation of energy consumption follows the delimitation of CO<sub>2</sub> emissions.

*Flaring* is not reported as energy use in 1A. Instead, flaring is reported in the following source categories:

- Flaring in refineries and in exploration/extraction is reported in 1B – Fugitive emissions.

- Flaring in manufacturing industries is reported in 2 – Industrial processes, particularly in 2B – Chemical industry. (In the energy balance, flaring in manufacturing is reported as "losses".)
- Flaring of landfill gas is reported in 6C – Waste incineration.

Emissions from *reducing agents* are reported in 2- Industrial processes. This contrasts with the delimitation in the energy balance, where use as reducing agents is reported as energy consumption.

In some special cases, CO<sub>2</sub> emissions from combustion are reported in other source categories, while emissions of other substances are reported in 1A Energy:

- CO-rich excess gas from metallurgical plants burnt on-site is reported in 2 – Industrial processes, according to IPCC guidelines. (Gas which is sold to other plants is reported in 1A Energy.)
- Coal used as fuel in some metallurgical plants which also use coal as a reducing agent is reported in 2 – Industrial processes.
- CO<sub>2</sub> from coke that is burned off from catalytic crackers in refineries is reported in 1B – Fugitive emissions. This also applies to CO<sub>2</sub> from coke calcining kilns. This combustion is currently reported as energy use of CO<sub>2</sub>-rich gas ("other gas") in the energy balance.

In these cases, energy consumption reported in the inventories follows the delimitation of the CO<sub>2</sub> emissions. This gives meaningful implied emission factors for CO<sub>2</sub>, while IEFs for other substances may be skewed.

At a small number of plants, CO<sub>2</sub> emissions are reported in the ETS system from *derived fuels* that are not included as energy use in the energy balance. The carbon in the fuels is likely reported as feedstock in the energy balance. These cases are handled in two different ways. Both methods should give correct total CO<sub>2</sub> emissions, but the correspondence to reported energy data is different. In both cases, no emissions of other substances from these fuels are currently estimated.

- For methanol production, CO<sub>2</sub> emissions from several fuels not included in the energy balance are reported as process emissions in 2B5.5 Methanol.
- In other cases, emissions from derived fuels are included in the total CO<sub>2</sub> which is entered into the inventory for the plants. Thus, the emissions are larger than the corresponding energy use that is reported in the inventory. As far as is currently known, this method is only used when emissions from derived fuels are small relative to total fuel use in the source category, mainly in 1A2c - Chemicals. The method leads to implied emission factors that are high relative to the standard range.

Emissions from *paraffin wax* are reported in 2G – Industrial processes: Other.

Combustion of *solid waste* and *hazardous waste* is reported in the energy section (district heating in 1A1a and in several manufacturing industries). No significant combustion of solid or hazardous waste occurs without energy recovery.

Combustion of *landfill gas* with energy recovery is reported in the energy section (mainly in 1A4a Commercial/Institutional). Flaring is reported in 6C waste incineration, as mentioned above.

Some special problems relating to allocation of reported total plant emissions are discussed in section 3.2.1.1.4.

### 3.2.1.1.3. Emissions reported by plants: overview

For some major manufacturing plants (in particular offshore activities, refineries, gas terminals, cement industry, production of plastics, ammonia production), emissions of one or more compounds, reported to the Norwegian Environment Agency from the plants, are used instead of figures calculated with general emission factors as described above. In these cases, the energy consumption at the

plants in question is subtracted from the total energy use before the general method is used to calculate the remaining emissions of the compound in question, in order to prevent double counting.

Emissions are reported to the Norwegian Environment Agency under a number of different reporting obligations. Most CO<sub>2</sub> emissions (except metal production etc.) are reported as part of the Emissions Trading System (ETS).

In the general equation (2.2),  $Emissions (E) = [(A - A_{PS}) \cdot EF] + E_{PS}$ ,  $E_{PS}$  represents the reported emission data, while  $A_{PS}$  represents the energy consumption at the plants. Note that for most plants, reported emissions are used only for a limited number of substances. For the remaining substances in the inventory, the general method with standard emission factors is used.

Reported figures are used for a relatively small number of plants, but as these contribute to a large share of the total energy use, a major part of the total emissions are based on such reported figures. For the source categories petroleum refining, manufacture of solid fuels and other energy industries and iron and steel, more than 90 per cent of the sector emissions are based on reported data from plants. An overview of the distribution between estimated and reported emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in 2012 in main sector groups is given in table 3.2

**Table 3.2. Overview of estimated and reported greenhouse gases CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O for the energy combustion in 2012**

	CO <sub>2</sub>		CH <sub>4</sub>		N <sub>2</sub> O	
	Estimated	Reported	Estimated	Reported	Estimated	Reported
<b>A. Fuel Combustion Activities (Sectoral Approach)</b> .....	<b>58 %</b>	<b>42 %</b>	<b>78 %</b>	<b>22 %</b>	<b>98 %</b>	<b>2 %</b>
<b>1. Energy Industries</b> .....	<b>7 %</b>	<b>93 %</b>	<b>10 %</b>	<b>90 %</b>	<b>87 %</b>	<b>14 %</b>
a. Public Electricity and Heat Production .....	56 %	44 %	100 %		65 %	35 %
b. Petroleum Refining .....		100 %	76 %	24 %	100 %	
c. Manufacture of Solid Fuels and Other Energy Industries .....	1 %	99 %	1 %	99 %	100 %	
<b>2. Manufacturing Industries and Construction</b> .....	<b>44 %</b>	<b>56 %</b>	<b>99 %</b>	<b>1 %</b>	<b>97 %</b>	<b>3 %</b>
a. Iron and Steel .....	7 %	93 %	100 %		100 %	
b. Non-Ferrous Metals .....	100 %		100 %		100 %	
c. Chemicals .....	9 %	91 %	98 %	2 %	75 %	25 %
d. Pulp, Paper and Print .....	100 %		100 %		100 %	
e. Food Processing, Beverages and Tobacco .....	100 %		100 %		100 %	
f. Other (Oil drilling, construction, other manufacturing) .....	52 %	48 %	100 %		100 %	
<b>3. Transport</b> .....	<b>100 %</b>		<b>100 %</b>		<b>100 %</b>	
a. Civil Aviation .....	100 %		100 %		100 %	
b. Road Transportation .....	100 %		100 %		100 %	
c. Railways .....	100 %		100 %		100 %	
d. Navigation .....	100 %		100 %		100 %	
e. Other Transportation (Snow scooters, boats, motorized equipment, pipeline transport) .....	100 %		100 %		100 %	
<b>4. Other Sectors</b> .....	<b>100 %</b>		<b>100 %</b>		<b>100 %</b>	
a. Commercial/Institutional .....	100 %		100 %		100 %	
b. Residential .....	100 %		100 %		100 %	
c. Agriculture/Forestry/Fisheries ...	100 %		100 %		100 %	
<b>5. Other (Military)</b> .....	<b>100 %</b>		<b>100 %</b>		<b>100 %</b>	

Reported means that emission figures in the national emission inventory are based on figures reported by the plants. Estimated means that the figures are estimated by Statistics Norway (activity data \* emission factor).

The reports are from the mandatory reporting obligation that is a part of the plants' permits given by the authorities, and from 2005 the emission data are from the emission trading system (ETS). The ETS was a voluntary system in the period 2005-2007, and has been a part of EU ETS since 2008. From 1997 there have been different voluntary agreements between national authorities and the industries. From 1997, the agreements covered the aluminum producers and from 2005 industries not included in the ETS. The industries have in the different voluntary agreements committed themselves to reduce their greenhouse gas emissions as a group. As part of the agreement, the plants have every year reported detailed activity data and emissions to the Norwegian Environment Agency. The agreement involves industries such as ferroalloy, aluminum and ammonia production.

#### 3.2.1.1.4. Emissions reported by plants: Energy data

Energy data for plants with reported emissions ( $A_{PS}$  in equation (2.2)) should be consistent both with the energy balance that is used for activity totals  $A$  and with the reported emission data. Consistency with emission data means that the energy data should correspond to the same activity as the reported emissions.

In most cases, figures on plant energy use in the inventory are based on data reported from the plants to Statistics Norway. This ensures consistency with the energy balance.

In the emission trading system (ETS), emissions are in most cases reported together with data on the corresponding energy use. Usually the energy data reported in the ETS are the same as those reported by the plants to Statistics Norway.

However, for some plants some of the energy data differ between reports to Statistics Norway and the ETS. This leads to problems with consistency.

- In a few cases the inventory uses plant energy data from the ETS instead of data from Statistics Norway's energy balance. In these cases, the difference is significant, and the ETS data are deemed to be the most reliable. The emission inventory will be inconsistent with the energy balance. Currently, this applies to CO-rich excess gas in iron and steel production for 2008 and later.
- In other cases with mainly small emissions, the inconsistency between energy data from Statistics Norway ( $A_{PS}$ ) and reported emissions data ( $E_{PS}$ ) may lead to deviations in implied emission factors. However, the deviations are usually small, and generally this should not be regarded as an important issue.

### 3.2.1.1.5. Emissions reported by plants: Allocation to combustion/ processes

In some cases, emissions are reported as a plant total which includes both combustion and process emissions. These emissions have to be allocated to the two emission categories. Two methods are currently used in the inventory:

- Emissions of particulates, heavy metals and POPs in several industries where it is likely that most of the emissions are from processes: All emissions are entered into the inventory as process emissions. Emissions from combustion are set to 0 in order to avoid double counting.
- Emissions of CH<sub>4</sub> from an oil refinery: Emissions from combustion are calculated from energy use with standard factors. The remaining part of reported emissions are entered as process emissions.

### 3.2.1.1.6. Emissions reported by plants: Allocation to fuels

The following discussion is relevant for cases where emissions are reported with a fuels split. This applies to greenhouse gases reported to the UNFCCC, and to emission statistics in Statistics Norway's Statbank. In other reporting, emissions are aggregated over fuels.

For some plants and substances, emissions are reported by fuel, but in most cases reported combustion emissions are often entered as a plant total. The emissions are then allocated to fuels bases on standard EFs using equation 3.1:/

$$(3.1) \quad E_{PS,f} = E_{PS} \cdot A_{PS,f} \cdot EF_f / \sum_f (E_{PS} \cdot EF_f)$$

where the subscript  $f$  denotes fuel type.

This means that any deviations in data will be distributed across all fuels at the plant. Typical situations include:

- Plants with atypical fuels which differ from standard emission factors
- Plants with errors or other inconsistencies in energy data

In such cases, implied emission factors may deviate from the standard range also for other fuels than the one which is really affected.

Plants/substances which are entered by fuel currently include among others:

- CO<sub>2</sub> emissions from natural gas in almost all activities
- CO<sub>2</sub> emissions from cement production, 2008 and later
- CO<sub>2</sub> emissions from iron and steel production, 2008 and later
- CO<sub>2</sub> and several other substances from oil and gas production, offshore and onshore
- Particulate matter from manufacturing of wood products
- Heavy metal and POP emissions from combustion of municipal solid waste and special waste

Fuel specific CO<sub>2</sub> emissions in reports from the emission trading system (ETS) are not entered into the inventory, except for the cases listed above. For other plants in the ETS, only the total plant emission is used.

### 3.2.1.2. Activity data

The annual energy balance, compiled by Statistics Norway, forms the framework for the calculation of emissions from energy use. The energy balance defines the total energy consumption for which emissions are accounted. However, a large part of the total emissions are based on reports from plants that use much energy, i.e. offshore activities and energy-intensive industries on shore. Energy consumption in these plants is included in the energy balance, but this consumption is subtracted before the remaining emissions are calculated by the standard method of multiplying energy use by emission factors. Energy figures reported from the plants to Statistics Norway, which are used in the energy balance, sometimes deviate from the energy figures used to estimate reported emission figures, and this may cause inaccuracies in implied emission factors.

The energy balance surveys the flow of the different energy carriers within Norwegian territory. It includes energy carriers used as raw materials and reducing agents, but these are presented in a separate item and are not included in the data used to estimate emissions from combustion. Some emissions vary with the combustion technology; a distribution between different sources is thus required. Total use of the different oil products is based on the Norwegian sales statistics for petroleum products. For other energy carriers, the total use of each energy carrier is determined by summing up reported/estimated consumption in the different sectors. A short summary of the determination of amounts used of the main groups of energy carriers and the distribution between emission sources is given below.

#### *Natural gas*

Most of the combustion of natural gas is related to extraction of oil and gas on the Norwegian continental shelf. The amounts of gas combusted, distributed between gas turbines and flaring, are reported annually to Statistics Norway by the Norwegian Petroleum Directorate (NPD). These figures include natural gas combusted in gas turbines on the various oil and gas fields as well as on Norway's four gas terminals on shore. However, emission figures of CO<sub>2</sub> from the largest gas consumers, e.g. offshore activities, gas terminals and petrochemical industry, are reported by the plants. The data are of high quality, due to the Norwegian system of CO<sub>2</sub> taxation on fuel combustion. Statistics Norway's annual survey on energy use in manufacturing industries and sales figures from distributors give the remainder. Some manufacturing industries use natural gas in direct-fired furnaces; the rest is burned in boilers and, in some cases, flared.

#### *LPG and other gases*

Consumption of LPG in manufacturing industries is reported by the plants to Statistics Norway in the annual survey on energy use. Figures on use of LPG in households are based on sales figures, collected annually from the oil companies. Use in agriculture and construction is based on non-annual surveys; the figure for agriculture is interpolated for years not included in surveys, whereas the figure for construction is adjusted annually, based on employment figures.

Use of *refinery gas* is reported to Statistics Norway from the refineries. The distribution between the sources direct-fired furnaces, flaring and boilers is based on information collected from the refineries in the early 1990's. However, the total emissions from the refineries included in the inventory are equal to emissions reported from the plants and are regarded being of high quality.

At some industrial plants, excess gas from chemical and metallurgical industrial processes is burned, partly in direct-fired furnaces and partly in boilers. These amounts of gases are reported to Statistics Norway. A petrochemical plant

generates *fuel gas* derived from ethane and LPG. Most of the gas is burned on-site, but fuel gas is also sold to several other plants. All use of fuel gas is reported as energy consumption in the inventory.

Several metallurgical plants generate *CO-rich excess gas* that is either burnt on-site or sold to adjacent plants. Two ferroalloy plants sell parts of their CO-rich gas to some other plants (one producer of ammonia, a district heating plant, iron and steel producers and mineral industry), where it is combusted for energy purposes. These amounts are reported as energy consumption.

One sewage treatment plant utilizes *biogas* extracted at the plant, and reports quantities combusted (in turbines). By definition, no CO<sub>2</sub> emissions arise from bio gas, but other emissions are estimated by Statistics Norway, using the same emission factors as for combustion of natural gas in turbines.

#### *Oil products*

Total use of the different oil products is based on Statistics Norway's annual sales statistics for petroleum products. The data are generally considered reliable (with some reservations which are accounted for further down in this chapter), since all major oil companies selling oil products report to these statistics and have an interest in the quality of the data. The statistics are corrected for direct import by other importers or companies. The use of sales statistics provides a total for the use of oil products. The use in the different sectors must sum up to this total. This is not the case for the other energy carriers. The method used for oil products defines use as identical to sales; in practice, there will be annual changes in consumer stocks, which are not accounted for.

However, since the late 1990s the distribution in the sales statistics between different middle distillates has not been in accordance with the bottom-up estimated consumption of the products. In particular, the registered sales of light fuel oil have generally been too low, and it is known that some auto diesel also is used for heating. In order to balance the accounts for the different products, it has since 1998 been necessary to transfer some amounts between products instead of using the sales figures directly. The most important transfer is from auto diesel to light fuel oil, but in addition some auto diesel has also been transferred to heavy distillate.

Due to inaccuracies in the reporting of sales of marine gas oil from approximately 2005, there is also some uncertainty connected to the distribution between domestic and international sea transport for the latest years.

Stationary use takes place in boilers and, in some manufacturing industries, in direct-fired furnaces. There is also some combustion in small ovens, mainly in private households. Mobile combustion is distributed between a number of different sources, described in more detail in chapter 3.2.4 Transport. In addition to oil products included in the sales statistics, figures on use of waste oil are given in Statistics Norway's statistics on energy use in the manufacturing industries. Statistics Norway also collects additional information directly from a few companies about the use of waste oil as a fuel source.

Generally, in Norway there is a continual shift between use of oil and hydroelectricity, corresponding to changes in prices. Between years, this may cause changes in use of oil products and corresponding emissions which can be considerable.

#### *Coal, coke and petrol coke*

Use of coal, coke and petrol coke in manufacturing industries is annually reported from the plants to Statistics Norway. The statistics cover all main consumers and are of high quality. Combustion takes place partly in direct-fired furnaces, partly in



boilers. Figures on some minor quantities burned in small ovens in private households are based on sales figures. In addition, the figure on an insignificant use of coal in the agricultural sector was formerly collected from one farmer. Since 2002, there has been no use of coal in Norwegian agriculture.

#### *Biofuels*

Use of *wood waste* and *black liquor* in manufacturing industries is taken from Statistics Norway's annual survey on energy use in these sectors.

Use of *wood* in households is based on figures on the amount of wood burned from the annual survey on consumer expenditure for the years before 2005 and for 2012. The statistics cover purchase in physical units and estimates for self-harvest. The survey figures refer to quantities *acquired*, which not necessarily correspond to *use*. The survey gathers monthly data that cover the preceding twelve months; the figure used in the emission calculations (taken from the energy balance), is the average of the survey figures from the year in question and the following year. For the years 2005-2011, the figures are based on responses to questions relating to wood-burning in Statistics Norway's Travel and Holiday Survey. The figures in this survey refer to quantities of wood *used*. The survey quarterly gathers data that cover the preceding twelve months. The figure used in the emission calculations is the average of 5 quarterly surveys. Figures on some minor use in agriculture and in construction are derived from earlier surveys for these sectors. Combustion takes place in boilers and in small ovens in private households.

Consumption figures for *wood pellets* and *wood briquettes* are estimates, based on annual information from producers and distributors.

Data on use of *peat* for energy purposes is not available, but according to the Energy Farm, the centre for Bioenergy in Norway, such use is very limited (Hohle 2005).

#### *Waste*

District heating plants and incineration plants annually report combusted amounts of waste (boilers) to Statistics Norway and the Norwegian Environment Agency. There is also some combustion in manufacturing industries, reported to Statistics Norway.

According to the Norwegian Pollution Act, each incineration plant has to report emission data for SO<sub>2</sub>, NO<sub>x</sub>, CO, NH<sub>3</sub>, particles, heavy metals and dioxins, and the amount of waste incinerated to the county governor. The county governor then reports this information to the Norwegian Environment Agency. If emissions are not reported, the general method to estimate emissions from waste incineration is to multiply the amount of waste used by an appropriate emission factor. Normally a plant specific emission factor is made for the component in question. This factor is based on the ratio between previous emission figures and quantities of waste burned. This factor is then multiplied with the amount of waste incinerated that specific year.

#### *Energy balance sheets vs. energy accounts*

There are two different ways of presenting energy balances: Energy balance sheets (EBS) and energy accounts. The energy figures used in the emission calculations are mainly based on the energy balance sheets.

The energy accounts follow the energy consumption in Norwegian economic activity in the same way as the national accounts. All energy used by Norwegian enterprises and households is to be included. Energy used by Norwegian transport trades and tourists abroad is also included, while the energy used by foreign transport industries and tourists in Norway is excluded.

The energy balance sheet follows the flow of energy within Norway. This means that the figures only include energy sold in Norway, regardless of the users' nationality. This leads to deviations between the energy balance sheet and the energy accounts, especially for international shipping and aviation. The energy balance sheet has a separate item for energy sources consumed for transportation purposes. The energy accounts place the consumption of all energy under the relevant consumer sector, regardless of whether the consumption refers to transportation, heating or processing.

Figures from the energy sources balance sheet are reported to international organisations such as the OECD and the UN. The energy balance sheet should therefore usually be comparable with international energy statistics.

Important differences between figures presented in the energy balance sheet (EBS) and figures used in the emission calculations (EC) are:

- Air transport: EC use only Norwegian domestic air traffic (excluding military), while EBS includes all energy sold in Norway for air transport, including military and energy used for international air transport.
- Coal/coke for non-energy purposes: This consumption is included in net domestic consumption in EBS, whereas EC include only energy used for combustion in the calculation of emissions from energy.

### 3.2.1.3. *Emission factors*

Emission factors used for the energy sector are given in Appendix B. Emission factors for CO<sub>2</sub> and SO<sub>2</sub> are independent of combustion technology. In cases where technology for cleansing of SO<sub>2</sub> has been installed, this will be reflected in the emission figures reported from the respective plants. For the other emission components further descriptions are also given for each source sector.

The emission factors of NO<sub>x</sub>, CO, NMVOC, NH<sub>3</sub>, N<sub>2</sub>O and CH<sub>4</sub> for stationary combustion have been evaluated by Norsk Energi for the Norwegian Environment Agency. The evaluation is described in the report "Vurdering av utslippsfaktorer for beregning av NO<sub>x</sub>-utslipp med mer fra stasjonær forbrenning i Norge" (Evaluation of NO<sub>x</sub> emissions factors etcetera from stationary combustion in Norway) (Norsk Energi 2003). The report focused mainly on NO<sub>x</sub>, but also emission factors for CO, NMVOC, NH<sub>3</sub>, N<sub>2</sub>O and CH<sub>4</sub> were considered.

The conclusion in Norsk Energi (2003) was that there are significant discrepancies between the emission factors from literature and the factors used in the inventory. Some of the emission factors used in the national inventory are higher and some lower than the emission factors found in literature. To some extent the discrepancy is due to the fact that the emission factors from literature are not reflecting technology used in Norway and therefore not are valid for Norwegian conditions. In addition it is considered that some of the Norwegian emission factors are based on more reliable data than the factors from literature. However, (Norsk Energi 2003) proposed to change some of the emissions factors, due to the fact that the factors from literature were considered to be of better quality than those used in the Norwegian emission inventory. One of the factors was the NO<sub>x</sub> emission factor for heavy fuel oil, see below. In general, for all other compounds the emissions factors proposed in Norsk Energi (2003) were lower than the emission factors that are used in the Norwegian emission inventory. We consider that the effect on national totals of not replacing the emission factors with the proposed factors in Norsk Energi (2003) has led to overestimated emissions. However, Norway is continuously considering all aspects of the Norwegian emission inventory, including the emission factors, and with the updated EMEP 2009 Guidelines (EMEP 2009) we now consider to evaluate the emission factors in our inventory.

### *CO<sub>2</sub>*

Emission factors for CO<sub>2</sub> are independent of technology. The factors for different fuels are based on the average carbon content in each fuel.

From the 2010 emission inventory, the standard factor for natural gas was changed from 2.34 kg/Sm<sup>3</sup> to 1.99 kg/Sm<sup>3</sup>. In practice, this factor is only used for consumption of dry gas outside the energy sector. The old factor reflected offshore combustion of rich gas. For the latter emissions, reported figures, based on field specific emission factors, are now used in the inventory.

Biofuels for transport are not handled as separate fuels. The consumption is included with gasoline and autodiesel. The CO<sub>2</sub> factors for these fuels are adjusted annually according to the biofuel content.

### *CH<sub>4</sub> and N<sub>2</sub>O*

For CH<sub>4</sub> and N<sub>2</sub>O, information on emission factors is generally very limited, because, unlike the CO<sub>2</sub> emission factors, they depend on the source of the emissions and the sector where the emissions take place. The emission inventory uses mostly default factors from IPCC (1997a). The emission factor for methane from fuel wood is taken from SINTEF (Karlsvik 1995). Due to lack of data, some emission factors are used for sector/source combinations other than those they have been estimated for.

### *NO<sub>x</sub>*

The NO<sub>x</sub> emission factors used in the Norwegian emission inventory have, as mentioned above, been evaluated by Norsk Energi in Norsk Energi (2003) and also in "NO<sub>x</sub>-utslipp i forbindelse med eventuell NO<sub>x</sub>-avgift" (Evaluation of NO<sub>x</sub> emissions in connection with implementing NO<sub>x</sub> tax) (Norsk Energi 2006). The conclusion in both reports is that the NO<sub>x</sub> emission factors used in the inventory are within the intervals Norsk Energi found in their own measured data and from literature.

Norsk Energi (2003) concluded that the general emission factor for heavy fuel oil should be considered to be changed from 4.2 to 5 kg NO<sub>x</sub> per tonne fuel and for chemical and metal industry from 5 to 6 kg NO<sub>x</sub> per tonne heavy fuel oil. The consumption of heavy fuel oil in stationary combustion in Norway is very small and NO<sub>x</sub> emissions in the Norwegian inventory from the largest consumers of heavy fuel oil in industry are based on plant specific data. Due to this, the proposed emission factors from Norsk Energi (2003, 2006) are not included in the Norwegian emission inventory. Norway intends to compare the NO<sub>x</sub> emission factors in our inventory with EMEP 2009 Guidelines.

### *SO<sub>2</sub>*

The emission factors for SO<sub>2</sub> from oil products change yearly, in accordance with variations in the sulphur content in the products. The presented factors refer to uncleaned emissions; in cases where the emissions are reduced through installed cleansing measures, this will be reflected in emission figures reported from the respective plants.

#### **3.2.1.4. Uncertainties**

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D, as well as under the individual underlying source categories.

Generally, the total energy use is less uncertain than the energy use in each sector. For some sectors (e.g. the energy and manufacturing industries) the energy use is well known, while it is more uncertain in households and the service sectors. The energy use in the most uncertain sectors has been adjusted in the official energy statistics, so that the sum of the energy use in all sectors equals the total sales.

**3.2.1.5. Completeness**

All known combustion with energy utilization in different industries and private households is included.

**3.2.1.6. QA/QC**

The emission sources in the energy sector are subjected to the QA/QC procedures described in section 1.5. Four documentation reports have been published describing the methodologies used for road traffic (Bang *et al.* 1999), aviation (Finstad *et al.* 2002a) and navigation (Tornsjø 2001) and (Flugsrud *et al.* 2010).

**3.2.2. Energy industries**

*IPCC 1A1, Key category for CO<sub>2</sub> from combustion of gas, liquid, solid and other fuels. Key category for CH<sub>4</sub> for combustion of gas and biomass  
NFR 1A1*

*Last update: 15.01.2014*

**3.2.2.1. Description**

Energy industries include emissions from electricity and heat generation and distribution, extraction of oil and natural gas, coal production, gas terminals and oil refineries. Norway produces electricity mainly from hydropower, so emissions from electricity production are small compared to most other countries. Due to the large production of oil and gas, the emissions from combustion in energy production are high.

Emissions from drilling at moveable offshore installations are included here. (Reallocated from navigation in this inventory cycle.) Emissions from these installations while not in operation (during transport, etc.) are included with 1A3D Navigation.

**3.2.2.2. Method**

A general description of the method used for estimation of emissions from fuel combustion is given in section 3.2.1.1. For waste incineration also a more detailed description of the methodology for some components is given in this section.

*Waste incineration**CO<sub>2</sub> and CH<sub>4</sub>*

Net CO<sub>2</sub> emissions from wood/ biomass burning are not considered in the inventory, because the amount of CO<sub>2</sub> released during burning is the same as that absorbed by the plant during growth. Carbon emitted in compounds other than CO<sub>2</sub>, e.g. as CO, CH<sub>4</sub> and NMVOC, is also included in the CO<sub>2</sub> emission estimates.

*N<sub>2</sub>O and NO<sub>x</sub>*

Emissions of NO<sub>x</sub> are reported from each plant to the Norwegian Environment Agency. An estimated amount of 2.5 per cent of this NO<sub>x</sub> is subtracted and reported to UNFCCC as N<sub>2</sub>O (Sandgren *et al.* 1996). Accordingly, the net NO<sub>x</sub> emissions constitute 97.5 per cent of the emissions reported by the plants. For some years, emissions of NO<sub>x</sub> have not been reported for a number of plants. In these cases, specific emission factors for the plants have been made, based upon earlier emissions and amounts of waste incinerated. These new factors have been used to estimate the missing figures.

*Particles*

Emissions of particles from district heating plants are reported to the Norwegian Environment Agency. The different plants started to report particulate emissions at various points in time. Most of them started reporting from 1994. Emissions of particles in the years before reporting have been assumed to be the same as in the first year the plant reported. New control device systems (mainly wet scrubbers) were installed at the end of the 1980s at the largest plants. Around 1995 more control device systems were installed as a result of stricter emission requirements. Most

plants today have fabric filter or electrofilter together with wet scrubbers. Only two plants do not have wet scrubbers.

The emission permits do not state which particle fraction that is going to be measured. It is common to measure total amount of particles. It is however presumed that the particles emitted are less than PM<sub>2.5</sub>. TSP and PM<sub>10</sub> are therefore the same as PM<sub>2.5</sub>.

#### *Dioxins*

Emissions of dioxins from waste burning at district heating plants are reported to the Norwegian Environment Agency. We have reported data for each plant from the period 1994/1995. Before 1994 we have only national totals. For estimating the emissions of dioxins for each plant before 1994 we derived an emission factor from total amount of waste burned together with the total dioxin estimate. The emissions of dioxins were estimated by multiplying the given emission factor of 20 µg/tonne waste by the amount of waste burned at each plant. This calculation was done for each of the missing years for plants that did not report emissions.

#### *Heavy metals*

The estimate of heavy metals from waste combustion at district heating plants is reported to the Norwegian Environment Agency. Before 1999 many emissions of heavy metals were reported together as one group. This made it difficult to use the data to estimate the emission of each component. From 1999 there are separate data for each component, but for As, Cr and Cu there are a few plants that have insufficient reporting. To calculate the emissions of heavy metals before 1999 we have estimated an emission factor for each plant with the aid of reported emission data and amount of waste burned at each plant. The emission factor derived has been used to calculate emissions for previous years by multiplying each specific emission factor with the amount burned for the corresponding year for each plant.

Every district heating plant had stricter emission requirements for particles from 1995. It is expected that the emissions of heavy metals, except for mercury, were reduced analogously. At the same time the emission of mercury was regulated from 0.1 mg/Nm<sup>3</sup> to 0.05 mg/Nm<sup>3</sup>. These regulations are considered while calculating emissions for previous years.

### **3.2.2.3. Activity data**

#### *Electricity and heat generation and distribution*

The energy producers annually report their use of different energy carriers to Statistics Norway. There is only some minor use of oil products at plants producing electricity from hydropower. Combustion of coal at Norway's only dual purpose power plant at Svalbard/Spitsbergen is of a somewhat larger size. The amount of waste combusted at district heating plants is reported annually both to Statistics Norway and the Norwegian Environment Agency. The data are considered to be of high quality.

#### *Extraction of oil and natural gas*

Production of oil and natural gas is the dominating sector for emissions from combustion in the energy industries in Norway. The Norwegian Petroleum Directorate annually reports the amounts of gas combusted in turbines and diesel burned in turbines and direct-fired furnaces on the oil and gas fields. The data are of high quality, due to the CO<sub>2</sub> tax on fuel combustion. These activity data are used for 1990-2002. From 2003 onwards, reported emission figures from the field operators are used.

#### *Coal production*

Norway's coal production takes place on Svalbard. The only coal producing company annually reports its coal consumption and some minor use of oil products. In addition to emissions related to Norway's own coal production, also

emissions from Russian activities are included in the Norwegian emission inventory. Russian activity data are scarce, and emissions from an estimated quantity of coal combusted in Russian power plants are calculated. Since 1999 there has been only one such plant, in earlier years there were two of those.

#### *Gas terminals*

Natural gas from the Norwegian continental shelf is landed, treated and distributed at gas terminals on shore. There are four gas terminals in Norway. The eldest started up before 1990, one in 1996 and two in 2007. Annual figures on natural gas combusted in turbines and flared are reported to the Norwegian Petroleum Directorate (figures on flaring at one plant is reported to the Norwegian Environment Agency).

#### *Gas power plants*

Norway had in 2011 two major gas power plant and several minor ones. The first of the large plants was opened in 2007 and runs intermittently, depending on electricity and gas prices. The second large plant was opened in 2010. Several of the smaller plants are back-up plants that are run only in emergency situations. Thus, there will be large annual fluctuations in emissions.

#### *Oil refineries*

The oil refineries annually report their use of different energy carriers to Statistics Norway. Refinery gas is most important, but there is also some use of LPG and oil products. Burning of coke while regenerating the catalyst in cracker units is reported under 1B2A4 – Fugitive emissions – Refining/Storage.

### **3.2.2.4. Emission factors**

Emission factors used for the energy sector are given in Appendix B. For some industries and components more information about the derivation of the emission factors are given in this section.

#### **3.2.2.4.1. CO<sub>2</sub>**

##### *Waste incineration*

The CO<sub>2</sub> emission factor for the fossil part of waste combusted in waste incineration plants in Norway was revised in 2011. The new factor is based on there being 2.708 tonnes CO<sub>2</sub> per tonne plastic combusted (based upon the same composition of polymers combusted as in Danish calculations (National Environmental Research Institute 2011)) and that 20 per cent of the combusted waste is fossil (Avfall Norge 2006). This factor is based on surveys of the composition of waste combusted in 2004 and before, and is used from 1996 onwards. In the mid 1990s there were conducted surveys on the composition of waste combusted, and the conclusion was that the content of fossil waste in combusted waste was about 9 per cent (Sandgren *et al.* 1996) – this factor is used before 1996. According to the report from Avfall Norge, the energy content in combusted waste is in average 12 GJ per tonne waste. In the energy figures used in the emission calculations, however, the factor 10.5 GJ per tonne waste, taken from (Sandgren *et al.* 1996), is still used for all years, in accordance with the energy balance. It is likely that there is a gradual increase in the content of fossil waste and that varying factors should be used for the years in the time period from 1990. This subject matter will be looked further into in coming years.

##### *Extraction of oil and natural gas*

For all years up to 2002 emissions of CO<sub>2</sub> from gas combustion offshore are calculated by Statistics Norway on the basis of activity data reported by the oil companies to NPD (the Norwegian Petroleum Directorate) and the Norwegian Environment Agency and appropriate emission factors. For 2003 and later, the data used in the inventory are emissions reported directly by the field operators. The latter are obliged to report these and other emissions annually to NPD and the Norwegian Environment Agency.

The CO<sub>2</sub> emission factor used for all years up to 1998, and for all fields except one, is an average (standard) factor based upon a survey carried out in the early 1990s (The Norwegian oil industry association 1993, 1994). From 1999 onwards, the emission factors employed increasingly reflect field specific conditions as individual emission factors have been reported directly from the fields. The measurement frequency varies among the installations. An increasing number uses continuous gas chromatography analysis. Table B5 in Appendix B displays the time series of such emission factors, expressed as averages.

The carbon content of gas burnt varies considerably between the various oil and gas fields. These changes are reflected in the reported emissions. Up to the early 1990s, most of the gas was used in the Ekofisk area, which has a below average carbon content. From around 2000, fields with higher carbon content came into production. In the last few years, there has again been a shift towards fields with somewhat lower carbon content.

#### *Gas terminals and gas-fired power plants*

The CO<sub>2</sub> emission factors for combustion of natural gas on gas terminals and power plants are based on continuous or daily plant-specific measurements.

#### *Oil refineries*

The CO<sub>2</sub> emission factor for combustion of refinery gas is based on daily or weekly plant-specific measurements. The refinery gas consists of hydrogen and various hydrocarbons. The composition is variable, leading to changing emissions factors measured as t CO<sub>2</sub>/t fuel or t CO<sub>2</sub>/TJ. A high hydrogen content leads to low emission factors as measured in t CO<sub>2</sub>/TJ. As an example, a gas with 40 per cent hydrogen and 60 per cent hydrocarbons with an average carbon number of 2 gives an emission factor of 50 t CO<sub>2</sub>/TJ. In the Norwegian inventory, the emission factors vary in the range 45-60 t CO<sub>2</sub>/TJ.

#### **3.2.2.4.2. CH<sub>4</sub>**

##### *Waste incineration*

The emission factor for combustion of waste (fossil part only) was calculated by the Norwegian Environment Agency (Sandgren *et al.* 1996).

#### **3.2.2.4.3. SO<sub>2</sub>**

##### *Russian electricity and heat production*

Emissions from combustion of coal for electricity production in the Russian settlements on Svalbard are included in the Norwegian emission inventory. Up to 1998 there were two Russian settlements with electricity and heat production: Barentsburg and Pyramiden. Since the coal production at Pyramiden was closed down in 1998, the settlement was abandoned, and all activity now takes place in Barentsburg. For SO<sub>2</sub>, emission factors are based on information from Trust Arktikugol in Moscow. From 1999 the factor 70 kg/tonne is used, and for earlier years 16 kg/tonne. The factor estimated figures are reduced by 60 per cent, due to the assumption that such an amount of the sulphur is bound in the ash.

#### **3.2.2.4.4. NO<sub>x</sub>**

##### *Offshore installations*

NO<sub>x</sub> emissions from diesel engines at offshore installations were revised in 2014 based on Karlsson and Finborud (2012). The recommended factors are shown in table 3.3.

**Table 3.3. Recommended emission factors for NO<sub>x</sub> for different engine types**

	Engine building year		Previous default factor
	Before 2000 kg NO <sub>x</sub> /tonne fuel	After 2000 kg NO <sub>x</sub> /tonne fuel	
200-1 000 rpm: Medium speed .....	54	53	70
1 000-1 500 rpm: High speed, lower range .....	50	50	60
> 1 500 rpm: High speed, higher range .....	45	44	55

Source: Karlsson and Finborud (2012).

From 2003, emissions at fixed installations and at moveable installations during drilling operations are taken from reports from operators. Some operators use default emission factors, whereas an increasing fraction use plant-specific factors.

In the implementation of the factors from Karlsson and Finborud (2012), the following principles were used:

- Reported emissions with implied emission factors less than 1 per cent from the old default values (70/60/55 kg/t) were assumed to having used the default factors. These emissions were reduced to the new default values for engines from before 2000 (54/50/45 kg/t).
- Other reported emissions were assumed to having used plant-specific factors and were left unchanged.
- Emissions from other consumption in engines were calculated with a general factor of 54 kg NO<sub>x</sub>/tonne. This applies to all emissions before 2003, and the remaining fraction of sales to the oil and gas industry from 2003 onwards.
- Emissions from use of marine gas oil for turbines has not been part of this revision.

#### **3.2.2.4.5. TSP, PM<sub>10</sub> and PM<sub>2.5</sub>**

##### *Electricity and heat generation*

Emission factors for TSP, PM<sub>10</sub> and PM<sub>2.5</sub> are based on emission data given in EPA (2002). EPA (2002) gives emission data based on measurements made from various boilers using different control device systems. The Norwegian power plant at Svalbard is equipped with a multicyclone, and emission factors derived from measurements from boilers controlled with multicyclone device systems are used.

#### **3.2.2.4.6. Dioxins and PAH**

##### *Electricity and heat generation*

Dioxin emissions from coal combustion at the power plants at Svalbard are derived from emission factors found in literature. The emission factor used is the emission factor recommended in Bremmer *et al.* (1994). The same emission factor is also used in Parma *et al.* (1995) and Hansen (2000). Burning of coal at power plants is also expected to give particle-bound dioxin emissions, but because of the effective control device using multicyclone collector, the emissions are expected to be low.

Emission factors for PAH-4, PAH-6 and PAH-total are derived from an emission profile developed from emission measurements from boilers using different control device systems (EPA 1998).

PAH emissions from waste incineration are calculated by emission factors and amount of waste burned. The emission factor used for calculating emissions of PAH before 1995 is 2.5 g PAH/tonne waste burned. It is assumed that the emissions have been reduced by 70 per cent since then because of stricter emission requirements from 1995. The new emission factors have been identified using information from Sweden. We have no plant or country specific emission profile of PAH from waste incineration at district heating plants in Norway. Instead an emission profile from a district heating plant in Sweden, burning wood powder, is used (Karlsson *et al.* 1992; Norwegian institute for air research and Norwegian institute for water research 1995).



### 3.2.2.4.7. Heavy metals

#### *Electricity and heat generation*

The emission factors for heavy metals used for calculating emissions from coal fired power plants are from EEA (2001). The factors are, however, not specific for coal fired power plants but standard factors recommended for calculating emissions from coal combustion in energy and transformation industries.

### 3.2.2.5. Uncertainties

Uncertainty estimates for greenhouse gases and long-range air pollutants are given in Appendix D. Since the energy use is well known for the energy industries, the uncertainty in the activity data is considered to be minor.

The uncertainty in the activity data is  $\pm 3$  per cent of the mean for oil,  $\pm 4$  per cent for gas and  $\pm 5$  per cent of the mean for coal/coke and waste.

In the case of the emission factors for CO<sub>2</sub>, the uncertainty is  $\pm 3$  per cent of the mean for oil,  $\pm 7$  per cent for coal/coke and gas and  $\pm 30$  per cent of the mean for waste.

Emission factors for CH<sub>4</sub> and N<sub>2</sub>O are very uncertain. Distributions are strongly skewed with uncertainties which lie below and above the mean by a factor of 2 and 3, respectively.

### 3.2.2.6. Completeness

Major missing emission sources are not likely.

### 3.2.2.7. Source specific QA/QC

The energy industries are subjected to the general QA/QC procedures described in section 1.5. Some source specific QA/QC activities were conducted in the following industries:

#### *Heat generation in district heating plants*

Emissions of heavy metals and POPs from waste incineration have been subject to detailed control. The estimates are based on measurements, but the values are uncertain due to high variability. Reported emission values can vary by orders of magnitude from year to year. Each historical value has been checked in the QA/QC process, and some data have been rejected and replaced by calculated values.

#### *Extraction of oil and natural gas*

For emissions of NO<sub>x</sub> from turbines offshore, time series over the emissions calculated with field specific emission factors have been compared with the emissions given, using the earlier used average emission factor.

From 2003 onwards field specific emission figures reported from the companies are used directly in the emission model. These figures are compared with emissions calculated on the basis of field specific activity data and emission factors.

#### *Oil refineries*

The CO<sub>2</sub> emissions reported from the refineries are compared with the emissions estimated by Statistics Norway on the basis of activity data and emission factors for the different energy carriers used.

Results from the above studies have so far shown that emission estimates are in agreement with the reported figures

### 3.2.3. Manufacturing industries and construction

*IPCC 1A2, Key category for CO<sub>2</sub> from combustion of gas, liquid, solid and other fuels. Key category for CH<sub>4</sub> for combustion of gas and biomass  
NFR 1A2*

*Last update: 23.05.2012*

#### 3.2.3.1. Description

Emissions from the sector of manufacturing industries and construction include industrial emissions to a large extent originating from the production of raw materials and semi-manufactured goods (e.g. metals, petrochemicals, pulp and paper and mineral products). These emissions are related to fuel combustion only, that is, emissions from use of oil or gas for heating purposes. Consumption of coal as feedstock and reduction medium is not included in this sector, but it is accounted for under the industrial processes sector (chapter 4).

#### 3.2.3.2. Activity data

Most of the emission figures are calculated on the basis of activity data and emission factors. For some large plants varying emission figures are based on reported figures from the plants.

Statistics Norway carries out annual surveys on energy use in manufacturing industries, which supply most of the data material for the calculation of combustion emissions in these sectors in cases when reported emission figures not are used. The energy use survey is assumed to cover approximately 96 per cent of the energy use in this sector. For the remaining companies, figures are estimated based on data from the sample, together with data on economic turnover, taking into account use of different energy carriers in the same industries and size groups. A change in methodology from 1998 has had minor consequences for the time series, since the energy use is mainly concentrated to a few major plants within the industry, from which data were collected both in the present and the earlier method. The data on energy use in manufacturing industries are considered to be of high quality. Information on use of waste oil and other hazardous waste is also collected through the energy use statistics.

For the construction industry, the figures on use of the different energy carriers are partly taken from the annual sales statistics for petroleum products and partly projected from earlier surveys; the energy data are considered rather uncertain. In some sectors autodiesel is mainly used in machinery and off-road vehicles, particularly in mining and construction. This amount of fuel is based on reported consumption of duty-free autodiesel in the manufacturing industries and on reported sales of duty-free autodiesel to construction. The methods for calculating emissions from motorized equipment are discussed in section 3.2.4.7. Emissions from off-road machinery in manufacturing industries and construction are currently reported in the CRF category 1A3e *Other transportation*. In the NFR, emissions from off-road machinery in industry are assigned to category 1A2f *ii*.

#### 3.2.3.3. Emission factors

Emission factors used for the energy sector are given in Appendix B.

##### *Ammonia*

The LPG used as fuel in the ammonia production is mainly a mix of propane/ butane and ethane with, respectively, the emission factors 3.01 and 2.93 tonne CO<sub>2</sub>/tonne gas. In some years, a small amount of a light fuel gas (composition of 60 per cent H<sub>2</sub> and 40 per cent CH<sub>4</sub>) from a producer of plastic is used, with an emission factor of 2.4 tonne CO<sub>2</sub> per tonne gas.

The blast furnace gas used as fuel has an emission factor of 0.714 t CO<sub>2</sub> per tonne gas. This gas is sold from a metal producer and is mainly used as fuel in ammonia production and reported under solid fuels. This leads to emission factors in the

range of 190-264 tonne CO<sub>2</sub>/TJ for solid fuels in source category 1A2c Chemical industry. The default emission factor for blast furnace gas in the 2006 guidelines is 70.8 tonne C/TJ, or 260 tonne CO<sub>2</sub>/TJ.

#### **3.2.3.4. Uncertainties**

Uncertainty estimates for greenhouse gases and long-range air pollutants are given in Appendix D. The energy use is considered well known for the manufacturing industries.

#### **3.2.3.5. Completeness**

Major missing emission sources are not likely.

#### **3.2.3.6. Source specific QA/QC**

There is no specific QA/QC procedure for this source. See section 1.5.1 for the description of the general QA/QC procedure.

### **3.2.4. Transport**

*IPCC 1A3*

*NFR 1A3*

#### **3.2.4.1. Aviation**

*IPCC 1A3a, Key category for CO<sub>2</sub>*

*NFR 1A3a*

*Last update: 13.06.2006*

##### **3.2.4.1.1. Method**

The calculation methodology applied is described in Finstad *et al.* (2002a). According to the IPCC Good Practice Guidance the methodology used is Tier 2 based on the detailed methodology in EEA (2001). This methodology allows estimation of emissions and fuel consumption for different types of aircraft according to the average flying distance and numbers of landings and take-offs (LTO). All movements below 1 000 m are included in the "Landing Take Off" (LTO) cycle. Movements over 1 000 m are included in the cruise phase. All emissions from international aviation are excluded from national totals, and are reported separately (see section 3.2.6.3).

##### **3.2.4.1.2. Activity data**

Statistics Norway annually collects data on use of fuel from the air traffic companies. These data include specifications on domestic use and amounts bought in Norway and abroad. The types of fuel used in aircraft are both jet fuel (kerosene) and aviation petrol. The latter is used in small aircraft only. Emissions from the consumption of jet kerosene in domestic air traffic are based directly on these reported figures. Domestic consumption of jet kerosene has been reported to Statistics Norway by the airlines since 1993. The survey is annual, but data from the surveys for 1993 and 1994 have not been used here, as one of the largest airlines in Norway was not included. Domestic consumption prior to 1995 is estimated by extrapolation on the basis of domestic kilometres flown and is more uncertain (Finstad *et al.* 2002a). Sales figures are used for the minor use of aviation petrol.

##### **3.2.4.1.3. Emission factors**

Emission factors used are given in Appendix B, table B1 and B3, and tables B6-B8.

The Norwegian Petroleum Industry Association provides emission factors for CO<sub>2</sub> and SO<sub>2</sub> for the combustion of jet fuel and gasoline (Finstad *et al.* 2002a). The emission factor for SO<sub>2</sub> varies annually depending on the sulphur content of the fuel used. Emission factors for particles are from Brock *et al.* (1999) and

Döpelheuer and Lecht (1998), and all particles are found to be less than PM<sub>2.5</sub> (Finstad *et al.* 2002a).

A default emission factor for N<sub>2</sub>O for all aircraft is used (IPCC 2000) and is valid for both LTO and the cruise phase. EEA (2001) and IPCC (IPCC 2000) suggest using an emission factor for CH<sub>4</sub>, given in Olivier (1991), to be 10 per cent of total VOC. This is, however, only valid for LTO since studies indicate that only insignificant amounts of methane is emitted during the cruise phase. No methane is therefore calculated for the cruise phase and all emissions are assumed to be VOC (HC).

The NO<sub>x</sub>, CO and VOC emission factors are aircraft specific as given in EEA (2001).

Only aggregated emission factors (kg/tonnes fuel used) are used in the Norwegian inventory. The emission factors are calculated based on total emission divided by activity data for LTO and in the cruise phase, respectively. Recalculations have been done based on the new methodology (EEA 2001; Finstad *et al.* 2002a) and this led to a change in emission factors for previous years. New emission factors back to 1980 have therefore been used in the inventory. Emission factors were calculated with activity data for 1989, 1995, and 2000. Factors for the years 1990-1994 and 1996-1999 were interpolated. Factors before 1989 and after 2000 were kept constant. Emission factors for small aircraft are the same for the whole period.

#### **3.2.4.1.4. Uncertainties**

##### *Activity data*

The uncertainty in the activity data for civil aviation is estimated to be ±20 per cent of the mean, primarily due to the difficulty in separating domestic emissions from emissions from fuel used in international transport (Rypdal and Zhang 2000). In a study on emissions from aircraft (Finstad *et al.* 2002a), fuel consumption was also estimated bottom-up and compared to the reported figures (see also section 3.2.4.1.6.). The estimated and reported data differed by about 10 per cent. However, the reported data are considered most accurate and were used in the calculation. As described above, data before 1995 are more uncertain than for later years. This may also to a certain degree affect the time series consistency.

##### *Emission factors*

The uncertainty in the CO<sub>2</sub> emission factors is ±3 per cent. The uncertainty in the emission factors for CH<sub>4</sub> and N<sub>2</sub>O lies below and above the mean by a factor of 2 and 3, respectively.

#### **3.2.4.1.5. Completeness**

Major missing emission sources are not likely.

#### **3.2.4.1.6. Source specific QA/QC**

In 2002 a methodology improvement was made in the emission calculations for civil aviation (Finstad *et al.* 2002a). According to the IPCC Good Practice Guidance the methodology used is Tier 2 based on the detailed methodology in EEA (2001). This methodology allows estimation of emissions and fuel consumption for different types of aircraft according to the average flying distance and numbers of landings and take-offs (LTO).

#### **3.2.4.2. Road transport**

*IPCC 1A3b, Key category for CO<sub>2</sub> and CH<sub>4</sub>*

*NFR 1A3b i-v*

*Last update: 14.04.2014*

#### 3.2.4.2.1. Method

Total emissions of CO<sub>2</sub> are estimated directly from total consumption of each fuel. The consumption of gasoline for road traffic is estimated as total sales minus consumption for other uses, i.e. a top-down approach. Other uses for gasoline are e.g. small boats, snow scooters and motorized equipment. For auto diesel, the total consumption in road traffic is all auto diesel charged with auto diesel tax, with two per cent addition for assumed tax free auto diesel used in road traffic. For the years prior to 1997, the auto diesel taxation was incomplete, and the consumption of auto diesel in road traffic was calculated as for gasoline, by subtracting the consumption for other uses. Other uses of auto diesel are e.g. motorized equipment in agriculture and construction. CNG and LPG are estimated by bottom-up approaches. The total consumption of each fuel is attributed to different vehicle classes based on results from the emission model of the Handbook of Emission Factors (HBEFA; (INFRAS 2009)).

Pollutants other than CO<sub>2</sub> are estimated by the emission model of the Handbook of Emission Factors (HBEFA; (INFRAS 2009)). The model uses a mileage approach: Emissions = mileage \* emission per km. The model results are used directly without any adjustment for discrepancies between estimated and registered fuel consumption.

The HBEFA model provides emission factors and possibilities for calculating emissions for segments and sub-segments for six vehicle classes: Passenger cars, light commercial vehicles, heavy commercial vehicles, urban buses, coaches and motorcycles (including mopeds). The segments are based on engine volume for passenger cars and motorcycles, total weight for heavy commercial vehicles, urban buses and coaches, and tare weight for light commercial vehicles. The segments are further disaggregated to subsegments based on fuel type and technology type (e.g. Euro-1 – Euro-5). The segments used for Norway in the HBEFA model are given in table 3.4.

**Table 3.4 Segments used for Norway in the HBEFA**

Vehicle class	Segment	Fuel type	Segment split based on	Engine volume/weight class
Passenger car	PC petrol <1,4L	Petrol	Engine volume	< 1.4 litres
	PC petrol 1,4-<2L	Petrol	Engine volume	1.4- 2.0 litres
	PC petrol >=2L	Petrol	Engine volume	>= 2.0 litres
	PC diesel <1,4L	Diesel	Engine volume	< 1.4 litres
	PC diesel 1,4-<2L	Diesel	Engine volume	1.4- 2.0 litres
	PC diesel >=2L	Diesel	Engine volume	>= 2.0 litres
	PC LPG	LPG	-	All engine volumes
Light commercial vehicles	LCV petrol M+N1-I	Petrol	Tare weight	< 1305 kilos
	LCV petrol N1-II	Petrol	Tare weight	>= 1305-1760 kilos
	LCV petrol N1-III	Petrol	Tare weight	>= 1760-3859 kilos
	LCV diesel M+N1-I	Diesel	Tare weight	< 1305 kilos
	LCV diesel N1-II	Diesel	Tare weight	>= 1305-1760 kilos
	LCV diesel N1-III	Diesel	Tare weight	>= 1760-3859 kilos
Heavy goods vehicles	RT petrol	Petrol	-	Alle gross weights
	RigidTruck <7,5t	Diesel	Gross weight	<= 7.5 tonnes
	RigidTruck 7,5-12t	Diesel	Gross weight	> 7.5 - 12 tonnes
	RigidTruck >12-14t	Diesel	Gross weight	> 12 - 14 tonnes
	RigidTruck >14-20t	Diesel	Gross weight	> 14 - 20 tonnes
	RigidTruck >20-26t	Diesel	Gross weight	> 20 - 26 tonnes
	RigidTruck >26-28t	Diesel	Gross weight	> 26 - 28 tonnes
	RigidTruck >28-32t	Diesel	Gross weight	> 28 - 32 tonnes
	RigidTruck >32t	Diesel	Gross weight	> 32 tonnes
	Tractor for AT <=7,5t	Diesel	Gross weight	<= 7.5 tonnes
	Tractor for AT>7,5-14t	Diesel	Gross weight	> 7,5 - 14 tonnes
	Tractor for AT>14-20t	Diesel	Gross weight	> 14 - 20 tonnes
	Tractor for AT>20-28t	Diesel	Gross weight	> 20 - 28 tonnes
	Tractor for AT >34-40t	Diesel	Gross weight	> 34 - 40 tonnes
	Tractor for AT >40-50t	Diesel	Gross weight	> 40 - 50 tonnes
	Tractor for AT >50-60t	Diesel	Gross weight	> 50 - 60 tonnes
Coach	Coach Std <=18t	Diesel	Gross weight	<= 18 tonnes
	Coach 3-Axes >18t	Diesel	Gross weight	> 18 tonnes
Urban bus	Ubus Midi <=15t	Diesel	Gross weight	<= 15 tonnes
	Ubus Std >15-18t	Diesel	Gross weight	>15 - 18 tonnes
	Ubus Artic >18t	Diesel	Gross weight	> 18 tonnes
	Ubus Std >15-18t CNG	CNG	Gross weight	>15 - 18 tonnes
	Ubus Artic >18t CNG	CNG	Gross weight	> 18 tonnes
Motorcycles and mopeds	Moped <=50cc (v<50kmh)	Petrol	Engine volume	<= 50 cc
	MC 2S <=150cc	Petrol	Engine volume	<= 150 cc
	MC 2S >150cc	Petrol	Engine volume	>150 cc
	MC 4S <=150cc	Petrol	Engine volume	<= 150 cc
	MC 4S 151-250cc	Petrol	Engine volume	151-250 cc
	MC 4S 251-750cc	Petrol	Engine volume	251-750 cc
	MC 4S >750cc	Petrol	Engine volume	> 750 cc

The model combines the number of vehicles within each segment with driving lengths for the same segments to produce annual national mileage per subsegment. For heavy goods vehicles, the vehicle number is corrected for vehicles driving with trailers, and the driving is split into three load classes (empty, half loaded and fully loaded).

The annual national mileage is split between shares driven in different traffic situations. The traffic situations are a combination of area (urban/rural), road type (e.g. trunk road and access road), speed limit and level of service (freeflow, heavy, saturated, and stop and go). The traffic situations are further disaggregated by gradients, where the amount of driving on roads with slopes ranging from -6 per cent to 6 per cent is specified for each traffic situation.

Hot emission factors are provided on the disaggregated level of subsegments and traffic situations with different gradients, and the emissions are estimated after these steps of disaggregation.

The HBEFA model provides emission factors for cold emissions and evaporative emissions (soak, running losses and diurnal), in addition to hot emission factors. In order to calculate cold and evaporative emissions, information on diurnal variation in curves of traffic, trip length distributions, parking time distributions and driving behaviour distributions must be provided, in addition to variations in mean air temperature and humidity.

#### 3.2.4.2.2. Activity data

All activity data are, as far as possible, updated for every year of the inventory. Data are taken primarily from official registers, public statistics and surveys. However, some of the data are based on assumptions. Many of the data sources are less comprehensive for the earliest years in the inventory. The sources of activity data are listed below:

- *Total fuel consumption*: the total amounts of fuels consumed are corrected for off-road use (in boats, snow scooters, motorized equipment, etc.). These corrections are estimated either from assumptions about the number of units, annual operation time and specific fuel consumption, or from assumptions about and investigations of the fraction of consumption used off-road in each sector. Statistics Norway's sales statistics for petroleum products supply the data for total fuel consumption (Statistics Norway Annually-b).
- *Number of vehicles*: the number of vehicles in the various categories and age groups is taken from the statistics on registered vehicles, which receives data from the official register of the Norwegian Directorate of Public Roads. The model input is number of vehicles per vehicle class for each inventory year, and the share of vehicles for any given combination of segment and fuel type. These data are combined with information on the introduction of technology classes to provide number of vehicles within each subsegment. The information on introduction of technology classes are for recent years based on information from the official register of the Norwegian Directorate of Public Roads, and on legislation for the years in which the information in the register is insufficient.
  - The HBEFA model distinguishes between two types of buses: urban buses, mainly used for urban driving, and coaches, mainly used for rural and motorway driving. Due to lack of specific information to make this split in the national vehicle register, the distinction between urban buses and coaches are based on a methodology used in Sweden (Swedish environmental protection agency 2011), where the split is made based on the ratio  $p/w$ . Here,  $p$  is equal to the maximum allowed number of passengers (number of seats plus number of allowed standing passengers), and  $w$  is equal to the gross vehicle weight. These data are available from the national vehicle register. Buses with a  $p/w$ -value above 3.75 are classified as urban buses, whereas buses with a  $p/w$ -value below 3.75 are classified as coaches.
- *Average annual mileage*: Mileages for passenger cars, light commercial vehicles, heavy goods vehicles, coaches and urban buses are from 2005 onwards based on odometer readings taken during annual or biannual roadworthiness tests. The readings are collected by the Directorate of Public Roads and further processed by Statistics Norway (Statistics Norway 2010a). For earlier years, most figures are determined from surveys by Statistics Norway or the Institute of Transport Economics. In some instances assumptions are needed.
  - The statistics on number of vehicles depict the vehicle fleet per 31 December of the inventory year, while the statistics on mileages represents annual driving for the entire year, including vehicles that have been scrapped or in other ways been in the vehicle fleet for only parts of the inventory year. To adjust for this discrepancy for the years 2005-2011, mean annual driving lengths for each vehicle category have been adjusted upwards in such a way that the totals correspond to the total annual traffic activity from the statistics on annual driving lengths.

- The average annual mileages vary as a function of age, with older vehicles generally driving shorter annual distances than newer vehicles. The correction of driving as a function of vehicle age is based on odometer readings taken during the roadworthiness test. The functions are calculated as the mean of the years 2005-2011, and the same correction curve is used for all years.
- Motorcycles and mopeds are not subject to roadworthiness tests in Norway. Average annual mileages are taken from a report on transport volumes in Norway (Vågane and Rideng 2010). Due to lack of data, corrections of annual mileage as a function of age for motor cycles and mopeds are taken from a Swedish survey (Bjørketun and Nilsson 2007) under the assumption that annual mileages as a function of age are comparable in Norway and Sweden.
- *Load data* are taken from the Road goods transport survey (Statistics Norway 2010b).
- *Transformation patterns* are calculated using information from Statistics Norway' Road goods transport survey on use of trailers and trailer size (Statistics Norway 2010b).
- *Traffic situations*: The Directorate of Public Roads has data on the annual number of vehicle-kilometres driven on national and county roads. The data are allocated by speed limits, road type, area type (urban/rural), and vehicle size (small/large). Traffic on municipal roads (approx. 15 per cent) is estimated by Statistics Norway based on road lengths, detailed population data, traffic on adjoining roads, etc. The HBEFA model has emission factors for different situations of traffic flow (freeflow, heavy traffic, saturated traffic, and stop and go). Assumptions have been made as to this distribution for the different combinations of area type, road type and speed limits for Norway. Effects of road gradients are included, based primarily on Swiss data supplied to the HBEFA.
- *Ambient conditions* (air temperature and humidity) are included in the model to calculate cold and evaporative emissions. An average of five larger Norwegian cities has been used for spring, summer, autumn and winter separately. The data are based on measurements from the Norwegian Meteorological Institute.
- *Trip length and parking time distributions* are calculated from the Norwegian travel survey (Institute of transport economics 1993). The distributions are given on an hourly basis.

#### 3.2.4.2.3. Emission factors

Emission factors (except CO<sub>2</sub>) are taken from the Handbook of Emission Factors (HBEFA). Factors are given as emission per vehicle kilometers for detailed combinations of subsegments and traffic situations.

The CO<sub>2</sub> factors used for ethanol is 1.91 kg CO<sub>2</sub>/kg and for biodiesel 2.85 kg CO<sub>2</sub>/kg.

Average factors are listed in Appendix B.

#### 3.2.4.2.4. Uncertainties

The uncertainty estimates are given in Appendix D.

The comparison of bottom up estimates of fuel consumption from HBEFA with total sales (source specific QA/QC) reveals a discrepancy of 5-15 per cent. This is deemed to be a reasonable difference. This discrepancy is handled differently for different emission components. The total consumption of each type of fuel is the most important parameter in relation to the reporting requirements of the UNFCCC, as this forms the basis for the calculation of CO<sub>2</sub> from road traffic (IPCC 2006). One kilogram of gasoline or autodiesel yields a fixed amount of CO<sub>2</sub> irrespective of vehicle type.



Guidelines for greenhouse gas reporting, the IPCC guidelines (IPCC 2006), states that CO<sub>2</sub> emissions should be calculated using fuel consumption, and that sold amount of fuel should form the basis. Calculations of emissions of CH<sub>4</sub>, N<sub>2</sub>O and many of the components of emissions reported to CLRTAP (e.g. NO<sub>x</sub> and particulates), however, depends on more detailed information about vehicle types and driving patterns, and here a more detailed model (for example HBEFA) should be applied. The relationship between emissions and fuel consumption must be considered differently for the emission components that are directly dependent on the composition and quantity of fuel (CO<sub>2</sub>, SO<sub>x</sub> and heavy metals) and those who to a larger extent depend on the type of vehicle and driving mode (eg. NO<sub>x</sub>, CH<sub>4</sub>, N<sub>2</sub>O, NH<sub>3</sub>, CO, particles).

Fuel consumption is not an input to HBEFA, where emissions are calculated based on mileage and number of vehicles in each subsegment of vehicle classes, as well as other data sets, such as cold start and age distribution of mileage. Fuel consumption is however calculated in the model similarly to emission calculations. The estimated fuel consumption for the country as a whole can be compared with sold fuel sales statistics for petroleum products and energy balance. The comparison shows that the fuel consumption calculated in HBEFA is systematically lower than the fuel in the energy balance, and that the difference is greater for auto diesel than for petrol. The difference has been between approximately 1 and 10 per cent for gasoline, and 4 and 15 per cent for diesel in the period 1990-2011. Exceptions are 1990 and 1991 for auto diesel when the difference was very small, and 1993, when the difference was almost 30 per cent. There is no increasing or decreasing trend in the deviations, but there seems to be a correlation between the deviation of petrol and diesel.

It is not known why there is a discrepancy between the consumption in the energy balance and bottom-up calculation in HBEFA, but there are several possible explanations as to why fuel sold does not match the fuel consumption calculated from road transport emission model:

1. *Fuel purchased by foreign vehicles.* Foreign vehicles are not included in the vehicle register statistics, even though they drive on Norwegian roads. Similarly, no fuel bought by Norwegian vehicles abroad is sampled. It is likely that there is no systematic "fuel tourism" across the Norwegian border, as there are no significant price differences between fuel prices in Norway and Sweden. The current calculations are based on the assumption that driving in Norway by foreign vehicles equals the driving of Norwegian vehicles abroad.
2. *Vehicles drives longer in reality than what the model calculates.* Seeing that the Technical Inspection of vehicles is a new data source for mileage, it is hard to imagine that mileages in the model are systematically underestimated. Motorcycles do not have such a Technical Inspection. They can however not explain the discrepancy between the calculated use and the amount of fuel sold. For example, they mostly run on gasoline, while the largest deviation is within auto diesel.
3. *Driving patterns.* There may be elements in the driving patterns that causes fuel consumption per kilometer per vehicle to be higher than what the model calculates. One possible reason here is that the fuel consumptions stated in the vehicle type approvals are used as part of the input to the model, and there is an ongoing discussion about whether these systematically underestimate consumption. These data are however available only for the latter part of the series, and can not explain the discrepancies in the 1990s.

Whether the emission calculations should be corrected for differences in fuel consumption depends on the pollutants in question. For those components that are directly dependent on the amount of fuel (CO<sub>2</sub>, SO<sub>2</sub>, heavy metals) it will always be appropriate to use the fuel consumption from the energy balance as a basis for calculation. For the other emission components the decision on whether to correct

for total fuel consumption or not will depend on what is causing the discrepancy between fuel consumption calculated in the model and fuel consumption in the energy balance. If the reason is that the total mileage is underestimated in the model, and that the energy balance represents a "truer" picture of the consumption of fuels, emissions should be corrected. If the discrepancy, however, is due to an underestimation of the fuel consumption per kilometer, the emission estimates should not be corrected unless one finds a clear correlation between changes in consumption per kilometer and emissions per kilometer for the relevant emission components. As long as we do not know the reason for the discrepancy, an assessment of data quality in the various input data is crucial to determining whether emissions should be reconciled against fuel sales or not.

In the previous model (Norwegian Pollution Control Authority 1993, Bang et al 1999), the emissions of all substances were corrected to account for the discrepancy between the energy balance and the model calculations, because the energy balance was considered the most secure data source. When HBEFA was introduced as the computational model, a new data source was also introduced, namely the mileage statistics from Statistics Norway. These statistics are based on data from periodical technical inspections, and goes back to 2005. This important new data source is considered to be of good quality, and it has changed the assessment of whether the emissions shall be corrected for the consumption in the energy balance or not. There is no reason to believe that the total run lengths are underestimated, and we consider it likely that the reason for the discrepancy lies in the estimates of fuel consumption per kilometer. The energy balance is based on the assessment that Norwegian purchases abroad correspond to foreign purchases in Norway, and the same assessment is applied to the emission calculations. We have not found any reason to believe that the reasons for the discrepancies in fuel consumption are directly correlated with driving behavior. It has therefore been assessed that HBEFA estimated emissions of pollutants that are not directly related to fuel consumption should not be reconciled with fuel consumption.

There are currently no comprehensive statistics on foreign vehicles driving in Norway. One possible explanation for the discrepancy between the calculated fuel consumption in HBEFA and sold quantity of fuel is that foreign driving in Norway exceeds Norwegian driving abroad. There has been an issue that the proportion of heavy vehicles with foreign vehicles increases. However, we see no clear increasing trend in the difference between the model results and sales. Better data related to foreign driving in Norway and the Norwegian driving vehicles abroad would strengthen or refute the current assumption that these two balance each other out.

#### **3.2.4.2.5. Completeness**

Major missing emission sources are not likely.

#### **3.2.4.2.6. Source specific QA/QC**

Top-down and bottom-up data on fuel consumption are compared for gasoline and diesel vehicles on an annual basis. The consumption of gasoline and auto diesel for road traffic is estimated as total sales minus consumption for other uses, i.e. a top-down approach. The HBEFA emission model also makes bottom-up estimates of consumption, which can be compared with the top-down data. The estimated fuel consumption from HBEFA deviates from the top-down estimate by approximately 5-15 per cent per year, with the higher value for auto diesel. The causes are on the one hand uncertainties in the amount of non-road use and on the other hand uncertainties in mileage and specific consumption in road transport.

However, the total consumption of auto diesel, and hence the CO<sub>2</sub> emission from this fuel, is well known. The uncertainty concerns the allocation between road and non-road use, connected to illegal use of diesel without road tax in road traffic. For

CH<sub>4</sub> and N<sub>2</sub>O, the total emissions may be sensitive to this allocation, due to different emission factors.

When inspected, taxed and tax free diesel can be identified by colour. The fine for illegal use of tax free diesel is currently from NOK 20 000,- and upwards. There is no reason to believe that this is a major problem.

### **3.2.4.3. Railways**

*IPCC 1A3c*

*NFR 1A3c*

*Last update: 18.03.2014*

#### **3.2.4.3.1. Description**

Railway traffic in Norway uses mainly electricity. Auto diesel is used at a small number of lines, for shunting etc. There is also a minor consumption of coal in museum railways.

#### **3.2.4.3.2. Method**

General estimation methodology for calculating combustion emissions from consumption figures and emission factors is used.

#### **3.2.4.3.3. Activity data**

Consumption figures for auto diesel used in locomotives are collected annually from the Norwegian State Railways. Consumption of coal is estimated based on information from different museum railways; the same figure is used for all years from 1990. There has been a continuous electrification of the railroads in Norway, and the diesel consumption is more than halved from the level in the early 1990's.

#### **3.2.4.3.4. Emission factors**

Emission factors for NO<sub>x</sub>, HC, CO, and PM<sub>10</sub> were estimated by Bang (1993) based on a literature survey and data on Norwegian usage profiles. The HC factor of 4 g/kg was used directly for NMVOC.

The other emission factors are the same as for diesel machinery in mining and quarrying (see section 3.2.4.7.4), with the following exceptions:

- N<sub>2</sub>O: 1.2 g/kg vs 1.3 g/kg for machinery (IPCC Guidelines)
- NH<sub>3</sub>: 0.007 g/kg vs 0.005 g/kg for machinery (EMEP/EEA Guidebook).

General emission factors for coal are used in the calculations.

#### **3.2.4.3.5. Uncertainties**

The consumption data are of high quality. Their uncertainty is estimated to be ±5 per cent of the mean. The uncertainty in the emission factor for CO<sub>2</sub> is ±3per cent of the mean, whereas for CH<sub>4</sub> and N<sub>2</sub>O the uncertainty is below and above the mean by a factor of 2 and 3, respectively.

#### **3.2.4.3.6. Completeness**

Major missing emission compounds are not likely.

#### **3.2.4.3.7. Source specific QA/QC**

Consumption data from the Norwegian State Railways have previously been compared with sales to railways according to the Petroleum statistics. However, the latter includes some consumption by buses operated by the Norwegian State Railways. From 1998, the reported sales of "tax-free" auto diesel to railways have been higher than the consumption data from the Norwegian State Railways, although there was only a minor difference in 2009. The reason for this discrepancy has not been checked. "Tax-free" auto diesel is only for non-road use, so consumption by buses should not be the cause.

**3.2.4.4. Electric railway conductions***IPCC 1A3c**NFR 1A3c**Last update: 01.09.2005***3.2.4.4.1. Method**

Electric railway conductions contain copper that is emitted in contact with trains. In the inventory copper emissions are calculated by emission factors and activity data.

**3.2.4.4.2. Activity data**

The activity data used for calculating emissions of copper from electric wires are annual train kilometers given by the Norwegian State Railways (NSB).

**3.2.4.4.3. Emission factors**

According to Norwegian State Railways (Rypdal and Mykkelbost 1997) the weight of a contact wire is 0.91 kg/meters. The weight is reduced by 20 per cent after 3 million train passes. This gives an emission factor of 0.06 g/train kilometers. It is, however, uncertain how much of this is emitted to air. In the inventory it is assumed that 50 per cent is emitted to air. This gives an emission factor of 0.03 g/train kilometer.

**Table 3.5. Emission factor for electric railway conductions. g/km**

	Emission factor (g/train kilometers)
Cu .....	0.03

**3.2.4.4.4. Uncertainties**

The emission factor used is uncertain. First, there is an uncertainty connected to the reduction of 20 per cent after 3 millions train passes. Secondly, there is uncertainty regarding the assumption that 50 per cent are emissions to air (Finstad and Rypdal 2003).

**3.2.4.4.5. Completeness**

No major components are assumed missing.

**3.2.4.4.6. Source specific QA/QC**

There is no specific QA/QC procedure for this source. See section 1.5.1 for the description of the general QA/QC procedure.

**3.2.4.5. Navigation***IPCC 1A3d, Key category for CO<sub>2</sub> and CH<sub>4</sub>**NFR 1A3d**Last update: 15.01.2014***3.2.4.5.1. Description**

According to CLRTAP and UNFCCC, Norwegian national sea traffic is defined as ships moving between two Norwegian ports. In this connection, installations at the Norwegian part of the continental shelf are defined as ports.

*Fishing* is described in section 3.2.5.

**3.2.4.5.2. Method**

Emissions from navigation are estimated according to the Tier 2 IPCC methodology. Emissions from moveable installations used in oil and gas exploration and extraction are split between 1A1 – energy industries (section 3.2.2) and navigation: Emissions from drilling are reported under 1A1, while emissions from transport and other activities are reported under navigation. Emissions from international marine bunkers are excluded from the national totals and are reported separately (section 3.2.6.2), in accordance with the IPCC Good Practice Guidance.

Annual emissions are estimated from sales of fuel to domestic shipping, using average emission factors in the calculations.

For 1993, 1998, 2004 and 2007 emissions have also been estimated based on a bottom-up approach. Fuel consumption data were collected for all categories of ships (based on the full population of Norwegian ships in domestic transport); freight vessels (bulk and tank), oil loading vessels, supply/standby ships, tug boats, passenger vessels, fishing vessels, military ships and other ships. Emissions were estimated from ship specific emission factors and fuel use. From this information, average emission factors were estimated for application in the annual update based on fuel sales. This approach is unfortunately too resource demanding to perform annually.

#### 3.2.4.5.3. Activity data

The annual sales statistics for petroleum products gives figures on the use of marine gas oil, heavy distillates and heavy fuel oil in domestic navigation. Information on fuel used in the ship categories in the bottom-up analysis is mainly given by data from the Business Sector's NO<sub>x</sub> fund for 2007 and by earlier SSB analyses for 1993 and 1998 (Tornsjø 2001), and 2004. Data on fuel consumed by public road ferries are available from the Directorate of Public Roads.

Information on fuel use at mobile drilling rigs is taken from the sales statistics, but information on use (whether it is used for drilling, stationary combustion etc.) is taken from Environmental Web (reported from oil companies to the Norwegian Environment Agency and the Norwegian Petroleum Directorate). Consumption during drilling activities are reported under "Energy industries" (CRF 1A1c). Only the remaining part of sales, assumed to be for drilling rigs during transit etc., is included with Navigation.

For marine gas oil, the amount used for navigation is equal to total sales figures except bunkers, after the deduction of estimated stationary use, mainly in oil and gas extraction, but also some minor use in manufacturing industries and construction. Due to inaccuracies in the reporting of distribution of marine gas oil between domestic and international shipping from approximately 2005, there is some uncertainty connected to the figures for the latest years.

Use of natural gas in navigation, which was introduced in 2000 and has increased considerably from 2007, is based on sales figures reported to Statistics Norway from the distributors.

#### 3.2.4.5.4. Emission factors

Emission factors used for navigation are given in Appendix B, table B1, table B3 and tables B12-B16.

##### *CO<sub>2</sub>*

For CO<sub>2</sub> the following standard emission factors based on carbon content are used:

- Marine gas oil/diesel and special distillate: 3.17 kg/kg fuel
- Heavy fuel oil: 3.20 kg/kg fuel

##### *N<sub>2</sub>O and CH<sub>4</sub>*

For liquid fuels the general/standard emission factors for N<sub>2</sub>O and CH<sub>4</sub> used in the emission inventory are taken from IPCC/OECD: 0.23 kg CH<sub>4</sub>/tonne fuel and 0.08 kg N<sub>2</sub>O/tonne fuel.

In the case of oil drilling, the employed factors are as follows:

- CH<sub>4</sub>: 0.8 kg/tonne marine gas oil/diesel; 1.9 kg/tonne heavy fuel oil
- N<sub>2</sub>O: 0.02 kg/tonne marine gas oil/diesel

Some natural gas is combusted in ferry transportation and offshore supply; the CH<sub>4</sub> emission factors used are based on the emission factors in table 3.6. From 2000, when the first gas vessel started operating, a mean factor for all ships weighted after consumption data for the different ship categories (ferries and supply ships) are calculated. The emission factors used in the inventory are given in Appendix B, table B15. Ferry consumption data used in the calculations are given by the Directorate of Public Roads (Norddal 2010).

**Table 3.6. Methane emission factors for gas operated vessels**

Vessel category	Methane emission factor (kg CH <sub>4</sub> / tonnes LNG)
Ferry (currently lean burn engines only) .....	44
Offshore supply (Currently dual fuel engines only) ...	80

Source: Bremnes Nielsen and Stenersen (2010).

### SO<sub>2</sub>

The emission factors are determined from the sulphur content of the fuel.

### NO<sub>x</sub>

NO<sub>x</sub> factors for different engine types (slow, medium and high speed) have been estimated by Marintek based on data from a comprehensive measure programme for NO<sub>x</sub> emissions from ships, which has been implemented under the leadership of the Business Sector's NO<sub>x</sub> fund. The new basis factors from Marintek apply to emissions from different engine types built before and after emission restrictions were implemented in 2000 (Bremnes Nielsen and Stenersen 2009).

**Table 3.7. Recommended emission factors for NO<sub>x</sub> for different engine types**

	Engine building year	
	Before 2000 kg NO <sub>x</sub> /tonne fuel	After 200 kg NO <sub>x</sub> /tonne fuel
Slow speed NO <sub>x</sub> factor .....	82	78
Medium speed NO <sub>x</sub> factor .....	54	53
High speed NO <sub>x</sub> factor .....	47	41

Source: Bremnes Nielsen and Stenersen (2009).

The factors were weighted in two steps: First, by engine type distribution within ship categories (passenger, general cargo, offshore, fishing, etc.). Secondly, by estimated fuel consumption among categories. The fuel consumption weights were calculated based on data for 1993, 1998, 2004 and 2007, which are years with good availability of activity data. Average factors for other years were interpolated. In the interpolation of the average factors over the time series, a peak in the use of shuttle tankers has been taken into consideration. The fact that we have reported data for public road ferries for some years, and a gradual change to new engines with lower emissions starting in 2000 due to new restrictions, has also been taken into consideration. The factors from Marintek are valid for engines with no particular NO<sub>x</sub> reduction measures. Information on installed NO<sub>x</sub> reduction equipment (SCR = selective catalytic reduction, etc) is obtained annually from the NO<sub>x</sub> fund and incorporated into the average factors. NO<sub>x</sub> reduction measures that have their effect primarily through reduced fuel consumption are excluded, as these effects are recorded through the reduction of total consumption. The NO<sub>x</sub> factors used in the inventory are documented in (Flugsrud *et al.* 2010).

For gas engines the NO<sub>x</sub> factor 5.6 kg NO<sub>x</sub>/ tonne LNG is established based on the mass of LNG consumed (Bremnes Nielsen and Stenersen 2010).

For offshore drilling rigs, the factor 54 kg NO<sub>x</sub>/tonne is used (Karlsson and Finborud 2012). See further discussion on NO<sub>x</sub> from offshore installations in the section on stationary combustion.

Average NO<sub>x</sub> factors for fishing and for general shipping are given in Appendix B, table B14.

*NH<sub>3</sub>*

Emissions of NH<sub>3</sub> from navigation are reported as "Not Estimated". The EMEP/EEA Guidbook (EEA 2013) has no emission factors, and in table 2-2 over "Contributions to total emissions" NH<sub>3</sub> is stated as "No emissions reported".

*Particles*

Factors for particulate matter are based on measurements performed by MARINTEK and literature sources. The factors are presented in table 3.8.

**Table 3.8. Particulate matter emission factors for oil and gas operated vessels**

Fuel	Emission factor	
	PM <sub>2.5</sub>	PM <sub>10</sub> , TSP
Marine gas oil, light fuel oils (kg/tonne) .....	1.5	1.6
Heavy fuel oil, heavy distillate (kg/tonne) .....	5.1	5.4
LNG (kg/1000 Sm <sub>3</sub> ) .....	0.032	0.032

Source: Bremnes Nielsen and Stenersen (2010).and Bremnes Nielsen (*pers.comm.*<sup>3</sup>)

For oil based fuels it is assumed that all particles are included in PM<sub>10</sub> and 95 per cent of the particles are included in PM<sub>2.5</sub> (Finstad *et al.* 2003).

Emission factors for particle emissions from gas operated vessels are based on measurements made by MARINTEK (Bremnes Nielsen, *pers.comm.*), which show 95-99 per cent emission reduction compared to marine gas oil.

**3.2.4.5.5. Uncertainties**

The estimation of fuel used by fishing vessels is assumed to be rather uncertain. There is also uncertainty connected to the fuel use for other domestic sea traffic due to uncertainty in the sales statistics for petroleum products. Particularly, the delimitation between sales of marine gas oil for national use and bunkers has become more uncertain from approximately 2005, due to new and less accurate reporting routines in some oil companies.

Some uncertainty is also connected to the emission factors.

The uncertainty in the activity data for navigation is assessed to be ±20 per cent. For CO<sub>2</sub> the uncertainty in the emission factors for ships and fishing vessels is ±3 per cent of the mean, while for CH<sub>4</sub> it ranges between -50 and +100 per cent of the mean. For N<sub>2</sub>O the uncertainty range is between -66 and +200 per cent of the mean (Rypdal and Zhang 2000). The uncertainty in the NO<sub>x</sub> factors depends both on the uncertainty in the basis factors from Marintek (Bremnes Nielsen and Stenersen 2009) and on the uncertainty in the allocations that are made of the factors between ship types and years. Marintek has estimated the uncertainty in their basis NO<sub>x</sub> factors for different engine types to ±5 per cent. Uncertainties in emission factors are shown in table 3.9.

**Table 3.9. Uncertainties in emission factors for ships and fishing vessels. Per cent**

	Standard deviation (2σ)
CO <sub>2</sub> .....	±3
CH <sub>4</sub> .....	-50 to +100
N <sub>2</sub> O .....	-66 to +200
SO <sub>2</sub> .....	±25
NO <sub>x</sub> <sup>1</sup> .....	±15
NMVOc .....	±50

<sup>1</sup> It is assumed that the uncertainty might be lower now than in this estimate from Rypdal and Zhang (2001) since more measures have been performed in connection with the Business Sector's NO<sub>x</sub> fund.

Source: Rypdal and Zhang (2000; 2001).

<sup>3</sup> Bremnes Nielsen, J. (2010): Personal information, email from Jørgen Bremnes Nielsen, 11 Nov. 2010, Marintek.

**3.2.4.5.6. Completeness**

Major missing emission sources are not likely.

**3.2.4.5.7. Source specific QA/QC**

As mentioned, emission estimates for ships have been made bottom-up for 1993 and 1998 (Tornsjø 2001) and for 2004 and 2007. These results have been compared with top-down data (from sales) on fuel consumption used in the annual estimates.

The outcome showed that data from sales were only 1 per cent higher than data from reported consumption in 2007. For 2004 the sales data were 27 per cent higher than the consumption data in the bottom-up analysis. This can be explained by the fact that the bottom-up method does not cover all ships, but it may also be that the domestic/international distinction is not specified precisely enough in the sales statistics. Another element, which not has been taken into account, is possible changes in stock. For the years 1993 and 1998 a deviation of -12 and -15 per cent, respectively, has been found. In the calculations, sales figures are used, as they are assumed to be more complete and are annually available.

**3.2.4.6. Pipeline**

*IPCC 1A3e*

*NFR 1A3e i*

*Last update: 22.03.2010*

Figures on natural gas used in turbines for pipeline transport at two separate facilities are reported annually from the Norwegian Petroleum Directorate to Statistics Norway. However, energy generation for pipeline transport also takes place at the production facilities. Specific data on consumption for transport are not available. Thus, the consumption at the two pipeline facilities does not give a correct picture of the activity in this sector. As a consequence, all emissions from pipelines are reported under NFR/IPCC 1A1.

**3.2.4.7. Motorized equipment**

*IPCC 1A3e etc. Key category for CO<sub>2</sub> and N<sub>2</sub>O from other mobile.*

*NFR 1A2f-ii etc.*

*Last update: 17.06.2013*

**3.2.4.7.1. Description**

The category "motorized equipment" comprises all mobile combustion sources except road, sea, air, and railway transport. Farm and construction equipment are the most important categories. Other categories include mines and quarries, forestry, snow scooters, small boats and miscellaneous household equipment.

**Emissions from motorized equipment are reported under several categories:**

	<i>IPCC</i>	<i>NFR</i>
Manufacturing and construction .....		1A2f-ii
Commercial and institutional .....	1A3e	1A4a-ii
Households .....		1A4b-ii
Agriculture/Forestry/Fishing .....	1A4c	1A4c-ii
Military .....	1A5b	1A5b

Primarily consumption of gasoline and auto diesel is considered. A small amount of fuel oil used for equipment in construction is also accounted for.

**3.2.4.7.2. Method**

Emissions are estimated through the general methodology described earlier, involving consumption figures and appropriate emission factors.



### 3.2.4.7.3. Activity data

Gasoline and auto diesel are handled differently. Consumption of *gasoline* is estimated bottom-up for each type of machinery based on data on the number of each type of equipment, usage and specific consumption.

*Snow scooters*: Number of equipment is obtained annually from the Norwegian Public Roads Administration. We assume a mileage of 850 km/year and a specific consumption of 0.15 l/km (National institute of technology 1991). A portion of 16 per cent of petrol consumption in agriculture is assigned to snow scooters. The remaining snow scooter fuel consumption is assigned to households.

*Chainsaws and other two-stroke equipment*: Only consumption in forestry is considered, based on felling data. Felling statistics are gathered by Statistics Norway. 50 per cent is supposed to be felled with use of chain saws, with a consumption of 0.33 l/m<sup>3</sup>. Note: Consumption has been kept fixed since 1994 based on a calculation by the Institute of Technology (Bang 1996).

*Lawn mowers and other four-stroke equipment*: Only consumption in households is considered.

Consumption of *auto diesel* is based on data from the energy balance. Auto diesel used in off-road vehicles has no road tax from 1993. Total use of auto diesel in motorized equipment is given as the difference between total sales of tax free diesel and estimated use for railway transportation. It is important to bear in mind that the total consumption of auto diesel in motorized equipment from 1993 is considered being of good quality since there from 1993 is no road tax on this part of the auto diesel. There is CO<sub>2</sub> tax on the auto diesel used for motorized equipment as well as for road traffic.

*Distribution of auto diesel between industries*: From 2001, a certain fraction of the consumption in a number of industries is allocated to motorized equipment, based on the distribution of taxed and tax-free diesel – the latter is meant for use outside road transport. The distribution formulas are based on figures from the statistics on energy use in manufacturing industries or from the sales statistics. The statistics on energy use in manufacturing industries did not have such a split before 2001, and therefore distribution formulas for 2001 are used for 2000 and earlier years.

### 3.2.4.7.4. Emission factors

Emission factors used are given in Appendix B.

For diesel machinery, emission factors for HC, CO, and PM<sub>10</sub> were estimated by Bang (1993), based on a literature survey and data on Norwegian usage profiles. Source for emission factor for NO<sub>x</sub> from diesel machinery is from Bang (1993) for motor gasoline and light fuel oils. For autodiesel emission factors from a Danish report (Winther and Nielsen 2006) is used. NMVOC factors were calculated by subtracting an assumed CH<sub>4</sub> fraction of 0.3 g/kg diesel.

### 3.2.4.7.5. Uncertainties

The estimates of consumption are considered quite uncertain, particularly for gasoline. However, the total consumption of gasoline is well known. For auto diesel, some uncertainty in the delimitation of different middle distillates may cause variations in figures on total use in motorized equipment between years.

### 3.2.4.7.6. Completeness

Major missing emission sources are not likely.

### 3.2.4.7.7. Source specific QA/QC

There is no source specific QA/QC procedure for this sector. See section 1.5.1 for the description of the general QA/QC procedure.

**3.2.4.8. Automobile tyre and brake wear***IPCC IA3b**NFR IA3b vi**Last update: 15.09.2014***3.2.4.8.1. Tyre wear****3.2.4.8.1.1. Description**

Tyre wear is a source for emission of particles, heavy metals and persistent organic pollutants. The tyres are worn down by 10 to 20 per cent of its total weight during its lifetime. Most of the rubber is lost during acceleration and braking. All rubber lost is assumed to be particles containing heavy metals and PAH.

**3.2.4.8.1.2. Method***Particles*

All rubber lost is assumed to be small particles. The emissions of particles are calculated based on emission factors and annual mileage.

*Heavy metals*

Rubber particles contain heavy metals. Emissions of the heavy metals As, Cd, Cu, Cr, Pb and Hg are calculated based on annual mileage and emission factors.

*PAH*

The particles emitted from tyre wear contain PAH. Emissions are calculated based on emission factors and annual mileage.

**3.2.4.8.1.3. Activity data**

Annual mileage is used for calculating the emissions from tyre wear. Annual mileage is given by the road traffic model, see section 3.2.4.2.

**3.2.4.8.1.4. Emission factors***Particles*

The emission factors used for calculating the emission of particles are given by TNO (Institute of environmental and energy technology 2002 and 2008). The emission factors are based on several Dutch and British studies. Recommended emission factors for TSP and PM<sub>10</sub> are taken from TNO 2002. Emission factor for PM<sub>2.5</sub> was set to be zero. A new report (TNO 2008) presents emission factors for all three fractions of particulate matter. The emissions factors for TSP and PM<sub>10</sub> are in the same range as the emission factors given in TNO 2002. In the Norwegian inventory it has been chosen to include PM<sub>2.5</sub> emissions using the same ratio between PM<sub>10</sub> and PM<sub>2.5</sub> in the Norwegian inventory as the ratio between PM<sub>10</sub> and PM<sub>2.5</sub> from TNO (2008). The emission factors used are given in table 3.10.

**Table 3.10. Emission factors for particles from tyre wear. kg/mill. km**

	TSP	PM <sub>10</sub>	PM <sub>2.5</sub>
Private cars .....	69	3.45	0.69
Van .....	90	4.5	0.9
Heavy duty vehicles .....	371.25	18.563	3.71
MC .....	34.5	1.725	0.35

Source: TNO (Institute of environmental and energy technology 2002)).

*Heavy metals*

The emission factors used for the heavy metals As, Cd, Cu, Cr and Pb are derived from a particle-heavy metal distribution given by Dutch studies (van den Brink 1996). The content of heavy metals in the particles, given by this distribution, is multiplied by the PM<sub>10</sub> emission factor (table 3.9). This gives the emission factors for the heavy metals As, Cd, Cu, Cr and Pb from tyre wear (table 3.11).

**Table 3.11. Emission factors for heavy metals from tyre wear. g/mill. km**

	As	Cd	Cu	Cr	Pb
Private cars .....	0.003	0.007	1.691	0.014	0.552
Van .....	0.005	0.009	2.205	0.018	0.720
Heavy duty vehicles ....	0.019	0.037	9.096	0.074	2.970
MC .....	0.002	0.003	0.845	0.007	0.276

The emission factor used for the estimation of the emissions of Hg is 0.079 g/ mill. km. This emission factor is derived from a study of heavy metal content in tyres (Bækken 1993) and an estimate of the amount of tyre in Norway in 1993 of 6000 tonnes (Finstad *et al.* 2001).

#### PAH

Emission factors for PAH are given in Finstad *et al.* (2001), but there is no information about how much of the emissions that are emitted to air, and how much that goes to soil and to water. All emissions are therefore supposed to be emitted to air. There is also no PAH profile available, so in lack of other data the same PAH profile as for burning of tyres is used (EPA 1998). PAH emission factors for tyre wear are given in table 3.12.

**Table 3.12. Emission factors for PAH from tyre wear. g/mill. km**

	PAH
Light duty vehicles .....	10.4
Heavy duty vehicles .....	0.1

Source: Finstad *et al.* (2001).

#### 3.2.4.8.1.5. Uncertainties

The calculation of emissions from tyre wear is uncertain. First, the emission factors for particles used are based on international studies and not on Norwegian conditions. There is also uncertainty concerning how much of the particles that is emitted to air. According to a Dutch judgement, all particles emitted to air are PM<sub>10</sub>. This is however only a judgement, and not based on scientific research. PAH emissions have been held constant since 1998.

The heavy metal emission factors are based on the particle emission factors for PM<sub>10</sub>, and since this factor is uncertain, the heavy metal emission factors will also be uncertain. The content of heavy metals in the particles emitted from tyre wear is based on a Dutch study and can therefore differ from Norwegian conditions and type of tyres used.

#### 3.2.4.8.1.6. Completeness

Tyre wear also leads to emissions of other heavy metal components, such as zinc, nickel etc., but these components are not included in the Norwegian emission inventory.

Until 2004, different methods for calculating the emissions of heavy metals from tyre wear were used. One method was used for calculating emissions of Pb, Cd and Hg (Finstad *et al.* 2001) and another for calculating emissions of Cu, Cr and As (Finstad and Rypdal 2003). From 2004 the same method has been used for all the heavy metal components.

#### 3.2.4.8.1.7. Source specific QA/QC

There is no specific QA/QC procedure for this source. See section 1.5 for the description of the general QA/QC procedure.

### 3.2.4.8.2. Brake wear

#### 3.2.4.8.2.1. Description

Brake blocks will wear during braking and this generates dust containing various metals. In the inventory, emissions of particles and heavy metals are included from this source.

#### 3.2.4.8.2.2. Method

##### *Particles*

Emissions of particles are calculated based on emission factors recommended by TNO and annual mileage.

##### *Heavy metals*

Emissions of lead, copper and chromium are calculated after a method described in SLB (Stockholms luft- och bulleranalys 1998). The calculations are based on annual brake wear, driven kilometers and the brake blocks' metal content.

##### *Brake wear, private cars and vans*

To calculate emissions, brake wear first has to be estimated. It is assumed that private cars change brake blocks every fourth year. The background for this assumption is that private cars, by normal driving, change brake blocks at front after 30 - 40 thousand kilometers and at the back after 60 -80 thousand kilometers. A private car drives in average 150 thousand kilometers each year. Assuming that the brake blocks are changed after 60 thousand kilometers, the car will be four years old when blocks first are changed.

The brake blocks at front weigh 0.13-0.15 kg and 0.09-0.11 kg at the back. It is assumed in the calculations that the brake blocks weigh 0.15 kg at the front and 0.11 kg at the back, that the brake blocks are worn 70 per cent before they are changed and that the front and back blocks are changed after 40 and 60 thousand kilometres, respectively. Brake wear per kilometer are given by equations (3.4) and (3.5)

$$(3.4) \quad \text{Front brake blocks (private cars): } 0.7 \cdot 4 \cdot 0.15 / 40\ 000$$

$$(3.5) \quad \text{Back brake blocks (private cars): } 0.7 \cdot 4 \cdot 0.11 / 60\ 000$$

The same method is used for calculating emissions from brake wear for vans and minibuses.

##### *Brake wear, heavy duty vehicles*

The number of brake blocks at a heavy duty vehicle varies with both brand and model. It is assumed that each front brake block weighs 2.5 kg and 3.5 kg at the back (Stockholms luft- och bulleranalys 1998). This means that a truck with four wheels have 12 kg of brake blocks. It is assumed that the blocks are changed after 100 thousand kilometers when the brake blocks are worn 70 per cent.

##### *Metal content*

The metal content in the brake blocks for cars have been tested (Stockholms luft- och bulleranalys 1998). For calculating the emissions from brake blocks, annual brake wear has been multiplied by the metal content. The metal content in the brake blocks in front of the car differs from the content in the brake blocks at the back (table 3.13). For heavy duty vehicles, the metal content is independent of age or type of brake block.

**Table 3.13. Metal content in brake blocks. mg/kg**

	Private cars		Heavy duty vehicles
	Front	Back	Front and back
Cr .....	137	73.4	165
Cu .....	117 941	92 198	9 031
Pb .....	9 052	18 655	457

How much of the heavy metal emissions that are emitted to air were investigated by Sternbeck *et al.* (2001). Tunnel experiments showed that approximately 20 per cent of the brake wear emissions were emitted to air. This result is used in the calculations of brake wear emissions.

### 3.2.4.8.2.3. Activity data

For calculating the emissions of particles and heavy metals, annual mileage are given by the road traffic model, see section 3.2.4.2.

### 3.2.4.8.2.4. Emission factors

#### *Particles*

Emission factors recommended by TNO (Institute of environmental and energy technology 2002), based on different European studies, are used (table 3.14).

**Table 3.14. Particle emission factors for brake wear. kg/mill. km**

	PM <sub>2.5</sub>	PM <sub>10</sub>	TSP
Private cars (BM1+DM1) .	6	6	6
Van (BN1+DN1) .....	7.5	7.5	7.5
Heavy duty vehicles .....	32.25	32.25	32.25
MC .....	3	3	3

Source: TNO (Institute of environmental and energy technology 2002).

#### *Heavy metals*

Emission factors for Cr, Cu and Pb are derived based on the above information and are given in table 3.15.

**Table 3.15. Heavy metal emission factors for brake wear. g/mill. km**

	Private cars and vans	Heavy duty vehicles
Cr .....	0.36	14.82
Cu .....	342.33	303.44
Pb .....	38.16	40.95

### 3.2.4.8.2.5. Uncertainties

There is high uncertainty in different steps in the emission calculations of heavy metals from brake wear, since many assumptions have been done. For example, there is uncertainty connected to the weight and the metal content of the brake blocks, and to the number of driven kilometers before blocks are changed.

### 3.2.4.8.2.6. Completeness

Brake wear also leads to emissions of other heavy metal components, such as zinc, nickel etc., but these components are not included in the Norwegian emission inventory.

No other major emission components are assumed missing.

### 3.2.4.8.2.7. Source specific QA/QC

There is no specific QA/QC procedure for this source. See section 1.5 for the description of the general QA/QC procedure.

**3.2.4.9. Automobile road abrasion**

IPCC 1A3b

NFR 1A3bvii

Last update: 18.03.2014

**3.2.4.9.1. Description**

Asphalt dust is emitted to air while using studded tires. The abrasion layer on asphalt roads can contain approximately 90 per cent stones (rock/minerals) and 5 per cent filler. The rest is bitumen. During studded tyre abrasion, stone materials are worn down to minor particles and will together with detached filler and bitumen whirl up and become airborne. How much dust/particles studded tires generate depends on:

- Weight of the stud
- The road surface resistance against abrasion
- Vehicle velocity
- Share of heavy vehicle
- If the road surface is dry, wet or ice coated

A great share of the dust from studded tyres will bind up to the water film when the road surface is wet. Some of it will however whirl up again when the road surface dries up. This is not included in the calculation.

Bitumen is a mixture of a great number of organic components, including PAH components. The emissions of PAH from road abrasion are calculated and included in the emission inventory. Calculated emissions of Cd are also included.

PM emissions from road abrasion are declining, due to implementation of measures. In the largest cities there is a tax to pay when you drive with studded tyres in the city. This, together with information from the authorities about problems caused by PM, has reduced the number of cars with studded tyres both in the cities and all over the country. In addition, the weight of the stud has been reduced and hence also the emissions of PM. Consequently, the emissions are decreasing even though the annual total driving length is increasing. In contrast, emissions from automobile tyre and brake wear are calculated by multiplying the driving length with an emission factor, not taking into account the type of tyres. Since the driving length is increasing, the emissions increase.

**3.2.4.9.2. Method***Particles*PM<sub>10</sub>

The method is prepared by TI/SINTEF and documented in Bang *et al.* (1999). For calculating average emission Q (ton/year) of PM<sub>10</sub> formula (3.6) is used:

$$(3.6) \quad Q_{PM10} \text{ (ton/year)} = \sum_{\text{All vehicle categories}} SPS * n * l * m * p * w * \alpha / 10^6$$

*SPS*: The specific wear of studded tyres (SPS). Gives an estimate of how much of the road surface that is worn off on one road kilometer of a vehicle with studded tyres

*n*: Number of cars of a vehicle category in the area

*l*: Annual mileage for a vehicle category in the area

*m*: Part of the year with studded tyres in the area (between 0 and 1)

*p*: Share of the vehicle category using studded tyres

*w*: Correction factor for wet and frozen road surface. In the calculation of *w*, frozen surface is given 0, wet surface 0.5 and dry surface 1. If the mileage with studded tyres on a wet and frozen surface respectively is *v* and *x*,  $w = (0.05*v) + (1(1-v-x))$

$\alpha$ : Share of the road dust in air that is PM<sub>10</sub>. There is no data for this factor. The share of PM<sub>10</sub> on ground is used as a reference. There is very varied data for

the size of this factor (Hedalen 1994). Hedalen gives a PM<sub>10</sub> share of 3-4 per cent. In the calculations 3 per cent is used as a first estimate. Hedalen (1994) states further that the PM<sub>2.5</sub> share of total road dust is 0.5-1 per cent.

The road surface has stronger wear resistance on roads with heavy traffic than on roads with little traffic. The SPS value can therefore vary with the amount of traffic. SPS values for different ÅDT<sup>4</sup> intervals were estimated based on analysis of track depths over the years 1988-1995 (Norwegian public roads administration 1996).

SPS is also dependent on the weight of the studs. The studs have in the recent years become lighter. The requirement in 1988 was that the stud on light vehicles should not exceed 2.0 gram, in 1990 this was changed to 1.8 gram, and it changed again in 1992 to 1.1 gram (Norwegian public roads administration 1997). The so-called "light studs" has a weight on 0.7 gram. Studs used on tyres for heavy vehicles could until 1992 weigh 8.0 gram, but this demand was changed to 3.0 gram. There are also other factors influencing the SPS values, for example the road surface wear resistance and the quality of the stone materials used.

SPS values used in the calculations are given in table 3.16. The SPS values are divided on classes of ÅDT (Evensen, *pers. comm.*<sup>5</sup>). Values are given for 1993-1997 and a prediction for 2002. For the years in between a moving average is calculated. For the years after 2002 the 2002 SPS values are used. In the calculations average values for SPS, weighted after the size of traffic load on roads with different ÅDT, are used. The values are given in g/km and are valid for all vehicles. To estimate how much of the emissions that originate from heavy vehicles, it is provided that heavy vehicles wear 5 times more than light vehicles. The vehicle velocity is not given as an own factor, since it is included in the calculation of SPS.

**Table 3.16. SPS values. g/km**

ÅDT	1973-1980	1981-1987	1988-1992	1993-1997	2002
0-1500 .....	22	20	20	18	16
1500-3000 .....	20	20	18	16	14
3000-5000 .....	16	15	14	12	10
>5000 .....	14	12	11	10	9
Average <sup>1</sup> .....	17.1	15.6	14.7	13.1	11.6

<sup>1</sup> Weight after traffic load on roads with different ÅDT.

Source: Evensen, *pers. comm.*

Annual traffic load (trafikkarbeid) ( $n \cdot l$  in the formula) used in the calculations are annual mileage given by the road traffic model, see section 3.2.4.2.

Use of studded tyres is forbidden in Norway from the first Monday after Easter and until 31<sup>st</sup> of October. There is an exception from this rule in the three northern counties, Nordland, Troms and Finnmark. In these counties, use of studded tyres is forbidden between 1<sup>st</sup> of May to 15<sup>th</sup> of October. It is assumed in the calculations that studded tyres are used the whole period when it is allowed. This means that  $m$  is 6.5/12 in the northern counties and 5.5/12 for rest of the country.

Shares of traffic load on studded tyres in the five largest towns in Norway are given in table 3.17. There has been a decrease in use of studded tyres in Norway during the latest years. The factor  $p$  in the formula will therefore vary from one year to another. Information regarding the share of studded tyres originates from the Norwegian Public Roads Administration. There is also national data on share of the car fleet with studded tyres. The data material is based on interviews of car drivers (Norwegian public roads administration 1995a, b, 1998). The question-

<sup>4</sup> ÅDT = Average annual daily traffic

<sup>5</sup> Evensen, R. (2007). Note for Johnny Johansen. 14/12 1997. Bærum: ViaNova.

naires were given out at daytime and caused that most of the answers were from local car drivers. Accordingly, the survey included too many car drivers with annual mileage over 20 000 km. The survey from 1997 was however done differently. In the calculation program, the studded tyre share was decided to be 0.2. This value was adjusted by the different local road administrations, based on interviews or other available knowledge. In 2000, the Norwegian Public Roads Administration made a new investigation over local use of studded tyre (Johansen and Amundsen 2000). In 2006, Gjensidige made a survey over the use of studded tyres in different counties in Norway, winter 05/06 (Vaaje 2006). For 2001-2004 averages of the two investigations are calculated for the counties. For the five largest cities data from the Norwegian Public Roads Administration was used also for 2001-2005, but for the rest of the country the results from Gjensidige (Vaaje 2006) was used. The data are given in table 3.18. For the period 1973-1990 it is assumed that the studded tyre share was 90 per cent.

**Table 3.17. Use of studded tyres in five prioritized communities. Share of traffic load with studded tyres. Light duty vehicles**

	1998/ 1999	1999/ 2000	2000/ 2001	2001/ 2002	2002/ 2003	2003/ 2004	2004/ 2005	2005/ 2006	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013
Oslo .....	51.9	32.4	21.2	31.3	29.2	28.4	24.0	19.9	20.3	17.0	16.4	14.3	14.4	16.1	15.2
Drammen .....	49.6	48.7	52.1	41.8	42.3	40.6	31.5	27.0	28.0	27.3	22.9	25.0	25.2	25.0	20.6
Stavanger .....	38.1	31.3	26.8	29.3	28.8	35.2	30.1	32.2	28.4	33.2	19.6	19.0	27.9	28.9	26.8
Bergen .....	37.0	29.4	28.3	31.0	30.7	30.4	30.3	29.6	21.4	10.5	14.7	14.3	12.3	18.0	16.6
Trondheim .....	67.0	64.4	62.1	44.4	40.2	38.8	38.1	32.9	31.2	19.4	28.6	28.6	25.8	28.4	35.3

Source: The Norwegian Public Roads administration

**Table 3.18. Averaged studded tyre share in Norway weighted by traffic load in the different counties. Light duty vehicles**

Year	
1990 .....	0.90
1991 .....	0.87
1992 .....	0.88
1993 .....	0.88
1994 .....	0.87
1995 .....	0.86
1996 .....	0.83
1997 .....	0.79
1998 .....	0.70
1999 .....	0.63
2000 .....	0.58
2001 .....	0.56
2002 .....	0.55
2003 .....	0.53
2004 .....	0.51
2005 .....	0.49
2006 .....	0.48
2007 .....	0.46
2008 .....	0.45
2009 .....	0.44
2010 .....	0.43
2011 .....	0.43
2012 .....	0.42

Source: Statistics Norway based on data from the Norwegian Public Roads Administration and Gjensidige.

To calculate the correction factor for humid road surface, traffic load data is used. This is divided into different road conditions after Evensen (*pers. comm.*<sup>6</sup>) (table 3.19). Share of wet and dry road surface will change some as a consequence of varied share of studded tyres. In the calculations for 1973-1997 a correction factor

<sup>6</sup> Evensen, R. (1997) Personal information, telephone call 20/11 1997. Bærum: ViaNova.



is used, based on the estimation that 80 per cent of light duty vehicles and 60 per cent of heavy duty vehicles use studded tyres.

**Table 3.19. Grouping of wet, dry and icy road surface**

	In the Norwegian emission inventory
Wet	Wet
Dry	Dry
Slush	Wet
Loose snow	Wet <sup>1</sup>
Hard snow	Hard snow/ice
Bare tracks	80 per cent dry and 20 per cent wet <sup>2</sup>

<sup>1</sup> Assumption made of NILU and Statistics Norway.

<sup>2</sup> Assumption made by Evensen (*pers. comm.*, 6).

### TSP

Hedalen and Myran (1994) analysed road dust depots from Trondheim and found that 30 weight percentage of the particles were below PM<sub>10</sub>. This gives a distribution where PM<sub>10</sub> is 0.3\*TSP. This distribution is used in the inventory.

### Cd

Emissions of Cd are calculated based on emission factors from Bækken (1993) and annually generated road dust of PM<sub>10</sub>.

### PAH

Emissions of PAH are calculated based on emission factors from Larssen (1985) and annually generated road dust of PM<sub>10</sub>.

#### 3.2.4.9.3. Activity data

##### Cd and PAH

The activity data used for calculating the emissions of Cd and PAH are annually generated PM<sub>10</sub> of road dust, see sectionr 3.2.4.9.2.

#### 3.2.4.9.4. Emission factors

##### Particles

The emission factors can be derived from the factors given under 0. The emission figures are calculated as a product of SPS values for the given year, the number of kilometers driven, part of the cars with studded tyres, part of the year with winter season, correction for icy surface and the PM<sub>10</sub> share of the emission ( $\alpha$ ). The emission factors do not reflect the whirl up of road dust. Heavy duty vehicles whirl up much more than light duty vehicles.

##### Cd

The Cd content in the bitumen is uncertain. According to Bækken (1993), the Cd content varies between 1.9 and 43 g Cd per tonne road dust. Statistics Norway has chosen an average emission factor of 22.5 g/ton, see table 3.20.

**Table 3.20. PAH and Cd emission factors from road dust<sup>1</sup>. g/tonne. PM<sub>10</sub> of road dust**

	Emission factor (g/tonne PM <sub>10</sub> from road dust)
Norwegian standard (PAH-total) ..	61.7
PAH-6 .....	24.7
PAH-4 .....	5.5
Cd .....	22.5

<sup>1</sup> Dry road surface.

Source: Finstad *et al.* (2001).

##### PAH

The PAH content in the bitumen is uncertain and can vary over time. According to Larssen (1985), the PAH content in airborne dust from wet roads is 330 ppm and 75 ppm from dry roads. Statistics Norway has chosen 85 ppm. In table 3.20, the emission factor of 85 g/ton is converted to correspond to the PAH components included in NS9815. This gives an emission factor of 61.7 g/ton for PAH-total.

**3.2.4.9.5. Uncertainties**

Particle distribution of road dust has also been investigated by others than Hedalen and Myran, among them the Norwegian Institute for Air Research (NILU). The results from these measurements show another distribution than Hedalen and Myran, with a PM<sub>10</sub>-fraction much lower than 30 weight percentage. In the calculation of PM<sub>10</sub>, data from Hedalen and Myran (1994) are used, and for consistency reasons the same source is used for estimating TSP, despite the uncertainty and the discrepancy with NILUs estimations.

The value of  $\alpha$  (PM<sub>10</sub> share in road dust) is very uncertain. An average velocity is assumed in the calculations. This is further complicated when road surface on roads with high velocities have another wear resistance than other road surfaces.

The emission factor used for calculating Cd emissions is uncertain since it is based on two measurements.

The estimation of the PAH content in road dust from Larssen (1985) is very uncertain, since it is based on only one measurement in Oslo, but it is the only estimate available, and is used in lack of other data.

**3.2.4.9.6. Completeness**

Major missing emission sources are not likely.

**3.2.4.9.7. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**3.2.5. Other sectors**

*IPCC 1A4, Key category for CO<sub>2</sub> from stationary combustion of gas, liquid, solid and other fuels and for mobile fuel combustion. Key category for CH<sub>4</sub> for combustion of gas and biomass*

*IPCC 1A5, Key category for CO<sub>2</sub> for military mobile combustion*

*NFR 1A4/1A5*

*Last update: 28.01.2013*

**3.2.5.1. Description**

The source category "Other sectors" includes *all* military combustion, *stationary* combustion in agriculture, forestry, fishing, commercial and institutional sectors and households, motorized equipment and snow scooters in agriculture and forestry, and ships and boats in fishing.

**3.2.5.2. Activity data**

*Motorized equipment* is described in section 3.2.4.7.

*Households*

Use of wood in households for the years 2005-2011 are based on responses to questions relating to wood-burning in Statistics Norway's Travel and Holiday Survey. The figures in the survey refer to quantities of wood *used*. The survey quarterly gathers data that cover the preceding twelve months. The figure used in the emission calculations is the average of five quarterly surveys. For the years before 2005 and for 2012 figures are based on the amount of wood burned from the annual survey on consumer expenditure. The statistics cover purchase in physical units and estimates for self-harvest. The survey figures refer to quantities *acquired*, which not necessarily correspond to *use*. The survey gathers monthly data that cover the preceding twelve months; the figure used in the emission calculations (taken from the energy accounts), is the average of the survey figures from the year in question and the following year. Combustion takes place in small ovens in private households.

Figures on use of coal and coal coke are derived from information from the main importer. Formerly, Norway's only coal producing company had figures on coal sold for residential heating in Norway. From about 2000, this sale was replaced by imports from abroad. Figures for LPG are collected from the suppliers. Heavy fuel oil is taken from the sales statistics for petroleum products. As the consumption of each energy carrier shall balance against the total sales in the sales statistics, use of fuel oil, kerosene and heavy distillates in households is given as the residual after consumption in all other sectors has been assessed. Use of natural gas is based on sales figures reported to Statistics Norway from the distributors.

#### *Agriculture*

Data on energy use in hothouses are collected in surveys performed regularly. Sales figures are used to project the figures for consumption of oil products in the years between. For biofuels and LPG figures are interpolated for years not included in surveys. The Agricultural Budgeting Board has figures on the use of gasoline, auto diesel and fuel oil in agriculture excluding hothouses. A figure on the minor use of coal was previously collected annually from the only consumer. Since 2002, however, there has been no known use of coal in the Norwegian agricultural activities. Use of natural gas in agriculture, which has increased considerably since it first was registered in 2003, is based on sales figures reported to Statistics Norway from the distributors.

#### *Fishing*

Figures on the use of marine gas fuel, heavy distillate and heavy fuel oil are identical with the registered sales to fishing in the sales statistics for petroleum products. In addition to these figures on use in large fishing vessels, a minor figure on estimated use of gasoline in small fishing boats is also included.

#### *Commercial and institutional sectors*

Figures on energy use in wholesale and retail trade and hotels and restaurants, are based on a survey for 2000, performed by Statistics Norway. For the following years, figures from this survey have been adjusted proportionally to the development in employment in the industries in question. For earlier years, the figures are based on a survey from the mid-1980s (Sagen 1987). LPG figures for the whole period from 1990 have, however, been estimated separately after consultation with an oil company.

For most other commercial and institutional sectors, the total use of fuel oil appears as a residual after the use in all other sectors has been estimated; the distribution of this residual between sub-sectors is done by using figures on energy use per man-labour year from the energy survey from the mid-1980s.

Use of heating kerosene in commercial industries is calculated by projecting a figure on use from the mid-1980s proportionally with the registered sales to buildings in industrial industries outside the manufacturing industries. The estimated total amount is distributed between sub-sectors by using figures on energy use per man-labour year from the mid-1980s survey.

Use of natural gas is based on sales figures reported to Statistics Norway from the distributors.

Calculated emissions from combustion of biogas at a sewage treatment plant are included for all years since 1993.

#### *Military*

Figures on fuel oil are annually collected directly from the military administration, while figures from the sales statistics for petroleum products are used for other energy carriers.

**3.2.5.3. Emission factor**

Emission factors used are given in Appendix B.

Emission factors for fuelwood are based on data for different oven technologies. Ovens made in 1998 and later have significantly improved combustion and reduced emissions. The factors are weighted based on information from the surveys of the amount of wood burned in ovens with the different technologies. The yearly weighted factors are given in appendix B.

**Table 3.21. Emission factors for fuelwood, g/kg dry matter**

	Open fireplaces	Ovens -1997	Ovens 1998-
NO <sub>x</sub> .....	1.3	0.97	0.97
CO .....	126.3	150	50.5
TSP .....	17.3	22.7	13.4
TSP large cities .....	17.3	17.4	12.2
PM <sub>10</sub> .....	17.0	22.2	13.1
PM <sub>10</sub> , large cities .....	17.0	17.1	12.0
PM <sub>2.5</sub> .....	16.4	21.6	12.7
PM <sub>2.5</sub> large cities .....	16.4	16.5	11.6
PAH – total .....	17.4	52	0.0226
PAH – OSPAR .....	6.1	8.1	0.0045
PAH - 4 .....	3	2.7	0.0025

Source: PAH : Finstad *et al* (2001), TSP, PM<sub>10</sub> and PM<sub>2.5</sub> : Seljeskog, M., F. Goile, et al. (2013) other pollutants : Haakonsen and Kvingedal (2001).

**3.2.5.4. Uncertainties**

Uncertainty in *fishing* is described together with navigation in section. 3.2.4.5.5.

The method used for finding the use of fuel oil, kerosene and heavy distillates in households implies a great deal of uncertainty regarding the quality of these figures, particularly for fuel oil, which is the most important of these three energy carriers. Since the late 1990s it also has been necessary to adjust figures for other sectors in order to get consumption figures for households that look reasonable. Hopefully, new surveys will improve the quality of these figures in the future.

As the total use of the different oil products is defined as equal to the registered sales, use in some sectors are given as a residual. This applies to use of heating kerosene and heavy distillates in households, and total use of fuel oil in commercial and institutional sectors. Accordingly, these quantities must be regarded as uncertain, as they are not based on direct calculations. This uncertainty, however, applies only to the distribution of use between sectors - the total use is defined as equal to registered sales, regardless of changes in stock.

There have been large variations in annual sales of military aviation kerosene; as stock changes are not taken into account, the actual annual use is uncertain.

**3.2.5.5. Completeness**

Major missing emission sources are not likely.

**3.2.5.6. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**3.2.6. International bunkers**

*IPCC - memo item*

*NFR - memo item*

*Last update: 31.03.2006*

### **3.2.6.1. Description**

Emissions from international bunkers (marine and aviation) have been estimated and reported separately from national estimates, in accordance with the IPCC Guidelines. Differences between the IEA (International Energy Agency) data and the data reported to UNFCCC in sectoral data for marine shipping and aviation are due to the fact that different definitions of domestic use are employed. In the Norwegian inventory, domestic consumption is based on a census in accordance with the IPCC good practice guidance. On the other hand, the IEA makes its own assessment with respect to the split between the domestic and the international market.

### **3.2.6.2. Shipping**

#### **3.2.6.2.1. Method**

Emissions are calculated by multiplying activity data with emission factors. The sales statistics for petroleum products, which is based on reports from the oil companies to Statistics Norway, has figures on sales for bunkers of marine gas oil, heavy distillates and heavy fuel oil. The same emission factors as in the Norwegian national calculations are used.

#### **3.2.6.2.2. Activity data**

Sales figures for international sea transport from Statistics Norway's sales statistics for petroleum products are used for marine gas oil, heavy distillates and heavy fuel oil.

#### **3.2.6.2.3. Emission factor**

Emission factors used for *Shipping* are described under *Navigation* in section 3.2.4.5.

### **3.2.6.3. Aviation**

#### **3.2.6.3.1. Method**

The consumption of aviation bunker fuel in Norway is estimated as the difference between total purchases of jet kerosene in Norway for civil aviation and reported domestic consumption. Figures on total aviation fuel consumption are derived from sales data reported to Statistics Norway from the oil companies. These data do not distinguish between national and international uses. Data on domestic fuel purchase and consumption are therefore collected by Statistics Norway from all airline companies operating domestic traffic in Norway. The figures on domestic consumption from airlines are subtracted from the total sales of jet kerosene to arrive at the total fuel sales for international aviation. The bottom-up approach of Norway is the detailed Tier 2 CORINAIR methodology. The methodology is based on detailed information on types of aircraft and number of LTOs, as well as cruise distances.

#### **3.2.6.3.2. Activity data**

Statistics Norway annually collects data on use of fuel from the air traffic companies, including specifications on domestic use and purchases of fuel in Norway and abroad.

#### **3.2.6.3.3. Emission factor**

Emission factors used for *Aviation* are described under *Aviation* in section 3.2.4.1.

### **3.2.7. CO<sub>2</sub> emissions from biomass**

#### *IPCC - memo item*

Emissions are estimated from figures in the energy accounts on use of wood, wood waste and black liquor. According to the guidelines, these CO<sub>2</sub> emissions are not included in the national total in the Norwegian emission inventory.

### 3.3. Energy production (fugitive emissions from fuels)

*IPCC 1B*

*NFR 1B*

#### 3.3.1. Overview

Emission sources included in the inventory from the sector *Fugitive emissions from fuels* are fugitive emissions from coal mining and handling, and from oil and natural gas.

Fugitive emissions from oil and natural gas include emissions from loading and refining of oil, gasoline distribution, and fugitive emissions from the gas terminals on shore. There are also fugitive emissions in connection with venting and flaring offshore.

#### 3.3.2. Fugitive emissions from coal mining and handling

*IPCC 1B1 a, Key category for CH<sub>4</sub>*

*NFR 1B1*

*Last update: 12.12.2013*

##### 3.3.2.1. Description

There are today two coal mines at Spitsbergen (the largest island in the Svalbard archipelago) operated by a Norwegian company. The second mine was opened in 2001. As the Norwegian GHG inventory, according to official definitions, shall include emissions from all activities at Svalbard, also emissions from Russian coal production have been estimated. Until 1998, there was production in two Russian coal mines, Barentsburg and Pyramiden, but since then, production takes place only in the Barentsburg mine. The Norwegian mines and Pyramiden are defined as surface mines, whereas Barentsburg is an underground mine. Russian production has in recent years been considerably smaller than the Norwegian production, and due to a fire that started in 2008 the production in 2008 and 2009 was very small. In autumn 2010, ordinary production was restarted. Russian activity data are more uncertain than the Norwegian, which causes a correspondingly higher uncertainty in the emission figures.

At Svalbard there was a smouldering fire in Pyramiden, the Russian mine that was closed down in 1998. At an inspection in 2005, no emissions were registered, which indicates that the fire had burnt out. Due to lack of data, emissions for earlier years from this fire have not been estimated. However, Norwegian authorities assume that these emissions are limited.

In the most recent emission inventory, emissions from NMVOC and particles from handling of coal are included for the first time.

##### 3.3.2.2. Method

*CO<sub>2</sub>*

Indirect CO<sub>2</sub> emissions from methane oxidized in the atmosphere are calculated by multiplying the calculated CH<sub>4</sub> emission with the factor 2.74 tonne CO<sub>2</sub> per tonne CH<sub>4</sub>. (See chapter 1.9 for more information on indirect CO<sub>2</sub>).

*CH<sub>4</sub>*

Emissions of methane from coal mining on Svalbard are calculated by multiplying the amount of coal extracted (raw coal production) with country specific emission factors (Tier 2). The calculations are performed by Statistics Norway.

*NMVOC*

NMVOC emissions from handling of coal are estimated by multiplying the amount of coal extracted (raw coal production) with Tier 2 emission factors from EMEP/EEA Guidebook 2013.

### *Particles*

Emissions of particles from handling of coal are estimated by multiplying the amount of coal extracted (raw coal production) with Tier 1 emission factors from EMEP/EEA Guidebook 2013.

#### **3.3.2.3. Activity data**

Figures on Norwegian production (raw coal production) are reported by the plant to Statistics Norway. Russian figures are reported to the Norwegian authorities on Svalbard; these figures are, however, regarded as highly uncertain, consisting of a mixture of figures on production and shipments.

#### **3.3.2.4. Emission factors**

##### *CH<sub>4</sub>*

For Norwegian coal production, a country specific emission factor of CH<sub>4</sub> from extraction of coal was determined in 2000 in two separate studies performed by IMC (2000) and Bergfald & Co AS (2000).

The emissions of methane from coal mining were in the study measured in two steps. First, coal was sampled and the methane content in coal was analysed (IMC 2000). The sampling process started after a long period (a week) of continuous production. Small samples of coal were removed directly from the coalface as soon as possible after a cut was taken. This was to minimise degassing losses in the samples if the face or heading had been standing for a long time.

The samples yielded an estimate of seam gas content of 0.535-1.325 m<sup>3</sup> methane per tonne coal derived from an average content of 0.79 m<sup>3</sup> per tonne. This factor includes the total possible methane emissions from coal mining, loading and transport on shore and on sea. The factor also includes the possible emission from handling and crushing of coal at the coal power plant.

Secondly, the methane content in ventilation air from the underground coal mines at Spitsbergen was measured (Bergfald & Co AS 2000). From the Norwegian mines the methane content in the ventilation air was measured to 0.1-0.4 m<sup>3</sup> methane per tonne coal.

Considering the measurements it was therefore decided to use 0.54 kg methane per tonne coal as emission factor when calculating methane emissions from coal mining in Norway.

According to IPCC's Good Practice Guidance, the Norwegian mines at Spitsbergen have characteristics that should define the mines as underground mines, whereas the emission factor we use is more characteristic for surface mines. The low content of methane is explained with the mine's location 300-400 metres *above* sea level. Furthermore, the rock at Spitsbergen is porous and therefore methane has been aired through many years.

For the Russian mine in Barentsburg, the emission factor for CH<sub>4</sub> has been estimated in the same manner as the Norwegian factor, based on measurements by Bergfald & Co AS (2000). This is an underground mine, which causes considerably higher emissions than from the Norwegian mines; we use the factor 7.16 kg methane per tonne coal for this mine. Pyramiden, the Russian mine that was closed down in 1998 is, however, situated more like the Norwegian mines; accordingly we use the same emission factor for this as for the Norwegian mines.

##### *NM VOC*

Emission factors for NM VOC are taken from EMEP/EEA Guidebook 2013. The Tier 2 factors used are 3 kg NM VOC per tonne coal for surface mines and 0.2 kg NM VOC per tonne coal for underground mines.

### *Particles*

Emission factors for particles are taken from EMEP/EEA Guidebook 2013. The same Tier 1 factors are used for both surface and underground mines. The factors are 0.089 kg particles per tonne coal for TSP, 0.042 kg particles per tonne coal for PM<sub>10</sub> and 0.005 kg particles per tonne coal for PM<sub>2.5</sub>.

#### **3.3.2.5. Uncertainties**

##### **3.3.2.5.1. Activity data**

The uncertainty in the activity data concerning Norwegian coal production is regarded as being low. The uncertainty in Russian data is considerably higher.

##### **3.3.2.5.2. Emission factor**

In the uncertainty analysis for greenhouse gases performed in 2006 (Appendix D) the uncertainty in the emission factor was estimated by expert judgments to as much as -50 to +100 per cent. But this estimate was based on the earlier use of an IPCC default emission factor in the calculations. Today, country specific factors based on measurements are used in the calculations and the uncertainty in the emission factors is probably lower than -50 to +100 per cent.

The emission factor we use for the Norwegian mines is an average of the measurement of methane in coal sampled in the study (IMC 2000). This average emission factor is two to eight times higher than the methane content measured in ventilation air by Bergfald & Co AS (2000). This should indicate that the chosen emission factor is rather conservative.

#### **3.3.2.6. Completeness**

Emissions from Russian coal extraction on Svalbard are now included in the Norwegian emission inventory. In accordance with 2006 IPCC Guidelines, it is intended to include also emissions of CH<sub>4</sub> from abandoned coal mines in future emission inventories. Apart from this, no major missing emission sources are known.

#### **3.3.2.7. Source specific QA/QC**

Independent methods to estimate the emission factors used in the calculations are described above in this chapter. Statistics Norway and the Norwegian Environment Agency carry out internal checks of the emission time-series and corrections are made when errors are detected; see chapter 1.5 for general QA/QC procedures.

### **3.3.3. Fugitive emissions from uncontrolled combustion and burning coal dumps**

*IPCC 1B1 b*

*NFR 1B1*

*Last update: 07.06.2011*

#### **3.3.3.1. Description**

In 2005, a fire broke out in one of the Norwegian coal mines at Spitsbergen, causing minor emissions.

#### **3.3.3.2. Method**

Emissions have been calculated by multiplication of the quantity of coal combusted by standard emission factors for combustion of coal.

#### **3.3.3.3. Activity data**

The company operating the mine has provided an estimate on the quantity of coal combusted in the fire.



#### **3.3.3.4. Emission factors**

Emission factors for direct-fired furnaces, as given in Appendix B, have been used in the calculations.

#### **3.3.3.5. Uncertainties**

The uncertainty in the activity data, that is the quantity of coal combusted, is unknown. However, as the emissions are small, the uncertainty is insignificant.

#### **3.3.3.6. Completeness**

The only fire in a Norwegian coal mine since 1990 is included. Emissions from a smouldering fire in a Russian mine, which is supposed to have lasted for several years, are not included in the emission inventory, due to lack of data. The same applies to another fire in 2008. These emissions are, however, probably insignificant.

#### **3.3.3.7. Source specific QA/QC**

There is no specific QA/QC procedure for this source.

### **3.3.4. Oil and natural gas**

*IPCC 1B2, 1B2a is key category for CO<sub>2</sub>, 1B2b for CH<sub>4</sub> and 1B2c for CO<sub>2</sub> and CH<sub>4</sub>  
NFR 1B2*

*Last update: 14.04.2014*

#### **3.3.4.1. Description**

*1B2a* covers emissions from loading and storage of crude oil, refining of oil and distribution of gasoline. Loading, unloading and storage of crude oil on the oil fields off shore and at oil terminals on shore cause direct emissions of CH<sub>4</sub> and NMVOC and indirect emissions of CO<sub>2</sub> from oxidised CH<sub>4</sub> and NMVOC. Non-combustion emissions from Norway's two oil refineries (a third was closed down in 2000) include CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>x</sub>, NMVOC, SO<sub>2</sub> and particulates. Gasoline distribution causes emissions of NMVOC, which lead to indirect CO<sub>2</sub> emissions.

*1B2b* covers fugitive emissions of CH<sub>4</sub> and NMVOC and indirect emissions of CO<sub>2</sub> from gas terminals on shore.

**Table 3.22. Fugitive emissions from oil and natural gas. Emission sources, compounds, methods, emission factors and activity data included in the Norwegian GHG inventory**

B Fugitive emissions from fuels	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	NM VOC	Method	Emission factor	Activity data
<b>1.B.2.a Oil</b>							
i. Exploration .....	IE	IE	NO	IE	Tier II	CS	PS
ii. Production .....	IE	IE	NO	IE	Tier II	CS	PS
iii. Transport .....	E	R/E	NO	R/E	Tier II	CS	PS
iv. Refining/Storage .....	R/E	R	NO	R	Tier I/II	CS	PS
v. Distribution of oil products .....	E	NE	NO	R/E	Tier I	C/CS	CS/PS
vi. Other .....	NO	NO	NO	NO			
<b>1.B.2.b Natural gas</b>							
i. Exploration .....	IE	IE	NO	IE	IE	IE	IE
ii. Production/Processing .....	IE	IE	NO	IE	IE	IE	IE
iii. Transmission .....	IE	IE	NO	IE	IE	IE	IE
iv. Distribution .....	IE	E	NO	IE	Tier II	OTH	CS/PS
v. Other leakage							
industrial plants, power stations .....	E	R	NO	R	Tier II	CS	PS
residential/commercial sectors .....	NO	NO	NO	NO			
<b>1.B.2.c</b>							
Venting							
i. Oil .....	IE	IE	NO	IE	Tier II	CS/PS	PS
ii. Gas .....	IE	IE	NO	IE	Tier II	CS/PS	PS
iii. Combined .....	R/E	R/E	NO	R/E	Tier II	CS/PS	PS
<b>Flaring</b>							
i. Oil (well testing) .....	R/E	E	E	R/E	Tier II	CS	PS
ii. Gas							
Gas and oil fields .....	R/E	R/E	E	R/E	Tier II	CS	PS
Gas terminals .....	R	R	E	R/E	Tier I	CS	CS
Refineries .....	R	R	R/E	E	Tier I	CS	CS
iii. Combined .....	IE	IE	IE	IE	Tier I	CS	CS

R = emission figures in the national emission inventory are based on figures reported by the plants. E = emission figures are estimated by Statistics Norway (Activity data \* emission factor). IE = Included elsewhere, NO = Not occurring, CS = Country specific, PS = Plant specific, Tier = the qualitative level of the methodology used, C=Corinair, OTH=Other.

*1B2c* covers fugitive emissions from venting and flaring. Venting emissions include emissions of CO<sub>2</sub>, CH<sub>4</sub> and NMVOC from exploration and production drilling of gas and oil, and reinjection of CO<sub>2</sub> at two oil fields (Sleipner and Snøhvit). The major source is cold vent and leakage of CH<sub>4</sub> and NMVOC from production drilling and hence indirect CO<sub>2</sub> emissions. CO<sub>2</sub> emissions vented to the atmosphere when the injection of CO<sub>2</sub> has to stop for maintenance etc. are reported in this sector. See sections 3.3.5 and 3.3.6 for further description of this source.

Most of the emissions in *1B2c* come from flaring of natural gas offshore (during both well testing, extraction and pipeline transport) and at gas terminals and flaring of refinery gas at the refineries. This flaring causes emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NMVOC, SO<sub>2</sub>, CO, particulates, PAH and dioxins. There is also some flaring of oil in connection with well testing - amounts flared and emissions are reported to NPD (the Norwegian Petroleum Directorate) and the Norwegian Environment Agency.

The major source in sector 1B2 is flaring of natural gas on the Norwegian continental shelf. Table 3.22 gives an overview over the calculations of the fugitive emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and NMVOC.

#### 3.3.4.2. Method

##### *Loading and storage of crude oil off shore and on shore CH<sub>4</sub> and NMVOC*

From 2003, emission of CH<sub>4</sub> and NMVOC from loading and storage of crude oil on shuttle tankers included in the GHG inventory are based on reported emission figures from the oil companies. Emissions, activity, and to some extent emission factors, are reported from each field operator into the database *Environmental Web*. The database is operated by NPD, the Norwegian Environment Agency and The

Norwegian Oil Industry Association (OLF). In addition the field operators each year deliver a report where they describe the activities during the last year.

Before 2003, the emissions of CH<sub>4</sub> and NMVOC were calculated by Statistics Norway. The calculation was based on the field specific amounts of crude oil loaded and stored multiplied with field specific emission factors. Field specific activity data and emission factors (the latter only to the Norwegian Environment Agency) used in the calculation were annually reported by the field operators to Statistics Norway and the Norwegian Environment Agency. Since year 2000 an increasing share of the shuttle tankers have had installed vapour recovery units (VRU), and emissions from loading of crude oil on shuttle tankers with and without VRU were calculated separately for each field. In addition, emission figures were annually reported to the Norwegian Environment Agency and used in the QC of the calculated emission figures.

Only emissions from loading and storage of the Norwegian part of oil production are included in the inventory. For the Norwegian oil terminals on shore, the emissions from loading of crude oil are reported annually from the terminals to the Norwegian Environment Agency. At one of the terminals VRU for recovering NMVOC was installed in 1996. The calculation of the emissions of CH<sub>4</sub> and NMVOC at the terminals is based upon the amount of crude oil loaded and oil specific emission factors dependent on the origin of the crude oil loaded.

The indirect CO<sub>2</sub> emissions from the oxidation of CH<sub>4</sub> and NMVOC in the atmosphere for this source category are calculated by Statistics Norway.

#### *Oil refineries*

##### *CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>x</sub>, NMVOC, SO<sub>2</sub> and particulates*

Emission figures from the oil refineries are reported to the Norwegian Environment Agency, and are after QA/QC procedures used in the emission inventory. CH<sub>4</sub> emissions from the largest refinery are, however, estimated by the Norwegian Environment Agency by multiplying the yearly amount of crude oil throughput by a plant specific emission factor.

The CO<sub>2</sub> emissions originate from the coke on the catalyst that is burned off and from the coke calcining kilns. The CO<sub>2</sub> emissions from catalytic cracker and calcining kilns are calculated from the formula (3.7):

$$(3.7) \text{ tonne CO}_2 \text{ per year} = ((\text{Nm}^3 \text{ RG per year} * \text{volume\% CO}_2) / 100 * (\text{molar weight of CO}_2 / 22.4)) / 1000$$

- the amount of stack gas (RG) is measured continuously
- the density of the stack gas is 1.31 kg/Nm<sup>3</sup>
- volume percentage of CO<sub>2</sub> is based on continuously measurements. However, if the refinery can document that the volume percentage of CO<sub>2</sub> is not fluctuating more than 2 per cent from last years report it is not mandatory to have continuous measurements.

Both CH<sub>4</sub> and NMVOC emissions are based on measurements carried out by Spectracyne in 2002 and 2005.

The indirect CO<sub>2</sub> from oxidized CH<sub>4</sub> and NMVOC is calculated by Statistics Norway.

#### *Gasoline distribution*

##### *NMVOC*

Emissions from gasoline distribution are calculated from figures on amounts of gasoline sold and emission factors for, respectively, loading of tanker at gasoline depot, loading of tanks at gasoline stations and loading of cars.

*Gas terminals**CH<sub>4</sub> and NMVOC*

Fugitive emissions of CH<sub>4</sub> and NMVOC from gas terminals are annually reported from the terminals to the Norwegian Environment Agency.

The emissions are calculated based on the number of sealed and leaky equipment units that is recorded through the measuring and maintenance program for reducing the leakage. The number of sealed and leaky equipment units is collected two times a year and the average number of the countings is used in the calculation. It is assumed in the calculation that a leakage has lasted the whole year if not the opposite is documented.

Measurements of the total emissions were carried out in 2002 and 2003.

*Gas distribution**CH<sub>4</sub>*

Emissions of CH<sub>4</sub> from three different subgroups of distribution of natural gas are estimated:

- High pressure transmission pipelines: Large diameter pipelines that transport gas long distances from field production and processing areas to distribution systems or large volume customers such as power plants or chemical plants. Emissions are calculated by multiplying pipeline distance with an emission factor.
- Low pressure distribution pipelines: Distribution pipelines which take the high-pressure gas from the transmission system at “city gate” stations, reduce the pressure and distribute the gas through primarily underground mains and service lines to individual end users. Emissions are calculated by multiplying pipeline distance with an emission factor.
- Storage: Emissions from end users’ storage. Emissions are calculated by multiplying the amount of gas consumed with an emission factor.

*Venting**CH<sub>4</sub> and NMVOC*

Emissions of CH<sub>4</sub> and NMVOC from cold venting and diffuse emissions for each field are reported annually to the Norwegian Environment Agency from the field operator. The emissions are mostly calculated by multiplying the amount of gas produced with an emission factor for each emission source identified at the field. The indirect CO<sub>2</sub> emissions are calculated by Statistics Norway. The vented CO<sub>2</sub> at Sleipner West and Snøhvit is measured.

*Flaring**CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NMVOC, CO, particulates, PAH and dioxins*

Emissions from flaring of natural gas off shore are calculated by Statistics Norway on the basis of field specific gas consumption data and emission factors. For CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>x</sub>, NMVOC and SO<sub>2</sub>, calculated emissions are used in the inventory for the years until 2002. From 2003, emissions of these pollutants from flaring offshore have been reported by the oil companies to NPD and the Norwegian Environment Agency are used in the inventory. The same method is used in the calculation of emissions from flaring in connection with well testing.

Emissions of CO<sub>2</sub>, CH<sub>4</sub> and NO<sub>x</sub> from flaring at gas terminals are reported for all years. For NMVOC, emissions are calculated for one gas terminal and reported figures used for the others. Other emissions from the gas terminals are based on activity data and emission factors.

The refineries annually report CO<sub>2</sub> emissions from flaring to the Norwegian Environment Agency. The emissions are calculated by multiplying the amount of gas flared with plant specific emission factors.

### 3.3.4.3. Activity data

#### *Loading and storage of crude oil off shore and on shore*

The amount of oil buoy loaded and oil loaded from storage tankers is reported by the field operators in an annual report to the Norwegian Environment Agency and the Norwegian Petroleum Directorate (NPD). The amount of oil loaded on shuttle tankers with or without VRU is separated in the report.

Before 2003, Statistics Norway gathered data on amounts of crude oil loaded at shuttle tankers and stored at storage vessels from the NPD. The data from each field are reported monthly by the field operators to NPD on both a mass and a volume basis. The allocation of the amount of crude oil loaded at shuttle tankers and stored at storage vessels with or without VRU is from the annually report the field operators are committed to deliver to the Norwegian Environment Agency and NPD.

The amount of oil loaded at on shore oil terminals is also reported to the Norwegian Environment Agency and NPD.

#### *Oil refineries*

The crude oil throughput is annually reported by the plant to the Norwegian Environment Agency.

#### *Gasoline distribution*

Gasoline sold is annually collected in Statistics Norway's sales statistics for petroleum products.

#### *Gas terminals*

Activity data that the terminals use in their emission calculations are sampled through the terminals measuring and maintenance program, whose aim is to reduce leakage.

#### *Gas distribution*

In the estimation of CH<sub>4</sub> emissions from storage, figures on use of natural gas from the energy statistics are used. Emissions from transmission and distribution are based on data on pipeline distances collected from gas distributors.

#### *Venting*

Amounts of gas produced or handled at the platforms are reported from NPD and used in the QC of the reported emissions.

#### *Flaring*

Amounts of gas flared at offshore oil and gas installations are reported monthly by the operators to the Norwegian Petroleum Directorate (NPD). Amounts flared at the gas terminals are reported to NPD and the Norwegian Environment Agency. Amounts of refinery gas flared are found by distributing the total amounts between different combustion technologies by using an old distribution key, based on data collected from the refineries in the early 1990s. This distribution was confirmed in 2003.

### 3.3.4.4. Emission factors

#### *Loading and storage of crude oil offshore and on shore*

For the years before 2003, emission factors used in the calculation of CH<sub>4</sub> and NMVOC emissions offshore are field specific and were reported to the Norwegian Environment Agency and NPD in an annual report. The Norwegian Environment Agency forwarded the emission factors to Statistics Norway. From 2003 the emission figures reported by the field operators are used in the inventory.

The evaporation rate varies from field to field and over time, and the emission factors are dependent on the composition of the crude oil as indicated by density

and Reid vapour pressure (RVP). The VOC evaporation emission factors are obtained from measurements, which include emissions from loading and washing of shuttle tankers. For some fields the emission factors are not measured, only estimated. The CH<sub>4</sub> content of the VOC evaporated is also measured so that total emissions of VOC are split between CH<sub>4</sub> and NMVOC.

The emission factors that the field operators use in their calculations are reported to the Norwegian Environment Agency and NPD. They report emissions factors with and without VRU and the split between CH<sub>4</sub> and NMVOC.

Loading on shore: The emission factors are considerably lower at one of Norway's two oil terminals than at the other, because the oil is transported by ship and therefore the lightest fractions have already evaporated. At the other terminal the oil is delivered by pipeline. The latter terminal has installed VRU, which may reduce NMVOC emissions from loading of ships at the terminal by about 90 per cent. NMVOC emissions at this terminal are estimated to be more than 50 per cent lower than they would have been without VRU. However, the VRU technology is not designed to reduce methane and ethane emissions.

#### *Oil refineries*

The emission factor used in the calculation of methane emissions from the largest refinery is based upon measurements performed by Spectracyne in 2002 and 2005. The EF is deduced from the measured methane emissions and the crude oil throughput in 2005.

#### *Gasoline distribution*

The emission factor for NMVOC from refuelling of gasoline in cars (1.48 kg NMVOC/tonne gasoline) is taken from EEA (2001).

#### *Gas distribution*

Since country specific emission factors for Norway not are available, Austrian factors are used in the estimations (Umweltbundesamt 2011). The factors for both storage and transmission may be too high.

**Table 3.23. Emission factors for gas distribution**

	CH <sub>4</sub> Emission factor	Unit
High pressure transmission pipelines ....	0.475	tonnes per km pipeline
Low pressure distribution pipelines .....	0.013	tonnes per km pipeline
Storage .....	0.005145	tonnes per mill. Sm <sup>3</sup> gas consumed

Source: (Umweltbundesamt 2011).

#### *Venting*

The emission factors used are listed in table 3.24.

**Table 3.24. Emission factors for cold vents and leakage at gas fields offshore**

	NMVOC Emission factor	CH <sub>4</sub> Emission factor	Calculation method
Emission source .....	[g/Sm <sup>3</sup> ]	[g/Sm <sup>3</sup> ]	
Glycol regeneration .....	0.065	0.27	
Gas dissolved in liquid from K.O. Drum .....	0.004	0.00	
Gas from produced water system .....	0.03	0.03	
Seal oil systems .....	0.015	0.01	
Leaks through dry compressor gaskets .....	0.0014	0.00	
Start gas for turbines <sup>1</sup> .....	0.4	0.36	Tonne per start up
Depressurisation of equipment .....	0.005	0.02	
Instrument flushing and sampling .....	0.00021	0.00	
Purge and blanket gas <sup>1</sup> .....	0.032	0.02	
Extinguished flare .....	0.014	0.02	
Leaks in process .....	0.007	0.02	
Depressurisation of annulus .....	0.0000005	0.00	
Drilling .....	0.55	0.25	Tonne per well

<sup>1</sup> The gas source is standard fuel gas.

Source: Aker Engineering (1992).

### Flaring

CO<sub>2</sub>: From 2003, CO<sub>2</sub> emission figures reported by the oil companies to the Norwegian Environment Agency and NPD are used in the inventory. For the years 1990-2002, average emission factors, based on field specific factors, are used, except for one field, for which a field specific factor is used for all years. In table 3.25, the CO<sub>2</sub> emission factors for flaring offshore and at one gas terminal are shown. The average emission factor for the three types of flares (high pressure, low pressure, maintenance flare) at one of the other gas terminal was in 2009 2.50 tonne CO<sub>2</sub>/tonne gas flared. For the two last gas terminals the average emission factors were 2.93 and 1.94 tonne CO<sub>2</sub> per tonne gas, respectively, in 2009.

Emission factors used in the calculations for well testing are shown in table 3.26.

**Table 3.25. Emission factors for flaring of natural gas at offshore oil fields and one gas terminal on shore**

	Average emission factor for flaring at one gas terminal tonne CO <sub>2</sub> /tonne natural gas	Average emission factor for flaring off shore kg CO <sub>2</sub> /Sm <sup>3</sup> natural gas
1990 .....	2.70	2.34
1991 .....	2.70	2.34
1992 .....	2.70	2.34
1993 .....	2.70	2.34
1994 .....	2.70	2.34
1995 .....	2.70	2.42
1996 .....	2.70	2.34
1997 .....	2.70	2.34
1998 .....	2.70	2.34
1999 .....	2.70	2.48
2000 .....	2.70	2.52
2001 .....	2.70	2.42
2002 .....	2.70	2.47
2003 .....	2.70	<b>2.46</b>
2004 .....	2.70	<b>2.52</b>
2005 .....	2.70	<b>2.46</b>
2006 .....	2.69	<b>2.44</b>
2007 .....	2.67	<b>2.33</b>
2008 .....	2.67	<b>2.33</b>
2009 .....	2.67	<b>2.55</b>
2010 .....	2.65	<b>2.67</b>
2011 .....	2.76	<b>2.88</b>
2012 .....	2.75	<b>2.81</b>

Source: The Norwegian Environment Agency/ Norwegian Petroleum Directorate.

NO<sub>x</sub>: A NO<sub>x</sub> emission factor at 1.4 g NO<sub>x</sub>/Sm<sup>3</sup> flared gas at off shore installations is based upon studies conducted by (SINTEF 2008). In the study two new experimental laws have been compared with DIAL-measurements of NO<sub>x</sub> emissions made on onshore flares.

PM<sub>10</sub>: The emission factor is based on (McEwen and Johnson 2011). In fig. 7, this paper gives a regression formula for the emission factor as a function of the heating value (GCV) as  $EF = 0.0578(HV) - 2.09$ . For Norwegian offshore flaring a heating value of 48 MJ/Sm<sup>3</sup> is suggested in (Bakken *et al.* 2008). This gives an emission factor of 0.856 g PM<sub>10</sub>/Sm<sup>3</sup>.

Other emission factors from flaring of gas are shown in appendix B. The same factors are used for flaring of gas in connection with *well testing*. For flaring of *oil*, the the emission factors are shown in the following table.

**Table 3.26. Emission factors for flaring of oil in connection with well testing**

Compounds (unit)	unit/tonnes flared oil	Source
CO <sub>2</sub> (tonnes) .....	3.2	(Norwegian pollution control authority 1990)
CH <sub>4</sub> (tonnes) .....	0.0004	Same factors as for fuel oil used for boilers in manufacturing
N <sub>2</sub> O (tonnes) .....	0.00003	
NO <sub>x</sub> (tonnes) .....	0.0037	(The Norwegian oil industry association 2009)
NM VOC (tonnes) .....	0.0033	
CO (tonnes) .....	0.018	
TSP (tonnes) .....	0.025	Measurements (OLF <sup>1</sup> )
PM <sub>10</sub> (tonnes) .....	0.0215	Use the same distribution as for combustion of heavy fuel oil in industry (EPA 2002)
PM <sub>2.5</sub> (tonnes) .....	0.014	
PAH (kg) .....	0.012	(The Norwegian oil industry association 1991)
PAH-OSPAR (kg) .....	0.0024	Use the same distribution as for combustion of heavy fuel oil in industry (EPA 1998)
PAH-4 (kg) .....	0.00024	
Dioxins (mg) .....	0.01	Measurements (OLF)

<sup>1</sup>The Norwegian Oil Industry Association (OLF).

#### 3.3.4.5. Uncertainties

The uncertainty in the emission factors for methane (Rypdal and Zhang 2000) and NMVOC (Rypdal and Zhang 2001) from *oil loading* is estimated to be ± 40 per cent and in the activity data ± 3 per cent.

The uncertainty in the amount of gas flared is in regarded as being low, ±1.4 per cent, based on data reported in the emission trading scheme (Climate and Pollution Agency 2011) and assumptions in Rypdal and Zhang (2000). The uncertainty in the CO<sub>2</sub> emission factor for flaring is ±4.5 (Climate and Pollution Agency 2011) and (Rypdal and Zhang 2000).

The uncertainty in CH<sub>4</sub> and NMVOC emissions from venting and, hence, in the indirect emissions of CO<sub>2</sub>, is much higher than for flaring.

The emission factors for both storage and transmission of natural gas are uncertain, since Austrian factors are used in lack of country specific Norwegian factors.

All uncertainty estimates for this source are given in Appendix D.

#### 3.3.4.6. Source-specific QA/QC and verification

Statistics Norway gathers activity data on oil and gas activities from the Norwegian Petroleum Directorate (NPD). These data are reported monthly by the field operators to NPD. The activity data are quality controlled by comparing them with the figures reported in the field operator's annual report to the Norwegian Environment Agency and NPD. The emissions calculated by Statistics Norway for 1990-2002 were compared with the emission data that the field operators reported to the Norwegian Environment Agency and NPD. From 2003, Statistics Norway estimate emissions based on activity data that the field operators monthly report to NPD, and reported emission factors. When discrepancies are found between the



two sets of data these are investigated and corrections are made if appropriate. If errors are found, the Norwegian Environment Agency contacts the plant to discuss the reported data and changes are made if necessary.

The reported emissions from the gas terminals are compared with previous years' emissions.

The Norwegian Environment Agency collects the activity data used for venting and flaring in the calculation from NPD. The figures are quality controlled by comparing them with the figures reported in the field operators' annual report to the Norwegian Environment Agency and NPD, and time series are checked.

The Norwegian Environment Agency perform internal checks of the reported data for venting from the field operators. Some errors in the time-series are usually found and the field operators are contacted and changes are made. The same procedure is followed to check the amount of gas reported as flared. The quality of the activity data is considered to be high, due to the fact that there is a tax on gas flared offshore. NPD has a thorough control of the amount of gas reported as flared.

## 4. Industrial processes

IPCC 2

NFR 2

### 4.1. Overview

This chapter provides descriptions of the methodologies employed to calculate emissions of greenhouse gases and long-range transboundary air pollutants from industrial processes. Only non-combustion emissions are included in this chapter. Emissions from fuel combustion in the manufacturing industries are reported in chapter 3 Energy. Emission figures are either reported by plants to the Norwegian Environment Agency or calculated by Statistics Norway, based on emission factors and activity data. The emission factors are collected from different sources, while the activity data used in calculations carried out by Statistics Norway mainly come from official statistics collected by Statistics Norway.

A specific QA/QC has been carried out for the industrial processes sector in 2006. The QA/QC covered the greenhouse gas emissions from the largest industrial plants to be included in the greenhouse gas inventory. The methodology for the performances of the QA/QC is presented in Appendix I.

### 4.2. Mineral products

IPCC 2A

NFR 2A

Last update: 15.04.2014

The sector category Mineral products in the Norwegian inventory include emissions from fourteen different products (see table 4.1). CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub>, particles, heavy metals and dioxins are components that are emitted during the production of mineral products and included in the inventory. Table 4.1 shows the various components emitted from the different activities, and for which components the emission figures in the national inventory are based on figures reported by the plants (R) and for which the figures are estimated by Statistics Norway (E).

**Table 4.1. Mineral products. Components emitted and included in the Norwegian inventory<sup>1</sup>**

Mineral products	CO <sub>2</sub>	SO <sub>2</sub>	NO <sub>x</sub>	NH <sub>3</sub>	Particles	Heavy metals	Dioxins
-- Cement production .....	R	R	NA	NA	R	R	R
-- Lime production .....	R	NA	NA	NA	R	R	NA
-- Limestone and dolomite use .....	R	NA	NA	NA	R	NA	NA
-- Other use of soda ash .....	E	NA	NA	NA	NA	NA	NA
-- Concrete pumice stone .....	R	R	NA	NA	R	NA	NA
-- Rock wool production .....	NA	NA	R	R	R	R	NA
-- Glass and glass fibre .....	R	NA	R	R	R	R	NA
-- Ore mines .....	NA	R	NA	NA	R	NA	R
-- Mining and extraction of stones and minerals .....	NA	NA	NA	NA	R	NA	NA
-- Production of mineral white .....	NA	NA	NA	NA	R	R	NA
-- Construction /repairing of vessels - Sandblasting .....	NA	NA	NA	NA	R	NA	NA
-- Sandpit and rock-chrushing plants .....	NA	NA	NA	NA	E	NA	NA
-- Construction and building .....	NA	NA	NA	NA	E	NA	NA
-- Leather preparing .....	NA	NA	NA	R	NA	NA	NA

<sup>1</sup> R means that emission figures in the national emission inventory are based on figures reported by the plants. E means that the figures are estimated by Statistics Norway (Activity data \* emission factor). NA = Not Applicable.

### 4.2.1. Cement production

*IPCC 2A1 Key category for CO<sub>2</sub>*

*NFR 2A1*

*Last update: 17.06.2009*

#### 4.2.1.1. Description

Two plants in Norway produce cement. Production of cement gives rise to both non-combustion and combustion emissions of SO<sub>2</sub> and CO<sub>2</sub>. The emission from combustion is reported in chapter 3 Energy. The non-combustion emissions originate from the raw material calcium carbonate (CaCO<sub>3</sub>). The resulting calcium oxide (CaO) is heated to form clinker and then crushed to form cement. The emissions of SO<sub>2</sub> and CO<sub>2</sub> from non-combustion are reported to The Norwegian Environment Agency.



SO<sub>2</sub> from cement production is emitted from sulphur in the fuel (reported under Energy) and in the raw materials, especially pyrite in limestone. Only the SO<sub>2</sub> from the raw materials should be counted as non-combustion emissions. Particles as well as heavy metals are emitted during the production process. More than 90 per cent of the emission of mercury is due to mercury in the limestone while the emissions of Pb, Cd, Cu, Cr and As originate both from processes and combustion of fuel. Emissions of dioxins are due to the thermal process in the clinker production.

#### 4.2.1.2 Method

*CO<sub>2</sub>*

Emission figures are reported by the two plants to the Norwegian Environment Agency. Figures are reported for all years since 1990. Emissions are estimated by the plants by multiplying the annual clinker production, including the Cement Kiln Dust (CKD), at the plant with plant specific emission factors (Andersen and Karstensen 1998). This is regarded as a Tier 2 method.

*SO<sub>2</sub>*

The plants annually report emissions of SO<sub>2</sub> to the Norwegian Environment Agency. Figures are based on measurements at the plants.

SO<sub>2</sub> emissions from production of cement come from energy carriers like e.g. coal and oil and from limestone. The sulphur from the energy carriers is to a large extent included in the clinker during the process. The emissions are distributed between combustion and non-combustion emissions based on studies conducted by Institute for Energy Technology in 1970 and 1999. Both studies indicate that 80-99 per cent of the sulphur from energy carriers is included in the clinker.

The total SO<sub>2</sub> emissions from the two plants are based on measurements. When the SO<sub>2</sub> emissions reported from the plant are not distributed between combustion and non-combustion emissions, the Norwegian Environment Agency distributes the total emissions, using the same percentage distribution as in the last year with reported distributed SO<sub>2</sub> emissions. The production technology is to some extent different for the two plants. In the last years, the distribution between combustion and non-combustion emissions is about 10/90 for one plant and 18/82 for the other plant. The difference is assumed to be due to the fact that one plant has a "by-pass" system where some of the flue gas is not in contact with the raw materials.

The amount of energy carriers used in cement production is subtracted from the energy balance to avoid double counting, see section 3.2.1.2.

*Particles*

Emissions have been reported to the Norwegian Environment Agency since 1991 for one plant and since 1992 for the other. It is believed that the reported figures also include emissions from combustion. Therefore emissions from combustion of

coal, coke and waste oil used in cement production are not calculated, to avoid double counting. The plants have installed particle filter.

Particle size distribution for emitted particles from cement production is found in TNO (Institute of environmental and energy technology 2002). In the Norwegian emission inventory, PM<sub>10</sub> and PM<sub>2.5</sub> are assumed to be 85 and 30 per cent of TSP, respectively.

#### *Heavy metals and POPs*

Emission figures for heavy metals are reported to the Norwegian Environment Agency. It is believed that these figures also include emissions from combustion. Therefore emissions from combustion of coal, coke and waste oil used in cement production are not calculated, to avoid double counting.

Dioxin figures are reported to the Norwegian Environment Agency. It is also here assumed that the reported figures include emissions from fuel combustion, therefore emissions from combustion are not calculated.

#### **4.2.1.3. Uncertainties**

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

Reported emission figures for particles have varied a great deal as a result of changes the plants have undergone to reduce emissions. There are also uncertain measurements due to annual variations.

Regarding the heavy metals, it has varied when the two plants started reporting the various components, and therefore estimations have been necessary for the years when reporting have been insufficient. The reported figures also vary from a year to another due to process technical conditions, variations in the metal content in the limestone used and uncertain measurements.

#### **4.2.1.4. Completeness**

Major missing emission components are not likely.

#### **4.2.1.5. Source specific QA/QC**

Statistics Norway occasionally calculate alternative emission figures for CO<sub>2</sub> and compare with the emission figures reported by the plants to the Norwegian Environment Agency to check if they are reasonable. The calculations are based on the clinker production (reported annually from the plants to Statistics Norway). The emission factors used are recommended by SINTEF (Andersen and Karstensen 1998) and are based on the actual composition of the raw materials used. These emission factors are calculated particularly for the two Norwegian factories and are 0.520 and 0.541 tonne CO<sub>2</sub> per tonne clinker, respectively. The IPCC default emission factor is 0.5071 tonne CO<sub>2</sub>/tonne clinker.

The calculated emission figures agree quite well with emissions figures reported by the plants.

The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

## **4.2.2. Lime production**

*IPCC 2A2 Key category for CO<sub>2</sub>*

*NFR 2A2*

*Last update: 05.06.2012*

#### **4.2.2.1. Description**

Three lime producing plants in Norway report process emissions of CO<sub>2</sub> to the Norwegian Environment Agency. One of the plants also reports emissions of particulate matter.

#### **4.2.2.2. Method**

##### *CO<sub>2</sub>*

All three plants calculate the emissions of CO<sub>2</sub> based on actual production volumes of lime and plant specific emission factors for CO<sub>2</sub> from limestone and dolomite respectively. The emissions are reported to the Norwegian Environment Agency. For one of the plants, emissions from 2002-2004 have been estimated by the Norwegian Environment Agency, based on activity data and plant specific emission factors. For the same plant, emissions for the years 1991-1997 have been interpolated by the Norwegian Environment Agency.

##### *Particles*

For one plant, emission figures for particulate matter have been reported to the Norwegian Environment Agency since 1990. Emission figures from 1990 to 1995 are based on calculations, using emission factors and production volume. Since 1996, the figures are a result of measurements at the plant. The plant has installed particle filter.

In the inventory, a particle size distribution suggested by TNO (Institute of environmental and energy technology 2002) is used. PM<sub>10</sub> is 0.4\*TSP while PM<sub>2.5</sub> is 0.08\*TSP.

#### **4.2.2.3. Activity data**

The activity data is the input of limestone and dolomite; these amounts are annually reported by the plants to the Norwegian Environment Agency. For two of the plants, the input of limestone is determined by adding up the production volumes of lime (weighed on a scale for trucks). Analysis of the contents of CaO in lime is then used to calculate the input of limestone. For the third plant, the amounts of limestone and dolomite going into the production process are weighed in batches. The weights of these batches are then added to get an annual figure. The lime production in Norway consists of quicklime and dolomitic lime. In 2010, all lime production was quicklime.

#### **4.2.2.4. Emission factors**

The plants use emission factors in the range of 0.4254 to 0.437 tonnes CO<sub>2</sub> per tonne limestone and 0.474 tonnes CO<sub>2</sub> per tonne dolime produced.

#### **4.2.2.5. Uncertainties**

Uncertainty estimate for the emission of CO<sub>2</sub> is given in Appendix D.

The particle distribution used is not specified for the plants, and the particles emitted might therefore have another distribution than the one suggested from TNO (Institute of environmental and energy technology 2002).

#### **4.2.2.6. Completeness**

Major missing emission components are not likely.

#### **4.2.2.7. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

### **4.2.3. Limestone and Dolomite Use**

*IPCC 2A3*

*NFR 2A3*

*Last update: 15.05.2013*

#### **4.2.3.1. Description**

Three plants report emissions from limestone and dolomite use to the Norwegian Environment Agency. One plant neutralizes sulphuric acid waste with limestone and fly ash. During the neutralization process CO<sub>2</sub> is produced. The use of fly ash decreases the CO<sub>2</sub> emissions compared with when limestone is used. The second plant is a brick producer and uses limestone in its production. The third plant produces calcium oxide and magnesium oxide from limestone and dolomite. One of the plants also reports emissions of particulate matter.

#### **4.2.3.2. Method**

*CO<sub>2</sub>*

The plants report emission figures for CO<sub>2</sub> to the Norwegian Environment Agency. The emissions are calculated by multiplying the amount of sulphuric acid and limestone with emission factors.

*Particles*

Emissions have been reported to the Norwegian Environment Agency since 2000. Reported figures for 2000 have been used for all years 1990-1999.

Statistics Norway has decided to use the same particle size distribution for production of cement as given in TNO (Institute of environmental and energy technology 2002). PM<sub>10</sub> and PM<sub>2.5</sub> are assumed to be 85 and 30 per cent of TSP, respectively.

#### **4.2.3.3. Activity data**

The amount of limestone and dolomite used by the plants in their calculation is annually reported to the Norwegian Environment Agency.

#### **4.2.3.4. Emission factors**

The emission factor for the plant that neutralizes sulphuric acid waste has been calculated by the Norwegian Environment Agency based on reported emissions and amounts of acid neutralized. The emission factor 0.44 tonnes CO<sub>2</sub> per tonne limestone used by the brick producing plant is the standard factor used in the EU Emission Trading System (EU ETS) for limestone. The plant producing calcium oxide and magnesium oxide has used the emission factor equal to the standard factor used in the EU ETS for limestone before it entered the EU ETS and uses plant specific emission factors after it has entered the EU ETS. The plant does not use limestone every year, but the factors for 2006, 2009 and 2010 are 0.41, 0.44 and 0.4504. The emission factor for dolomite used by the plant producing calcium oxide and magnesium oxide is equal to the standard factor used in the EU ETS (0.44) before it entered the EU ETS and plant specific factors after it has entered the EU ETS. The plant does not use dolomite every year, but the emission factors for 2005-2007 are 0.45, 0.46 in 2008 and 0.477 in 2009.

#### **4.2.3.5. Uncertainties**

Uncertainty estimates are given in Appendix D.

The particle distribution used is not specified for the plants, and the particles emitted might therefore have another distribution than the one suggested by TNO (Institute of environmental and energy technology 2002).

#### **4.2.3.6. Completeness**

Major missing emission components are not likely.

#### **4.2.3.7. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

#### **4.2.4. Other use of soda ash**

*IPCC 2A4b*

*NFR -*

*Last update: 15.05.2013*

##### **4.2.4.1. Description**

Glass wool and nickel production plant report emissions due to soda ash use. In addition, some soda ash is used in chemical industry where consumption is assumed to be non-emissive. However, the net import of soda ash is higher than the sum of the amounts consumed in these industries. Therefore, CO<sub>2</sub> emissions from other use of soda ash are estimated.

There are no data on soda ash in Norway in production statistics (PRODCOM) from Statistics Norway.

##### **4.2.4.2. Method**

*CO<sub>2</sub>*

Emission figures for CO<sub>2</sub> are estimated using the emission factor for soda ash use in Table 2.1 in the IPCC Guidelines 2006: 0.41492 tonnes CO<sub>2</sub>/tonne soda ash. The activity data is net import in tonnes, minus consumption in glass wool and nickel production and chemical industry.

It is assumed that use in chemical industry is non-emissive. This assumption is based on table 2.7 in IPCC Guidelines 2006, "Emissive and non-emissive uses of carbonates".

##### **4.2.4.3. Uncertainties**

As sufficient information to determine where the rest of the imported soda ash has been consumed not has been obtained, there is some uncertainty as to whether all soda ash consumption in fact is emissive.

There is also some uncertainty associated with the foreign trade statistics, as well as with the assumption that the CO<sub>2</sub> is emitted the same year as the soda ash is imported.

According to the IPCC Guidelines 2006, there is negligible uncertainty associated with the emission factor, given that the correct emission factor is applied.

##### **4.2.4.4. Completeness**

It is believed that all figures from all major importers are included in the inventory. Double counting is avoided by subtracting the amounts used in glass wool and nickel production. The Norwegian Environment Agency has so far not found any other point sources that report emissions of CO<sub>2</sub> from soda ash use.

##### **4.2.4.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. However, when the calculation first was included in the inventory, a comparison was made between figures on net import of soda ash in foreign trade statistics and in the Norwegian Product Register. Import figures from the Product Register for the period 2000-2011 never constituted more than 41 per cent of the amounts imported according to the foreign trade statistics. Thus, it was assumed that the net import in the foreign trade statistics is a good proxy for the total quantity of soda ash used in Norway.

See section 1.5 for the description of the general QA/QC procedure.

#### **4.2.5. Concrete pumice stone**

*IPCC 2A7*

*NFR 2A7iii*

*Last update: 15.04.2014*

##### **4.2.5.1. Description**

Two factories produced concrete pumice stone until 2004 when one of them was closed down. The plants report emissions of CO<sub>2</sub>, SO<sub>2</sub> and particles to the Norwegian Environment Agency. Non-combustion emissions of SO<sub>2</sub> originate from the clay used in the production process.

##### **4.2.5.2. Method**

*CO<sub>2</sub>*

Emission figures for CO<sub>2</sub> are reported to the Norwegian Environment Agency, based on the use of dolomite. The emission factor used is 0.48 tonnes CO<sub>2</sub>/tonne dolomite.

*SO<sub>2</sub>*

Emission figures for SO<sub>2</sub> are reported to the Norwegian Environment Agency, based on measurements at the two manufacturing plants in Norway. The plants have installed flue gas desulphurisation equipment.

*Particles*

The plants have reported emissions of particles to the Norwegian Environment Agency since 1990. It is assumed that the reported figures include both process and combustion emissions, so emission calculations from fuel combustion are not done for these two plants. The plants have installed particle filters.

No information concerning particle size is found in national or international literature, but the Norwegian Environment Agency assumes that most of the particles emitted from these plants are smaller than PM<sub>10</sub>. Statistics Norway has decided to use the same particle size distribution for production of cement as given in TNO (Institute of environmental and energy technology 2002). PM<sub>10</sub> is therefore assumed to be 0.85\*TSP and PM<sub>2.5</sub> is 0.3\*TSP.

##### **4.2.5.3. Uncertainties**

The particle size distribution used is not specific for production of concrete pumice stone, but used due to lack of specific size distribution data for this source. The particle size distribution can therefore only be seen as an estimate.

##### **4.2.5.4. Completeness**

Particles often contain heavy metals, but type of metals and volumes will depend on the origin of the particles. Metals might therefore be emitted during production of concrete pumice stone. Statistics Norway and the Norwegian Environment Agency have, however, no data available for calculating emissions of heavy metals from this source.

##### **4.2.5.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

#### **4.2.6. Rock wool production**

*IPCC -*

*NFR 2A7iii*

*Last update: 08.06.2012*

##### **4.2.6.1. Description**

Three plants in Norway produced rock wool until 2003 when one of them was closed down. In the inventory, emission figures for NO<sub>x</sub>, NH<sub>3</sub>, particles and heavy



metals are included. NO<sub>x</sub> is emitted from a hardening process after the rock wool is melted. Particles originate from the cutting of the mineral wool and from fuel used in the production. The emissions of heavy metals are partly due to use of coal/coke, but mainly due to the stone used in the production. Emissions of dioxins and PAHs are neither reported nor calculated since emissions of these components are minor or not occurring.

#### 4.2.6.2. Method

##### NO<sub>x</sub>

Emission figures are reported to the Norwegian Environment Agency.

##### NH<sub>3</sub>

Emission figures are reported to the Norwegian Environment Agency. Figures exist from 1992. It is assumed in the inventory that emission figures for 1990 and 1991 are the same as the reported figure in 1992.

##### Particles

Emission figures are reported to the Norwegian Environment Agency. Most of the emissions come from the spin chamber, and the particle size is assumed to be less than 1 µm. Particles emitted from the fabric filter are also assumed to be smaller than 1 µm. All emissions are therefore set to be smaller than PM<sub>2.5</sub>. All assumptions are made by the Norwegian Environment Agency in accordance with the industry. It is assumed that the reported figures include both non-combustion and combustion emissions. Combustion emissions of particles are therefore not calculated.

##### Heavy metals and POPs

Emission figures for Pb, Cd, As and Cr have been reported annually from one of the plants to the Norwegian Environment Agency since 1999. The figures are based on measurements. It is assumed that the reported figures include combustion emissions, and emission calculations from fuel combustion are not done for these heavy metals. Statistics Norway has calculated the emission figures for missing years (1990-1998) based on reported figures in 1999 and production rates for previous years. For the two plants not reporting, Statistics Norway calculates emissions based on derived emission factors from the one plant that reports and production volumes at each plant.

#### 4.2.6.3. Activity data

Production volumes of rock wool are annually reported from the plants to the Norwegian Environment Agency.

#### 4.2.6.4. Emission factors

##### Heavy metals

A default emission factor is derived for each component (Pb, Cd, As and Cr) based on the annually reported emission figures and production rates from the one plant reporting. The derived emission factors are used to calculate emissions from the two other plants (one of these were closed down in 2003) (table 4.2).

**Table 4.2. Emission factors for Pb, Cd, As and Cr from production of rock wool. g/tonne produced rock wool**

Component	Emission factors (g/tonne produced rock wool)
Lead (Pb) .....	0.164
Cadmium (Cd) .....	0.001
Arsenic (As) .....	0.031
Chromium (Cr) .....	0.703

Source: The Norwegian Environment Agency and calculations at Statistics Norway.

**4.2.6.5 Uncertainties***Activity data*

The activity data is assumed to be of good quality since this is production rates reported from each plant to the Norwegian Environment Agency.

*Emission factors*

Several conditions influence the emission of heavy metals, such as production rates and raw materials, and these factors can vary from one plant to another. To derive emission factors based on one plant's reported emission figures and production volume and use these factors to estimate emissions at other plants is therefore quite uncertain.

**4.2.6.6. Completeness**

Major missing emission components are not likely.

**4.2.6.7. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.2.7. Glass and glassfibre production**

*IPCC 2A73*

*NFR 2A7iii*

*Last update: 08.05.2013*

**4.2.7.1. Description**

Five plants producing glass or glass fibre are included in the emission inventory, based on emission reports to the Norwegian Environment Agency. A sixth plant also reports emissions of particles to the Norwegian Environment Agency but these emissions are very small and are therefore not included in the inventory. PAH and dioxin emissions are neither calculated nor measured although glass production might be a dioxin source (see completeness section 4.2.6.4).

**4.2.7.2. Method***CO<sub>2</sub>*

Two plants producing glass wool and one plant producing glass fibre report emission figures on CO<sub>2</sub> to the Norwegian Environment Agency. The two glass wool production plants report emissions from the use of soda, limestone and dolomite, while the glass fibre producer reports emissions from the use of limestone and dolomite.

*NO<sub>x</sub>*

The two glass fibre producing plants annually report emission figures for NO<sub>x</sub> to the Norwegian Environment Agency. The emission figures are based on calculations.

*NH<sub>3</sub>*

The two glass fibre producing plants annually report emission figures for NH<sub>3</sub> to the Norwegian Environment Agency. The emission figures are based on measurements.

*Particles*

The two plants producing glass fibre have reported emission figures since 1990 to the Norwegian Environment Agency. The one glass-producer with particle emissions has reported since 1995. Emission figures from 1990 to 1994 were therefore assumed to be the same as reported figures in 1995. This plant was however closed down in 1999.

TNO (Institute of environmental and energy technology 2002) suggests using a particle size distribution of the emissions where PM<sub>2.5</sub> is 80 per cent of TSP and

PM<sub>10</sub> is 90 per cent of TSP, and this size distribution is used in the Norwegian inventory.

#### *Heavy metals and POPs*

Emission of lead has been reported from two glass-producers to the Norwegian Environment Agency. One of them was closed down in 1999. The emission of lead is due to the lead content in the raw material used. Emission of arsenic was reported in the early nineties when one of the plants used raw materials containing arsenic. No arsenic emissions were reported in the period 1993-2004. In 2005, a minor figure was reported, which also has been used for the following years. Emissions of other heavy metals are not reported, so we assume there are not significant emissions.

#### **4.2.7.3. Uncertainties**

For the years where reported emission figures for particles do not exist, Statistics Norway has assumed that emissions are in the same order of magnitude as for the first year of reporting. This is uncertain and only an estimate, since it does not consider annual changes in raw materials, production rates, nor possible cleaning devices.

#### **4.2.7.4. Completeness**

Production of glass can be a source for dioxin emissions, but no reported figures are available. Emission factors are found in literature, but since activity data (production rate) is not available and it is assumed that the emission factor is dependent on type of glass produced, emissions are not calculated.

Emissions of particles are also reported from three other glass-producers in Norway, but since annual emissions are low (less than 1 tonne), they are not included in the inventory.

#### **4.2.7.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### **4.2.8. Ore mines**

*IPCC -*

*NFR 2A7i*

*Last update: 27.05.2010*

#### **4.2.8.1. Description**

Three ore mines are included in the Norwegian Inventory, but one of the mines was closed down in 1996. Emission figures of SO<sub>2</sub>, particles and dioxins are included. The treatment of ore generates emissions of SO<sub>2</sub>, and particles are also emitted. Dioxin emissions are due to the thermal process during the pellet production. The ore mine which closed down in 1996, had large dioxin emissions due to the thermal process during the pellet production.

#### **4.2.8.2. Method**

*SO<sub>2</sub>*

The ore mine which was closed down in 1996, reported emission figures for SO<sub>2</sub> to the Norwegian Environment Agency. None of the two other ore mines report any non-combustion SO<sub>2</sub> emissions.

*Particles*

All the three ore mines report emission figures for particles to the Norwegian Environment Agency. Emissions for the two existing ore mines are reported from respectively 1994 and 1996 and it is assumed by Statistics Norway, in accordance with the Norwegian Environment Agency, that emissions for previous years have been in the same order of size.

The size distribution used in the Norwegian inventory is according to TNO (Institute of environmental and energy technology 2002) (table 4.3).

**Table 4.3. Particle size distribution for particles emitted from ore mining. Ratio X<sup>1</sup>/TSP**

Component	Particle size distribution (ratio)
TSP .....	1
PM <sub>10</sub> .....	0.49
PM <sub>2.5</sub> .....	0.07

<sup>1</sup> X is either PM<sub>2.5</sub>, PM<sub>10</sub> or TSP.

Source: TNO (Institute of environmental and energy technology 2002).

#### *Dioxins*

Emissions of dioxins are registered only for the ore mine which was closed down in 1996. Emission figures were first reported to the Norwegian Environment Agency in 1994 and emissions for previous years have been assumed by Statistics Norway, in accordance with the Norwegian Environment Agency, to be in the same order of size as the reported figure in 1994.

#### **4.2.8.3. Uncertainties**

For years where reported emission figures do not exist for particles and dioxins, Statistics Norway has assumed, in accordance with the Norwegian Environment Agency, that the emissions are in the same order of size as for the first year of reporting. This is uncertain and a result of lack of better data. The size of the particles emitted from ore mining will also depend on the type of ore and production process. The particle size distribution used in the inventory does not consider these differences.

#### **4.2.8.4. Completeness**

SO<sub>2</sub> emissions are only included in the inventory for the ore mine that was closed down in 1996. The SO<sub>2</sub> emissions from the two other ore mines are not included in the inventory.

#### **4.2.8.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### **4.2.9. Mining and extraction of stones and minerals**

*IPCC -*

*NFR 2A7i*

*Last update: 01.09.2005*

#### **4.2.9.1. Description**

Mining and extraction of stones and minerals are done by several plants. Particles are emitted during these processes.

#### **4.2.9.2. Method**

*Particles*

Emission figures are reported to the Norwegian Environment Agency. Reported figures exist from 1992. Emission figures for 1990 and 1991 are assumed by Statistics Norway, in accordance with the Norwegian Environment Agency, to be the same as reported figures in 1992. An exception is one plant, which only reported emissions for 1992. For this plant, Statistics Norway has calculated emissions based on production rates for previous and later years.

It is given for most plants that they use fabric filter or textile fibre to clean their particle emissions. It is assumed by the Norwegian Environment Agency that the particles emitted are larger than PM<sub>10</sub>. The Norwegian inventory uses the size distribution recommended by TNO (Institute of environmental and energy technology 2002) for sandpits and rock-crushing plants (table 4.4).

#### **4.2.9.3. Uncertainties**

For years where reported emission figures do not exist, Statistics Norway has assumed that emissions are in the same order of size as for the first year of reporting. This is uncertain and a result of lack of better data. The size of the particles emitted from mining and extraction will also depend on the type of stone/mineral and production process. The particle size distribution used in the inventory does not consider these differences.

#### **4.2.9.4. Completeness**

Emission of particles is often a source of heavy metal emissions since particles often contain heavy metals. Type of metals will however depend on the origin of the particles. Metals might therefore be emitted during mining and extraction of stones and minerals. There are, however, no data available for calculating emissions of heavy metals.

#### **4.2.9.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### **4.2.10. Production of mineral white (plaster)**

*IPCC -*

*NFR 2A7iii*

*Last update: 01.09.2005*

#### **4.2.10.1. Description**

Two plants producing mineral white in Norway are included in the inventory with their emissions of mercury and particles. The mercury content in the raw materials leads to emission of mercury, and during the production process, particles are emitted.

#### **4.2.10.2. Method**

*Particles*

Emission figures are reported to the Norwegian Environment Agency. Reported emission figures exist since 1992 and figures for 1990 and 1991 are assumed by Statistics Norway, in accordance with the Norwegian Environment Agency, to be the same as the figures reported in 1992. The particles are purified through a fabric filter, and it is assumed by the Norwegian Environment Agency that the particles emitted after the filter are smaller than PM<sub>10</sub>.

According to TNO (Institute of environmental and energy technology 2002), PM<sub>2.5</sub> is 30 per cent of TSP, while PM<sub>10</sub> is assumed to be the same as TSP. The Norwegian inventory uses this distribution.

*Heavy metals*

The plants have reported emission figures to the Norwegian Environment Agency since 2000. For one of the plants, historical emissions are based on reported figures for 2000 and production volumes. For the other plant, emission figures for 1990-1999 are assumed to be the same as the reported figure for 2000, due to lack of production data for previous years. Annual emissions are assumed to be low.

#### **4.2.10.3. Activity data**

Production volumes for calculation of historical emissions of mercury for one of the plants are reported to the Norwegian Environment Agency.

#### **4.2.10.4. Emission factors**

Emission factors for mercury are derived from historical calculations for one plant, based on reported figures for the first year of reporting and production volumes.

#### **4.2.10.5. Uncertainties**

Historical emissions of mercury for both plants are uncertain. For one plant, the emission figures are based on a derived emission factor and production volumes and do not take into account changes in raw materials and possible cleaning devices. For the other plant, it is assumed, due to lack of historical production data, that the historical emissions are the same as the reported figures for 2000. This is just an estimate and does not consider annual changes in raw materials, production rates, or possible cleaning devices.

The particle size distribution used in the inventory is not specific for the plants. The particles emitted might therefore have another distribution than the one suggested by TNO, which is used in the inventory.

#### **4.2.10.6. Completeness**

Major missing emission components are not likely.

#### **4.2.10.7. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### **4.2.11. Construction and repairing of vessels - Sandblasting**

*IPCC -*

*NFR 2A7iii*

*Last update: 01.09.2005*

#### **4.2.11.1. Description**

Five plants constructing and repairing vessels are included in the inventory with their particle emissions. One of the plants was closed down in 2000. Emission of particles is due to the different processes during construction and repairing of vessels, but most of the particles are emitted from sandblasting.

#### **4.2.11.2. Method**

*Particles*

Emission figures are reported to the Norwegian Environment Agency.

For four of the five plants, there are no information regarding cleaning device, but it is assumed by the Norwegian Environment Agency that they have fabric filter and/or wet washer. For the last one, particle emissions are purified in cyclones, and the size of the particles emitted is larger than PM<sub>10</sub>.

It is difficult to decide particle size of the particles emitted based on the above information. It is however assumed by the Norwegian Environment Agency that most of the particles are larger than PM<sub>10</sub> and therefore all particles are assumed to be TSP.

#### **4.2.11.3. Uncertainties**

The size of the particles emitted is uncertain and will depend on the cleaning device used at each plant. The different activities during construction and repairing can also result in emission of particles of different sizes.

#### **4.2.11.4. Completeness**

Emission of particles is often a source of heavy metal emissions since particles often contain heavy metals. Type of metals will however depend on the origin of the particles. Metals might therefore be emitted during sandblasting and repairing/construction of vessels. There are however no data available for calculating emissions of heavy metals.

**4.2.11.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.2.12. Sandpit and rock-crushing plant**

IPCC -

NFR 2A7iii

Last update: 01.09.2005

**4.2.12.1. Method**

Particles will be emitted during crushing of rocks and at sandpits. In the inventory, emissions are estimated based on the production of sand and crushed stone from the production statistics at Statistics Norway, and emission factors recommended by Fontelle (*pers. comm.*<sup>7</sup>).

**4.2.12.2. Activity data**

The production of sand and crushed stone is annually given by Statistics Norway's production statistics.

**4.2.12.3. Emission factors**

The emission factors used are based on Fontelle (*pers. comm.*<sup>7</sup>) (table 4.4).

**Table 4.4. Particle emission factors for sandpits and rock-crushing plants. Ratio X<sup>1</sup>/TSP**

Component	g/tonne produced
TSP .....	160
PM <sub>10</sub> .....	60
PM <sub>2.5</sub> .....	0

<sup>1</sup> X is either PM<sub>2.5</sub>, PM<sub>10</sub> or TSP.  
Source: Fontelle (*pers. comm.*<sup>7</sup>).

**4.2.12.4. Uncertainties**

This emission source is highly uncertain since the emissions will vary from one place to another depending on the different processes in use, type of raw materials and of course the activity level. Little information is available in the literature. The emission factors used are only based on one source and are uncertain. In addition, there is uncertainty regarding the activity data. The PRODCOM codes used in the production statistics include total production of sand and crushed stone in Norway, but some of it might not be relevant for these calculations.

**4.2.12.5. Completeness**

Emission of particles is often a source of heavy metal emissions since particles often contain heavy metals. Type of metals will however depend on the origin of the particles. Metals might therefore be emitted during crushing at sandpits and rock-crushing plants. There are however no data available for calculating emission of heavy metals.

**4.2.12.6. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.2.13. Construction and building**

IPCC -

NFR 2A7ii

Last update: 01.09.2005

**4.2.13.1. Description**

Construction and building includes a lot of different activities that will generate particle emissions.

<sup>7</sup> Fontelle, J.P. (2002). Personal information (e-mail correspondence), April 2002, CITEPA.

**4.2.13.2. Method***Particles*

Emission factors and activity data are used to estimate the Norwegian emissions.

**4.2.13.3. Emission factors**

The emission factors used are based on an evaluation the French institute CITEPA made of different emission factors from this source and their calculation of average emission factors for TSP, PM<sub>10</sub> and PM<sub>2.5</sub> (table 4.5).

**Table 4.5. Particle emission factors for building and construction. Tonne/hectare/year**

Component	Tonne/hectare/year
TSP .....	9.79
PM <sub>10</sub> .....	1.52
PM <sub>2.5</sub> .....	0.52

Source: Fontelle (*pers.comm.*<sup>7</sup>).

**4.2.13.4. Activity data**

The activity data used is the annual area of completed buildings from the building statistics at Statistics Norway.

**4.2.13.5. Uncertainties**

The particle emissions depend on climate conditions as well as building traditions and building materials. Since the emission factors used are based on surveys in other countries than Norway, these factors might not be ideal for Norwegian conditions.

**4.2.13.6. Completeness**

Building of roads, railways, tunnels and demolition of buildings is also a source of particle emissions, but no emission factors are found in the literature, and therefore such emissions are not included in the inventory.

**4.2.13.7. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.2.14. Leather preparing***IPCC -**NFR 2A7iii*

*Last update: 01.09.2005*

**4.2.14.1. Method***NH<sub>3</sub>*

NH<sub>3</sub> is used to adjust the pH level in the fattening and colouring process in leather preparing. This means that NH<sub>3</sub> is dissolved in an aqueous solution to feed fatty substances to leather. One plant reports emission figures for NH<sub>3</sub> to the Norwegian Environment Agency. Emission figures are available from 1994. Emissions for the years 1990-1993 are assumed by Statistics Norway and the Norwegian Environment Agency to be the same as the reported figure for 1994. The emission of NH<sub>3</sub> reported by the plant is equal to the consumption of NH<sub>3</sub>.

**4.2.14.2. Uncertainties**

It is not clear if it is correct to assume that all NH<sub>3</sub> consumed is emitted to air. This assumption may have to be revised.

**4.2.14.3. Completeness**

Major missing emission components are not likely.

**4.2.14.4. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.



### 4.3. Chemical Industry

IPCC 2B

NFR 2B

Last update: 16.01.2013

In the Norwegian emission inventory, there are 14 different activities included under chemical industry. Nearly all emission figures from this industry included in the inventory are reported from the plants to the Norwegian Environment Agency. Production of carbides causes emissions of many components, but most of the other activities within the sector chemical industry cause only emissions of one or two components (table 4.6).

**Table 4.6. Chemical industry. Components emitted and included in the Norwegian inventory**

	CO <sub>2</sub>	CO	N <sub>2</sub> O	NO <sub>x</sub>	CH <sub>4</sub>	NM VOC	SO <sub>2</sub>	NH <sub>3</sub>	PM	HM	POP
<b>Production of</b>											
Ammonia .....	R	NA	NA	IE <sup>1</sup>	NA	NA	NA	NA	NA	NA	NA
Nitric acid .....	NA	NA	R	R	NA	NA	NA	R	R	NA	NA
Other fertilisers ..	NA	NA	NA	R	NA	NA	NA	R	NA	NA	NA
Silicon carbide ...	R+E	E	NA	NA	R	R	R	NA	R	R	R
Calcium carbide .	R	NA	NA	R	NA	R	NA	NA	R	R	NA
Methanol .....	R	NA	NA	NA	R	R	NA	NA	NA	NA	NA
Titanium dioxide...	R	NA	NA	NA/R	NA	NA	R	NA	R	R	NA/R
Sulphuric acid ....	NA	NA	NA	NA	NA	NA	R	NA	NA	NA	NA
Plastic .....	R+E	NA	NA	NA	R	R	NA	R	R	NA	R
Explosives .....	NA	NA	NA	R	NA	NA	NA	NA	NA	NA	NA
Chloralkali .....	NA	NA	NA	NA	NA	NA	NA	NA	NA	R	NA
Pigments .....	NA	NA	NA	NA	NA	NA	NA	NA	NA	R	NA
Soap .....	NA	NA	NA	NA	NA	NA	NA	NA	R	NA	NA
Paint/varnish.....	NA	NA	NA	NA	NA	NA	NA	NA	R	NA	NA

E = Figures estimated by Statistics Norway.

R = Figures reported by the plant to the Norwegian Environment Agency.

NA = Not Applicable.

IE = Included Elsewhere.

<sup>1</sup> Included in reported figures for nitric acid and other fertilisers.

#### 4.3.1. Production of fertilisers

##### 4.3.1.1. Ammonia Production

IPCC 2B1, Key category for CO<sub>2</sub>

NFR -

Last update: 29.05.2013

##### 4.3.1.1.1. Description

In Norway, ammonia is produced by catalytic steam reforming of wet fuel gas (containing ethane, propane and some buthan). This is one of the steps during fertiliser production. Hydrogen is needed to produce ammonia, and wet fuel gas is the basis for the production of hydrogen. A substantial amount of CO<sub>2</sub> is recovered from the production process.

##### 4.3.1.1.2. Method

CO<sub>2</sub>

The CO<sub>2</sub> emission figures in the Norwegian emission inventory model are based on annual reports from the only ammonia producing plant. The plant calculates the emissions by multiplying the amount of each gas used with gas specific emission factor. The plant has reported consistent figures back to 1990. A part of the CO<sub>2</sub>, which is generated during the production process, is captured and sold for other use (in soft drinks etc.), and therefore deducted from the emission figures for this source and reported in IPCC sector 2D2, as described in section 4.5.2.3. Some of the captured CO<sub>2</sub> is exported to other countries, but is nevertheless included in the Norwegian emission inventory.

*NO<sub>x</sub>*

During the production of ammonia there are some non-combustion emissions of NO<sub>x</sub>. These emission figures are included in the reported NO<sub>x</sub> emission from nitric acid production and production of other fertilisers.

**4.3.1.1.3. Emission factor***CO<sub>2</sub>*

The emission factors used in the calculations of emissions are based on the composition of the gases consumed. The plant states that the composition is based on daily analyses and that the composition of the gases is stable.

**4.3.1.1.4. Uncertainties**

The amount of gas is measured by using turbine meters and the meters are controlled by the Norwegian Metrology Service. The uncertainty in the measurement of propane and butanes is calculated to ± 0.2 and ethane ± 0.13 per cent. The mix of propane/butanes is as average 60 per cent propane and 40 per cent butanes. The uncertainties in the figures reported by the plant are believed to be limited. Uncertainty estimates are given in Appendix D.

**4.3.1.1.5. Completeness**

Major missing emission components are not likely.

**4.3.1.1.6. Source specific QA/QC**

The plant annually reports the total amount of gas consumed to Statistics Norway. The emission figures reported from the plant are occasionally compared to calculations done by Statistics Norway based on total amount of gas consumed and an emission factor of 3 tonnes CO<sub>2</sub>/tonne LPG, as recommended by IPCC (1997a). The calculated emission figures agree quite well with emission figures reported by the plant. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

**4.3.1.2. Production of nitric acid**

*IPCC 2B2, Key category for N<sub>2</sub>O*

*NFR 2B2*

*Last update: 27.05.2010*

**4.3.1.2.1. Description**

There are two plants in Norway where nitric acid is produced. Nitric acid is used as a raw material in the manufacture of nitrogenous-based fertiliser. The production of nitric acid (HNO<sub>3</sub>) generates nitrous oxide (N<sub>2</sub>O) and NO<sub>x</sub> as by-products of high temperature catalytic oxidation of ammonia (NH<sub>3</sub>). The production of nitrogenous-based fertiliser also leads to emissions of particles.

The two plants have together five production lines. One production line was rebuilt in 1991 and in 2006 two lines were equipped with technology to decompose N<sub>2</sub>O by extension of the reactor chamber. Since then, all production lines have to a certain extent been equipped with this technology.

**4.3.1.2.2. Method**

*NO<sub>2</sub> and NO<sub>x</sub>*

The two plants report the emissions of N<sub>2</sub>O and NO<sub>x</sub> to the Norwegian Environment Agency. The N<sub>2</sub>O emissions have been continuously measured since 1991 at one production line, and from 2000 at another. The emissions at the three other production lines were previously based on monthly and weekly measurements, but from 2008 figures on N<sub>2</sub>O emissions from all production lines are based on continuous measurements.

*NH<sub>3</sub>*

Emission figures for NH<sub>3</sub> are annually reported to the Norwegian Environment Agency.

*Particles*

Both plants report emission figures to the Norwegian Environment Agency and have done so since 1990 and 1992. One of the plants has also reported emissions from combustion, but since it is only 1 per cent of the non-combustion emissions, these figures are included in the figures for non-combustion emissions. For this plant, there is no information regarding cleaning devices and size of the particles emitted, but the Norwegian Environment Agency assumes that the particles are smaller than PM<sub>10</sub>. For the other plant, a fabric filter was installed in the beginning of the 1990s.

In lack of plant specific information regarding particle size distribution of the emitted particles, Statistics Norway uses the distribution given by TNO (Institute of environmental and energy technology 2002) for production of nitrogenous-based fertilisers where PM<sub>10</sub> is 0.8\*TSP and PM<sub>2.5</sub> is 0.6\*TSP.

**4.3.1.2.3. Uncertainties**

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D. The uncertainty in the measurements of N<sub>2</sub>O is estimated to be ±7 per cent based on expert judgement by the industry (Yara 2006) and data reported in the emission trading scheme (Klif 2011). However, in the 2006 report to the Norwegian Environment Agency one plant reported that the uncertainty in measurements of N<sub>2</sub>O was calculated to ±1-3 per cent.

There is uncertainty regarding the size of the particles emitted since there is no plant specific information available. The distribution recommended by TNO is used in lack of other data.

**4.3.1.2.4. Completeness**

Major missing emission components are not likely.

**4.3.1.2.5. Source specific QA/QC**

The plants report the production of HNO<sub>3</sub> to the Norwegian Environment Agency. They compare the trends in the production data with the trend in N<sub>2</sub>O emission and use this as a quality check.

There is no other source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

**4.3.2. Carbide production**

*IPCC 2B4, Key category for CO<sub>2</sub>*

*NFR 2B4*

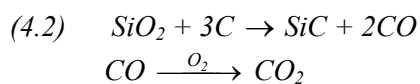
*Last update: 20.05.2009*

**4.3.2.1. Description**

Silicon carbide was produced at three plants until 2006 when one plant was closed down. Previously, calcium carbide was produced at one plant. This plant was closed down in 2003.

**4.3.2.2. Silicon carbide****4.3.2.2.1. Description**

Silicon carbide (SiC) is produced by reduction of quartz (SiO<sub>2</sub>) with petrol coke as a reducing agent.



In the production of silicon carbide, CO<sub>2</sub> and CO are released as by-products from the reaction between quartz and carbon. Sulphur, CH<sub>4</sub>, NMVOCs, particles, heavy metals and PAH may also be emitted during the production process. Sulphur originates from the petrol coke.

#### 4.3.2.2.2. Method

In 2006, Norway changed the method for calculating CO<sub>2</sub> emissions from silicon carbide production from the mass balance method described in the Revised 1996 IPCC Guidelines (using input of reducing agents) to an EF-based method (using crude silicon carbide production as activity data). Both methods are regarded as being Tier 2 methods in IPCC 2006. During the review of the initial report in 2007 the reviewer questioned the change of method, but concluded after consideration that the two methods provide very similar results, except for 1990, and that the use of the present method is justified.

#### CO<sub>2</sub>

Emission figures are reported by the plants to the Norwegian Environment Agency. All the three plants have estimated the CO<sub>2</sub> emissions by multiplying the amount of crude silicon carbide produced with an emission factor. Indirect emissions of CO<sub>2</sub> are calculated by Statistics Norway based on the emission of CH<sub>4</sub>, see chapter 1.9.

#### NM VOC

Emission figures are reported to the Norwegian Environment Agency by the plants. The emissions are calculated by multiplying annual production of silicon carbide by an emission factor. From 2007 and onwards, the emission factor is based on measures made once a year. For previous years, an average of the measured emissions in 2007 and 2008 is applied.

#### CH<sub>4</sub>

Emission figures are reported annually by the plants to the Norwegian Environment Agency. Emissions are calculated by the plants using a country specific emission factor and amount of produced crude silicon carbide.

#### CO

The emissions of CO are calculated by Statistics Norway from the consumption of petrol coke and an emission factor in accordance with the IPCC Guidelines (IPCC 1997a).

#### SO<sub>2</sub>

Emission figures are reported to the Norwegian Environment Agency by the plants. The emissions are calculated from the consumption of petrol coke in dry weight and the sulphur content in the coke. It is assumed that 3 per cent of the sulphur is left in the product or as wastage.

#### Particles

Emission figures for particles are reported to the Norwegian Environment Agency. Two of the plants have reported since 1990 while the third has reported since 1991. Emission figures for 1990 for this plant are assumed by Statistics Norway and the Norwegian Environment Agency to be the same as the reported figure for 1991. For one of the plants, reported figures have not been used in the inventory for 1990-1993, since the plant means these emission figures are not representative, but a result of different measurement and calculation methods. For this plant, reported emission figures for 1994 have been used for 1990-1993.

There is no detailed information about the particle size distribution for the emissions from silicon carbide production. The Norwegian Environment Agency

assumes the emissions have the same particle size distribution as emissions of particles from production of ferroalloys, where all particles are expected to be smaller than PM<sub>2.5</sub>. This is however an uncertain estimate. This leads to a distribution where TSP=PM<sub>10</sub>=PM<sub>2.5</sub>.

#### *Heavy metals*

Emission figures have been reported to the Norwegian Environment Agency since 1999/2000. For Pb, Hg and Cd, historical emissions are based on emission factors derived from reported emission figures and production rates for the first year of reporting. Using these emission factors for each plant together with production rates for previous years, historical emissions have been calculated. Cd is reported from one plant for the years after 1992. The calculations for Pb and Cd have been corrected for dust regulations, while emissions of mercury are not affected by these regulations.

Historical emissions of Cu, Cr and As are based on dust emissions for each plant. This has been recommended by the Norwegian Environment Agency, since historical production rate data lack for some years and because changes in emissions will be easier to find when installation of dust control systems reduces the emissions of these metals. Emissions of As are reported to the Norwegian Environment Agency from one plant. Reported figures exist since 1992, and emissions in 1990 and 1991 are assumed to be the same as reported figures in 1992.

Emission figures for Cu, Cr and Pb are annually reported for all the three plants. In 1999, the plants also reported Hg and Cd due to a heavy metal investigation under the leadership of the Norwegian Environment Agency. After 1999, the plants have not been required to report these metals due to low emissions. Still, one of the plants have reported Cd and Hg figures for all following years, whereas another has reported only Cd; for this plant the 1999 figure for Hg has been used for all later years. For the plant which now has been closed down, the 1999 figures for both Cd and Hg have been used for all later years when the plant still was operating.

#### *POPs*

Emission figures for PAH are reported from the plants to the Norwegian Environment Agency. Two of the plants have reported emissions since 1991, while the third one has only reported since 1997. Historical emissions back to 1990 have been calculated based on production rates and an emission factor derived from the first year of reporting and production rate for that year. No PAH profile is available for this source, so lacking of other information, the same profile as for aluminium production is used (table 4.7). No emissions of dioxins are reported or calculated.

**Table 4.7. Distribution of PAH emissions from silicon carbide production. Ratio X<sup>1</sup>/PAH**

Component	Distribution of PAH emissions (ratio)
PAH (Norwegian standard) .....	1
PAH-6 (OSPAR) .....	0.3
PAH-4 (CLRTAP) .....	0.15

<sup>1</sup> X is either PAH, PAH-6 or PAH-4.

Source: Finstad *et al.* (2001).

#### **4.3.2.2.3. Activity data**

The activity data used by the plants for the calculation of CO<sub>2</sub> and CH<sub>4</sub> emissions are the amount of silicon carbide produced. The activity data used by the plants for the calculation of SO<sub>2</sub> emissions is the consumption of petrol coke in dry weight. The activity data used by Statistics Norway for the calculation of CO emissions is the consumption of petrol coke reported to Statistics Norway. Historical calculations of particle emissions are based on annual production rates and dust emission figures reported to the Norwegian Environment Agency.

#### 4.3.2.2.4. Emission factors

##### *CO<sub>2</sub>*

All three plants have used the emission factor 2.62 tonne CO<sub>2</sub> per tonne produced crude silicon carbide (IPCC 2006).

##### *CH<sub>4</sub>*

For calculation of methane emissions, the country specific emission factor 4.2 kg CH<sub>4</sub>/tonne crude SiC is used. The factor used is based on measurements in the plants.

##### *CO*

CO emissions are calculated from the consumption of petrol coke, using a factor of 0.4 tonnes CO/tonnes petrol coke, as recommended by Rosland (1987).

##### *NM VOC*

From 2007 and onwards the emission factor is based on measurements made once a year. The emission factors for 2007 are 10.906 tonne NMVOC/kilotonne SiC for one of the plants in operation and 10.84 tonne NMVOC/kilotonne SiC for the other. For previous years, the emission factor for the latter plant has been more or less constant whereas the emission factor for the first plant varies.

#### 4.3.2.2.5. Uncertainties

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

##### *Heavy metals*

The historical calculations for heavy metals are based on derived emission factors for each plant and either production or dust data for previous years, and can only be seen as estimates. The emission figures reported also vary from one year to another, and this is assumed to be, in addition to differences in raw materials, a result of few and uncertain measurements. For the one plant that has not reported emission figures for Hg and Cd since 1999, the same emission figures as those reported in 1999 are used for later years. For the other plant, emissions of Cd have been reported for all years since 1992. Emission figures for Hg have not been reported since 1999. The emission figure for 1999 is used for later years. This is also highly uncertain, but the emission figures are very small and have only marginal impact on the total emissions of these metals.

##### *Particles*

The particle size distribution used is not specific for production of silicon carbide, but used due to lack of specific size distribution data for this source. The particle size distribution can therefore only be seen as an estimate. For the years where reported emission figures do not exist, Statistics Norway has assumed that emissions are in the same order as the first year of reporting. This is uncertain and a result of lack of better data.

#### 4.3.2.2.6. Completeness

Major missing emission components are not likely.

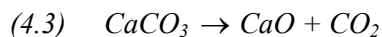
#### 4.3.2.2.7. Source specific QA/QC

The quality of the reported figures of CO<sub>2</sub> is from time to time controlled by Statistics Norway and the Norwegian Environment Agency. Statistics Norway calculates the emissions from the consumption of petrol coke reported by the plant to Statistics Norway and the emission factor of 2.51 tonnes CO<sub>2</sub>/tonne petrol coke (Raanes and Olsen 1998). The comparison shows accordance between the reported data and Statistics Norway's estimates. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

### 4.3.2.3. *Production of calcium carbide*

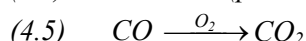
#### 4.3.2.3.1. **Description**

One plant in Norway was producing calcium carbide until 2003. The production of calcium carbide generates CO<sub>2</sub> emissions when limestone is heated and when petrol coke is used as a reducing agent. The process can be described through the following equations:



which takes place when limestone (calcium carbonate) is heated.

and



where petrol coke is used as a reducing agent to reduce the CaO to calcium carbide. Some of the carbon from petrol coke will be sequestered in the product, but not permanently. Thus, this carbon is included in the emission estimate. NMVOC originates from the use of petrol coke in the production process, and NO<sub>x</sub> is mainly produced during the high temperature oxidation of nitrogen in the air. Particles are also emitted during the production process. Emission of heavy metals is a result of the heavy metal content in the raw materials.

#### 4.3.2.3.2. **Method**

##### *CO<sub>2</sub>*

The figures in the National emission inventory are based on emission figures reported from the plant to the Norwegian Environment Agency. The emission estimates are based on the amount of calcium carbide produced each year and an emission factor estimated by Raaness and Olsen (1998). Some of the carbon from petrol coke will be sequestered in the product, but not permanently. Thus, this carbon is included in the emission estimate.

##### *NO<sub>x</sub>*

Emission figures for NO<sub>x</sub> were annually reported to the Norwegian Environment Agency. The reported values are based on calculations.

##### *NMVOC*

Reported figures were annually reported to the Norwegian Environment Agency, based on calculations.

##### *Particles*

Emission figures for particles were reported from 1992. Figures for 1990 and 1991 are assumed to be the same as for 1992. It does not exist any detailed information about the particle size distribution of the emissions from calcium carbide production. The Norwegian Environment Agency assumes that the emissions are in the same order as emission of particles from production of ferroalloys, where all particles are expected to be smaller than PM<sub>2.5</sub>. This is however an uncertain estimate. A particle size distribution where PM<sub>10</sub> and PM<sub>2.5</sub> is expected to be the same as TSP, is used in the Norwegian Inventory.

##### *Heavy metals and POPs*

Emission figures for heavy metals were reported to the Norwegian Environment Agency from 1999. Historical emissions are calculated based on production rates for Pb, Cd and Hg, and based on particle emissions for As, Cu and Cr (see section 4.3.2.3.3).

No emission figures for PAH or dioxins are available.

#### 4.3.2.3.3. Activity data

Particle emissions used in the calculations of As, Cu and Cr have been reported to the Norwegian Environment Agency.

#### 4.3.2.3.4. Emission factors

The emission factor used by the plants in the calculation of CO<sub>2</sub> varies from year to year in the range from 1.48-1.59 tonne CO<sub>2</sub>/ tonne calcium carbide (SINTEF and Det Norske Veritas 2004). The default IPCC factor is 1.8 tonnes/tonne. Raaness and Olsen (1998) concludes that the one reason for the difference between the factors is that the IPCC assumes that all calcium carbonate is calcinated. However, in the production process at the plant they first produced CaC that gives CO<sub>2</sub> emissions. Some of the CaC was then refined to DICY in a process that consumed CO<sub>2</sub>. This CO<sub>2</sub> gas was collected from one of the first steps of the CaC production. The net consumption of CO<sub>2</sub> in production of DICY is according to SINTEF about 1.3 tonne CO<sub>2</sub> per tonne DICY produced. This implies that the specific CO<sub>2</sub> IEF varies between years, corresponding to variations in DICY production.

#### 4.3.2.3.5. Uncertainties

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

#### *Heavy metals*

Historical emissions are based on a derived emission factor for the first year of reporting (1999) and calculated with production/particle emission figures for previous years. This is uncertain and only an estimate in lack of other data.

#### *Particles*

The particle size distribution used is not specific for production of calcium carbide, but used due to lack of specific size distribution data for this source. The particle size distribution can therefore only be seen as an estimate. For the years where reported emission figures do not exist, Statistics Norway has assumed that emissions are in the same order of magnitude as for the first year of reporting. This is uncertain and a result of lack of better data.

#### 4.3.2.3.6. Completeness

Major missing emission components are not likely.

#### 4.3.2.3.7. Source specific QA/QC

For CO<sub>2</sub>, the data reported from the plant has been compared to calculations done by Statistics Norway. The amount of calcium carbide produced has been reported by the plant to Statistics Norway, and was multiplied with the emission factor 1.71 tonnes/ tonne (Raaness and Olsen 1998). The default IPCC factor is 1.8 tonnes/tonne. This amount was subtracted 1.3 tonnes of CO<sub>2</sub> per tonnes DICY produced. The netto emission was then estimated. There is no other source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

### 4.3.3. Manufacture of other inorganic chemicals

*IPCC 2B5, Key category for CO<sub>2</sub>*

*NFR 2B5*

*Last update: 16.05.2013*

#### 4.3.3.1. Production of methanol

##### 4.3.3.1.1. Description

One plant in Norway produces methanol. Natural gas and oxygen are used in the production of methanol. The conversion from the raw materials to methanol is done in various steps and on different locations at the plant. CH<sub>4</sub> and NMVOC are



emitted during the production process. Indirect emissions of CO<sub>2</sub> are calculated by Statistics Norway based on the emission of CH<sub>4</sub> and NMVOC, see chapter 1.9. Emissions from flaring of natural gas in connection with production of methanol are now reported under 2B5, as recommended by IPCC's review team.

#### 4.3.3.1.2. Method

The plant reports emission figures for CH<sub>4</sub>, NMVOC and NO<sub>x</sub>, to the Norwegian Environment Agency. The reported emissions are based on measurements. Emissions from flaring of natural gas are estimated by multiplying the amount of gas flared with the emission factors shown in table 4.8.

**Table 4.8. Emission factors for flare**

Component	Flare natural gas kg/1000 Sm <sup>3</sup>
SO <sub>2</sub>	0
CO <sub>2</sub>	2340
CO	1.5
NO <sub>x</sub>	<sup>1</sup>
Particles	0.0018
NMVOC	0.06
CH <sub>4</sub>	0.24
N <sub>2</sub> O	0.02
	mg/tonne
Pb	0.25
Cd	1.7
Hg	1
Cu	16
Cr	21
As	3.8
Dioxins	0.00005
PAH	15.3
PAH-4	0
PAH-Ospar	0.85

<sup>1</sup>Reported to the Norwegian Environment Agency.

#### 4.3.3.1.3. Uncertainties

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

#### 4.3.3.1.4. Completeness

Major missing emission components are not likely.

#### 4.3.3.1.5. Source specific QA/QC

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

### 4.3.3.2. Production of titanium dioxide

#### 4.3.3.2.1. Description

One plant in Norway produces titanium dioxide. The ore is crushed and pulverized in mills. The crushed raw material is separated in various steps. Ilmenite and the by-product magnetite are cleaned during acid treatment and flotation. The ilmenite concentrate is drained and the water content is reduced to approximately 3.5 per cent. Emissions of SO<sub>2</sub>, heavy metals and particles from the plant are included in the inventory. The particle emissions are a result of the crushing of the ore in the mills and from the annealing furnace, while the heavy metal emissions are due to the metal content in the raw material used.

Another plant produces titanium dioxide slag and also pig iron as a by-product. The raw material is the mineral ilmenite, and coal is used as a reducing agent. SO<sub>2</sub>

originates from the sulphur in the reducing agent used, while  $\text{NO}_x$  is produced primarily by the high temperature oxidation of nitrogen in the air. Heavy metal emissions are due to the metallurgical melting process and the content of heavy metals in the raw materials used. All emissions from this plant are registered under 2B5.

#### **4.3.3.2.2. Method**

##### *CO<sub>2</sub>*

For pig iron, the method used for all years can be defined as a calculation based on carbon balance. This method accounts for all the carbon in the materials entering the process and subtracts the  $\text{CO}_2$  captured in the products.

##### *SO<sub>2</sub>*

The emission figures for  $\text{SO}_2$  are based on calculations and are reported annually to the Norwegian Environment Agency.

##### *NO<sub>x</sub>*

The emission figures for  $\text{NO}_x$  for the plant producing titanium dioxide slag are estimated and reported to the Norwegian Environment Agency.

##### *Particles*

Since 1990, emissions of particles have been reported annually to the Norwegian Environment Agency. The particles are assumed to be of a size less than  $\text{PM}_{2.5}$ .

##### *Heavy metals and POPs*

Both plants report emission figures to the Norwegian Environment Agency. One plant reports emission figures for Pb, Cd and Hg for the period 1990 to 1999. After 1999, there has not been any reporting, as a result of very small emission figures. No emissions of persistent organic pollutants are reported or calculated.

The other plant reports emission figures for Pb, Cd, Cr, Cu, As and Hg. Emissions exist from 1990, 1992 or later, depending on type of heavy metal. For dioxins and PAH, reported figures have only been available from 1999. In lack of production rate data for previous years, it has been assumed that yearly emissions are the same as in the first year of reporting

#### **4.3.3.2.3. Uncertainties**

##### *Heavy metals and POPs*

Reported emission figures vary from one year to another, partly due to differences in raw materials, but mainly as a result of uncertain measurements. The reported figures are based on a limited number of measurements, and the emissions will vary from minute to minute, since the production of pig iron is a non-continuous process. For the years where reported emission figures do not exist, Statistics Norway has assumed that emissions are in the same order as the first year of reporting. This is uncertain and a result of lack of better data.

##### *Particles*

The particle size distribution used is only an assumption, and we can not preclude that the distribution is different from the one used in the inventory.

#### **4.3.3.2.4. Completeness**

Major missing emission components are not likely.

#### **4.3.3.2.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

#### **4.3.3.3. Production of sulphuric acid**

##### **4.3.3.3.1. Description**

Three plants in Norway produced sulphuric acid until March 2006 when one of them was closed down. The production of sulphuric acid leads to emissions of SO<sub>2</sub>. All the three plants report the emissions from the production to the Norwegian Environment Agency, but only one plant have specified that the emissions come from the production of sulphuric acid. For the two other plants, the emissions have been included in the reported emissions from the plants' main production (production of nickel and zinc, respectively).

##### **4.3.3.3.2. Method**

The plant reports annually emission figures for SO<sub>2</sub> to the Norwegian Environment Agency. The reported figures are based on measurements.

##### **4.3.3.3.3. Uncertainties**

No source specific uncertainty is known.

##### **4.3.3.3.4. Completeness**

Major missing emission components are not likely.

##### **4.3.3.3.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

#### **4.3.3.4. Production of plastic**

##### **4.3.3.4.1. Description**

Three plants report emissions to the Norwegian Environment Agency under this source category. One of the plants produces ethylene, one propylene and polyethylene and the third plant has vinyl chloride production. Two of the reporting plants were merged up to 2001.

Various components are emitted during the production of plastic. CH<sub>4</sub> and NMVOC emissions are from leakages in the process. Direct CO<sub>2</sub> emissions are from combustion and are reported in chapter 3 Energy.

During the production process of ethylene and vinyl chloride there is an oxide chloride step for production of ethylene chloride, followed by cracking to vinyl chloride monomer and hydrochloric acid. Various chloride components are produced during these processes, including dioxins. However, most of the dioxins end up in the EDC-tar, which is combusted in an own chloride recycling installation. Particles (PVC-dust) are also emitted during the production of vinyl chloride.

Emissions from flaring of fuel gas in connection with production of plastic are now reported under 2B5.

##### **4.3.3.4.2. Method**

###### *CO<sub>2</sub>*

One plant reports CO<sub>2</sub> emissions from recycling of hazardous waste to hydrochloric acid. In addition, indirect emissions of CO<sub>2</sub> are calculated based on the emissions of CH<sub>4</sub> and NMVOC, see chapter 1.9.

###### *CH<sub>4</sub>, NH<sub>3</sub> and NMVOC*

Emission figures are annually reported to the Norwegian Environment Agency. Reported CH<sub>4</sub> and NMVOC emissions are based on measurements. The emissions of NH<sub>3</sub> are regarded as equal to use. As some of the ammonia is stored in the product, the emissions are probably somewhat overestimated.

*Particles*

Emission figures have been reported to the Norwegian Environment Agency since 1992. Emission figures for 1991 and 1990 are assumed to be the same as reported figures in 1992. The particle emissions have decreased since 1996 as a result of installation of cleaning devices. The emissions are purified in cyclones, but there is no available information regarding particle size. In lack of plant specific information, the distribution  $TSP=PM_{10}=PM_{2.5}$ , as in TNO (Institute of environmental and energy technology 2002), is used in the calculation.

*Dioxins*

The plant producing vinyl chloride reports dioxin emission figures. Figures are reported since 1990 except for 1992 and 1994. Emission figures for 1992 and 1994 are based on the reported data for 1991 and 1993.

**4.3.3.4.3. Uncertainties**

Uncertainty estimates for greenhouse gases are given in Appendix D. It is difficult to measure leakages of  $CH_4$  and NMVOC and therefore the uncertainty is regarded as being high.

The particle size distribution used is not specific for the plants, and the particles emitted might therefore have another distribution than the one suggested by TNO.

**4.3.3.4.4. Completeness**

Major missing emission components are not likely.

**4.3.3.4.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

**4.3.3.5. Production of explosives****4.3.3.5.1. Description**

There has been one plant in Norway producing explosives, but the plant was closed down in 2001. Nitric acid was used as a raw material in the manufacture of explosives, and during the production of nitric acid,  $NO_x$  was emitted.

**4.3.3.5.2. Method** *$NO_x$* 

Emission figures were annually reported to the Norwegian Environment Agency, and the figures were based on calculations.

**4.3.3.5.3. Uncertainties**

No source specific uncertainty is known.

**4.3.3.5.4. Completeness***Particles*

Reported emission figures to the Norwegian Environment Agency exist only for 1997-1999. Annual emissions were so low that they have not been included in the Norwegian inventory.

**4.3.3.5.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.3.3.6. Chloralkali production**

**4.3.3.6.1. Description**

One plant in Norway produced chloralkali until 2005. Before 1997, mercury was used in the chloralkali production and emitted during the process. In 1997, the plant changed its production process and stopped using mercury, but in the following years there were still some mercury emissions.

**4.3.3.6.2. Method**

*Hg*

Emission figures were reported to the Norwegian Environment Agency.

**4.3.3.6.3. Uncertainties**

No source specific uncertainty is known.

**4.3.3.6.4. Completeness**

Major missing emission components are not likely.

**4.3.3.6.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.3.3.7. Production of pigments****4.3.3.7.1. Description**

Two plants are included in the inventory. One plant produces copper oxide for bottom paint and emits copper to air during the production process. Emissions of Cd and Pb have been reported since 2002. Emissions for 1990-2001 are set to be the same as the reported figure in 2002. Also minor amounts of arsenic and chromium are emitted. The other plant produces zinc chromate, and chromium is emitted.

**4.3.3.7.2. Method**

Emission figures are reported to the Norwegian Environment Agency.

**4.3.3.7.3. Uncertainties**

Reported emission figures for 1990 and 1991 for the plant producing zinc chromate are not occurring. In the inventory, the same figure as reported for 1992 is used for 1990 and 1991.

**4.3.3.7.4. Completeness**

Major missing emission components are not likely.

**4.3.3.7.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.3.3.8. Production of soap****4.3.3.8.1. Method**

Two plants producing soap have reported emission figures for particles to the Norwegian Environment Agency. One of the plants has only reported for 1990 and 1991. The plant has after 1991 had a temporary permission without reporting requirements and is therefore not included after 1991 due to lack of data. The other plant reported figures for 1992-1994. Emissions for 1990 and 1991 are assumed to be the same as reported figure in 1992, while emissions for 1995-1997 are assumed to be the same as reported figure in 1994. Annual emission figures are low.

The particles have been purified through filters and scrubbers and the Norwegian Environment Agency assumes the sizes of the particles are smaller than PM<sub>2.5</sub>.

**4.3.3.8.2. Uncertainties**

For the years where reported emission figures do not exist, Statistics Norway has assumed that emissions are in the same order as reported in one of the other years. This is uncertain and a result of lack of better data.

**4.3.3.8.3. Completeness**

Major missing emission components are not likely.

**4.3.3.8.4. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.3.3.9. Paint and varnish production****4.3.3.9.1. Method**

One plant producing paint has reported emission figures for particles to the Norwegian Environment Agency since 1995, after first getting an emission permit in 1994. Annual emissions are small. It is assumed by the Norwegian Environment Agency that the particles emitted are smaller than PM<sub>2.5</sub>.

**4.3.3.9.2. Uncertainties**

No source specific uncertainty is known.

**4.3.3.9.3. Completeness**

Major missing emission components are not likely.

**4.3.3.9.4. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure QA/QC procedure

**4.4. Metal production**

*IPCC 2C*

*NFR 2C*

*Last update: 17.06.09*

Metal production in Norway includes plants producing iron and steel, ferroalloys, aluminium, nickel and zinc and also magnesium until spring 2006. Production of anodes is also included in this chapter. As shown in table 4.9, most of the figures in the national inventory are from the plants' annual reports to the Norwegian Environment Agency.

**Table 4.9. Metal production. Components emitted and included in the Norwegian inventory**

	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	PFCs	SF <sub>6</sub>	SO <sub>2</sub>	NO <sub>x</sub>	NH <sub>3</sub>	NM VOC	CO	PM	HM	POP	
<b>Production of:</b>														
2C1 Iron and steel ...	R	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	R	R	R
2C2 Ferroalloys .....	R	R	R	NA	NA	R	R	NA	E	NA	R	R	R	R
2C3 Primary aluminium .....	R	NA	NA	R	R	R	E	NA	NA	NA	R	R	R/E	
2C4 Secondary aluminium .....	NA	NA	NA	NA	R	NA	NA	R	NA	NA	R	R	R	R
2C4 Magnesium .....	R	NA	NA	NA	R	R	NA	NA	NA	R	R	R	R	R
2C5 Nickel .....	R	NA	NA	NA	NA	R	R	R	NA	NA	R	R	NA	NA
2C5 Zinc .....	NA	NA	NA	NA	NA	R	NA	NA	NA	NA	R	R	NA	NA
2C5 Anodes .....	R	NA	NA	NA	NA	R	R	NA	NA	NA	R	R	R	R

E = Figures estimated by Statistics Norway (Activity data \* emission factor). R = Figures reported by the plant to the Norwegian Environment Agency. NA = Not Applicable.

#### 4.4.1. Production of iron and steel

IPCC 2C1

NFR 2C1

Last update: 29.05.2013

##### 4.4.1.1. Description

Three plants producing iron and steel are included in the Norwegian inventory, one of these report only emission figures for particles. One plant producing titanium dioxide slag also produces pig iron as a by-product. All emissions from this plant are registered under 2B5. For a steel producing plant, process emissions of CO<sub>2</sub> come from the consumption of various types of scrap iron.

Heavy metal emissions are due to the metallurgical melting process and the content of heavy metals in the raw materials used. Particles are also emitted during the process.

##### 4.4.1.2. Method

CO<sub>2</sub>

In the Norwegian emission inventory, emission figures for CO<sub>2</sub>, annually reported to the Norwegian Environment Agency, are used.

For steel, the CO<sub>2</sub> emissions stem from an Electric Arc Furnace (EAF) where scrap iron is melted with other carbon materials. The emissions from the scrap iron are calculated based on the use of each types of scrap iron and the appurtenant content of carbon in each type of scrap iron. E.g., in 2010 the plant used 10 types of scrap iron. The types of scrap iron are according to the UK steel protocol, and the carbon content in the types of scrap used varies from 0.15 per cent up to 4 per cent. The other input materials to the EAF are coal, lime, electrodes and the metals ferromanganese, ferrosilicon and silicomanganese. The outputs are steel, dust and slag. The net emissions from the mass balance are the process emissions.

##### Particles

One plant has reported figures since 1990 while the other has only reported since 1998. For this plant, historical emissions in the period 1990-1997 have been assumed to be the same as the reported figure in 1998, since production rate data for previous years are not available.

The Norwegian Environment Agency assumes that the particles emitted in the production of iron and steel are smaller than PM<sub>2.5</sub>. We can, however, not disregard that some of the particles emitted are larger than PM<sub>2.5</sub>.

##### Heavy metals and POPs

One plant reports emission figures to the Norwegian Environment Agency. Reported figures for heavy metals (Pb, Cd, Cr, Cu, As and Hg) exist from 1990, 1992 or later, depending on type of heavy metal. For dioxins and PAH, reported figures have only been available from 1997 and 1999. Diffuse emissions have been included from one plant. In lack of production rate data for previous years, it has been assumed that yearly emissions are the same as in the first year of reporting.

##### 4.4.1.3. Uncertainties

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

##### Heavy metals and POPs

Reported emission figures vary from one year to another, partly due to differences in raw materials, but mainly as a result of uncertain measurements. The reported figures are based on a limited number of measurements, and the emissions will vary from minute to minute, since the production of iron and steel is a non-continuous process. For the years where reported emission figures do not exist, Statistics Norway has

assumed that emissions are in the same order as the first year of reporting. This is uncertain and a result of lack of better data.

#### *Particles*

The particle size distribution used is only an assumption, and we can not preclude that the distribution is different from the one used in the inventory. For the years where reported emission figures do not exist, Statistics Norway has assumed that emissions are in the same order of magnitude as for the first year of reporting. This is an uncertain estimate due to lack of better data.

#### **4.4.1.4. Source specific QA/QC**

Annually reported figures on CO<sub>2</sub> emissions are controlled by the Norwegian Environment Agency. In addition, the reported figures are occasionally compared with calculations at Statistics Norway using the amount of reducing agents and emission factors. This method is recommended by IPCC when data from measurements are not available.

Adjustments and recalculations have been done for years where reported emission figures seem to be unreasonably high or low compared with previous years. This is applicable when the variations in the reported emission figures do not have a natural explanation. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

#### **4.4.2. Production of ferroalloys**

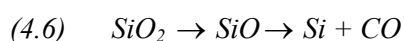
*IPCC 2C2, Key category for CO<sub>2</sub>*

*NFR 2C2*

*Last update: 15.04.2014*

##### **4.4.2.1. Description**

There were 12 plants producing ferroalloys in Norway in 2012. One plant closed down in 2001, two plants were closed down during 2003 and two in 2006. One plant was out of production in 2006, but started up again in 2007. Ferrosilicon, silicon metal, ferromanganese and silicon manganese are now produced in Norway. Ferrochromium was produced until summer in 2001. Ferrosilicon with 65 to 96 per cent Si and silicon metal with 98-99 per cent Si is produced. The raw material for silicon is quartz (SiO<sub>2</sub>). SiO<sub>2</sub> is reduced to Si and CO using reducing agents like coal, coke and charcoal.



The waste gas CO and some SiO burns to form CO<sub>2</sub> and SiO<sub>2</sub> (silica dust).

Some of the CO generated from coal is sold for energy use to other industries. The amount of CO gas sold is hence subtracted from the emissions reported under this category and included in energy use in manufacturing industries and construction (IPCC 1A2, NFR 1A2).

In ferroalloy production, raw ore, carbon materials and slag forming materials are mixed and heated to high temperatures for reduction and smelting. The carbon materials used are coal, coke and some biocarbon (charcoal and wood). Electric submerged arc furnaces with graphite electrodes or consumable Söderberg electrodes are used. The heat is produced by the electric arcs and by the resistance in the charge materials. The furnaces used in Norway are open, semi-covered or covered.

The CO stems from the production process. In open or semi-closed furnaces the CO reacts with air and forms CO<sub>2</sub> before it is emitted. This is due to high temperature and access to air in the process. In a closed furnace the CO does not develop to CO<sub>2</sub> as there is no access to air (oxygen) in the process. The waste gas is then led from the furnace and used as an energy source or flared, and is reported



under the relevant energy sectors. The technical specification of the furnaces is irrelevant since emissions are calculated using a mass balance or calculated by multiplying the amount of reducing agents in dry weight with country specific emission factors.

Several components are emitted from production of ferroalloys. Emission of CO<sub>2</sub> is a result of the oxidation of the reducing agent used in the production of ferroalloys. From the production of ferromanganese (FeMn), silicon manganese (SiMn) and ferrochromium (FeCr) there is only CO<sub>2</sub> emissions. SO<sub>2</sub> originates from the sulphur in the reducing agent used, while NO<sub>x</sub> is produced primarily by the high temperature oxidation of nitrogen in the air. NMVOC, N<sub>2</sub>O and CH<sub>4</sub> emissions originate from the use of coal and coke in the production processes by producing ferrosilicon and silicon metal. Heavy metals are emitted from the raw materials (ore) during the metallurgical process, and the particles emitted are mainly silica dust generated during the production process.

#### 4.4.2.2. Method

##### CO<sub>2</sub>

Emission data based on calculations is reported from each plant in an annual report to the Norwegian Environment Agency. The method used in the calculation of CO<sub>2</sub> emissions from the production of ferroalloys is in accordance with the method recommended by the IPCC (IPCC 1997a, 2000, 2006).

The plants have used two different methods to calculate the CO<sub>2</sub> emissions. Most of the plants base their calculations on carbon mass balance in the process (method I). In the carbon mass balance the emissions of CO<sub>2</sub> are calculated by adding the total input of C in raw materials before subtracting the total amount of C in products, wastes and sold gases (Tier 3). The carbon content of each raw material is from carbon certificates from the suppliers. The carbon in each product, CO gas sold etc., is calculated from the mass of product and carbon content.

The other plants calculate the emissions from the dry weight consumption of the reducing agents and electrodes and country specific emission factors for coal, coke, petrol coke, electrodes, carbonate ore, anthracite, limestone and dolomite (method II) (Tier 2) see table 4.11.

The two methods are regarded as being consistent and each plant has used the same method for the entire time series. Indirect emissions of CO<sub>2</sub> are calculated by Statistics Norway based on the emission of CH<sub>4</sub>, see chapter 1.9.

##### CH<sub>4</sub> and N<sub>2</sub>O

Emission figures are reported annually by each plant to the Norwegian Environment Agency. Measurements performed at Norwegian plants producing ferroalloys indicate emissions of N<sub>2</sub>O in addition to CH<sub>4</sub>.

The emissions of CH<sub>4</sub> and N<sub>2</sub>O are influenced by the following parameters:

- The silicon level of the alloy (65, 75, 90 or 98 % Si) and the silicon yield
- The method used for charging the furnace (batch or continuously)
- The amount of air used to burn the gases at the top controlling the temperature in off gases.

The emission factors used in the inventory represent the longer-term average N<sub>2</sub>O and CH<sub>4</sub> concentration measurements outside the peaks in concentration, which occur due to avalanches (sudden fall of large amounts of colder charge into the furnace). These occur from time to time, and are not fully reflected in the emission factors. We regard the emission factors as conservative, particularly for the early 1990s when the avalanches were more frequent than in the latest years.

All companies apply sector specific emission factors in the emission calculation, see table 4.12. The factors are developed by the Norwegian Ferroalloy Producers

Research Organisation (FFF) and standardized in a meeting with The Federation of Norwegian Process Industries (PIL) (today named Federation of Norwegian Industries) in February 2007.

### *SO<sub>2</sub>*

Each plant annually reports emission figures to the Norwegian Environment Agency. Some of the sulphur is trapped in the product. For production of ferromanganese and silicon manganese, 98-99 per cent of the sulphur is trapped, while for other ferroalloys it is assumed that about 5 per cent is trapped. The emissions are calculated from the consumption of reducing agents and electrodes and the content of sulphur in the materials.

### *NO<sub>x</sub>*

Emissions of NO<sub>x</sub> originate from production of ferrosilicon and silicon metal. Ferromanganese, ferrochrome and silicomanganese do not have significant emissions of NO<sub>x</sub>. Emission figures are annually reported by each plant to the Norwegian Environment Agency. The reported emissions are calculated either from the production of metal and metal specific emission factors, see table 4.13, or on the basis of continuous measurements.

### *NM VOC*

The emissions are estimated by Statistics Norway from the consumption of reducing agents and an emission factor.

### *Particles*

All plants producing ferroalloys report emission figures to the Norwegian Environment Agency. Some have reported since 1990, others since 1992. For plants reported since 1992, emission figures from 1990 and 1991 have been assumed to be the same as reported figures in 1992. According to the ferroalloy industry, particles emitted are smaller than PM<sub>2.5</sub> (Eikeland, *pers.comm.*<sup>8</sup>). This is, however, an assumption, and we can not preclude that some of the particles might be larger than PM<sub>2.5</sub>. In the inventory, we have decided to use this distribution for all particles emitted from the production of ferroalloys. This means that TSP=PM<sub>10</sub>=PM<sub>2.5</sub>.

### *Heavy metals*

Emission figures for heavy metals are reported from all plants producing ferroalloys after the Norwegian Environment Agency in 1999 imposed larger metallurgical plants to map their emissions of heavy metals. Most plants have therefore reported figures to the Norwegian Environment Agency since 1999, but some reported for the first time in 2000 and 2001. An emission factor has been derived for each plant, based on the emission figure and production rate for the first year of reporting. These emission factors have been used together with production rates for each year to calculate the emissions back to 1990 for each plant.

### *Dioxins*

All plants producing ferrosilicon report emission figures for dioxins to the Norwegian Environment Agency. It varies, however, when the plants started reporting, so calculations of historical figures back to 1990 have been necessary. An emission factor was derived for each plant based on reported emission data and production rates, and this factor was used to calculate historical emissions based on production rates for each year.

None of the four plants producing ferromanganese and ferrochromium<sup>9</sup> report emission figures for dioxins to the Norwegian Environment Agency. The reason is probably that the emissions are so small that they are not measured and therefore

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<sup>8</sup> Eikeland (2002): Personal information, e-mail dated 29/05 2002. [Elkem@elkem.no](mailto:Elkem@elkem.no)

<sup>9</sup> The ferrochromium plant was closed down in 2003.

not reported (the Norwegian Pollution Control Authority, pers. comm.10). Instead, the emissions are calculated by Statistics Norway based on the general emission factor for combustion of coke and coal in the industry (table 4.15).

### PAH

Emissions of PAH from the production of ferroalloys are reported to the Norwegian Environment Agency for plants producing ferrosilicon and silicon metal. All these plants have reported emission figures since 2000. Historical emissions back to 1990 have been calculated based on production rates for each year and an emission factor derived for each plant based on reported figures for 2000, 2001 and 2002. Reported figures and historical calculations are only done for plants producing ferrosilicon and silicon metal. This is based on the assumption that these alloys are produced in open ovens and therefore cause larger emissions of PAH compared to other alloys that are produced in closed ovens, and are assumed to cause no or minor emissions of PAH.

The PAH emission figures are reported according to Norwegian Standard, but no PAH profile is available. In lack of other data, the same profile as for aluminium production is used.

**Table 4.10. Distribution of PAH emissions from production of ferroalloys**

Component	Distribution of PAH emissions (ratio)
PAH (Norwegian standard) .....	1
PAH-6 (Ospar) .....	0.3
PAH-4 (CLRTAP) .....	0.15

Source: Finstad *et al.* (2001).

### 4.4.2.3. Activity data

#### CO<sub>2</sub>

The plants' calculations of emissions are based on the consumption of gross reducing agents and raw materials (carbonate ore, limestone and dolomite).

#### CH<sub>4</sub> and N<sub>2</sub>O

The gross production of different ferroalloys is used in the calculation by the plants.

#### NM VOC

The amounts of reducing agents that are used for the calculation of NM VOC emissions are annually reported to Statistics Norway from each plant.

### 4.4.2.4. Emission factors

#### CO<sub>2</sub>

Emission factors used by the plants in the Tier 2 calculations are shown in table 4.11. The factors are from Norwegian sources, based on the actual composition of the raw materials.

**Table 4.11. Emission factors for production of ferroalloys. Tonnes CO<sub>2</sub>/tonne reducing agent or electrode**

	Coal	Coke	Petrol coke	Elec-trodes	Carbo-nate ore	Dolomite, limestone
Ferrosilicon .....	3.08	3.36	-	3.36	-	-
Silicon metal .....	3.12	3.36	-	3.54	-	-
Ferrochromium .....	-	3.22	-	3.51	-	-
Silicon manganese ..	-	3.24	3.59	3.51	0.16-0.35	0.43-0.47
Ferromanganese .....	-	3.24	3.59	3.51	0.16-0.35	0.43-0.47

Source: SINTEF (Monsen 1998; Monsen and Olsen 1998; Raaness 1998).

<sup>10</sup> Norwegian Pollution Control Authority (2001): Units for dioxins (dioxins.doc). Personal information C. Benestad, 13/03 2001, Oslo: Norwegian Pollution Control Authority.

*CH<sub>4</sub> and N<sub>2</sub>O*

The plants apply sector specific emission factors in the emission calculations, see table 4.12. The factors are developed by the Norwegian Ferroalloy Producers' Research Organisation (FFF) and standardized in a meeting with The Federation of Norwegian Process Industries (PIL) (today named Federation of Norwegian Industries) in February 2007.

**Table 4.12. Emission factors for CH<sub>4</sub> and N<sub>2</sub>O from production of ferroalloys. Emission factors in kg per tonne produced ferroalloy**

Alloy, charging routines and temperature	Si-met			FeSi-75%			FeSi-65%		
	Batch-charging	Sprinkle-charging <sup>1</sup>	Sprinkle-charging and >750°C <sup>2</sup>	Batch-charging	Sprinkle-charging <sup>1</sup>	Sprinkle-charging and >750°C <sup>2</sup>	Batch-charging	Sprinkle-charging <sup>1</sup>	Sprinkle-charging and >750°C <sup>2</sup>
kg CH <sub>4</sub> per tonne metal	0.1187 M	0.0881 M	0.1000 E	0.0890 E	0.0661 E	0.0750 E	0.0772 E	0.0573 E	0.0650 E
kg N <sub>2</sub> O per tonne metal	0.0433 E	0.0214 E	0.0252 E	0.0297 E	0.0136 E	0.0161 E	0.0117 E	0.0078 E	0.0097 E

<sup>1</sup> Sprinkle-charging is charging intermittently every minute.

<sup>2</sup> Temperature in off-gas channel measured where the thermocouple cannot 'see' the combustion in the furnace hood.

M=measurements and E= estimates based on measurements

*NO<sub>x</sub>*

The emission factors used by the ferrosilicon plants in the calculations are based on measurements carried out at three plants.

The emission factors in table 4.13 are based on several measuring campaigns at four different ferroalloy plants that were carried out from 1995 to 2007. Each measurement period lasted 4 to 8 hours with different operation conditions. Based on this, emission factors for different ferroalloys and operational conditions have been established. The measurements have been carried out by Det norske Veritas, Norsk Energi, SINTEF and TÜV.

The silicon plants have applied a new method. They have used online measurement instruments to measure the emissions of NO<sub>x</sub>. The measurements were undertaken in 2010. The instrument applied is NEO laser gas and Testo 350 as a control of the results from the NEO laser gas device. So far there are only two plants where the online measurement devices are installed on a permanent basis. For the other plants the online measurement instruments are used periodically to derive emission factors. The following emission factors are used by four plants in one major ferroalloy producing company (kg NO<sub>x</sub>/tonne metal produced): 27 (based on measuring campaigns), 34 and 39 (based on online measurements) and 45 (based on a combination of online measurements and campaigns).

The uncertainties associated with the measurements mainly come from measurement of off-gas flow and measurement of concentration of the NO<sub>x</sub> in the off-gas. In addition, the periodical measurement campaigns will not include all variations in the emissions gained over time.

**Table 4.13. Emission factors for production of ferrosilicon. Kg NO<sub>x</sub> /tonne metal produced.**

	Normal operations	Dryss - charging	Dryss- charging > 750 °C	Source
Ferrosilicon 75 per cent ...	15.3	7.0	8.3	Measured in 1995 at Rana Metal and the Thamshavn plant 2005
Ferrosilicon 65 per cent ...	6.0	4.0	5.0	Estimations <sup>1</sup>

<sup>1</sup> Estimations means that this emission factor is not measured but estimated by the plants based on general process experiences.

*NM VOC*

Statistics Norway uses an emission factor of 1.7 kg NMVOC/tonne coal or coke (EPA 1986) in the calculations.

*Dioxins*

The emission factors used by the plants in the calculations are given in table 4.14.

**Table 4.14. Emission factors for production of ferroalloys. µg dioxin /tonne metal produced**

	Normal operations	Dryss - charging	Dryss-charging > 750 °C	Source
Silicon metal .....	3	1.2	0.2	Measured in 1995 at the Fiskaa plant
Ferrosilicon 90 per cent ...	4	1.2	0.2	Estimations <sup>1</sup>
Ferrosilicon 75 per cent ...	5	1.2	0.2	Measured in 1995 at Rana Metall
Ferrosilicon 65 per cent ...	5	1.2	0.2	Estimations
Si96 .....	3	1.2	0.2	Estimations

<sup>1</sup> Estimations means that this emission factor is not measured but estimated by the plants based on general process experiences.

Emission calculations of dioxins for plants not reporting figures to the Norwegian Environment Agency use an emission factor for combustion of coke and coal in the industry (table 4.15).

**Table 4.15. Emission factor used by Statistics Norway to calculate dioxin emissions from production of ferro manganese/chromium**

	Emission factor
Coal and coke .....	1.6 µg/tonne

Source: Bremmer *et al.* (1994) and Finstad *et al.* (2002b).

*PAH*

The emission factors used by the plants in the calculations are given in table 4.16.

**Table 4.16. Emission factors for production of ferroalloys. g PAH /tonne metal produced**

	Normal operations	Dryss - charging	Dryss-charging > 750 °C	Source
Silicon metal .....	3	2.6	1.6	Measured in 1995 at the Fiskaa plant
Ferrosilicon 90 per cent ...	2	2	1	Estimations <sup>1</sup>
Ferrosilicon 75 per cent ...	1.5	1.3	0.8	Measured in 1995 at Rana Metall and the Thamshavn plant
Ferrosilicon 65 per cent ...	1	1.3	0.8	Estimations
Si96 .....	3	2.6	1.6	Estimations

<sup>1</sup> Estimations means that this emission factor is not measured but estimated by the plants based on general process experiences.

**4.4.2.5. Uncertainties**

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

*Particles*

The inventory uses a particle size distribution which is an assumption from the ferroalloy industry and not based on measurements. We can therefore not preclude that some of the particles might be larger than PM<sub>2.5</sub>.

*Heavy metals and POPs*

Historical emissions are based on derived emission factors for the first year of reporting, and calculated using production figures for previous years. This is uncertain since the calculation method does not consider quality changes of the raw materials or changes in the production profile at each plant that can have big impact on yearly emissions.

**4.4.2.6. Source specific QA/QC***CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O*

The Norwegian Environment Agency compared the reported emissions from the plants with emission data given in "the white book" (SINTEF and Det Norske

Veritas 2004) and other relevant data available. In some cases, the emission data were verified by making control calculations based on emission factors and activity data. In all cases, the construction of charts and figures of emissions and activity data helped identifying missing data and possible errors.

All the main producers of ferroalloys in Norway were contacted and asked to supply missing emission and activity data, and to explain any possible errors identified. The feedback from the companies made it possible to make corrections and filling of gaps in the series of data.

A complete time series from 1990 to 2004 could be established for all three relevant greenhouse gas parameters for most companies. Data from "the white book" and the reported company data corresponded well.

During the review of the initial report in 2007, activity data like coal, coke, electrodes, petrol coke and bio carbon were collected from each plant once again and so were emissions of CH<sub>4</sub> and N<sub>2</sub>O based on EFs shown in Table 4.12. With very few exceptions the AD reported in the CRF are data that the plants have reported to the Norwegian Environment Agency. The IEF for the sector and also for each plant is fluctuating from year to year mainly due to variation in sold CO and in production of ferroalloy products.

The CO<sub>2</sub> emissions are in addition occasionally calculated by Statistics Norway based on IPCC's recommended Tier 1 method, using the reported amount of reducing agents (raw material) used. Emission factors used are the factors in table 4.11. The calculated emissions are used as a quality check of the reported data.

The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

#### *NO<sub>x</sub>, NMVOC and CO*

The reported emission figures for NO<sub>x</sub>, NMVOC and CO are compared with calculations at Statistics Norway.

For the quality check on the reported NO<sub>x</sub> emission figures, an emission factor estimated from two ferroalloy plants are used together with production data. The applied emission factor of 11.7 kg NO<sub>x</sub>/ tonne ferroalloy is rather uncertain since it is estimated from measurements at only two of the Norwegian ferroalloy plants.

Emission figures for NMVOC are controlled by multiplying the amount of reducing agents with an emission factor recommended by EPA (1986).

#### *PAH*

In 2004, there was a quality improvement of the historical calculation of PAH. PAH was first included in the Norwegian Inventory in 2000, and at that time only two plants producing ferrosilicon and silicon metal reported emission figures to the Norwegian Environment Agency for the year 1999. The ferroalloy industry and the Norwegian Environment Agency therefore derived emission factors to estimate PAH emissions from the production of ferrosilicon and silicon metal (Benestad, *pers. comm.*<sup>11</sup>). It was then decided to use these factors in the Norwegian inventory to calculate PAH emissions. From 2000, all plants producing ferrosilicon and silicon metal, however, started reporting emission figures to the Norwegian Environment Agency, and these figures have been used instead of the calculated emissions based on emission factors and activity data. In 2004, the historical emissions were recalculated. Based on the plants' reported emission figures for 2000, 2001 and 2002 and production volumes, a specific emission factor for each plant was derived. These factors were then used to recalculate the plants' historical

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<sup>11</sup> Benestad, C. (2000): Personal information, e-mail dated 30/10 2000.

emissions of PAH. A specific emission factor for each plant was considered better to use for historical emissions, instead of using a default emission factor for all plants. The specific emission factors derived for each plant with the new method were lower than those suggested by Benestad (*pers. comm.*<sup>11</sup>), and this caused approximately 2-12 per cent lower yearly PAH emissions from 1990 to 1999 from this source.

#### 4.4.3. Production of primary aluminium

*IPCC 2C3, Key category for CO<sub>2</sub> and PFC (SF<sub>6</sub>: 2C4, Key category for SF<sub>6</sub>)  
NFR 2C3*

*Last update: 30.06.2008*

##### 4.4.3.1. Description

There are seven plants in Norway producing aluminium. Both prebaked anode and the Soederberg production methods are used.

In the Soederberg technology, the anodes are baked in the electrolysis oven, while in the prebaked technology the anodes are baked in a separate plant. In general, the emissions are larger from the Soederberg technology than from the prebaked technology. There has been a shift from Soederberg to prebaked technology. In 1990, 57 per cent of the aluminium production in Norway was produced with prebaked technology and the share of aluminium production from prebaked increased to 92 per cent in 2009. Two new plants with prebaked technology were established in 2002 and two plants using Soederberg technology were closed down in 2001 and 2003. Since 2007 three plants using Soederberg technology have been closed down, one in 2007, one in 2008 and one in 2009. There is now only one plant left where Soederberg technology is used.

Production of aluminium leads to emissions of various components, such as CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, perfluorocarbons (PFCs), heavy metals and persistent organic pollutants. The emission of CO<sub>2</sub> is due to the electrolysis process during the production of aluminium, while the SO<sub>2</sub> emissions are from the sulphur in the reducing agents used. NO<sub>x</sub> is primarily produced by the high temperature oxidation of nitrogen in the air. All plants also report emissions of particles, heavy metals and PAH. Emissions of heavy metals are due to the metal content in the raw materials used and the reducing agents.

##### 4.4.3.2. Method

*CO<sub>2</sub>*

The inventory uses the emission figures reported to the Norwegian Environment Agency, calculated by each plant on the basis of consumption of reducing agents. This includes carbon electrodes, electrode mass and petroleum coke. The emission factors are primarily calculated from the carbon content of the reducing agents.

Previously, Statistics Norway estimated the CO<sub>2</sub> emissions from consumption data provided by the plants, but now figures reported by the plants are used. Reported figures are available since 1992. For 1990 and 1991 there were no data, hence recalculation was made using production data and reported emission data for 1992. The aluminium industry calculates the CO<sub>2</sub> emissions separate for each technology. The following methods are used:

*CO<sub>2</sub> from Prebake Cells*

$$(4.7) \quad Q = A * C * 3.67$$

Where

*Q* is the total yearly emissions of CO<sub>2</sub>

*A* is the yearly net consumption of anodes

*C* is per cent carbon in the anodes

3.67 is the mol-factor CO<sub>2</sub>/C

*CO<sub>2</sub> from Soederberg Cells*

$$(4.8) \quad Q = S * 3.67 * (K * C1 + P * C2)$$

Where

$Q$  is the total yearly emissions of CO<sub>2</sub>

$S$  is the yearly consumption of Soederberg paste

$K$  is the share of coke in the Soederberg paste

$P$  is the share of pitch in the Soederberg paste

$K + P = 1$

$C1$  is the fraction of carbon in the coke. Fraction is per cent Carbon/100

$C2$  is the fraction of carbon in the pitch. Fraction is per cent Carbon/100

*SO<sub>2</sub>*

The plants report emission figures of SO<sub>2</sub> to the Norwegian Environment Agency.

The figures are estimated by each plant based on the amounts of reducing agents used and their sulphur content. All plants have installed flue gas treatment, like, for example, sea water scrubber.

*NO<sub>x</sub>*

NO<sub>x</sub> emissions are estimated by Statistics Norway from the level of production and an emission factor derived from measurements at two Norwegian plants. The figure is rather uncertain.

*Perfluorocarbons (PFCs)*

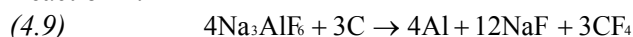
The emissions of PFC are reported annually by the plants to the Norwegian Environment Agency.

Perfluorinated hydrocarbons (PFCs), e.g. tetrafluoromethane (CF<sub>4</sub>) and hexafluoroethane (C<sub>2</sub>F<sub>6</sub>), are produced during anode effects (AE) in the Prebake and Soederberg cells, when the voltage of the cells increases from the normal 4-5V to 25-40V. During normal operating condition, PFCs are not produced. The fluorine in the PFCs produced during anode effects originates from cryolite. Molten cryolite is necessary as a solvent for alumina in the production process.

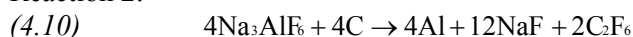
Emissions of PFCs from a pot line (or from smelters) are dependent on the number of anode effects and their intensity and duration. Anode effect characteristics will be different from plant to plant and also depend on the technology used (Prebake or Soederberg).

During electrolysis two perfluorocarbon gases (PFCs), tetrafluoromethane (CF<sub>4</sub>) and hexafluoroethane (C<sub>2</sub>F<sub>6</sub>), may be produced in the following reactions:

Reaction 1:



Reaction 2:



The national data are based on calculated plant specific figures from each of the seven Norwegian plants. The plants have used the Tier 2 method in their calculations, which are based on a technology specific relationship between anode effect performance and PFCs emissions. The PFCs emissions are then calculated by the so-called slope method, where a constant slope coefficient (see table 4.17), given as kg CF<sub>4</sub>/tonne Al/anode effect minutes per cellday, is multiplied by the product of anode effect frequency and anode effect duration (in other words, by the number of anode effect minutes per cell day), and this product is finally multiplied by the annual aluminium production figure (tonnes of Al/year). The basis for the plants calculations of PFCs is the amount of primary aluminium produced in the potlines and sent to the cast house. Thus, any remelted metal is not included here. The formula for calculating the PFC emissions is:



$$(4.11) \quad \text{kg CF}_4 \text{ per year} = S_{CF_4} \cdot AEM \cdot MP$$

and

$$(4.12) \quad \text{kg C}_2\text{F}_6 \text{ per year} = \text{kg CF}_4 \text{ per year} \cdot F_{C_2F_6/CF_4}$$

Where :

$S_{CF_4}$  = "Slope coefficient" for CF<sub>4</sub>, (kg PFC/t<sub>Al</sub>/anode effect minutes/cellday)

$AEM$  = anode effect minutes per cellday

$MP$  = aluminium production, tonnes Al per year

$F_{C_2F_6/CF_4}$  = weight fraction of C<sub>2</sub>F<sub>6</sub>/CF<sub>4</sub>

**Table 4.17. Technology specific slope and overvoltage coefficients for the calculation of PFCs emissions from aluminium production**

Technology <sup>a</sup>	"Slope coefficient" <sup>b,c</sup>		Weight fraction	
	(kg PFC/t <sub>Al</sub> )/ (anode effect/cellday)		C <sub>2</sub> F <sub>6</sub> /CF <sub>4</sub>	
	$S_{CF_4}$	Uncertainty (±per cent)	$F_{C_2F_6/CF_4}$	Uncertainty (±per cent)
CWPB .....	0.143	6	0.121	11
SWPB .....	0.272	15	0.252	23
VSS .....	0.092	17	0.053	15
HSS .....	0.099	44	0.085	48

a. Centre Worked Prebake (CWPB), Side Worked Prebake (SWPB), Vertical Stud Soederberg (VSS), Horizontal Stud Soederberg (HSS).

b. Source: Measurements reported to IAI, US EPA sponsored measurements and multiple site measurements.

c. Embedded in each slope coefficient is an assumed emission collection efficiency as follows: CWPB 98 per cent, SWPB 90 per cent, VSS 85 per cent, HSS 90 per cent. These collection efficiencies have been assumed based on measured PFC collection fractions, measured fluoride collection efficiencies and expert opinion.

"Slope coefficient" is the number of kg CF<sub>4</sub> per tonne aluminium produced divided by the number of anode effects per cellday. The parameter cellday is the average number of cells producing on a yearly basis multiplied with the number of days in a year that the cells have been producing. Measurements of PFCs at several aluminium plants have established a connection between anode parameters and emissions of CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>. The mechanisms for producing emissions of PFCs are the same as for producing CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>. The two PFC gases are therefore considered together when PFC emissions are calculated. The C<sub>2</sub>F<sub>6</sub> emissions are calculated as a fraction of the CF<sub>4</sub> emissions.

The Tier 2 coefficients for Centre Worked Prebake cells (CWPB) are average values from about 70 international measurement campaigns made during the last decade, while there are fewer data (less than 20) for Vertical Stud Soederberg cells (VSS). The main reason for the choice of the Tier 2 method is that the uncertainties in the facility specific slope coefficients are lower than the facility specific based slope coefficients in Tier 3. This means that there is nothing to gain in accuracy of the data by doing measurements with higher uncertainties.

#### *Sulphur hexafluoride (SF<sub>6</sub>)*

SF<sub>6</sub> used as cover gas in the aluminium industry is assumed to be inert, and SF<sub>6</sub> emissions are therefore assumed to be equal to consumption. At one plant, SF<sub>6</sub> was used as cover gas in the production of a specific quality of aluminium from 1992 to 1996. The aluminium plant no longer produces this quality, which means that SF<sub>6</sub> emissions have stopped.

#### *Particles*

Emission figures have been reported to the Norwegian Environment Agency since 1990. The Norwegian Environment Agency assumes that the particles emitted are smaller than PM<sub>10</sub>. According to TNO (Institute of environmental and energy technology 2002), PM<sub>10</sub> is 97 per cent of TSP, and PM<sub>2.5</sub> is 43 per cent of TSP. The Norwegian inventory uses the particle size distribution suggested by TNO (Institute of environmental and energy technology 2002).

*Heavy metals*

The plants report emission figures to the Norwegian Environment Agency. The first requirement for reporting came in 1999, so emission figures before that are insufficient. The concentrations of heavy metals in the air emissions are very low and therefore impossible to measure. Emissions are therefore calculated at each plant, based on the mass flow.

*Dioxins*

Since the process uses coal and coke as reducing agents, it is assumed that production of primary aluminium gives dioxin emissions. Reported figures for dioxins are not available. The emissions are believed to be so small that reporting is not necessary. Emissions are therefore calculated based on the combustion factor for coal in the industry.

*PAH*

The reported emission data are assumed to be according to Norwegian standard (NS9815). It is further assumed by the Norwegian Environment Agency that the emissions are due to emissions from the use of the Soederberg method. Historical emission figures have been calculated based on changes in production of aluminium after the Soederberg method.

The PAH profile has been measured at three plants. These profiles show little variation. Based on these profiles it is believed that PAH-4 accounts for 15 per cent and PAH-OSPAR 30 per cent of total PAH emissions from production of aluminium after the Soederberg method (table 4.18).

**Table 4.18. Distribution of PAH emissions from production of primary aluminium. Ratio**

Component	Distribution of PAH emissions (ratio)
PAH (Norwegian standard) .....	1
PAH-6 (Ospar) .....	0.3
PAH-4 (CLRTAP) .....	0.15

**4.4.3.3. Activity data***NO<sub>x</sub>*

The activity data for the NO<sub>x</sub> calculation are production figures, which are reported annually from the plants to the Norwegian Environment Agency.

*Dioxins*

The calculation of emissions of dioxins is based on consumption of raw materials. The figures are reported annually from the plants to Statistics Norway.

**4.4.3.4. Emission factors***NO<sub>x</sub>*

Statistics Norway uses the emission factor 0.00071 tonnes NO<sub>x</sub>/ tonne produced aluminium in the calculations. This emission factor is assumed by the Norwegian Environment Agency and is based on measurements.

*Dioxins*

Emissions of dioxins are calculated based on the consumption of coal and an emission factor from Bremmer *et al.* (1994).

**Table 4.19. Emission factor used to calculate dioxin emissions from aluminium production**

	Emission factor	Source
Coal and coke .....	1.6 µg/tonne	Bremmer <i>et al.</i> (1994)

**4.4.3.5. Uncertainties**

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

*Perfluorocarbons (PFCs)*

The uncertainties in the so-called tier 2 slope coefficients from IAI (International Aluminium Institute) is lower (6 per cent and 17 per cent for CWPB and VSS cells, respectively), compared to the measured facility specific based slope coefficients, where the uncertainties are around 20 per cent, even when the most modern measuring equipment is used (the continuous extractive-type Fourier Transform Infrared (FTIR) spectroscopic system). Control measurements in two Hydro Aluminium plants (Karmøy and Sunndal) done in November 2004, showed that the measured values for CWPB and VSS cells were well within the uncertainty range of the tier 2 slope coefficients.

*Particles*

The particle size distribution are not reported by the plants. Actual emissions are probably somewhat different from those estimated with the size distribution from TNO (Institute of environmental and energy technology 2002).

**4.4.3.6. Completeness**

Major missing emission components are not likely.

**4.4.3.7. Source specific QA/QC**

The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

*CO<sub>2</sub>*

The emission figures reported by the plants are checked by the Norwegian Environment Agency. Statistics Norway occasionally makes own estimates based on the consumption of reducing agents and production data collected in an annual survey and average emission factors. If errors are found, the plants are contacted and changes in the emissions are made when necessary.

*Perfluorocarbons (PFCs)*

The emission figures from the aluminium plants are reported to the Norwegian Environment Agency annually. As a quality control, it is checked that the reports are complete. Each figure is compared with similar reports from previous years and also analysed, taking technical changes and utilisation of production capacity during the year into account. If errors are found, the Norwegian Environment Agency contacts the plant to discuss the reported data, and changes are made if necessary.

The Norwegian Environment Agency has regular meetings with the aluminium industry where all plants are represented. This forum is used for discussion of uncertainties and improvement possibilities.

The Norwegian Environment Agency's auditing department are regularly auditing the aluminium plants. As part of the audits, their system for monitoring, calculation and reporting of emissions are checked.

*PAH*

The Norwegian Environment Agency had recently audits at all aluminium plants to check their system for monitoring of emissions of PAH. It will be considered whether similar audits should have climate gases as the main target.

*Heavy metals*

First requirement for reporting of heavy metals was given in 1999, and the reported figures were that year based on concentration measurements. The concentration of heavy metals in the air emissions are very low and therefore subject to high degree of uncertainty. The reported emission figures showed large differences from plant to plant, also in the cases where the raw materials came from the same supplier. The Norwegian Environment Agency has had a long discussion with the

aluminium industry to find a better method to estimate heavy metals from aluminium production. In 2001 it was decided that reported figures should be based on calculations. New calculations have shown that earlier calculations gave too high emissions of heavy metals. It was therefore recommended by the Norwegian Environment Agency to recalculate historical reported data based on the new calculation method. Recalculation of historical data are normally based on production rate data, but due to very low emissions and relative stable production rates, historical data are set to be the same as the first year of reporting.

#### **4.4.4. Production of secondary aluminium**

*IPCC -, (SF<sub>6</sub>: 2C4, Key category for SF<sub>6</sub>)*

*NFR 2C3*

*Last update: 21.05.2013*

##### **4.4.4.1. Description**

One open mill in Norway is handling secondary aluminium production. Heavy metals and persistent organic pollutants (dioxins and PAH) are emitted in the production of secondary aluminium due to the remelting process. Particles are also emitted during the production process. For earlier years there have also been some emissions of NH<sub>3</sub> and SF<sub>6</sub> from another plant which closed down in 2001.

##### **4.4.4.2. Method**

*NH<sub>3</sub>*

For the years 1993-2001, emissions of NH<sub>3</sub> were reported from one plant. This plant closed down in 2001.

*Sulphur hexafluoride (SF<sub>6</sub>)*

For the years 1998, 1999 and 2000, emissions of SF<sub>6</sub> were reported to the Norwegian Environment Agency from the plant which closed down in 2001.

*Particles*

The plant has reported emission figures to the Norwegian Environment Agency from 1993. Emission figures for 1990 to 1992 are in the inventory assumed to be the same as the reported figure in 1993. The following particle size distribution is assumed and used in the Norwegian inventory; PM<sub>10</sub> is 0.8\*TSP and PM<sub>2.5</sub> is 0.32\*TSP (Institute of environmental and energy technology 2002).

*Heavy metals and POPs*

The figures are reported annually to the Norwegian Environment Agency. Emission figures exist since 1993, and emissions before 1993 have been supposed to be the same as reported figures in 1993.

The emission figures for heavy metals are based on metal analyses of dust samples. Figures of Pb, Cd and Cr have been reported since 1997. Annual figures can vary a lot from one year to another, and therefore we have used mean values for years when the changes can not be explained by the industry. We have assumed that the emission figures for 1990-1996 are the same as reported figures in 1997, since there are no reported figures of heavy metals and PAH before 1997.

##### **4.4.4.3. Uncertainties**

*Heavy metals and POPs*

The reported figures for heavy metals are estimated based on heavy metal content in the dust samples. The metal content were only analysed for a few dust samples yearly and the reported figures are therefore only a presumption of yearly emission figures. Calculation of emission figures before 1997 are assumed to be the same as reported figures in 1997, and this gives highly uncertain figures since raw materials and production variations may have changed during the period.

The reported emission figures for dioxins and particles vary from one year to another, and it is assumed that this is due to uncertain measurements and process readjustments.

#### 4.4.4.4. *Source specific QA/QC*

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

#### 4.4.5. **Production of magnesium**

*IPCC 2C5, (SF<sub>6</sub>: 2C4)*

*NFR 2C5*

*Last update: 27.05.2010*

##### 4.4.5.1. *Description*

There has been one magnesium producing plant in Norway. The plant closed down the production of primary magnesium in 2002. The production of cast magnesium continued, but this production has no CO<sub>2</sub> emissions from processes. During 2006 also the production of remelting Mg stopped. From the mid-1970s, both the magnesium chloride brine process and the chlorination process were used for magnesium production. Since 1991, only the chlorination process was in use.

Production of magnesium leads to non-combustion CO<sub>2</sub> and CO emissions. During the calcination of dolomite (MgCa(CO<sub>3</sub>)<sub>2</sub>) to magnesium oxide, CO<sub>2</sub> is emitted. During the next step, magnesium oxide is chlorinated to magnesium chloride, and coke is added to bind the oxygen as CO and CO<sub>2</sub>. SO<sub>2</sub> is emitted due to the sulphur in the reducing agent used.

In the foundry, producing cast magnesium, SF<sub>6</sub> is used as a cover gas to prevent oxidation of magnesium. The Norwegian producer of cast magnesium has assessed whether SF<sub>6</sub> used as cover gas reacts with other components in the furnace. The results indicate that it is relatively inert, and it is therefore assumed that all SF<sub>6</sub> used as cover gas is emitted to air.

##### 4.4.5.2. *Method*

*CO<sub>2</sub>*

The inventory uses emission figures reported to the Norwegian Environment Agency. Previously, Statistics Norway calculated the CO<sub>2</sub> emissions by using annual production volumes and the emission factor recommended by SINTEF (Olsen *et al.* 1998).

*SF<sub>6</sub>*

Studies performed by the Norwegian producer have assessed that SF<sub>6</sub> used as cover gas is inert. Therefore the consumption figures for the cover gas (SF<sub>6</sub>) are used as the emission estimates in accordance with the IPCC Guidelines (IPCC 1997b, a). The SF<sub>6</sub> emissions were reported annually to the Norwegian Environment Agency.

*CO*

Emission figures of CO were reported annually to the Norwegian Environment Agency. These emissions disappeared when the plant closed down the production of primary magnesium in 2002.

*SO<sub>2</sub>*

The SO<sub>2</sub> emissions were estimated from the amounts of reducing agent used (coke) and their sulphur content and reported from the plants to the Norwegian Environment Agency.

*Particles*

The plant reported emission figures for particles for the first time for the year 1992. Emissions of particles for 1990 and 1991 are assumed to be larger than the reported

figure in 1992, since a cleaning device was installed in 1992. Statistics Norway has no information that can be used to estimate emissions in 1990 and 1991, so the inventory uses the reported emission figure for 1992 also for 1990 and 1991. The Norwegian Environment Agency assumes that reported figures also include emissions from combustion.

No information is found regarding the particle size distribution for particles emitted during magnesium production. In lack of other data, we use the same distribution as for aluminium production (PM<sub>10</sub> is 97 per cent of TSP, and PM<sub>2.5</sub> is 43 per cent of TSP).

#### *Heavy metals and POPs*

Emission of heavy metals is due to the metal content in the reducing agent used. Emission data of Hg, As, Cr and dioxins were reported to the Norwegian Environment Agency. When the plant closed down the production of primary magnesium in 2002, the emissions of As disappeared. Reported figures of heavy metals have only been available since 2000. Emission figures are calculated back to 1990 based on the production rate for each year.

During the chlorination process and the use of coke as a reducing agent, dioxins are emitted. Emission figures for dioxins were reported to the Norwegian Environment Agency from 1990.

#### **4.4.5.3. Activity data**

The Norwegian emission inventory uses production volumes as activity data in the calculation of CO<sub>2</sub>. This method is recommended by SINTEF (Olsen *et al.* 1998). The consumption figures used as emission figures for SF<sub>6</sub> were reported to the Norwegian Environment Agency.

#### **4.4.5.4. Emission factor**

An emission factor of 4.07 tonnes CO<sub>2</sub>/tonnes produced magnesium is used by Statistics Norway to calculate the annual emissions of CO<sub>2</sub> (Olsen *et al.* 1998).

#### **4.4.5.5. Uncertainties**

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

#### *Particles*

For years where reported emission figures do not exist, Statistics Norway has assumed that emissions are in the same order as that of the first year of reporting. This is uncertain and a result of lack of better data. The particle size distribution used is not specific for production of magnesium, but used due to lack of specific size distribution data for this source. The particle size distribution can therefore only be seen as an estimate.

#### *Heavy metals*

Historical emissions are based on a derived emission factor for the first year of reporting and calculated with production figures for previous years. This is uncertain and only an estimate since it does not consider annually changes in raw materials nor possible cleaning devices.

#### **4.4.5.6. Completeness**

Major missing emission components are not likely.

#### **4.4.5.7. Source specific QA/QC**

The latest reported emission data from the plant were compared with previous reported data and the emissions were compared with the production.

#### 4.4.6. Other metals

*IPCC 2C5*

*NFR 2C5*

*Last update: 21.05.2013*

In addition to the metals in the previous chapters, nickel and zinc are also produced in Norway.

##### 4.4.6.1. Production of nickel

###### 4.4.6.1.1. Description

One plant in Norway produces nickel. During the production of nickel, CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub>, particles and heavy metals are emitted. CO<sub>2</sub> is emitted in the production of nickel, due to the soda from the production of nickel carbonate and use of coke as a reducing agent, while SO<sub>2</sub> is a result of the sulphur content in the coke used. NO<sub>x</sub> is produced primarily by the high temperature oxidation of nitrogen in the air. Emission of heavy metals is due to the metal content in reducing agent used. Particles are also emitted during the production process. PAHs and dioxins are not reported or calculated.

###### 4.4.6.1.2. Method

*CO<sub>2</sub>*

Emission figures are annually reported from the plant to the Norwegian Environment Agency. The figures are calculated by using the emission factor 0.415 tonnes CO<sub>2</sub>/tonne soda ash used in the production process.

*SO<sub>2</sub>*

Emission figures of SO<sub>2</sub> are reported from the plant to the Norwegian Environment Agency based on continuous measurements. Flue gas treatment is installed at the plant.

*NO<sub>x</sub>*

Emission figures of NO<sub>x</sub> are annually reported from the plant to the Norwegian Environment Agency. The emission figures are based on calculations.

*NH<sub>3</sub>*

Emission figures based on calculations are annually reported from the plant to the Norwegian Environment Agency.

*Particles*

Emission figures for particles have been reported to the Norwegian Environment Agency since 1992. Emissions in 1990 and 1991 are assumed to be the same as the reported figure in 1992. The emission permit sets requirements to emissions from the melting furnace, transport, crushing and packing of the raw materials and products. The Norwegian Environment Agency assumes that the particles emitted are smaller than PM<sub>2.5</sub>. This means that TSP=PM<sub>10</sub>=PM<sub>2.5</sub> is used in the inventory.

*Heavy metals and POPs*

Emission figures for Cu have been reported to the Norwegian Environment Agency since 1990. Reported figures for Cd, Hg and Pb were available from 1990-1994, but because of low emissions the plant stopped reporting these metals.

###### 4.4.6.1.3. Uncertainties

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

*Particles*

The particle size distribution used is only an assumption and we can not preclude that the distribution might be different than the one suggested. The particle size distribution can therefore only be seen as an estimate.

**4.4.6.1.4. Completeness**

Major missing emission components are not likely.

**4.4.6.1.5. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

**4.4.6.2. Production of zinc****4.4.6.2.1. Description**

One plant in Norway produces zinc. SO<sub>2</sub>, particles and heavy metals are emitted during the process. Emission of SO<sub>2</sub> originates from the sulphur in the reducing agent used.

**4.4.6.2.2. Method***SO<sub>2</sub>*

The plant reports emission figures to the Norwegian Environment Agency. The SO<sub>2</sub> emissions are estimated from infrequent measurements combined with calculations.

*Particles*

Emission figures for particles have been reported since 1991. Emissions for 1990 are assumed to be the same as the reported figure for 1991. It is assumed that of the particles emitted, 90 per cent is PM<sub>10</sub> and 80 per cent is PM<sub>2.5</sub> (Institute of environmental and energy technology 2002) and this particle size distribution is used in the Norwegian inventory.

*Heavy metals and POPs*

The plant reports emission figures for Cd, Pb, Hg, Cu, Cr and As. Reported figures exist since 1992, and emissions in 1990 and 1991 are assumed to be the same as reported figures in 1992.

Figures are not reported for PAH and dioxins.

**4.4.6.2.3. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**4.4.7. Manufacture of anodes***IPCC 2C5**NFR 2C5*

*Last update: 21.05.2013*

**4.4.7.1. Description**

Four plants in Norway produce anodes. Three plants produce prebaked anodes and one plant produces coal electrodes. These are alternatives to the use of coal and coke as reducing agents in the production process for aluminium and ferroalloys. The anodes and coal electrodes are produced from coal and coke. The production of anodes and coal electrodes leads to emissions of CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, PAH and heavy metals.



#### 4.4.7.2. Method

##### *CO<sub>2</sub>*

The emissions of CO<sub>2</sub> from the production of anodes are calculated by each plant and the method is based on the Aluminium Sector Greenhouse Gas Protocol by the International Aluminium Institute (International Aluminium Institute 2005). The fourth plant produces coal electrodes and Söderberg anodes for ferroalloy production. The emissions are calculated from the consumption of anthracite and petrol coke. In addition, pitch is included in production. The calculations of CO<sub>2</sub> from processes are uptime in hours multiplied with emission factors for each feedstock. For calcinations of anthracite the emission factor is 167 kg CO<sub>2</sub> per uptime hour and for petrol coke 238 kg CO<sub>2</sub>. In addition there is an emission from energy use that is reported in the energy sector.

##### *SO<sub>2</sub> and NO<sub>x</sub>*

Emission figures of SO<sub>2</sub> are based on measurements while NO<sub>x</sub> emissions are calculated by the plants and reported to the Norwegian Environment Agency.

##### *Particles*

Production of anodes leads to emission of particles. One of the plants has reported emissions since 1990, while the other one has reported since 1992. Emission figures for 1990 and 1991 are assumed to be the same as the reported figure in 1992 for this plant. The Norwegian Environment Agency assumes that the particles emitted are smaller than PM<sub>10</sub>, but also expects some to be smaller than PM<sub>2.5</sub>. No information has been found regarding the particle size distribution, so in lack of other data we use the same distribution profile as used for production of aluminium where PM<sub>10</sub> is 97 per cent of TSP and PM<sub>2.5</sub> is 43 per cent of TSP.

##### *PAH*

Emission figures for PAH are based on measurements and reported from both plants to the Norwegian Environment Agency. One plant has developed a new and better method for measuring PAH. This method is used for the period 1992 to 2003. The reported figures of PAH are assumed to be according to the Norwegian standard (NS9815). Measurements from production of Soederberg paste (at three Norwegians plants) and a PAH-profile of baked anodes from EPA are used to derive a PAH-profile to find the emission of PAH-OSPAR and PAH-4. Based on these profiles it is assumed that PAH-OSPAR and PAH-4 account for respectively 25 per cent and 5 per cent of the total PAH emissions (table 4.20).

**Table 4.20. Distribution of PAH emissions from production of anodes. Ratio**

Component	Distribution of PAH emissions (ratio)
PAH (Norwegian standard) .....	1
PAH-6 (Ospar) .....	0.25
PAH-4 (CLRTAP) .....	0.05

Source: Norwegian pollution control authority (1999b).

##### *Heavy metals*

Production of anodes leads to emission of heavy metals due to the metal content in the reducing agents (coke and coal). Emission figures are based on measurements and are reported for arsenic and mercury from one plant since 2001, and for lead since 2004. Emission figures have not been measured or reported before 2001 for As and Hg and before 2004 for Pb, and are therefore not available for previous years. Historical emission figures back to 1990 are assumed to be the same as reported figures for 2001 for As and Hg and 2004 for Pb.

#### 4.4.7.3. Uncertainties

Historical calculations of heavy metals from 1990 to 2001 are very uncertain since they are assumed to be the same as reported figures for the first year of reporting (2001). Annual changes in production volumes, coke quality and the amount of heavy metals in the reducing agents are not taken into account, and the historical emissions can only be seen as an estimate in lack of better data.

**4.4.7.4. Completeness**

Major missing emission components are not likely.

**Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

**4.5. Other production**

*IPCC 2D*

*NFR 2D*

**4.5.1. Pulp and paper**

*IPCC 2D1*

*NFR 2D1*

*Last update: 21.05.2013*

**4.5.1.1. Description**

Pulp and paper production has three major processing steps; pulping, bleaching and paper production. Kraft (sulphate) pulping is the most widely used pulping process and is generally used to produce strong paper products. The Kraft pulping process includes bleaching, chemical recovery and by-products recovery. The sulphite pulping is another chemical pulping process. It produces a weaker paper than some other types of pulping, but the pulp is less coloured, making it more suitable for printing, often with little bleaching. In Norway, SO<sub>2</sub> and particles are reported emitted from production of pulp and paper. In the Kraft pulping process, sodium sulphide and sodium hydroxide are used to chemically dissolve the lignin that binds the cellulose fibres, and in the acid sulphite pulping process, sulphurous acid solution is used. SO<sub>2</sub> is emitted in these processes. There are also reported non-combustion CO<sub>2</sub> emissions from two plants in this sector. The emissions originate from use of limestone.

**4.5.1.2. Method**

*CO<sub>2</sub>*

The CO<sub>2</sub> emissions are calculated by multiplying the amount of limestone by an emission factor. For the years 1990-97 the emissions are calculated by the Norwegian Environment Agency based upon activity data reported to the Norwegian Environment Agency by the plant and emission factor. The emissions in the period 1998-2004 are reported in the plant's application for CO<sub>2</sub>-permits within the Norwegian emissions trading scheme. From 2005 and onwards, the plant reports the emissions through the annual reporting under the emissions trading scheme.

*SO<sub>2</sub>*

Emission figures are reported from producers of chemical pulp to the Norwegian Environment Agency. SO<sub>2</sub> is measured continuously and emission estimates are made from these measurements.

*Particles*

Four plants producing pulp and paper, report non-combustion emissions of particles to the Norwegian Environment Agency. Two of these plants have not reported emission figures from combustion and it is assumed that the reported non-combustion emission figures include emissions from combustion. It varies when the plants started reporting emission figures for particles, and due to lack of data, emission for those years is assumed to be the same as in the first year of reporting.

Two of the plants state that they clean the emissions by electric filter and wet scrubbers, and it is assumed by the Norwegian Environment Agency that the particles emitted are smaller than PM<sub>2.5</sub>. The other two clean their emissions using

only wet scrubbers, and it is assumed the particles are smaller than PM<sub>10</sub>. According to TNO (Institute of environmental and energy technology 2002), PM<sub>2.5</sub> is 20 per cent of PM<sub>10</sub> and PM<sub>10</sub> is the same as TSP.

#### 4.5.1.3. Activity data

##### CO<sub>2</sub>

Activity data are reported by the plant to the Norwegian Environment Agency. The amount of limestone is calculated from purchased amount, adjusted for the amount of limestone in storage at the beginning and end of the year.

#### 4.5.1.4. Emission factor

##### CO<sub>2</sub>

The emission factor used in the calculation is 0.44 tonne CO<sub>2</sub> per tonne limestone.

#### 4.5.1.5. Uncertainties

Uncertainty estimates for emission of CO<sub>2</sub> are given in Appendix D.

The particle size distribution used is not plant specific and might therefore be different from the one suggested by TNO.

#### 4.5.1.6. Completeness

Major missing emission components are not likely.

#### 4.5.1.7. Source specific QA/QC

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

### 4.5.2. Food and Drink

IPCC 2D2, Key Category for CO<sub>2</sub>

NFR 2D2

Last update: 18.03.2014

#### 4.5.2.1. Description

This source category includes NMVOC emissions from production of bread and beer, CO<sub>2</sub> from carbonic acid mainly used in breweries, export of captured CO<sub>2</sub> and CO<sub>2</sub> from production of bio protein. Emissions of NMVOC from spirit manufacture are considered insignificant and are not included in the inventory.

#### 4.5.2.2. Production of bread and beer

##### 4.5.2.2.1. Method

###### NMVOC

Production of bread and beer (and other similar yeast products) involves fermentation processes that lead to emission of NMVOC (ethanol). Emissions are calculated based on production volumes and emission factors.

##### 4.5.2.2.2. Activity data

Production volumes of bread and beverages are annually reported to Statistics Norway.

##### 4.5.2.2.3. Emission factors

The emission factors are taken from EEA (1996).

**Table 4.21. NMVOC emission factors from production of bread and beverage**

	Emission factor	Unit
Production of bread .....	0.003	tonnes/tonnes produced
Production of beverage .....	0.2	kg/1000 litres

Source: EEA (1996).

**4.5.2.2.4. Uncertainties**

The emission factors used are recommended by EEA (1996) and are not specific for Norwegian conditions.

**4.5.2.2.5. Completeness**

Major missing emission components are not likely.

**4.5.2.2.6. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure. The specific QA/QC carried out in 2006 for greenhouse gases from industrial processes is described in Appendix I.

**4.5.2.3. Carbonic acid to breweries**

As mentioned under section 4.3.1.1, some CO<sub>2</sub> from ammonia production is used as carbonic acid in carbonated beverages. During the ammonia production, CO<sub>2</sub> is generated and then captured and sold to other companies in Norway or exported. Most of it is sold for lemonade production. All of the emissions are reported under this source, although the largest part of the emissions takes place after the bottles are opened, and not in the breweries. Also exported CO<sub>2</sub> is included in the Norwegian emission inventory.

The figures are based on the sales statistics from the ammonia producing plant.

**4.5.2.4. Production of bio protein**

CO<sub>2</sub> emissions from production of bio protein from natural gas at one plant 2001-2005 are included. The bio protein was used as animal fodder. Emission data reported from the plant to the Norwegian Environment Agency are used.

**4.6. Consumption of halocarbons and SF<sub>6</sub>**

*IPCC 2F, Key category for HFC*

*NFR -*

*Last update: 15.04.2014*

**4.6.1. HFCs and PFCs from products and processes****4.6.1.1. Description**

HFCs and PFCs can be used as substitutes for ozone depleting substances (CFCs and HCFCs) that are being phased out according to the Montreal Protocol. They are used in various applications, including refrigeration and air conditioning equipment, as well as in foam blowing, fire extinguishers, aerosol propellants and for analysing purposes. There is no production of HFCs and PFCs in Norway (however, PFCs are emitted as a by-product during the production of aluminium, see chapter 4.4.3). HFCs and PFCs registered for use in Norway are HFC-23, HFC-32, HFK-125, HFC-134, HFC-134a, HFC-143, HFC-143a, HFC-152a, HFC-227ea and PFC-218. The most significant gases, measured in CO<sub>2</sub> equivalents are HFC-134a, HFC-143a and HFC-125. Measured in metric tonnes emissions of the low-GWP HFC-152a are also significant. Due to high taxation, the use of PFCs in product-applications is very low.

In January 2003 a tax on import and production of HFC and PFC was introduced. In July 2004 this tax was supplemented with a refund system for the destruction of used gas. From January 2014, the tax has been 330 NOK (approximately 40 Euro) per tonnes of CO<sub>2</sub> equivalents. In May 2010, EU regulation (EC) No 842/2006 on certain fluorinated greenhouse gases was included in Norwegian legislation.

**4.6.1.2. Method**

Actual emissions of HFCs and PFCs are calculated using the Tier 2 methodology. This methodology takes into account the time lag in emissions from long lived sources, such as refrigerators and air-conditioning equipment. The chemicals slowly leak out from seams and ruptures during the lifetime of the equipment. The

leakage rate, or emission factor, varies considerably depending on type of equipment. Bjønness (2013) gives a more thorough description of the methodology.

Potential emissions are calculated employing the Tier 1b methodology, which only considers the import, export and destruction of chemicals in bulk and in products without time lag. The ratio between potential (Tier 1b) and actual emissions (Tier 2) has decreased from about 3:1 before 2000 to 5:4 in 2012.

#### **4.6.1.3. Activity data**

There is no production of HFC or PFC in Norway. Hence all emissions of these chemicals are originating from imported chemicals. The methodology requires that annual imported amounts of each chemical are obtained by source category. Various data sources are used.

Amounts of chemicals imported in bulk were up to 2009 obtained from the Norwegian Environment Agency. After 2009 bulk data are collected from the Norwegian Directorate of Customs and Excise.

Time series for imported and exported amounts of chemicals in products are based on collected data for some years, and data previous to and between these years are estimated. For the years 1995-1997 data were collected through a survey performed in 1999 (Rypdal 1999). Data on imports from customs statistics were collected for the years 2005-2006 and 2010-2012. They are collected annually after 2011.

Amounts of chemicals destructed after collection from retired equipment are annually reported to Statistics Norway from the company in charge of the destruction.

Bjønness (2013) gives a more thorough description of the activity data. A provisional distribution of chemicals by application category was used for 2012, based on the 2011 distribution. The totals per gas, however, were collected from the Norwegian Directorate of Customs and Excise.

#### **4.6.1.4. Emission factors**

Leakage rates and product lifetimes used in the calculations are shown in table 4.22.

**Table 4.22. Emission factors for HFCs from products and lifetime of products**

Source category	Lifetime (years)	Production/initial emission (per cent of initial charge)	Lifetime emission (per cent of initial charge/year)
<b>Refrigeration</b>			
Domestic Refrigeration .....	15 <sup>1</sup>	NO	0,5 <sup>1</sup>
Commercial Refrigeration			
- Stand-alone Commercial Applications .....	10 <sup>1</sup>	NO	3,5 <sup>1</sup>
- Medium and Large Commercial Refrigeration .	15 <sup>1</sup>	2 <sup>1</sup>	10 <sup>1</sup>
Transport Refrigeration .....	9 <sup>1</sup>	1 <sup>1</sup>	20 <sup>1</sup>
Industrial Refrigeration .....	15 <sup>1</sup>	2 <sup>1</sup>	10 <sup>1</sup>
Residential and Commercial A/C, including heat pumps .....	15 <sup>1</sup>	1 <sup>1</sup>	4 <sup>1</sup>
Mobile Air-Conditioning .....	12 <sup>1</sup>	NO	NA
<b>Foam</b>			
Hard Foam .....	20 <sup>1</sup>	5 <sup>1</sup>	4,5 <sup>1</sup>
Soft Foam .....	NO	NO	NO
<b>Fire protection</b> .....	15 <sup>1</sup>	2 <sup>2</sup>	5 <sup>1</sup>
<b>Aerosols</b>			
Metered Dose Inhalers .....	2 <sup>1</sup>	NO	50 <sup>1</sup>
Other aerosols .....	2 <sup>1</sup>	NO	50 <sup>1</sup>
<b>Solvents</b> .....	2 <sup>1</sup>	NO	50 <sup>1</sup>

<sup>1</sup>IPCC 1996<sup>2</sup>Country specific SFT 99:03

#### 4.6.1.5. Uncertainties

In 2006, the uncertainties of the different components of the national greenhouse gas inventory were evaluated in detail by Statistics Norway (See Appendix D). Both the leakage rate (emission factor) and the stored amount of chemicals (activity data) are considered quite uncertain. The total uncertainties for the emission estimates for consumption of halocarbons are estimated to be  $\pm 50$  per cent for both HFCs and PFCs.

#### 4.6.1.6. Completeness

Major missing emission sources are not likely

#### 4.6.1.7. Source specific QA/QC

In addition to the general QA/QC procedures (see section 1.5), the consistency of time series are checked for both activity data and emissions. The time series are checked for each individual HFC/PFC and application category.

### 4.6.2. Emissions of SF<sub>6</sub> from products and processes

#### 4.6.2.1. Description

SF<sub>6</sub> is used as an insulation medium in high tension electrical equipment including gas insulated switchgear (GIS) and circuit breakers. There is no production of SF<sub>6</sub> in Norway. In March 2002, a voluntary agreement was signed between the Ministry of Environment and the most important users and producers of GIS (gas-insulated switchgear). According to this agreement, emissions from this sector should be reduced by 13 per cent in 2005 and 30 per cent in 2010 with 2000 as base year. For the following up of this agreement, the users (electricity plants and distributors) and producer (one factory) have reported yearly to the government. This voluntary agreement was terminated successfully in 2010, but a continuation is being discussed.

#### 4.6.2.2. Method

The general methodology for estimating SF<sub>6</sub> emissions was revised in 1999 (Norwegian pollution control authority 1999a), while the sector-specific methodology for GIS was revised in the 2010 reporting based on new information

from the agreement. The current method for GIS is largely in accordance with the Tier 3a methodology in the IPPC Good Practice Guidance (IPCC 2000).

The method for other sources is largely in accordance with the Tier 2 methodology in the IPPC guidelines for emission inventories (IPCC 1997b, a). For tracer gas, production of semiconductors, medical use and other minor uses, the activity data are annual consumption as estimated in (Norwegian Pollution Control Authority 1999a). However, for tracer gas some major research projects expired in 2001 and 2006, respectively, and the consumption has been reduced. For sound-insulating windows and footwear, the emissions are calculated from estimated stock of SF<sub>6</sub> in the products, and from production of windows. Footwear with SF<sub>6</sub> was imported, and the use ended in 2001. Activity data are annual additions of SF<sub>6</sub> to the product stock, as estimated in (Norwegian Pollution Control Authority 1999a). The calculations take into account imports, exports, recycling, accumulation in bank, technical lifetimes of products, and different rates of leakage from processes, products and production processes. From 2003 and onwards emission estimates reported directly from users and producers, according to the voluntary agreement, are important input.

Emissions from production of GIS (one factory) were included for the first time in 2003. The company has, as part of the voluntary agreement with the Ministry of the Environment, made detailed emission estimates back to 1985. These emissions constitute a significant part of national emissions of SF<sub>6</sub>. In recent years emissions rates have been considerably reduced due to new investments and better routines. The company now performs detailed emission calculations based on accounting of the SF<sub>6</sub> use throughout the whole production chain.

#### 4.6.2.3. Activity data

Data are collected from direct consultations with importers and exporters of bulk chemicals and products containing SF<sub>6</sub>, and from companies that use SF<sub>6</sub> in various processes.

#### 4.6.2.4. Emission factors

Leakage rates and product lifetimes used in the calculations are shown in tables 4.23 and 4.24.

**Table 4.23. Yearly rate of leakage of SF<sub>6</sub> from different processes**

Emission source	Leakage rate (per cent of input of SF <sub>6</sub> )
Secondary magnesium foundries .....	100
Tracer gas in the offshore sector .....	0
Tracer gas in scientific experiments .....	100
Production of semiconductors .....	50
Medical use (retinal surgery) .....	100
Production of sound-insulating windows .....	2
Other minor sources .....	100

Source: Norwegian pollution control authority (1999a).

**Table 4.24. Product lifetimes and leakage rates from products containing SF<sub>6</sub>**

Product emission source	Yearly rate of leakage (per cent of remaining content)	Product lifetime (years)
Gas-insulated switchgear (GIS) .....	1	30
Sealed medium voltage switchgear .....	0.1	30
Electrical transformers for measurements ..	1	30
Sound-insulating windows .....	1	30
Footwear (trainers) .....	25	9
Other minor sources .....	..	..

Source: Norwegian pollution control authority (1999a).

#### 4.6.2.5. Completeness

Major missing emission components are not likely.

#### 4.6.2.6. Source specific QA/QC

During the work on the new methodology for 2004 emissions, historical data were recalculated, emission factors from different sources were established and the bank of SF<sub>6</sub> in existing installations was estimated. For GIS, information from the industry, attained through the voluntary agreement with the Ministry of the Environment, was important input in this recalculation.

### 4.7. Other: Lubricants and waxes

IPCC 2G

NFR-

Last update: 08.01.2008

#### 4.7.1. Paraffin wax use

##### 4.7.1.1. Description

Paraffin waxes are produced from crude oil and used in a number of different applications, including candles, tapers and the like. Combustion of such products results in emissions of fossil CO<sub>2</sub>.

##### 4.7.1.2. Method

Emissions of CO<sub>2</sub> from the burning of candles, tapers and the like are calculated using a modified version of equation 5.4 for Waxes – Tier 1 Method of the 2006 IPCC Guidelines:

$$(4.13) \text{ Emissions} = PC \cdot PF \cdot CC_{wax} \cdot 44/12$$

Where:

CO<sub>2</sub> Emissions = CO<sub>2</sub> emissions from waxes, tonne CO<sub>2</sub>

PC = total candle consumption, TJ

PF = fraction of candles made of paraffin waxes

CC<sub>wax</sub> = carbon content of paraffin wax (default), tonne C/TJ (Lower Heating Value basis)

44/12 = mass ratio of CO<sub>2</sub>/C

Consumption figures on paraffin wax are multiplied by the default net calorific values (NCV) given in the 2006 IPCC Guidelines. Net consumption in calorific value is then converted to carbon amount, using the value for carbon content (Lower Heating Value basis) and finally to CO<sub>2</sub> emissions, using the mass ratio of CO<sub>2</sub>/C.

##### 4.7.1.3. Activity data

Statistics Norway collects data on import, export and sold amounts of "Candles, tapers and the like (including night lights fitted with a float)". Using these data, net consumption of paraffin waxes and other candle waxes (including stearin) can be calculated.

##### 4.7.1.4. Emission factors

Parameter values used in the emissions calculations are given in table 4.25.

**Table 4.25. Parameters employed when calculating emission figures**

Parameters	Factor	Unit
Net calorific value (NCV) .....	40.20	TJ/Gg
Carbon content (CC <sub>wax</sub> , Lower Heating Value basis) ...	20.00	tonnes C/TJ = kg C/GJ
Mass ratio of CO <sub>2</sub> /C .....	3.67	-
Fraction of paraffin wax (PF) .....	0.66	-

The assumption of 0.66 as the fraction of all candles being made of paraffin waxes is based on estimates obtained in 2007 from one major candle and wax importer (estimating approx. 0.5) and one Norwegian candle manufacturer (estimating approx. 0.8). The importer estimated the fraction to be about 5 per cent higher in



1990. However, since this possible change is considerably smaller than the difference between the two fraction estimates, we have chosen to set this factor constant for the whole time series. The fraction of paraffin waxes has probably varied during the period, as it, according to the importer, strongly depends on the price relation between paraffin wax and other, non-fossil waxes. However, at present we do not have any basis for incorporating such factor changes.

Furthermore, we assume that practically all of the candle wax is burned during use, so that emissions due to incineration of candle waste are negligible.

#### **4.7.1.5. Uncertainties**

According to the 2006 IPCC Guidelines, the default emission factors are highly uncertain. However, the default factor with the highest uncertainty is made redundant in our calculations, due to the level of detail in our activity data.

#### **4.7.1.6. Completeness**

Emissions from the incineration of products containing paraffin wax, such as wax coated boxes, are covered by emission estimates from waste incineration.

#### **4.7.1.7. Source specific QA/QC**

There is no specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

## 5. Solvent and other product use

IPCC 3

NFR 3

### 5.1. Overview

This chapter describes emissions from solvents and other products. Use of solvents and products containing solvents result in emissions of non-methane volatile organic compounds (NMVOC), which are regarded as indirect greenhouse gases. The NMVOC emissions will over a period of time in the atmosphere oxidise to CO<sub>2</sub>.

In addition to solvents emitting NMVOC, there are other products that emit other volatile components. Creosote treated materials and tarry jointing paste cause emissions of PAH (poly-aromatic hydrocarbons). PAH and dioxins are also emitted during production of asphalt. Emissions of N<sub>2</sub>O from anaesthesia procedures and propellants, mercury from mercury-containing products as well as emissions from combustion of tobacco are also included in the Norwegian inventory.

### 5.2. Solvent losses (NMVOC)

IPCC 3A, 3B 3C and 3D

NFR 3A, 3B, 3C and 3D

Last update: 13.01.2014

#### 5.2.1. Method

Our general model is a simplified version of the detailed methodology described in chapter 6 of the EMEP/CORINAIR Guidebook 2007 (EEA 2007). It represents a mass balance *per substance*, where emissions are calculated by multiplying relevant activity data with an emission factor. For better coverage, point sources reported from industries to the Norwegian Environment Agency and calculated emissions from a side model for cosmetics are added to the estimates. For a detailed description of method and activity data, see Holmengen and Kittilsen (2009).

It is assumed that all products are used the same year as they are registered, and substances are not assumed to accumulate in long-lived products. In other words, it is assumed that all emissions generated by the use of a given product during its lifetime take place in the same year as the product is declared to our data source, the Norwegian Product Register. In sum, this leads to emission estimates that do not fully reflect the actual emissions taking place in a given year. Emissions that in real life are spread out over several years all appear in the emission estimate for the year of registration. However, this systematic overestimation for a given year probably more or less compensates for emissions due to previously accumulated amounts not being included in the estimate figures.

No official definition of solvents exists, and a list of substances to be included in the inventory on NMVOC emissions was thus created. The substance list used in the Swedish NMVOC inventory (Skårman *et al.* 2006) was used as a basis. This substance list is based on the definition stated in the UNECE Guidelines<sup>12</sup>. The list is supplemented by NMVOC reported in the UK's National Atmospheric Emissions Inventory (NAEI) (AEA 2007). The resulting list comprises 678 substances. Of these, 355 were found in the Norwegian Product Register for one or more years in the period 2005-2007.

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<sup>12</sup> "Volatile compound (VOC) shall mean any organic compound having at 293.15 degrees K a vapor pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use."

### *Cosmetics*

Cosmetics are not subject to the duty of declaration. The side model is based on a study in 2004, when the Norwegian Environment Agency calculated the consumption of pharmaceuticals and cosmetics (Norwegian pollution control authority 2005a). The consumption was calculated for product groups such as shaving products, hair dye, body lotions and antiperspirants. The consumption in tonnes each year is calculated by using the relationship between consumption in Norwegian kroner and in tonnes in 2004. Figures on VOC content and emission factors for each product group were taken for the most part from a study in the Netherlands (IVAM 2005), with some supplements from the previous Norwegian solvent balance (the previous NMVOC emission model).

### *NMVOC and CO<sub>2</sub>*

The use of solvents leads to emissions of non-methane volatile organic compounds (NMVOC) which is regarded as an indirect greenhouse gas. The NMVOC emissions will over a period of time in the atmosphere oxidise to CO<sub>2</sub>, which is included in the total greenhouse gas emissions reported to UNFCCC (see chapter 1.9).

## **5.2.2. Activity data**

The data source is the Norwegian Product Register. Any person placing dangerous chemicals on the Norwegian market for professional or private use has a duty of declaration to the Product Register, and import, export and manufacturing is reported annually. The only exception is when the amount of a given product placed on the market by a given importer/producer is less than 100 kg per year.

The information in the data from the Product Register makes it possible to analyse the activity data on a substance level, distributed over product types (given in UCN codes; (The Norwegian product register 2007)), industrial sectors (following standard industrial classification (NACE), including private households (no NACE), or a combination of both. As a consequence, the identification of specific substances, products or industrial sectors that have a major influence on the emissions is greatly facilitated.

### *Cosmetics*

The side model for cosmetics is updated each year with data on from the Norwegian Association of Cosmetics, Toiletries and Fragrance Suppliers (KLF).

### *Point sources*

Data from nine point sources provided by the Norwegian Environment Agency are added to the emissions estimates. The point sources are reported from the industrial sector "Manufacture of chemicals and chemical products" (NACE 20). In order to avoid double counting, NMVOC used as raw materials in this sector are excluded from the emission estimates from the Product Register data.

## **5.2.3. Emission factors**

Emission factors are specific for combinations of product type and industrial sector. Emission factors from the Swedish model for estimating NMVOC emissions from solvent and other product use (Skårman *et al.* 2006) are used. The emission factors take into account different application techniques, abating measures and alternative pathways of release (e.g. waste or water). These country-specific emission factors apply to 12 different industries or activities that correspond to sub-divisions of the four major emission source categories for solvents used in international reporting of air pollution (EEA 2007).

It is assumed that the factors developed for Sweden are representative for Norwegian conditions, as we at present have no reason to believe that product types, patterns of use or abatement measures differ significantly between the two countries. Some adjustments in the Swedish emission factors were made when the model was first developed (see Holmengen and Kittilsen (2009)) and several improvements of single emissions factors have been made in the following years.

In accordance with the Swedish model, emission factors were set to zero for a few products that are assumed to be completely converted through combustion processes, such as EP-additives, soldering agents and welding auxiliaries. Quantities that have not been registered to industrial sector or product type are given emission factor 0.95 (maximum). Emission factors may change over time, and such changes may be included in this model. However, all emission factors are at the moment constant for all years.

#### 5.2.4. Uncertainties

##### *Uncertainty in emission factors*

The emission factors are more detailed in the new NMVOC model than in the previous model, as this model can take into account that emissions are different in different sectors and products, even when the substance is the same. However, for this to be correct, a thorough evaluation of each area of use is desirable, but not possible within a limited time frame. Thus, the emission factor is set with general evaluations, which leads to uncertainty.

The emission factors are taken from several different sources, with different level of accuracy. The uncertainties in emission factors depend on how detailed assessment has been undertaken when the emission factor was established. Some emission factors are assumed to be unbiased, while others are set close to the expected maximum of the range of probable emission factors. This, together with the fact that the parameter range is limited, gives us a non-symmetrical confidence interval around some of the emission factors. For each emission factor we thus have two uncertainties; one negative (n) and one positive (p). These are aggregated separately, and the aggregated uncertainty is thus not necessarily symmetrical.

##### *Uncertainty in activity data*

For the activity data, the simplified declarations and the negative figures due to exports lead to known overestimations, for which the uncertainty to a large extent is known. A more elaborate problem in calculations of uncertainty is estimating the level of omissions in declaration for products where the duty of declaration does apply. In addition, while declarations with large, incorrect consumption figures are routinely identified during the QA/QC procedure, faulty declarations with small consumption figures will only occasionally be discovered. There is however no reason to believe that the Product Register data are more uncertain than the data source used in the previous model (statistics on production and external trade), as similar QA/QC routines are used for these statistics.

The errors in activity data are not directly quantifiable. Any under-coverage in the Product Register is not taken into account. Skårman *et al.* (2006) found that the activity data from the Swedish Product register had an uncertainty of about 15 per cent. The Norwegian Product Register is assumed to be comparable to the Swedish, and thus the uncertainty in the activity data is assumed to be 15 per cent. For some products, simplified declarations give an indication of maximum and minimum possible amounts. In these cases, the maximum amount is used, and the positive uncertainty is set to 15 per cent as for other activity data, while the negative uncertainty is assumed to be the interval between maximum and minimum amount. All activity data are set to zero if negative.

For a detailed description of the uncertainty analysis, see Holmengen and Kittilsen (2009). The variance of total emission was estimated from the variance estimates obtained for emission factors and activity data, using standard formulas for the variance of a sum and the variance of a product of independent random variables. The aggregated uncertainties in level and trend are given in table 5.1 and 5.2.

**Table 5.1. Uncertainty estimates for level of NMVOC emissions, 2005-2007. Tonnes and per cent**

Uncertainty in level	Negative (n)	Negative (n) (per cent of total emissions)	Positive (p)	Positive (p) (per cent of total emissions)
2005 .....	2 288	4.58	1 437	2.88
2006 .....	1 651	3.70	1 103	2.47
2007 .....	1 299	2.79	1 168	2.51

**Table 5.2. Uncertainty estimates for trend in NMVOC emissions, 2005-2007. Tonnes**

Uncertainty in trend	Negative (n)	Positive (p)	95% confidence interval for change
2005-2006 .....	2 135	1 067	(-7 366 , -4 164)
2006-2007 .....	1 420	947	(407 , 2 774)
2005-2007 .....	1 882	1 076	(-5 286 , -2 328)

### 5.2.5. Completeness

No major missing emission sources are likely.

### 5.2.6. Source specific QA/QC

- Large between-year discrepancies in the time series of substance quantities are routinely identified and investigated, in order to correct errors in consumption figures.
- Large within-year discrepancies between minimum and maximum quantities in simplified declarations are routinely identified and investigated, in order to prevent overestimation for substances where consumption figures are given in intervals.
- Large within-year discrepancies between totals for industrial sectors (NACE) and totals for products (UCN) are routinely identified and investigated, in order to detect erroneous or incomplete industrial sectoral and product type distribution.

## 5.3. Use of solvents

*IPCC -*

*NFR 3C*

*Last update: 01.09.2005*

### 5.3.1. Creosote-treated materials

#### 5.3.1.1. Description

Creosote is mainly used in quay materials and conduction poles, but also in fence poles and roof boards. In Norway there is a requirement that all creosote in use should contain less than 50 mg/kg benzo(a)pyren (Miljøverndepartementet 2004). PAH-components will evaporate from the creosote-treated materials in hot weather. In addition, PAH-components will evaporate during impregnation. The smallest PAH-components, like naphthalene, are most volatile, but several components used in wood treatment will not evaporate.

#### 5.3.1.2. Method

Emissions of PAH are calculated based on the import of creosote oil and emission factors. For simplicity, it is assumed that all PAH is emitted the same year as the materials are produced.

#### 5.3.1.3. Activity data

Data on imported amounts of creosote oil are taken from Statistics Norway's statistics on external trade.

**5.3.1.4. Emission factors**

The emission factor used is taken from (Finstad *et al.* 2001). It is assumed that imported creosot oil contains on average 55 per cent PAH and that one per cent will evaporate during the lifetime of the creosot-treated materials.

**5.3.1.5. Uncertainties**

In the inventory it is assumed that all PAH is emitted the same year as the materials are used. This is however not the case, since PAH will be emitted as long as the creosote-treated materials are in use. However, most of it is likely to be emitted during the first years.

**5.3.1.6. Completeness**

No major missing emission components or sources are likely.

**5.3.1.7. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

**5.3.2. Tarry jointing paste****5.3.2.1. Description**

Tarry jointing paste is resistant to oil and fuels, and is therefore used in concrete constructions where spills of such products can occur, e.g. in joints in bridges, auto repair shops and airports. Tarry jointing paste contains PAH-components that can evaporate to air.

**5.3.2.2. Method**

The Norwegian institute for air research (NILU) and the Norwegian institute for water research (NIVA) (1995) have estimated an annual emission of 125 kg PAH/year. This estimation is based on imported tarry paste and a tar content of 16 per cent. This kind of jointing paste is mainly used at airports. There is no available PAH-profile for this emission, and due to the lack of data, the same PAH-profile as that of asphalt production is used (table 5.3). The emission is assumed to be rather constant each year.

**Table 5.3. Emission of PAH from use of tarry jointing paste<sup>1</sup>. kg PAH/year**

Norwegian standard 9815	125
Borneff (PAH-6) .....	3
LRTAP (PAH-4) .....	0.0

<sup>1</sup> Emission factors are from production of asphalt.

**5.3.2.3. Uncertainties**

There is uncertainty regarding the PAH-profile since in lack of a specific profile, the same PAH-profile as for asphalt production is used.

**5.3.2.4. Completeness**

There are a couple of very minor sources of PAH that are not included in the Norwegian inventory. PAH-containing products are used in tar paper and fishing nets. According to NILU/NIVA (1995), the annual emissions are low. In Rypdal and Mykkelbost (1997), emission factors of 0.3 g/tonnes and 28 g/tonnes are given for tar paper and fishing net respectively, but emissions from these sources are not included in the inventory.

Also anticorrosive paint used for treatment of ships and platforms is a potential source of PAH emissions. In Rypdal and Mykkelbost (1997), emission factors of 7.5 mg/ship/year at shipyard, 1.9 mg/ship/year at harbour and 96 mg/ship/year in service are given. This presupposes treatment every third year. The emissions are low compared to other sources, and are not included in the inventory.

### 5.3.2.5. Source specific QA/QC

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

## 5.4. Production of asphalt

IPCC -

NFR 3C

Last update: 01.09.2005

### 5.4.1. Method

PAH

Most of the asphalt produced in Norway uses the batch-method (Haakonsen *et al.* 1998). Emissions are calculated by multiplying the amount of asphalt produced with an emission factor.

Dioxins

Asphalt preparations and asphalt recycling are supposed to be a possible dioxin source, especially in countries using extensive recycling, and that use salt on the roads during winter. A lot of salt is used on Norwegian roads during winter, and when this asphalt is heated during recycling, it is assumed to give emissions of dioxins (Hansen 2000).

### 5.4.2. Activity data

The activity data used is production of asphalt in Norway. In NILU/NIVA (1995), there is a figure of production of asphalt from 1991. The same figure is used for all years due to lack of better data.

### 5.4.3. Emission factors

PAH

NILU/NIVA (1995) estimated the emission of PAH to be 15 mg/tonne asphalt. This includes however naphthalene and other components not to be included in PAH after Norwegian standard (NS3815). However, if this emission factor is combined with speciation data from Jepsens miljøteknikk (1991), an emission factor of 2.8 mg/tonne is found. This agrees well with the emission factor 2.0 mg/tonne suggested by EPA (U.S. Environmental protection agency).

Dioxins

Two emission factors are found in the literature. OSPAR (The Oslo and Paris Convention) (Norwegian pollution control authority 2001) suggests an emission factor of 0.047 µg/tonne asphalt. This emission factor is however assumed to be very high since it is based on data from a plant only re-circulating old asphalt. Fyns Amt (2000) operates with a much lower emission factor, which probably reflects dioxin emissions from preparation of new asphalt. Since Norway both makes new asphalt and recycles old asphalt it is assumed that an emission factor in between those suggested from OSPAR and Fyns Amt would be most correct for Norwegian conditions (table 5.4).

**Table 5.4 Dioxin emission factor for asphalt production. µg I-TEQ/tonne produced asphalt**

Source	Emission factor
OSPAR (Norwegian pollution control authority 2001) ...	0.047
Fyns Amt (2000) .....	0.0022
Emission factor chosen .....	0.025

### 5.4.4. Uncertainties

The activity data used are from 1991, and due to lack of better information, the same figure has been used for all years. The emission factors used, both for estimating PAH and dioxins, are also uncertain. The annual emissions are low however, and will not have any impact on the total level of these types of emissions.

#### **5.4.5. Completeness**

No major missing emission components are likely.

#### **5.4.6. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### **5.5. Other product use**

*IPCC 3D*

*NFR 3D*

*Last update: 05.10.2011*

#### **5.5.1. Use of N<sub>2</sub>O in anaesthesia**

##### **5.5.1.1. Method**

N<sub>2</sub>O is used in anaesthesia procedures and will lead to emissions of N<sub>2</sub>O. The figures are based on N<sub>2</sub>O data from the two major producers and importers in 2000. Annual consumption is estimated on basis of these figures and the number of births and number of bed-nights in hospitals for each year.

##### **5.5.1.2. Activity data**

For this source, actual sale of N<sub>2</sub>O is used for the year 2000. Number of births and bed-nights in hospitals are annually taken from the Statistical yearbook of Norway.

##### **5.5.1.3. Emission factors**

As mentioned, no emission factors are used, since the figures are based on sales of N<sub>2</sub>O.

##### **5.5.1.4. Uncertainties**

The figures are uncertain. There may be small importers not included in Statistics Norway's telephone survey in 2000, but the emissions are small, so it is believed that the uncertainty is at an acceptable level.

##### **5.5.1.5. Completeness**

A minor consumption from small importers may be missing, but these probably account for an insignificant fraction of the total N<sub>2</sub>O emissions.

##### **5.5.1.6. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

#### **5.5.2. Use of N<sub>2</sub>O as propellant**

N<sub>2</sub>O is used as a propellant in spray boxes and this use will lead to emissions of N<sub>2</sub>O. It is also used in research work, for instance in the food industry and at universities. Small amounts are used at engineering workshops, among others for drag-racing. There is no production of N<sub>2</sub>O for these purposes in Norway.

##### **5.5.2.1. Method**

Information on sales volumes has been reported by the plants to Statistics Norway. Statistics Norway assumes that all propellant is released to air.

##### **5.5.2.2. Activity data**

Information has been gathered from the plants indicating that there is no production or sale of N<sub>2</sub>O for use as a propellant in Norway. The N<sub>2</sub>O is already in the spray cans when imported. There was no import of these spray cans prior to 1993. Activity data for the year 2003 has been used for all years since.

For activity data on N<sub>2</sub>O used in research work and in drag racing, data on imported amounts in 2002 has been used for all years.



### 5.5.2.3. *Uncertainties*

The figures for one year are used for all years. It is believed that all figures from all major importers are included in the inventory.

### 5.5.2.4. *Completeness*

No major missing emission components are likely.

### 5.5.2.5. *Source specific QA/QC*

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

## 5.5.3. **Mercury-containing products**

### 5.5.3.1. *Method*

Breakage of mercury-containing thermometers, fluorescent tubes and various measuring and analytical instruments leads to emissions of mercury. The emission estimates are based on an annual report from the Norwegian Environment Agency ("Miljøgifter i produkter"). The sale of mercury-containing thermometers and fluorescent tubes has decreased strongly since the mid-1990s, and the mercury content in these products has been reduced. A prohibition against the production, import and export of mercury-containing products entered into force in 1998, except for some thermometers for professional use, which were prohibited in 2001. Since these products have long operating life times, there will be emissions from these products for many years. In the calculations, however, it is assumed that the emissions occur the same year as the product is sold.

For thermometers, it is assumed that all mercury is emitted in hospitals, despite some breakage of mercury-containing thermometers that occur in households. For fluorescent tubes, all emissions are placed in households, although emissions occur in all sectors. For measuring and analytical instruments, all emissions are placed under research and development work.

### 5.5.3.2. *Uncertainties*

The emissions are assumed to be emitted the same year as the products are sold. This is not accurate, since most of these products have long operating life times. It is however impossible to predict the annual breakage and the mercury content in each of them.

### 5.5.3.3. *Completeness*

No major missing emission components are likely.

### 5.5.3.4. *Source specific QA/QC*

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

## 5.5.4. **Tobacco**

### 5.5.4.1. *Method*

*NO<sub>x</sub>, NMVOC, CO, particles, heavy metals and POPs*

The emission components included from the combustion of tobacco are NO<sub>x</sub>, NMVOC, CO, particles, heavy metals and POPs (Persistent organic pollutants). Emission figures have been calculated by multiplying the annual consumption of tobacco with emission factors for each pollutant. As recommended by the UNFCCC ERT (expert review team), emissions from use of tobacco are reported under NFR 3D.

### 5.5.4.2. *Activity data*

The total consumption of tobacco in Norway is given by the net import of tobacco from Statistics Norway's external trade statistics.

**5.5.4.3. Emission factors**

Table 5.5 gives emission factors used for tobacco combustion. For NO<sub>x</sub>, NMVOC and CO the emission factors are calculated by Statistics Norway, based on values given in Directorate for Health (1990).

**Table 5.5. Emission factors used for tobacco combustion**

	Tobacco (unit/kg tobacco)	Source
NO <sub>x</sub> (kg)	0.0034652	Statistics Norway, Directorate for Health (1990)
NMVOC (kg)	0.0048374	Statistics Norway, Directorate for Health (1990)
CO (kg)	0.1215475	Statistics Norway, Directorate for Health (1990)
TSP (kg)	0.04	TNO (Institute of environmental and energy technology 2002)
PM <sub>10</sub> (kg)	0.04	TNO (Institute of environmental and energy technology 2002)
PM <sub>2.5</sub> (kg)	0.04	TNO (Institute of environmental and energy technology 2002)
Pb (g)	0.00005	Finstad <i>et al.</i> (2001)
Cd (g)	0.0001	Finstad <i>et al.</i> (2001)
Hg (g)	0.0001	Finstad <i>et al.</i> (2001)
As (g)	0.000159	Finstad and Rypdal (2003)
Cr (g)	0.000354	Finstad and Rypdal (2003)
Cu (g)	0.000152	Finstad and Rypdal (2003)
PAH (g)	0.00825	Finstad <i>et al.</i> (2001)
PAH OSPAR (g)	0.00125	Finstad <i>et al.</i> (2001)
Dioxins (µg)	0.0013	Finstad <i>et al.</i> (2002b)

**5.5.4.4. Uncertainties**

The emissions are assumed to be emitted the same year as the products are imported.

**5.5.4.5. Completeness**

Tobacco bought tax free abroad and tobacco smuggled are not included in the inventory.

**5.5.4.6. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

## 6. Agriculture

IPCC 4

NFR 4

### 6.1. Overview

Agriculture contributes particularly to CH<sub>4</sub>, N<sub>2</sub>O and NH<sub>3</sub> emissions. Domestic animals are the major source of CH<sub>4</sub> emissions from agriculture. Both enteric fermentation and manure management contribute to non-combustion emissions of CH<sub>4</sub>. Manure management also generates emissions of N<sub>2</sub>O.

Microbiological processes in soil lead to emissions of N<sub>2</sub>O. Three sources of N<sub>2</sub>O are distinguished in the IPCC methodology and are included in the Norwegian inventory:

1. direct emissions from agricultural soils (from use of synthetic fertilisers, animal excreta nitrogen used as fertiliser, biological nitrogen fixation, crop residues, industrial and urban wastes (sewage sludge) and cultivation of soils with a high organic content)
2. direct soil emissions from animal production (emissions from droppings on pastures)
3. N<sub>2</sub>O emissions indirectly induced by agricultural activities (N losses by volatilisation, leaching and runoff).

Animal manure and the use of fertiliser and sewage sludge also generate emissions of NH<sub>3</sub>. Another source of NH<sub>3</sub> is treatment of straw using NH<sub>3</sub> as a chemical. Non-combustion emissions of particles in the agricultural sector are also calculated.

There are also some emissions arising from the burning of agricultural residues described in chapter 6.6.

### 6.2. Activity data – animals

The same data for number of animals of the various animal groups is used in all the different calculations of emissions.

The main sources of the livestock statistics are the register of production subsidies (sheep for breeding, goats, breeding pigs, poultry for egg production and beef cows), statistics of approved carcasses (animals for slaughter) and the Cow Recording System at TINE BA<sup>13</sup> (heifers for breeding and dairy cows). These sources cover 90-100 per cent of the animal populations. The coverage in the register of production subsidies is shown in table 6.1

**Table 6.1. Estimated coverage of animal populations in the register of production subsidies 2012**

	Percentage covered in the statistics
Dairy cows .....	100
Beef cows .....	99.99
Sheep .....	99.8
Goats .....	99.9
Laying hens .....	99.2
Chicks for breeding .....	99.99
Other poultry for breeding .....	89.8
Sows .....	99.0
Young pigs for breeding .....	98.4
Deer .....	99.9
Other (ostrich, lama...) .....	unknown

Source: Estimations by Statistics Norway.

<sup>13</sup> TINE BA is the sales and marketing organisation for Norway's dairy cooperative and covers most of the milk production and the meat production induced by milk production)

The statistics of approved carcasses covers close to 100 per cent of all slaughtered animals. Home slaughter is not included, but the extent of home slaughter is very low due to legal restrictions. Even animals consumed by producers are in most cases registered at the slaughterhouses. The number of dairy cows and heifers for breeding derive from the Cow recording systems. Between 98 and 99 per cent of all dairy cows are registered here, and in addition, the number used in the inventory is adjusted for this missing part.

The registers are updated annually. In addition to the animals included in these registers, an estimate of the number of horses that are not used in farming is obtained from the Norwegian Agricultural Economics Research Institute (NILF). The number of reindeer is obtained from the Norwegian Reindeer Husbandry Administration.

For some categories of animals not living a whole year, for instance lambs, lifetime is taken into account to get a yearly average for the number of animals. An expert judgment suggests an average lifetime of 143 days for lambs (UMB, *pers. comm.*<sup>14</sup>). The formula for calculating the average figure for lambs will then be:

$$(6.1) \quad \text{Lambs} * \frac{143}{365}$$

For dairy cows, additional information from the Cow Recording System concerning annual milk production and proportion of concentrate in the diet is used (Tine BA *annually*). The Cow Recording System also supplies annual information about slaughter age for heifers and bulls and data for estimating live weight of dairy cows and heifers for breeding, and also the age of young cows' at their first calving (Moen, *pers. comm.*<sup>15</sup>).

For heifers and bulls for slaughter, animal numbers are based on data from statistics of approved carcasses which provide data on numbers slaughtered and slaughter weights. Combined with slaughter age from the Cow Recording System, this gives a precise estimation of animal life time for each animal slaughtered. One principal draw-back of this method for estimating animal population is that emissions in all stages of these animals' lives will be accounted for in the year of slaughter, even though the emissions of the early stages of the lives of the animals to a large extent took place in the previous year. In a stable population of animals, this error is automatically adjusted, and since animal populations are relatively stable, this error is considered much smaller compared to errors related to estimating animal year based on animal populations in the register of production subsidies which was previously used (see table 6.2). The new data sources also ensure a better coherence between animal numbers, life time and weight.

The number of heifers bred for new milking cows is estimated corresponding to the method used for heifers and bulls for slaughter.

<sup>14</sup> UMB (2001): Expert judgement by Department of Animal Science, Ås: Norwegian University of Life Sciences.

<sup>15</sup> Moen, O. (*annually*): Personal information, email from Oddvar Moen Tine Rådgivning annually.

**Table 6.2. Estimated animal years for cattle**

	Heifer for replacement	Heifers for slaughter	Bulls for slaughter	Beef cows <sup>1</sup>	Dairy cows
1990 .....	326 681	47 020	289 945	8 193	325 896
1991 .....	322 819	46 839	289 637	9 502	321 722
1992 .....	322 101	48 711	300 402	11 949	320 442
1993 .....	318 159	48 172	293 055	13 838	316 054
1994 .....	312 956	48 701	292 839	17 331	310 034
1995 .....	313 952	47 103	284 237	20 334	310 346
1996 .....	318 442	47 520	286 633	23 186	314 199
1997 .....	312 338	46 443	293 941	27 446	307 099
1998 .....	307 964	49 325	301 152	30 889	301 923
1999 .....	311 703	56 717	320 420	34 846	304 769
2000 .....	293 585	63 512	285 349	42 324	284 880
2001 .....	287 891	65 843	267 167	45 317	278 482
2002 .....	281 844	63 919	273 243	45 831	272 296
2003 .....	280 485	60 391	274 314	48 727	270 270
2004 .....	264 357	58 846	270 546	50 605	263 422
2005 .....	266 514	57 619	268 145	54 841	255 663
2006 .....	255 563	58 446	264 751	55 706	250 903
2007 .....	243 835	56 607	254 452	57 609	246 624
2008 .....	240 399	54 831	244 243	60 401	238 550
2009 .....	236 786	53 397	242 854	63 803	210 554
2010 .....	235 582	53 410	237 354	67 110	209 094
2011 .....	235 117	48 778	231 191	68 539	201 165
2012 .....	232 026	42 863	225 104	70 434	203 592

<sup>1</sup> Counted animals

Source: Cow Recording System at TINE BA (dairy cows) and estimations by Statistics Norway.

There are some differences between the number of animals used in these calculations and the FAO statistics. The explanation is that the figures reported to the FAO are provided by the Norwegian Agricultural Economics Research Institute (NILF). NILF makes an overall estimation for the agricultural sector, which is the basis for the annual negotiations for the economic support to the sector. This estimate includes a grouping of all agricultural activities, comprising area, number of animals and production data. This method is a little different from the one used by Statistics Norway.

### 6.3. Emissions from enteric fermentation in domestic livestock

*IPCC 4A, Key category for CH<sub>4</sub>*

*NFR -*

*Last update: 11.08.2014*

#### 6.3.1. Description

An important end product from the ruminal fermentation is methane (CH<sub>4</sub>). The amount of CH<sub>4</sub> produced from enteric fermentation is dependent on several factors, like animal species, production level, quantity and quality of feed ingested and environmental conditions. According to IPCC (2000) the method for estimating CH<sub>4</sub> emission from enteric fermentation requires three basic items:

1. The livestock population must be divided into animal subgroups, which describe animal type and production level.
2. Estimate the emission factors for each subgroup in terms of kilograms of CH<sub>4</sub> per animal per year.
3. Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emission, and sum across the subgroups to estimate total emission.

#### 6.3.2. Method

A Tier 2 methodology is used for calculating CH<sub>4</sub> from enteric fermentation for the main emission sources cattle and sheep. The Tier 2 methodology used is described

more in detail in Appendix H. The methodology for calculating CH<sub>4</sub> from enteric fermentation for the other animal categories is in accordance with IPCC's Good Practice Guidance Tier 1 method (IPCC 1997b, a). The numbers of animals of each kind and average emission factors of tonnes CH<sub>4</sub>/animal/year for each kind of animal are used to calculate the emissions.

### 6.3.3. Activity data

The Tier 2 method of calculation which is implemented for cattle and sheep requires subdividing the cattle and sheep populations by animal type, physiological status (dry, lactating or pregnant) live weight and age. Table 6.3 describes the animal categories used for cattle and sheep in the calculations.

**Table 6.3. Categories of cattle and sheep used in the Norwegian calculations of methane emission from enteric fermentation**

Categories of cattle and sheep
Dairy cows
Beef cows
Replacement heifers
Finisher heifers, < one year
Finisher heifers, > one year
Finisher bulls, < one year
Finisher bulls, > one year
Breeding sheep, > one year
Breeding sheep, < one year
Slaughter lamb, < one year. Jan- May
Slaughter lamb, < one year. Jun- Dec

Average daily weight gain (ADG), which is utilized in the calculations for growing cattle, was in 2005 taken from the Cow Recording System when the Tier 2 model was developed.

**Table 6.4. Important parameter inputs in the calculations of methane emissions from cattle**

	Annual milk production, dairy cows. kg/animal/year	Proportion of feed concentrate in the rations of mature dairy cows. Per cent	Carcass weight at time of slaughter, heifer > 1 year. kg	Age at time of slaughter, heifers > 1 year. Months	Carcass weight at time of slaughter, bulls > 1 year. kg	Age at time of slaughter, bulls > 1 year. Months
1990 .....	6 320	39.1	185	21.6	255	19.7
1991 .....	6 206	38.6	184	21.6	254	19.7
1992 .....	6 233	39.7	186	21.6	257	19.7
1993 .....	6 400	37.3	190	21.8	262	19.7
1994 .....	6 376	36.6	198	22.1	273	19.7
1995 .....	6 326	36.8	200	22.2	276	19.7
1996 .....	6 265	37.0	202	22.2	279	19.7
1997 .....	6 199	36.9	201	21.8	281	19.7
1998 .....	6 207	37.0	203	22.2	287	19.7
1999 .....	6 170	36.9	202	22.1	281	19.2
2000 .....	6 156	36.4	202	22.3	269	18.8
2001 .....	6 164	36.6	205	22.7	279	19.5
2002 .....	6 278	36.1	205	22.5	283	19.7
2003 .....	6 420	36.7	208	22.8	289	19.8
2004 .....	6 594	37.1	212	22.9	292	19.8
2005 .....	6 723	37.7	216	22.8	296	19.3
2006 .....	6 742	38.5	213	22.8	297	19.4
2007 .....	6 961	39.4	212	22.4	296	18.8
2008 .....	7 144	39.8	213	22.5	298	18.7
2009 .....	7 276	40.1	219	22.8	301	18.6
2010 .....	7 373	41.0	221	22.8	302	18.5
2011 .....	7 309	41.9	210	22.5	297	18.4
2012 .....	7 509	42.9	205	22.7	294	18.3

Source: Cow Recording System at TINE BA (dairy cows) and estimations by Statistics Norway

For sheep and lamb the parameters used in the calculations apart from the number of animals are fixed due to lack of annual data (table 6.5)

**Table 6.5. Important parameter inputs in the calculations of methane emissions from sheep**

	Carcass weight. kg	Age at slaughter. Months	Conversion factor for methane. Per cent
Breeding sheep > 1 year .....	35		6.5
Breeding sheep < 1 year .....	29		4.5
Lamb for slaughter .....	19	4.8	4.5

#### 6.3.4. Emission factors

For cattle and sheep the following basic equation is used to calculate the CH<sub>4</sub> emission factor for the subgroups (Tier 2):

$$(6.2) \quad EF = (GE \cdot Y_m \cdot 365 \text{ days/yr}) / 55.65 \text{ MJ/kg CH}_4$$

Where:

$EF$  = emission factor, kg CH<sub>4</sub>/head/yr

$GE$  = gross energy intake, MJ/head/day

$Y_m$  = CH<sub>4</sub> conversion rate, which is the fraction of gross energy in feed converted to CH<sub>4</sub>.

$M$  = animal category

This equation assumes an emission factor for an entire year (365 days). In some circumstances the animal category may be alive for a shorter period or a period longer than one year and in this case the emission factor will be estimated for the

specific period (e.g. lambs living for only 143 days and for beef cattle which are slaughtered after around 540 days, varying from year to year). Further description of the determination of the variables GE and  $Y_m$  for the different animal categories is given in Appendix H.

The emissions from domestic reindeer, deer, ostrich and fur-bearing animals are also included in the Norwegian calculations. The emission factor 14.0 kg/animal/yr is used for domestic reindeer (Karlengen et al. 2012). Emission factors for goat, deer, ostrich and fur-bearing animals are developed by scaling emission factors for other animals that are assumed most similar with regard to digestive system and feeding. These factors were again assessed by Karlengen *et al.* (2012). The results are shown in table 6.6. For the other animal categories the Tier 1 default emission factors for each kind of animal (IPCC 1997a) is used. Emissions from poultry are omitted because neither national factors nor standard IPCC factors are estimated.

**Table 6.6. Emission factors for CH<sub>4</sub> from enteric fermentation and different animal types**

Animal	Emission factor (Tonnes/animal/year)
Horses .....	0.018
Goats .....	0.013
Pigs .....	0.0015
Reindeer .....	0.014
Deer .....	0.02
Ostrich .....	0.00002
Fur-bearing animals .....	0.0001

Source: IPCC (1997b), Karlengen et al. (2012).

### 6.3.5. Uncertainties

#### *Activity data*

The uncertainty in the data is considered to be within  $\pm 5$  per cent. There is also an uncertainty related to the fact that some animals are only alive part of the year and how long this part is.

#### *Emission factors*

Although the emissions depend on several factors and therefore vary between different individuals of one kind of animal, average emission factors for each kind are used in the tier 1 methodology for all animal categories except cattle and sheep, where a Tier 2 methodology is used. The standard deviation of the emission factors is considered to be  $\pm 40$  per cent, which is the estimate from (IPCC 2006). An uncertainty estimate of  $\pm 25$  per cent is used for the emission factors for cattle and sheep in the Tier 2 methodology (Volden, *pers. comm.*<sup>16</sup>).

### 6.3.6. Completeness

Major missing emission sources are not likely.

### 6.3.7. Source specific QA/QC

In 2001, a project was initiated to improve the estimate of the number of animals. This was completed in 2002. In 2012, a further revision of the numbers of bulls and heifers was implemented (see section 6.2). The revised data on animal populations form the basis for the emission calculations for all years. In 2005-2006, Statistics Norway and the Norwegian Environment Agency carried out a project in cooperation with the Norwegian University of Life Sciences, which resulted in an update of the emission estimations for cattle and sheep using a tier 2 method.

<sup>16</sup> Volden, H. (2006): Personal information, email from Harald Volden 27/01-06, Ås: Norwegian University of Life Sciences.



## 6.4. Emissions from manure management

IPCC 4B Key category for N<sub>2</sub>O and CH<sub>4</sub>

NFR 4B

Last update: 11.08.2014

### 6.4.1. Description

The relevant pollutants emitted from this source category are CH<sub>4</sub> (IPCC 4B(a)), N<sub>2</sub>O (IPCC 4B(b)) and NH<sub>3</sub> (NFR 4B). Emissions from cattle are most important in Norway for all three components.

Organic material in manure is transformed to CH<sub>4</sub> in an anaerobic environment by microbiological processes. The emissions from manure depend on several factors; type of animal, feeding, manure management system and weather conditions (temperature and humidity).

During storage and handling of manure (i.e. before the manure is added to soils), some nitrogen is converted to N<sub>2</sub>O. The amount released depends on the system and duration of manure management. Solid storage and dry lot of manure is the most important source.

Emissions of NH<sub>3</sub> from manure depend on several factors, e.g. type of animal, nitrogen content in fodder, manure management, climate, time of spreading of manure, cultivation practices and characteristics of the soil. In the IPCC default method a NH<sub>3</sub> volatilisation fraction of 20 per cent is used for the total N excretion by animals in the country. However, in the Norwegian emission inventory, yearly updated NH<sub>3</sub> volatilisation values from Statistics Norway's NH<sub>3</sub> model are used, because this is expected to give more correct values for Norway. The estimated national volatilisation fractions have differed between 18-21 per cent since 1990, and are now close to the IPCC default value of 20 per cent.

### 6.4.2. Method

CH<sub>4</sub>

For sheep, goat, horse, deer, ostrich, reindeer, mink and fox IPCC Tier 1 method are used for the estimations of emission of CH<sub>4</sub> from manure management. The emission factors used are based on country specific expert judgements (Karlengen et al 2012) where such exists (horse, ostrich, mink and fox, deer and reindeer), while for sheep and goat the IPCC default emission factors are used.

For cattle, swine and poultry emissions of methane from manure are estimated using the following equations, in accordance with the IPCC Tier 2 method (IPCC 2000).

$$CH_4 \text{ Emissions} = EF * \text{Population}$$

$$EF_i = VS_i * 365 \text{ days/year} * B_{0i} * 0.67 \text{ kg/m}^3 * \sum_{(j,k)} MCF_{jk} * MS_{ijk}$$

EF<sub>i</sub> = annual emission factor for defined livestock population *i*, in kg

VS<sub>i</sub> = daily VS excreted for an animal within defined population *i*, in kg

B<sub>0i</sub> = maximum CH<sub>4</sub> producing capacity for manure produced by an animal within defined population *i*, m<sup>3</sup>/kg of VS

MCF<sub>jk</sub> = CH<sub>4</sub> conversion factors for each manure management system *j* by climate region *k*

MS<sub>ijk</sub> = fraction of animal species/category *i*'s manure handled using manure system *j* in climate region *k*

The factors VS, B<sub>0</sub> and MCF are average factors meant to represent the whole country. The population of animals are consistent with the animal data used elsewhere in the inventory (see chapter 6.1). For young cattle, this implies that the VS production is estimated for the whole average life time/time until first calving and not per animal year. The amount of volatile solids (VS) for other cattle are

estimated directly as kg/animal/year. The VS factors are based on Karlengen et al. (2012), and is based on the same data sources used in the estimations of nitrogen excretion factors used in estimations of N<sub>2</sub>O from manure. For swine and poultry country specific estimates of the University of Life Sciences (NMBU) for the percentage of the manure in dry matter that are volatile solids are used. Background data used for the estimations of VS are given in table 6.7 below, and in annex X, table AX-9 in Norwegian Environment Agency (2014c).

The factor B<sub>0</sub> represents the maximum potential production of methane under optimum conditions. For dairy cattle, the B<sub>0</sub> factors are based on new Norwegian research (Morken et al. 2013), for other cattle and poultry the default IPCC factors are used, and for pigs the factor is based on literature studies (Morken et al. 2013).

**Table 6.7. Norwegian factors for amount of manure (in d.m.), VS and B<sub>0</sub> used to estimate CH<sub>4</sub> from manure management with the IPCC Tier 2 method. 2012**

	Manure (kg dry matter per animal)	VS %	VS, kg per animal	VS, total, tonnes	B <sub>0</sub>
<b>Non-dairy cattle</b> .....				<b>287 971</b>	
Beef cows .....			964	67 923	0,17
Replacement heifer .....			946	100 898	0,17
Finisher heifer .....			722	17 985	0,17
Finisher bulls .....			648	101 166	0,17
<b>Dairy cattle</b> .....				<b>301 342</b>	
Dairy cattle .....			1 480	301 342	0,23
<b>Poultry</b> .....				<b>95 005</b>	
Hens .....	13,15	0,9	11,84	47 937	0,32
Chicks bred for laying hens, animal places .....	3,1	0,9	2,79	2 697	0,32
Chicks for, slaughter animal places .....	4,08	0,9	3,67	36 046	0,32
Ducks for breeding .....	30	0,9	27	55	0,32
Ducks for slaughter animal places .....	8,12	0,9	7,31	130	0,32
Turkey and goose for breeding .....	30	0,9	27	311	0,32
Turkey and goose for slaughter, animal places .....	17,23	0,9	15,51	7 829	0,32
<b>Swine</b> .....	<b>0,14</b>			<b>80 257</b>	
Young pigs for breeding .....	113	0,9	101,7	4 336	0,3
Sows .....	437,3	0,9	393,57	20 920	0,3
Pigs for slaughter, animal places .....	131,34	0,9	118,21	55 001	0,3

Sources:

Manure, dry matter poultry and swine: Karlengen et al. (2012)

VS%, poultry: expert estimate Birger Svihus NMBU, email 03.01.2013

VS%, swine: expert estimate Nils Petter Kjos, NMBU, email 03.01.2013.

VS per animal, cattle: Estimates based on Karlengen et al. (2012)

B<sub>0</sub>: Morken et al. (2013) for dairy cattle and swine and IPCC (2000) for other animal groups.

For MCF, standard IPCC factors from GPG are used for solid storage and pasture are used. For liquid system the default MCF from IPCC (1997b) is used based on recommendations in Morken et al. (2013).

**Table 6.8. Norwegian factors for MCF used to estimate CH<sub>4</sub> from manure management with the IPCC Tier 2 method**

	MCF	Source
Liquid system .....	0.1	IPCC (1997b)
Solid storage and drylot .....	0.01	IPCC (2000)
Pasture range and paddock .....	0.01	IPCC (2000)

Norwegian values are used for the fraction of total excretion per species for each management system (MS) and for pasture. The fractions are updated every year and are given in table 6.9. The yearly update of MS is based on annual information about the pasture times for dairy cattle and dairy goat and changes in the internal distribution between the subcategories in each animal group from year to year.

**Table 6.9. Fraction of total excretion per specie for each management system and for pasture (MS). 2012**

	Anaerobic Lagoon	Liquid system	Solid storage and drylot	Pasture range and paddock	Other manure management systems
Dairy cattle .....	0	0.76	0.06	0.18	0
Non-dairy cattle .....	0	0.64	0.05	0.31	0
Poultry .....	0	0.27	0.73	0	0
Sheep .....	0	0.25	0.30	0.45	0
Swine .....	0	0.88	0.12	0	0
Other animals .....	0	0.30	0.33	0.36	0

Source: Data for storage systems from Statistics Norway (Statistics Norway 2004) and (Statistics Norway 2001b) (poultry) and data for pasture times from (Tine BA annually) (Dairy cattle, goat), Statistics Norway's Sample Survey 2001 (Statistics Norway 2002b) (non-dairy cattle, sheep) and expert judgements.

### $N_2O$

In Norway, all animal excreta that are not deposited during grazing are managed as manure.  $N_2O$  emissions from manure are estimated in accordance with the IPCC default method (IPCC 1997a[b]), but with Norwegian values for N in excreta from different animals according to table 6.10. The rationale for the Norwegian values for N in excreta is given in Karlengen et al. (2012). The N-excretion factors for cattle, poultry and pigs have been scientifically investigated, while the remaining categories have been given by expert judgements (Karlengen et al. 2012). Based on typical Norwegian feedstock ratios, the excretion of nitrogen (N) were calculated by subtracting N in growth and products from assimilated N and P. Comparisons have also been made with emission factors used in other Nordic countries and IPCC default factors.

The factors for cattle are based on equations where animal weight, production (milking cows), life time (young cattle) and protein content in the fodder are activity data used in the equations.

The Nordic feed evaluation system (NorFor) was used to develop the nitrogen factors for cattle. The excretion of N in the manure were calculated as the difference between their intake, and the sum of that excreted in milk, fetus and deposited in the animal itself. The procedure used for calculating the excretion of feces and N consisted of two steps:

1. Simulations in "NorFor" were conducted to gain values for the feces/manure characteristics covering a wide variation of feed characteristics ( N content) and production intensities (milk yield/meat production)
2. The results from the simulations were used to develop regression equations between feces/manure characteristics and parameters related to the diet (N content) and animal characteristics (milk yield, weight, age etc).

Calculations of N-factors based on these equations have been made back to 1990 for cattle. For poultry and pigs, N-factors have been estimated for 2011 in Karlengen (2012). The factors used until this update were estimated in 1988 (Sundstøl and Mroz (1988), and are regarded as still valid for 1990. A linear interpolation has been used for the years between 1990 and 2011. For the remaining animal categories the N in excreta are considered constant throughout the time series. More background data for the calculations are given in Annex X, Table AX-7, AX-8 and AX-9 in Norwegian Environment Agency (2014c).

Norwegian values are also used for the fraction of total excretion per species for each management system (MS) and for pasture. The fractions are updated every year and are provided in table 6.9. The same fractions are used in the calculations of  $CH_4$  from manure.

This distribution of manure between the various management systems and animal categories is estimated in a model used for calculating  $NH_3$  emissions from

manure. Consequently, the distributions between different storage systems and pasture by animal category used in the estimations of both N<sub>2</sub>O and NH<sub>3</sub> emissions are coherent.

**Table 6.10. N in excreta from different animals. 2012. kg/animal/year unless otherwise informed in footnote**

	kg/animal/year <sup>1</sup>
Dairy cow .....	125.0
Beef cow .....	64.5
Replacement heifer <sup>2</sup> .....	84.6
Bull for slaughter <sup>2</sup> .....	65.5
Finishing heifer <sup>2</sup> .....	64.2
Young cattle <sup>3</sup> .....	41.7
Horses .....	50.0
Sheep < 1 year .....	7.7
Sheep > 1 year .....	11.6
Goats .....	13.3
Pigs for breeding .....	23.5
Pigs for slaughtering <sup>4</sup> .....	3.2
Hens .....	0.670
Chicks bred for laying hens <sup>4</sup> .....	0.046
Chicks for slaughtering <sup>4</sup> .....	0.030
Ducks, turkeys/ goose for breeding .....	2.0
Ducks, turkeys/ goose for slaughtering <sup>4</sup> .....	0.4
Mink .....	4.3
Foxes .....	9.0
Reindeer .....	6.0
Deer .....	12.0

<sup>1</sup> Includes pasture.

<sup>2</sup> Factors for excreted nitrogen apply for the whole life time of animals, and nitrogen is calculated only when animals are slaughtered/replaced. This is described in section 6.2.

<sup>3</sup> Average factor for all heifers for slaughter and replacement and bulls for slaughter, per animal and year.

<sup>4</sup> Per animal. For these categories, life time is less than a year. This means that the number of animals bred in a year is higher than the number of stalls (pens).

Source: Karlengen et al. (2012) and estimations by Statistics Norway.

**Table 6.11. Fraction of total excretion per species for each management system and for pasture 2012**

	Anaerobic lagoon	Liquid system	Solid storage and dry lot	Pasture range and paddock	Other manure management systems
Dairy cattle .....	0	0.76	0.06	0.18	0
Non-dairy cattle ...	0	0.64	0.05	0.31	0
Poultry .....	0	0.27	0.73	0	0
Sheep .....	0	0.25	0.30	0.45	0
Swine .....	0	0.88	0.12	0	0
Other animals .....	0	0.30	0.33	0.36	0

Source: Data for storage systems from Statistics Norway (2004) and Gundersen and Rognstad (2001) (poultry) and data for pasture times from (Tine BA *annually*) (Dairy cattle, goat), Statistics Norway's Sample Survey 2001 (Statistics Norway 2002) (non-dairy cattle, sheep) and expert judgements.

The emissions of nitrous oxide from manure are estimated using the following equation, in accordance with the IPCC Tier 2 method (IPCC 1997b, a):

$$(6.4) \quad E = \sum_s \left\{ \left[ \sum_i (N_i \cdot Nex_i \cdot MS_{i,s}) \right] \cdot EF_s \right\}$$

*E*: Emissions of N<sub>2</sub>O-N (kg N<sub>2</sub>O-N/year, N<sub>2</sub>O-N is the nitrogen amount in the nitrous oxide compound)

*N*: Population of animals

*Nex*: Annual average N excretion (kg N/animal/year)

*MS*: Fraction of total excretion per specie for each management system

*EF*: N<sub>2</sub>O emission factor (kg N<sub>2</sub>O-N/kg N)

*s*: Manure management system

*i*: Species

### 6.4.3. Activity data

*CH<sub>4</sub>, N<sub>2</sub>O and NH<sub>3</sub>*

Emissions are estimated from the animal population. How the animal population is estimated is described in section 6.2.

Activity data on storage systems are scarce, and the only source practically available is the Sample survey of agriculture and forestry 2003 (Statistics Norway 2004) and the Statistics Norway survey of different storage systems in 2000 (Gundersen and Rognstad 2001). Data on storage systems for other years are unavailable. Analyses and estimations of the effects on emissions of the assumed changes in storage systems since 1990 show that the assumed change is of little significance to the emissions. In addition, data on animal populations are used to estimate the amounts of manure. The method for estimating animal population is described in section 6.2.

The manure is distributed to the following storage systems categories:

- Manure cellar for slurry (Liquid system)
- Manure pit for slurry (Liquid system)
- Indoor built up/deep litter (Solid storage and dry lot)
- Outdoor built up/enclosure (Solid storage and dry lot)
- Storage for solid dung and urine (Solid storage and dry lot)

Each of these categories are given for all combinations of the following regions and productions:

Regions:

- South-Eastern Norway
- Hedmark and Oppland
- Rogaland
- Western Norway
- Trøndelag
- Northern Norway

Production:

- Cattle
- Pigs
- Sheep and goats
- Poultry
- Horses, farm raised fur-bearing animals

### 6.4.4. Emission factors

*CH<sub>4</sub>*

The calculated average emission factors for different animal types are shown in table 6.12. They are country specific factors, which may deviate from the IPCC default values.

**Table 6.12. Average CH<sub>4</sub> emission factors for manure management in the Norwegian method. kg/animal/year**

	Emission factor <sup>1</sup>
Dairy cattle .....	17.96
Bulls <sup>2</sup> .....	5.07
Heifers <sup>2</sup> for slaughter .....	5.57
Heifers for breeding <sup>2</sup> .....	7.34
Non-dairy cattle < 1 yearBeef cows .....	7.45
Horses .....	2.95
Sheep > 1 year .....	0.19
Sheep < 1 year .....	0.19
Dairy goats .....	0.12
Other goats .....	0.12
Sows	
Young pigs for breeding 0,28.....	1.08
Pigs for slaughter <sup>3</sup> .....	0.28
Hens .....	0.32
Chicks bred for laying hens .....	0.087
Chicks for slaughter <sup>3</sup> .....	0.02
Ducks for breeding .....	0.027
Ducks for slaughter <sup>3</sup> .....	0.198
Turkey and goose for breeding .....	0.054
Turkey and goose for slaughter <sup>3</sup> .....	0.198
Mink, males .....	0.114
Mink, females .....	0.27
Fox, males .....	0.54
Fox, females .....	0.43
Reindeer .....	0.87
Deer .....	0.36
Ostrich .....	0.9

<sup>1</sup> Includes pasture.

<sup>2</sup> Factors apply for the whole life time of animals, This is described in section 6.2.

<sup>3</sup> Per animal place. This means that the factor includes all animals bred in one place (pen) during the year

Source: Karlengen et al. (2012), IPCC (2000), Morken et al. (2013) and estimations by Statistic Norway

### N<sub>2</sub>O

The IPCC default values for N<sub>2</sub>O emission factors from manure management are used in the calculations. These are consistent with the good practice guidance (IPCC 2000).

**Table 6.13. N<sub>2</sub>O emission factors for manure management per manure management system**

Manure management system	Emission factor, kg N <sub>2</sub> O-N/kg N
Liquid system .....	0.001
Solid storage and dry lot .....	0.02
Pasture range and paddock .....	0.02

Source: IPCC (1997a[b]).

### NH<sub>3</sub>

Emission factors vary with production and storage system; in the model there is no variation between regions. The factors are based on data from Denmark, Germany and Netherlands, since measurements of NH<sub>3</sub> losses in storage rooms have so far not been carried out in Norway. The factors are shown in table 6.14.

**Table 6.14. Emission factors for various storage systems and productions. Per cent losses of N of ammonium N**

	Storage system						
	Gutter		Manure pit for slurry with lid	Drainage to gutter			
	Manure cellar for slurry	Open manure pit for slurry		Open flag-stones	Indoor built up/deep litter	Outdoor built up/enclosure	Storage for solid dung and urine
<b>Cattle, milking cow</b>							
Loss from animal room	5	5	5	5	8	8	5
Loss from storage room	2	9	2	2	15	15	15
Total loss	7	14	7	7	23	23	20
<b>Pigs</b>							
Loss from animal room	15	15	15	15	15	15	20
Loss from storage room	4	6	2	2	25	25	30
Total loss	19	21	17	17	40	40	50
<b>Sheep and goats</b>							
Loss from animal room	5	5	5	5	8	8	5
Loss from storage room	2	6	2	2	10	10	10
Total loss	7	11	7	7	18	18	15
<b>Poultry</b>							
Loss from animal room	12	10	12	12	25	25	25
Loss from storage room	15	15	15	15	25	25	25
Total loss	27	25	27	27	50	50	50
<b>Other animals</b>							
Loss from animal room	5	0	0	0	15	15	15
Loss from storage room	10	0	0	0	15	15	15
Total loss	15	0	0	0	30	30	30

Source: Morken et al (2005)

The factors are combined with the activity data in the Statistics Norway survey of different storage systems in 2000 (Gundersen and Rognstad 2001) and the Sample survey of agriculture and forestry 2003 (Statistics Norway 2004), and emission factors for NH<sub>3</sub> emissions from storage of manure and stalled animals are calculated for production and region (table 6.15). To estimate losses, these emission factors are in turn multiplied with the amount of manure (based on number of animals and N-factors per animal, table 6.10).

**Table 6.15. Average emission factors for the manure storage systems used, distributed on type of animal production and region. Per cent losses of N of ammonium N**

	South-Eastern Norway	Hedmark/ Oppland	Rogaland	Western Norway	Trøndelag	Northern Norway
Cattle .....	10.1	8.4	8.0	8.0	7.7	7.9
Pigs .....	26.2	22.1	19.8	20.3	21.0	21.2
Sheep and goats .	13.3	12.6	9.2	11.4	11.9	11.5
Poultry .....	47.0	46.4	38.7	37.3	41.7	44.5
Other animals .....	25.7	24.7	17.1	19.1	23.5	21.6

Source: Statistics Norway, NH<sub>3</sub>-model estimations.

### 6.4.5. Uncertainties

Uncertainty estimates are provided in Appendix D.

#### 6.4.5.1. Activity data

##### CH<sub>4</sub>

The data for the number of animals are considered to be known within ±5 per cent. Other activity data are the different kinds of treatment of manure (which will determine the emission factor), which have been assessed by expert judgements. This will contribute to the uncertainty.

##### N<sub>2</sub>O and NH<sub>3</sub>

The data for the number of animals are considered to be known within ±5 per cent.

For the emissions of N<sub>2</sub>O from manure management, Norwegian data for N in excreta are used. The nitrogen excretion factors are uncertain, but the range is considered to be within ±15 per cent (Rypdal 1999). The uncertainty is connected to differences in excretion between farms in different parts of the country, that the survey farms may not have been representative, general measurement uncertainty and the fact that fodder and fodder practices have changed since the factors were determined.

There is also an uncertainty connected to the division between different storage systems for manure, which is considered to be within ±10 per cent, and the division between storage and pasture, which is considered to be within ±15 per cent.

#### 6.4.5.2. Emission factors

##### CH<sub>4</sub>

Norway is using the IPCC default factors (Tier 2 methodology) for the emission of CH<sub>4</sub>, but with some national data. The emission factors are considered to have an uncertainty range of ±25 per cent (Rypdal and Zhang 2000).

##### N<sub>2</sub>O

For the emission of N<sub>2</sub>O from different storage systems, IPCC default emission factors are used. They have an uncertainty range of -50 to +100 per cent (IPCC 2000) except for the storage category "daily spread" where it is not applicable.

##### NH<sub>3</sub>

Ammonia emissions from agriculture are estimated based on national conditions. There are uncertainties in several parameters (fraction of manure left on pastures, amount of manure, conditions of storage, conditions of spreading and climate conditions. An uncertainty analysis for the revised NH<sub>3</sub> model, which has been in



use since 2003, has not been performed. However, the revision of the model is believed to have reduced the uncertainty. Also the new estimations of nitrogen excretion from animals (Karlengen et al. 2012) is believed to have reduced uncertainty further.

#### 6.4.6. Completeness

Major missing emission sources are not likely.

#### 6.4.7. Source specific QA/QC

In a Nordic project in 2002, the results for emissions of both CH<sub>4</sub> and N<sub>2</sub>O from manure management in the national emission inventories have been compared with the results using the IPCC default methodology and the IPCC default factors (Petersen and Olesen 2002). This study contributed to discover differences and gaps in each of the Nordic national methodologies.

Statistics Norway, in cooperation with the Norwegian University of Life Sciences (NMBU), made improvements in 2003 in the calculation model for NH<sub>3</sub> emissions from the agricultural sector. Data sources used for the recalculations in the revised NH<sub>3</sub> model are coefficients from the Norwegian University of Life Sciences, and two surveys from Statistics Norway; a manure survey (Gundersen and Rognstad 2001) and the sample survey of agriculture and forestry (2001) (Statistics Norway 2002).

Statistics Norway's detailed manure survey gave more extended activity data which are better related to emission source categories, for manure management and spreading. New loss factors for different manure management categories are also used in the revised NH<sub>3</sub>-model. These factors are closer connected to specific activities.

In 2011, the Norwegian University of Life Sciences (NMBU) published a comparison of the methodologies used for calculating CH<sub>4</sub> emissions from manure management in Sweden, Finland, Denmark and Norway (Morken and Hoem 2011).

In a project in 2012 at the Norwegian University of Life Sciences (NMBU) that updated the Norwegian nitrogen excretion factors and the values for manure excreted for the different animal species, comparisons were made with the corresponding factors used in Sweden, Denmark and Finland and with IPCC default factors as a verification of the Norwegian factors (Karlengen et al. 2012).

A project with the aim to revise the Norwegian CH<sub>4</sub> conversion factors (MCF) for the manure storage systems in use was conducted at the Norwegian University of Life Sciences (NMBU) in 2013. The maximum CH<sub>4</sub> producing capacity (B<sub>0</sub>) was also revised for cattle manure.

### 6.5. Direct and indirect emissions from agricultural soils

*IPCC 4D, Key category for N<sub>2</sub>O*

*NFR 4D*

*Last update: 11.08.2014*

#### 6.5.1. Description

Three sources of N<sub>2</sub>O from agricultural soils are distinguished in the IPCC methodology, namely:

- Direct emissions from agricultural soils (from use of synthetic fertilisers, animal excreta nitrogen used as fertiliser, biological nitrogen fixation, crop residues, industrial and urban wastes and cultivation of soils with a high organic content);
- Direct soil emissions from animal production (emissions from droppings on pastures);

- N<sub>2</sub>O emissions indirectly induced by agricultural activities (N losses by volatilisation, leaching and runoff).

The use of synthetic fertilisers, animal excreta nitrogen and sewage sludge used as fertiliser, and droppings on pastures also result in emissions of NH<sub>3</sub>. For the first three sources, the calculated amount of nitrogen that is emitted directly as N<sub>2</sub>O has been corrected for the nitrogen emitted as NH<sub>3</sub>.

## 6.5.2. Method

### 6.5.2.1. Synthetic fertiliser

#### N<sub>2</sub>O

The direct emissions of N<sub>2</sub>O from use of synthetic fertiliser are calculated from data on total annual amount of fertiliser sold in Norway and its nitrogen content corrected for the amount of synthetic fertiliser applied in forest. The resulting amount that is applied on agricultural fields is multiplied with the IPCC default emission factor. The emissions are corrected for NH<sub>3</sub> that volatilises during spreading.

#### NH<sub>3</sub>

The calculations of NH<sub>3</sub> emissions from the use of synthetic fertiliser are based on the amounts of nitrogen supplied and emission factors for the percentage of nitrogen emitted as NH<sub>3</sub> during spreading.

### 6.5.2.2. Manure applied to soils

#### N<sub>2</sub>O

In Norway, all animal excreta that are not deposited during grazing are used as manure and applied to soils. Further, it is assumed that animals do not emit N<sub>2</sub>O themselves, but emissions of N<sub>2</sub>O and NH<sub>3</sub> from manure management before manure application on fields are taken into account (see section 6.4.2).

The emission of N<sub>2</sub>O from manure used as fertiliser is calculated by multiplying the total amount of N in manure used as fertiliser with the IPCC default emission factor. The N<sub>2</sub>O emissions are corrected for NH<sub>3</sub> that volatilises during spreading.

#### NH<sub>3</sub>

Statistics Norway's NH<sub>3</sub> model is used for calculating emissions of NH<sub>3</sub> from spreading of manure on cultivated fields and meadow. A spreading module in the NH<sub>3</sub> model gives the relative distribution of manure spread as fertiliser, distributed on different spreading methods. Total emissions from spreading are estimated by emission factors for each different spreading method multiplied by the amount of manure nitrogen. The total amount of manure nitrogen is estimated by the number of animals and nitrogen excretion factors for each type of animal.

### 6.5.2.3. N<sub>2</sub>O from biological nitrogen fixation

Another source of N<sub>2</sub>O emissions is biological nitrogen fixation. The most important N-fixing crop in Norway is clover. The amount of nitrogen fixed by a crop is very uncertain, and it is difficult to assign a conversion factor for N<sub>2</sub>O emissions derived from nitrogen fixation (IPCC 1997b, a). The amount of nitrogen fixed is multiplied with the IPCC default emission factor.

### 6.5.2.4. N<sub>2</sub>O from crop residues

Concerning re-utilisation of nitrogen from crop residues, there is only limited information. N<sub>2</sub>O emissions associated with crop residue decomposition are calculated by using the Tier 1b method, as described in the IPCC (IPCC 2000). Due to lack of national or default factors, factors from the Swedish National Inventory (Swedish environmental protection agency 2005) have been used for the Residue/Crop ratio for grass and green fodder, for Frac<sub>DM</sub> for rapeseed, potato, roots for feed and green fodder, and for Frac<sub>N</sub> for grass, rapeseed and green fodder. Factors from the Austrian National Inventory Report (Umweltbundesamt 2005)

have been used for vegetables. The fraction of crop residue burned on field was updated in 2012 by the Norwegian Agricultural Authorities<sup>17</sup>. This reduced the fraction for 2011 from 7.5 to 4 per cent.

$$(6.5) F_{CR} = \sum_i \left[ \frac{Crop_i * (Res / Crop)_i * Frac_{DMi} * Frac_{Ni}}{Frac_{Ni} * (1 - Frac_{BURNi} - Frac_{REMOVEDi})} \right]$$

$F_{CR}$  = N in crop residue returned to soils (tonnes)

$Crop_i$  = Annual crop production of crop i (tonnes)

$Res/Crop$  = The residue to crop product mass ratio (table 6.16)

$Frac_{DM}$  = Dry matter content (table 6.16)

$Frac_N$  = Nitrogen content (table 6.16)

$Frac_{BURN}$  = Fraction of crop residue burned on field

$Frac_{REMOVED}$  = Fraction of crop residue removed used as fodder and straw in animal rooms

**Table 6.16. Factors used for calculation of the nitrogen content in crop residues returned to soils**

	Residue/Crop	Frac <sub>DM</sub>	Frac <sub>N</sub>
Grass <sup>1</sup> .....	0.25	0.85	0.014
Wheat .....	1.3	0.85	0.0028
Rye .....	1.6	0.85	0.0048
Ryewheat .....	1.45	0.85	0.0038
Barley .....	1.2	0.85	0.0043
Oats .....	1.3	0.85	0.007
Rapeseed .....	1.8	0.91	0.0107
Potatoes .....	0.4	0.2	0.011
Roots for feed .....	0.3	0.2	0.0228
Green fodder .....	0.25	0.835	0.013
Vegetables .....	0.8	0.2	0.005
Peas .....	1.5	0.87	0.0142
Beans .....	2.1	0.855	0.0142

<sup>1</sup> Including perennial grasses and grass-clover mixtures

Source: IPCC (2000), Swedish Environmental Protection Agency (2005), Umweltbundesamt (2005), Statistics Norway.

#### 6.5.2.5. $N_2O$ from industrial and urban wastes

##### $N_2O$

No data are available for the amount of N in industrial waste applied as fertiliser, but this source is assumed to be very limited in Norway. Data for the  $N_2O$  emission arising from sewage sludge applied on fields has been calculated by multiplying the amount of nitrate in the sewage sludge applied with the IPCC default emission factor. Statistics Norway's waste water statistics annually gives values for the amount of sewage sludge and the fraction of the sewage sludge that is applied on fields. The N-content in the sludge is given in Statistics Norway (2001), and the same value of 2.82 per cent is used for all years.

##### $NH_3$

To calculate  $NH_3$  emissions from sewage sludge used as fertiliser, the fraction of N in manure lost as  $NH_3$  is used ( $Frac_{gasm}$ ). The loss equals to total N in sewage sludge multiplied by  $Frac_{gasm}$ .

#### 6.5.2.6. $N_2O$ from cultivation of soils with a high organic content

Large  $N_2O$  emissions occur as a result of cultivation of organic soils (histosols) due to enhanced mineralization of old, N-rich organic matter (IPCC 1997b, a). The emissions are calculated using the IPCC default emission factor of 8 kg  $N_2O$ -N/ha per year, and estimations of the area of cultivated organic soil in Norway. The area estimate of organic soils is based on measurements of C in the soil. National figures for the carbon content in agricultural soils is estimated on the basis of carbon and area data from a soil database by The Norwegian Forest and Landscape

<sup>17</sup> Johan Kollerud, Norwegian Agricultural Authorities, unpublished material 2012.

Institute, which covers about 50 per cent of the agricultural area in Norway. The figures are scaled up to national level by using an area resource database by The Norwegian Forest and Landscape Institute and a soil database by the Norwegian Institute for Agricultural and Environmental Research. The soil database contains results from about 600 000 soil samples. The soil samples represent about 65 per cent of the farms in Norway (Grønlund *et al.* 2008).

The soil mapping was mainly carried out in 1994, which gives a relatively accurate figure for the area estimate this year, ca. 830 000 km<sup>2</sup>. After 1995 the area is reduced both by the transition to mineral soil after the peat layer is decomposed and that cultivated moors are left unmanaged. This reduction has to some extent been counteracted by cultivation of earlier unmanaged moors. Mean area figures for the development in cultivated area after 1994 have been estimated by Bioforsk (Grønlund, *pers. comm*<sup>18</sup>.) based on assumptions of a yearly area decline of about 1 per cent due to transition of peat and abandonment of cultivated moors, and a yearly cultivation of new moor of 2 000 hectares.

#### **6.5.2.7. Direct soil emissions from animal production (emissions from droppings on pastures)**

*N<sub>2</sub>O*

The fraction of the total amount of animal manure produced that is droppings on pastures is given by national data for the distribution of manure to different storage systems and data for pasture times (table 6.11). The amount of N deposited during grazing is multiplied with the IPCC default emission factor.

*NH<sub>3</sub>*

Statistics Norway's NH<sub>3</sub> model is used for calculating the emissions of NH<sub>3</sub> from pastures. Animal population data, data for pasture times, and factors for the nitrogen amount in excreta for different animal categories give the nitrogen amounts for the animal categories on pastures. Specific emission factors by animal category are used.

#### **6.5.2.8. N losses by volatilisation**

Atmospheric deposition of nitrogen compounds fertilises soils and surface waters, and enhances biogenic N<sub>2</sub>O formation. Climate and fertiliser type influence the NH<sub>3</sub> volatilisation. Deposition of NH<sub>3</sub> is assumed to correspond to the amount of NH<sub>3</sub> that volatilises during the spreading of synthetic fertiliser, storage and spreading of manure and sewage sludge, and volatilisation from pastures. This amount is obtained from Statistics Norway's NH<sub>3</sub> model. The N<sub>2</sub>O emissions are calculated by multiplying the amount of N from deposition with the IPCC default emission factor.

#### **6.5.2.9. N<sub>2</sub>O from leaching and runoff**

A considerable amount of fertiliser nitrogen is lost from agricultural soils through leaching and runoff. Fertiliser nitrogen in ground water and surface waters enhances biogenic production of N<sub>2</sub>O as the nitrogen undergoes nitrification and denitrification. The fraction of the fertiliser and manure nitrogen lost to leaching and surface runoff may range from 10 to 80 per cent. IPCC (IPCC 1997b, a) proposes a default value of 30 per cent, but in the Norwegian inventory a national factor of 22 per cent is used, that is believed to give better results under Norwegian conditions. This country specific factor has been calculated based on an estimate of the amount of nitrate leaching (Bechmann *et al.* (2012) which comes from a runoff model by the Norwegian Centre for Soil and Environmental Research. The figure is an estimated average based on measurements of N-leaching in 12 small watershed areas, and expresses the discharge to nearest surface water recipient. Behind this average figure, there is a huge variation in N-leaching, depending on weather conditions, soil types, farm practices, geographical location etc. Climate

<sup>18</sup> Grønlund, A. (2012): Personal information, email from Arne Grønlund June 7 2012, Ås: Bioforsk.

data, soil data, agricultural practices etc. are monitored closely in these 12 watershed areas. The areas are chosen so that they together make up a representative selection of Norwegian farming with regard to farming practices, geographical localization and climate and soil conditions. The amount of nitrogen lost to leaching is multiplied with the IPCC default emission factor to calculate the emission of N<sub>2</sub>O.

### 6.5.3. Activity data

#### N<sub>2</sub>O

The activity data significant for the estimation of direct and indirect emissions of N<sub>2</sub>O from agricultural soils and N<sub>2</sub>O emissions from pastures, and the sources for the activity data are listed in table 6.17.

The calculation of emissions from use of nitrogen fertiliser is based on sales figures for each year. It was a strong price increase for nitrogen fertiliser, which caused a stock building in 2008 and corresponding lower purchases in 2009. In addition, new fertilisation standards may have brought about reduced amounts of fertiliser. To correct for this, a transfer of fertiliser use has been made from 2008 to 2009.

**Table 6.17. Activity data for non-combustion emissions of N<sub>2</sub>O in the agriculture**

	Sources
Consumption of synthetic fertiliser	Total sale of synthetic fertiliser from Norwegian Food Safety Authority (Annually). Fertilising of forest from Statistics Norway's Silvicultural statistics. (Statistics Norway Annually-c)
Number of animals	Statistics Norway (applications for productions subsidies, no. and weight of approved carcasses), The Cow Recording System at TINE BA
Distribution between manure storage systems	Sample Survey of agriculture and forestry 2003 (Statistics Norway 2004) and Gundersen and Rognstad (2001)
Pasture times for different animal categories	(Tine BA <i>annually</i> ) (Dairy cattle, goat), Statistics Norway's Sample Survey 2001 (Statistics Norway 2002) (non-dairy cattle, sheep), expert judgements
Biological N-fixation	Aakra and Bleken (1997)
Crop yield	Statistics Norway, agriculture statistics (Statistics Norway Annually-a)
Amount of sewage sludge	Statistics Norway, waste water statistics (annual data)
Fraction sewage sludge applied on fields	Statistics Norway, waste water statistics (annual data)
Area of cultivated organic soils	(Grønlund <i>et al.</i> 2012) and Grønlund, pers. comm <sup>19</sup> .

#### NH<sub>3</sub>

##### *Synthetic fertiliser*

The Norwegian Food Safety Authority calculates a total value for annual consumption of synthetic fertilisers in Norway based on sales figures. These data are corrected for the amount of fertiliser used in forests, which is provided by silviculture statistics from Statistics Norway. The silviculture statistics provides the weight of the fertiliser used on wet forest land (moor) and on dry forest land annually. An expert judgement has been made, which concludes that almost only NPK (nitrogen, phosphorus, potassium) with a nitrogen content of 15 per cent is used on wet forest land. On dry forest land it is assumed that half of the used synthetic fertiliser is NPK and the other half is fertiliser with a nitrogen content of 30 per cent (Rypdal *et al.* 2005).

For the calculation of the emission of NH<sub>3</sub> we need a specification of the use of different types of synthetic fertiliser. This is given by the Norwegian Food Safety Authority for the years from 2000. Due to lack of data for the years before 2000, we have to assume that the percentual distribution between the usage of different fertiliser types is the same as in 1994 for these years.

<sup>19</sup> Grønlund, A. (2010): Personal information, email from Arne Grønlund 16/8-2010, Ås: Bioforsk.

*Animal manure applied to soil and pasture*

There are several sources of activity data on spreading of manure in the NH<sub>3</sub>-model. The main sources are the manure survey in 2000 by Statistics Norway (Gundersen and Rognstad 2001), various sample surveys of agriculture and forestry 1990-2007 and the animal population. Animal population is updated annually. The animal population estimation methodology is described in section 6.2. Data from the manure survey do only exist for 2000, while the data from the sample surveys have been updated for several, but not all, years.

Data for time on pasture and share of animals on pasture are collected from the Sample Survey in Statistics Norway 2001 and from TINE BA (TINE BA is the sales and marketing organisation for Norway's dairy cooperative and covers most of the milk production). The data from TINE BA comprises pasture data for goats and milking cows and are updated annually. All other pasture data are from the Statistics Norway Sample survey 2001. The parameters used in the calculations and their sources are shown in table 6.18.

**Table 6.18. Parameters included in the estimation of NH<sub>3</sub> emissions from manure**

Parameters (input)	Sources
Number of animals	Statistics Norway (applications for productions subsidies, no. and weight of approved carcasses), The Cow Recording System at TINE BA
Nitrogen factors for manure	Various sources, compiled by Statistics Norway
Area where manure is spread, split on cultivated field and meadow.	Statistics Norway (Sample Surveys of Agriculture, various years), Gundersen and Rognstad (2001)
Area and amount where manure is spread, split on spring and autumn.	Gundersen and Rognstad (2001)
Amount of manure is spread, split on spring and autumn.	Statistics Norway (Sample Surveys of Agriculture, various years) Gundersen and Rognstad (2001), expert judgements, Statistics Norway's Sample Survey 2007
Addition of water to manure	Gundersen and Rognstad (2001), expert judgements,
Spreading techniques	Statistics Norway (Sample Surveys of Agriculture), Gundersen and Rognstad (2001), expert judgements,
Usage and time of harrowing and ploughing.	(Tine BA <i>annually</i> ) (Dairy cattle, goats), Statistics Norway's Sample Survey 2001 (Statistics Norway 2002) (non-dairy cattle, sheep), expert judgements.
Pasture times for different animal categories	

**6.5.4. Emission factors***N<sub>2</sub>O*

The IPCC default emission factor of 0.0125 kg N<sub>2</sub>O-N/kg N has been used for all sources of direct N<sub>2</sub>O emissions from agricultural soils, with the following two exceptions: Emissions of N<sub>2</sub>O from animals on pastures are calculated using the IPCC factor of 0.02 kg N<sub>2</sub>O-N/kg N, and the emissions that occur as a result of cultivation of organic soils are calculated by using the IPCC default emission factor of 8 kg N<sub>2</sub>O-N/ha per year (IPCC 2000).

The IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg NH<sub>3</sub>-N is used to calculate emissions of N<sub>2</sub>O from deposition of N from volatilised NH<sub>3</sub>. The IPCC default emission factor of 0.025 kg N<sub>2</sub>O-N/kg N lost to leaching/runoff is used.

**Table 6.19. Emission factors for NH<sub>3</sub>-N for different fertilisers**

Fertiliser	Emission factor ( per cent of applied N)
Urea .....	15
Ammonium sulphate and Ammonium nitrate .....	5
Calcium nitrate .....	0
Calcium ammonium nitrate .....	1
NPK (Nitrogen, phosphorus, potassium) .....	1
Other .....	1

Source: ECETOC (1994) and Norsk Hydro, *pers. comm.*<sup>20</sup>

### NH<sub>3</sub>

#### *Synthetic fertiliser*

Different types of synthetic fertilisers are being used, resulting in different emissions of NH<sub>3</sub>. Their respective share is based on sales statistics provided annually by the Norwegian Food Safety Authority for the years from 2000. For earlier years the distribution is based on data from 1994. The NH<sub>3</sub> emission factors (per cent loss of N) for the different types of fertilisers are shown in table 6.19.

#### *Animal manure applied to soil and pasture*

Emission factors for spreading of stored manure vary with spreading method (Gundersen and Rognstad 2001), water content (Statistics Norway 2007), type and time of treatment of soil (Gundersen and Rognstad 2001), time of year of spreading (Gundersen and Rognstad 2001; Statistics Norway 2007), cultivation, and region. The basic factors used are shown in table 6.20.

**Table 6.20. Emission factors for NH<sub>3</sub>-N for various methods of spreading of manure. Per cent of ammonium N**

			Western and northern Norway			Southern and eastern Norway		
			Spring	Summer	Autumn	Spring	Summer	Autumn
<b>Meadow</b>								
Surface spreading			0.5	0.6	0.4	0.5	0.6	0.4
Injection			0.1	0.1	0.05	0.1	0.1	0.05
Water mixing			0.3	0.3	0.2	0.3	0.3	0.2
Dry manure			0.04	0.1	0.1	0.04	0.1	0.1
<b>Open fields</b>								
Method	Time before down-moulding	Type of down-moulding						
Surface spreading	0-4 hrs	plow	0.2		0.2	0.15		0.3
Surface spreading	+ 4 hrs	plow	0.5		0.35	0.4		0.4
Surface spreading	0-4 hrs	harrow	0.4		0.35	0.35		0.35
Surface spreading	+ 4 hrs	harrow	0.5		0.45	0.45		0.45
Water mixing	0-4 hrs	plow	0.1		0.1	0.1		0.15
Water mixing	+ 4 hrs	plow	0.25		0.2	0.2		0.25
Water mixing	0-4 hrs	harrow	0.2		0.2	0.2		0.2
Water mixing	+ 4 hrs	harrow	0.3		0.25	0.25		0.25
Dry manure			0.04		0.1	0.04		0.1

Source: Morken and Nesheim (2004).

<sup>20</sup> Norsk Hydro (1995): Personal information, Kaarstad, Norsk Hydro.

**Table 6.21. Average NH<sub>3</sub> emission factors for cultivated fields and meadows after time of spreading and region. 2011. Per cent of ammonium N.**

	South-Eastern Norway		Hedmark/Oppland		Rogaland		Western Norway		Trøndelag		Northern Norway	
	Field	Meadow	Field	Meadow	Field	Meadow	Field	Meadow	Field	Meadow	Field	Meadow
Spring	32.9	44.4	35.3	44.3	23.2	48.2	4.0	40.2	28.4	46.9	5.1	47.6
Autumn	28.6	33.3	28.9	33.2	21.3	34.4	10.0	28.9	30.9	34.4	11.0	33.2

Source: Statistics Norway, NH<sub>3</sub>-model estimations.

The factors in table 6.20 are combined with the activity data in the Sample survey of agriculture and forestry 2007 (Statistics Norway 2007) and a time series on mixture of water in manure, and emission factors for NH<sub>3</sub> emissions from spreading of manure distributed to meadow and cultivated fields, time of season and region are calculated (see table 6.21). These factors are in turn connected to activity data that are updated in the years since 1990, i.e. number of animals (amount of manure), time of spreading and type of cultivation of the areas where the manure is spread.

The emission factors used for the calculation of the NH<sub>3</sub> emissions from grazing animals are shown in table 6.22. These are the same as the emission factors used in Germany (Dämmgen *et al.* 2002) and Denmark (Hutchings *et al.* 2001).

**Table 6.22. NH<sub>3</sub> emission factors from droppings from grazing animals on pasture. Per cent of ammonium N**

	N-loss/N applied
Cattle .....	7.5
Sheep and goats .....	4.1
Reindeer .....	4.1
Other animals .....	7.5

Source: Dämmgen *et al.* (2002), Hutchings *et al.* (2001).

## 6.5.5. Uncertainties

### 6.5.5.1. Activity data

There are several types of activity data entering the calculation scheme:

*Sales of nitrogen fertiliser:* The data are based on sales figures during one year (The Norwegian Food Safety Authority). The uncertainty in the sales figures is within  $\pm 5$  per cent (Rypdal and Zhang 2000). In addition comes a possible error due to the fact that sales do not necessarily equal consumption in a particular year, due to storage. The share of the various types of nitrogen fertiliser is assumed to be the same as in an investigation in 1994, and the error connected to this approach has probably increased over the years. The effect for the uncertainty in activity data due to these two factors has not been quantified, but it is assumed that it can be more important than the uncertainty in the sales figures.

NH<sub>3</sub> losses from fertiliser containing ammonium (NH<sub>4</sub>) are related to soil pH. This could probably also lead to uncertainty, but Norwegian soils are very dominated by soils with low pH, which leads to small losses of this type.

*Amount of nitrogen in manure:* The figures are generated for each animal type, by multiplying the number of animals with a nitrogen excretion factor. The nitrogen excretion factors are uncertain. The range is considered to be within  $\pm 15$  per cent (Rypdal 1999). The uncertainty is connected to differences in excreted N between farms in different parts of the country, that the survey farms may not have been representative, general measurement uncertainty and the fact that fodder and feeding practices have changed since the factors were determined.

The uncertainty connected to the estimate of the amount of manure is higher than for the amount of synthetic fertiliser used.



*Fate of manure:* There is significant uncertainty connected to the allocation of manure between what is used as fertiliser and droppings on pastures.

*Atmospheric deposition of NH<sub>3</sub>:* The data are based on national NH<sub>3</sub> emission figures. These are within  $\pm 30$  per cent (Rypdal 1999).

*Leakage of nitrogen:* The upper limit for the leakage is the applied nitrogen. The uncertainty is roughly about  $\pm 70$  per cent (Rypdal 1999).

#### **6.5.5.2. Emission factors**

*N<sub>2</sub>O*

Uncertainty estimates used for the N<sub>2</sub>O emission factors are given in Appendix D.

*NH<sub>3</sub>*

The uncertainty in the estimate of emissions of NH<sub>3</sub> from use of fertiliser is assessed to be about  $\pm 20$  per cent (Rypdal and Zhang 2001). This uncertainty could be lower if better data on fertiliser composition were obtained. The uncertainty is higher for animal manure ( $\pm 30$  per cent (Rypdal and Zhang 2001)). This is due to uncertainties in several parameters (fraction of manure left on pastures, amount of manure, conditions of storage, conditions of spreading and climate conditions) (Rypdal and Zhang 2001). Other factors that could lead to uncertainty are variation in storage periods, variation in house types and climate, and variation in manure properties.

#### **6.5.6. Completeness**

All sources described in the IPCC reporting guidelines are included in the estimates. However, the emission factors might not be reflecting national conditions.

#### **6.5.7. Source specific QA/QC**

In a Nordic project in 2002, the estimates for emissions of direct and indirect N<sub>2</sub>O from agricultural soils in the national emission inventories were compared with the results using the IPCC default methodology and the IPCC default factors. The results for the Nordic countries are presented in a report (Petersen and Olesen 2002).

Statistics Norway, in cooperation with the Norwegian University of Life Sciences (NMBU), made in 2003 improvements in the calculation model for NH<sub>3</sub> emissions from the agricultural sector. Data sources used for the recalculations in the revised NH<sub>3</sub> model are coefficients from the Norwegian University of Life Sciences, and two surveys from Statistics Norway; a manure survey (Gundersen and Rognstad 2001) and the sample survey of agriculture and forestry (2001).

In 2006, the methodology used for estimating N<sub>2</sub>O from crop residues was changed to the method Tier 1b recommended in (IPCC 2000). The new method is more detailed and is supposed to better reflect the real emissions than the earlier used national method.

In 2009, the earlier used constant estimate for the area of cultivated organic soils was replaced with new estimates for the whole time series. The recalculations give a decrease in N<sub>2</sub>O emissions for the whole period. The time series for the area of cultivated organic soils was revised by Bioforsk in 2012 based on more information about the yearly decline of moor.

There was a strong price increase for nitrogen fertiliser, which caused a stock building in 2008 and corresponding lower purchases in 2009. The calculation of N<sub>2</sub>O emissions from use of nitrogen fertiliser is based on sales figures for each year. To correct for this, a transfer of fertiliser from 2008 to 2009 was made in the calculations.

In a project in 2012 at the Norwegian University of Life Sciences (NMBU) that updated the Norwegian nitrogen excretion factors for the different animal species, comparisons were made with the corresponding factors used in Sweden, Denmark and Finland and with IPCC default factors as a verification of the Norwegian factors (Karlengen et al. 2012).

A new  $Frac_{leach}$  factor was estimated in a study by Bioforsk (Norwegian Institute for Agricultural and Environmental Research) in 2012 (Bechmann et al. 2012). The updated factor is based on the data from the Agricultural Environmental monitoring program (JOVA).

A project with the aim to revise the Norwegian  $CH_4$  conversion factors (MCF) for the manure storage systems in use was conducted at the Norwegian University of Life Sciences (NMBU) in 2013. The maximum  $CH_4$  producing capacity (Bo) was also revised for cattle manure.

## 6.6. Emissions from agricultural residue burning (agricultural wastes)

IPCC 4F

NFR 4F

Last update: 19.03.2014

### 6.6.1. Description

Burning of agricultural residues gives emissions of standard non-fossil combustion products. Emissions of  $CH_4$ ,  $N_2O$ ,  $NO_x$ , CO,  $NH_3$ , NMVOC,  $SO_2$ , particles and the heavy metals Pb, Cd, Hg, As, Cu and Cr, and PAH and dioxins are included in the inventory.

### 6.6.2. Method

The emissions from the burning of crop residues are being calculated in accordance with a Tier 1 approach (EEA 2009):

$$E_{\text{Pollutant}} = AR_{\text{residue\_burnt}} * EF_{\text{Pollutant}}$$

$E_{\text{Pollutant}}$  = emission (E) of pollutant

$AR_{\text{residue\_burnt}}$  = activity rate (AR), mass of residue burnt (dry matter)

$EF_{\text{Pollutant}}$  = emission factor (EF) for pollutant

### 6.6.3. Activity data

The annual amount of crop residue burned on the fields is calculated based on crop production data for cereals and rapeseed from Statistics Norway, and estimates of the fraction burned made by the Norwegian Crop Research Institute, Norwegian Agriculture Agency and Statistics Norway. For cereals a water content of 15 per cent is used (IPCC 1997a) and the water content for rapeseed is set to 9 per cent (Swedish environmental protection agency 2005). The activity data are consistent with the data used in the estimations of  $N_2O$  from crop residues.

## 6.6.4. Emission factors

**Table 6.23. Emission factors for agricultural residue burning**

Components	Emission factors	Unit	Source
<b>Greenhouse gases</b>			
CH <sub>4</sub>	2.4	kg/ tonnes crop residue (d.m.) burned	(IPCC 1997a)
N <sub>2</sub> O	0.0469	kg/ tonnes crop residue (d.m.) burned	(IPCC 1997a)
<b>Precursors</b>			
NO <sub>x</sub>	2.4	kg/ tonnes crop residue (d.m.) burned	(EEA 2009)
CO	58.9	kg/ tonnes crop residue (d.m.) burned	(EEA 2009)
SO <sub>2</sub>	0.3	kg/ tonnes crop residue (d.m.) burned	(EEA 2009)
NM VOC	6.3	kg/ tonnes crop residue (d.m.) burned	(EEA 2009)
NH <sub>3</sub>	2.4	kg /tonnes crop residue (d.m.) burned	(EEA 2009)
<b>Heavy metals</b>			
Pb	0.865	g/ tonnes crop residue (d.m.) burned	(EEA 2009)
Hg	0.008	g/ tonnes crop residue (d.m.) burned	(EEA 2009)
Cd	0.049	g/ tonnes crop residue (d.m.) burned	(EEA 2009)
As	0.058	g/ tonnes crop residue (d.m.) burned	(EEA 2009)
Cr	0.22	g/tonnes crop residue (d.m.) burned	(EEA 2009)
Cu	0.354	g/ tonnes crop residue (d.m.) burned	(EPA 2002)
<b>Particles</b>			
TSP, PM <sub>10</sub>	5.8	kg/ tonnes crop residue (d.m.) burned	(EEA 2009)
PM <sub>2.5</sub>	5.5	kg/ tonnes crop residue (d.m.) burned	(EEA 2009)
<b>POPs</b>			
PAH-total	30.0	g/ tonnes crop residue (d.m.) burned	(Norwegian institute for air research and Norwegian institute for water research 1995), (EPA 1998)
PAH-6	13.9	g/ tonnes crop residue (d.m.) burned	(Norwegian institute for air research and Norwegian institute for water research 1995), (EPA 1998)
PAH-4	3.0	g/ tonnes crop residue (d.m.) burned	(Norwegian institute for air research and Norwegian institute for water research 1995), (EPA 1998)
Dioxins	17	µg I-TEQ/tonnes crop residue (d.m.) burned	(Norwegian pollution control authority 2001)

### *Heavy metals and POPs*

The emission factors recommended in EPA (2002) are used for Cu. For the other heavy metals default emission factors from the EMEP/EEA emission inventory guidebook are used (EEA 2009). The emissions of dioxins and PAH are calculated based on emission factors respectively from OSPAR (Norwegian pollution control authority 2001) and NILU/NIVA (Norwegian institute for air research and Norwegian institute for water research 1995). The emission profile used for PAH is the one presented for open burning of garden waste (EPA 1998).

### 6.6.5. Uncertainties

Uncertainty estimates for the greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

### 6.6.6. Completeness

The main emission components from burning of agricultural residues are considered to be covered in the emission calculations.

### 6.6.7. Source specific QA/QC

In 2002, the emissions of CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, CO, Pb, Hg, Cd, PAHs and dioxins from agricultural residual burning were included in the Norwegian inventory, and in 2003, the emissions of particles, As, Cr and Cu were added. In 2011, also emissions of SO<sub>2</sub>, NMVOC and NH<sub>3</sub> were included in the inventory. The time series were included but it should be noted that the figures for the earlier years have a higher uncertainty than the more recent years.

## 6.7. Other agricultural emission sources

*IPCC -*

*NFR 4G*

*Last update: 15.02.2011*

### 6.7.1. Description

Straw treated with NH<sub>3</sub> to be utilised as fodder is a source of NH<sub>3</sub> emissions in Norway. Agricultural activities are also a source of non-combustion emissions of particles.

### 6.7.2. NH<sub>3</sub> emissions from treatment of straw

#### 6.7.2.1. Method

Emissions of NH<sub>3</sub> from treatment of straw depend only on the amount of NH<sub>3</sub> used. The total amount of NH<sub>3</sub> used for treatment of straw in Norway is multiplied with the share of the NH<sub>3</sub> that is not integrated in the straw.

#### 6.7.2.2. Activity data

The amount of NH<sub>3</sub> used per year is obtained from the Budget Committee for Agriculture (NILF 2010). The area of cultivated fields is annually updated from Statistics Norway's agriculture statistics.

#### 6.7.2.3. Emission factor

It is estimated that 65 per cent of the NH<sub>3</sub> applied is not integrated with the straw, and is therefore emitted after the treatment (Morken 2003). The same estimation is being used in Denmark.

#### 6.7.2.4. Uncertainties

Uncertainty in the estimate of emissions from NH<sub>3</sub> treatment of straw is rather low ( $\pm 5$  per cent) (Rypdal and Zhang 2001).

#### 6.7.2.5. Completeness

Major missing emission components are not likely.

#### 6.7.2.6. Source specific QA/QC

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### 6.7.3. Particle emissions from the agricultural sector

Agriculture is responsible for various types of non-combustion emissions of particles. This is for example dust from crops that are harvested, soil dust from work with agricultural machines, wood particles from felling of trees etc.

#### 6.7.3.1. Method

Due to the relatively few analyses of particle emissions from agriculture, the calculations from this source are limited. Emission figures for three types of non-combustion emissions of particles from the agriculture are calculated; emissions from reaper, and from loading and transport on the fields. The total grain cultivation area in Norway is multiplied with emission factors, which gives emissions per area unit. For other actual activities in the agricultural fields, no emission factors have been found.

**6.7.3.2. Activity data**

The total grain cultivation area in Norway is used as activity data. Data source used is statistics from Statistics Norway on the area on holdings used for grain seeds.

**6.7.3.3. Emission factor**

The emission factors used are shown in table 6.24. These factors refer to wheat cultivation, but they are used for all grain cultivation in Norway. The factors are based on measurements of particles with a diameter less than 7 µm. No measurements have been made for estimating the ratio between PM<sub>2.5</sub>, PM<sub>10</sub> and TSP. Therefore the estimation has been made that the calculated emission figures (in reality PM<sub>7</sub>) is PM<sub>10</sub> = PM<sub>2.5</sub> = TSP.

**Table 6.24. Emission factors for non-combustion emissions of particles from the agricultural sector. g/km<sup>2</sup>**

Emission source	
Reaper .....	170
Loading .....	12
Transport .....	110

Source: EPA (1998).

**6.7.3.4. Uncertainties**

No uncertainty analysis has been made for this source. The few studies made in this field give a relatively high uncertainty for this source.

**6.7.3.5. Completeness**

The information about this emission source is poor, and it is likely that there are more particle sources from the agricultural sector than included here.

**6.7.3.6. Source specific QA/QC**

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

## 7. Waste

IPCC 1A and 6

NFR 1A1a

### 7.1. Overview

This sector includes emissions from landfills (6A), waste water handling (6B) and small-scale waste incineration (6C). Emissions from waste incineration included here are emissions from flaring, except flaring from energy sectors, and emissions from cremation and hospital waste (until 2005). The main emissions from waste incineration are included in the energy sector (1A), since all incineration of municipal, industrial and medical waste in Norway now is done with energy recovery. The source sector *6D Waste other* covers emissions from municipal sewage sludge applied to parks etc., emissions from accidental car fires, building fires, and emissions from recovering processes in the waste trade.

### 7.2. Solid waste disposal on land

IPCC 6A, Key category for CH<sub>4</sub>

NFR 6A

#### 7.2.1. Managed waste disposal on land

IPCC 6A1

NFR 6A1

Last update: 22.05.2013

##### 7.2.1.1. Description

CH<sub>4</sub> and non-fossil CO<sub>2</sub> are emitted during biological decomposition of waste. This transformation of organic matter takes place in several steps. During the first weeks or months, decomposition is aerobic, and the main decomposition product is CO<sub>2</sub>. When there is no more oxygen left, the decomposition becomes anaerobic, and methane emissions start to increase. After a year or so, CH<sub>4</sub> emissions reach a peak, after that the emissions will decrease over some decades (Jensen *et al.* 1999; Barlaz 2004).

The emissions of methane have decreased considerably since 1990 due to reduction of the amount of degradable waste disposed at disposal sites. This reduction in emissions is the result of several measures which were introduced in the waste sector, particularly in the 1990s. With a few exceptions, it was then prohibited to dispose easily degradable organic waste, sewage sludge included, at landfills in Norway. From 1 July 2009 it is prohibited to deposit biodegradable organic waste to landfills and this will result in reduced methane emissions. In 1999 a tax was introduced on waste delivered to final disposal sites, and in 2013 this tax was 289 NOK per tonne waste. There is a possibility of exemption from the prohibition of depositing biodegradable waste at landfills – in such cases the tax is 479 NOK per tonne waste.

In addition to the policy measures described above, landfills receiving biodegradable waste (waste containing degradable organic carbon (DOC)) are required to collect and treat landfill gas. In 2012, 75 landfills who had installed a landfill gas extraction system reported extraction of gas, and 14.1 ktonnes of methane were recovered. In addition, the amounts of waste recycled have increased significantly since 1990. The total amount of waste generated has increased by 39 per cent from 1995 to 2011. Due to the increase in material recycling and energy utilization in the period, the amount disposed at landfills has dropped substantially since 2007, and is at its lowest since 1995. As a consequence of the prohibition against depositing of biodegradable waste of 1 July 2009 there has been a strong decrease in waste depositing. Since building the necessary treatment capacity would take time, temporary exemptions were granted in certain cases in a

transitional period. There were given many permits for disposal of biodegradable waste for one year extra, some extended out 2010, and a few within 2011. The transitional period ended on 31 December 2012. The amount of waste generated in 2011 was 5 per cent higher than in 2010.

### 7.2.1.2. Method

#### *CH<sub>4</sub>*

Norway uses the IPCC Waste model for estimating CH<sub>4</sub> emissions from SWDS (solid waste disposal sites) (Tier 3). This is a FOD (first order decay) spreadsheet model based on waste composition data. The amounts of different types of degradable waste material (food, paper, wood, textile and plastic) in MSW (municipal solid waste) are entered separately into the model.

The model starts with the calculation of the amount of dissimilating DDOC<sub>m</sub> (mass of dissimilable organic carbon = the part of DOC (degradable organic carbon) that will dissimilate (degrade) under anaerobic conditions) contained in the amount of material being landfilled.

As this is a first order reaction, the amount of product formed will always be proportional to the amount of reactant. This means that it is of no concern to the process when the DDOC<sub>m</sub> came into the landfill. As far as we know the amount of DDOC<sub>m</sub> in the landfill at the start of the year, all years can be considered to be the first calculating year. This simplifies calculations. With reaction start set to be on January 1 the year after landfilling, the “motor” of the new calculating model has been made out of these two very simple equations:

$$(7.1) \quad DDOC_{mdiss} = (DDOC_{ma(ly)} + DDOC_{md}) * (1 - e^{-k})$$

$$(7.2) \quad DDOC_{ma} = (DDOC_{ma(ly)} + DDOC_{md}) * e^{-k}$$

Equation (7.1) calculates DDOC mass dissimilating (*DDOC<sub>mdiss</sub>*), from the not dissimilated DDOC mass accumulated from last year (*DDOC<sub>ma(ly)</sub>*), plus DDOC mass landfilled last year (*DDOC<sub>md</sub>*). Equation (7.2) calculates the DDOC mass accumulated as not dissimilated (*DDOC<sub>ma</sub>*), for next year's calculations from the same basis as equation (7.1).

After that the amount of dissimilated DDOC<sub>m</sub> has been found, CH<sub>4</sub> produced and CH<sub>4</sub> emitted is found by using the same set of procedures and factors as in the former model.

The full set of equations is found below. If the reaction is set to start in the year of landfilling, separate calculations have to be made for that year and two extra calculating equations will have to be added. They are included in the equations below.

To calculate DDOC<sub>md</sub> from the amount of material:

$$(7.3) \quad DDOC_{md} = W * MCF * DOC * DOC_f$$

To calculate DDOC<sub>m</sub> accumulated in the SWDS:

$$(7.4) \quad DDOC_{ml} = DDOC_{md} * e^{-k * ((13-M)/12)}$$

$$(7.5) \quad DDOC_{ma} = DDOC_{ma(ly)} * e^{-k} + DDOC_{ml}$$

To calculate DDOC<sub>m</sub> dissimilated:

$$(7.6) \quad DDOC_{mdi} = DDOC_{md} * (1 - e^{-k * ((13-M)/12)})$$

$$(7.7) \quad DDOC_{mdiss} = DDOC_{ma(ly)} * (1 - e^{-k}) + DDOC_{mdi}$$

To calculate methane produced from DDOC dissimilated:

$$(7.8) \quad CH_4_{prod} = DDOC_{mdiss} * F * 16/12$$

To calculate methane emitted:

$$(7.9) \quad CH_4_{emitted \text{ in year } T} = (\sum CH_4_{prod}(T)) - R(T) * (1-OX)$$

Where:

- $W$  : amount landfilled
- $MCF$  : Methane Correction Factor
- $M$  : Month number for reaction start. (January 1, year after landfilling, M=13)
- $DOC$  : Degradable Organic Carbon
- $DOC_f$  : Fraction of DOC dissimilating, anaerobic conditions
- $DDOC$  : Dissimilatable Organic Carbon, anaerobic conditions
- $DDOC_{md}$  : DDOC mass landfilled
- $DDOC_{ml}$  : DDOC mass left not dissimilated from DDOCm landfilled, year of landfilling
- $DDOC_{ma}$  : DDOC mass left not dissimilated at end of year
- $DDOC_{ma(ly)}$  : DDOC mass accumulated from last year
- $DDOC_{mdi}$  : DDOC mass dissimilated from DDOCm landfilled, year of landfilling
- $DDOC_{mdiss}$  : DDOC mass dissimilated in calculation year
- $CH_4_{prod}$  : CH<sub>4</sub> produced
- $F$  : Fraction of CH<sub>4</sub> by volume in generated landfill gas
- $16/12$  : Conversion factor from C to CH<sub>4</sub>
- $R(T)$  : Recovered CH<sub>4</sub> in year of calculation
- $OX$  : Oxidation factor (fraction).

### 7.2.1.3. Activity data

The methane is formed by decomposition of biological waste in landfills. The decomposition time varies from material to material. Easily degradable waste (food, etc.) has the shortest decomposition time, while wood waste has the longest decomposition time. Other materials do not emit methane at all, either because they are inorganic (metal, glass, etc.) or because they break down extremely slowly (plastic). It is therefore of vital importance for the calculations that the waste quantities used as input to the model are correct, both total quantity and the distribution by material.

Data on the amount of different waste materials is taken from Statistics Norway's waste accounts. Statistics Norway's waste accounts consist of data from several sources, such as special surveys, register data and statistics, sorting analyses, indirect data sources such as production statistics, foreign trade statistics and different factors combined with activity data. Data from all these sources are put together and used in the waste accounts, which give an overview of waste quantities in Norway, divided into type of product, material, industry and method of treatment.

Historic data have been recalculated from the former waste category basis, to a waste material basis. The amount of each material type deposited is estimated based on surveys and sorting analyses. The model is based on types of waste materials, for instance food waste (including garden waste), paper, wood and textiles. Some adaptations are made (see below). All sources of waste, MSW, industrial, commercial, construction and demolition waste are accounted for in these annual surveys.

#### *Municipal landfills*

Historical data for the years before 1973 on municipal solid waste deposited are based upon:



1. New statistics on municipal waste, divided into household waste and industrial waste (1974 to 1997)
2. Estimates based on population
3. The assumption that less people were connected to public waste management during the forties and fifties.

Since 1974, the amount of municipal waste is based upon questionnaires and linear interpolation. Surveys were held in 1974, 1980 and 1985. The amounts of waste deposited at landfills are allocated to material based on sorting analyses. For the period 1995-2010 the amounts of waste are taken from the waste accounts, with four adaptations:

- The content of wood in woodcontaining sludge deposited at industrial sites is added to the amount of deposited wood from the waste accounts. The amount of woodcontaining sludge deposited at industrial sites decreased to 0 in year 2000.
- Textiles are supposed to consist of 50 per cent plastic (Norwegian pollution control authority 2005b). The plastic fraction of deposited textiles is therefore subtracted from the amount of deposited textiles and added to deposited plastic.
- Sludge. The amount of sludge deposited at MSWDS are taken from waste water statistics.
- The material category "Other materials" is assumed to contain degradable organic matter with an average half-life. This degradable share is added to the amount of paper. The amount of decomposable organic materials in landfilled 'other' is estimated by  $0.5 * \text{'other combustible'}$  in landfilled mixed waste from all sectors +  $0.2 * \text{'other materials'}$  from manufacturing (other sectors not relevant). Landfilled 'other materials' is the dominating of the two fractions, comprising 70 to 95 per cent of the total. The factor of 0.2 is based on detailed study of the basic data, showing that in 2008, 40 per cent of the corresponding waste category came from industries with mainly biodegradable organic production waste. Of this, (at least) half was assumed to be non-organic in order to get permission for landfilling the waste. Earlier reference years showed lower shares coming from industries with biodegradable organic production waste. Thus, the fraction of 0.2 is judged to be conservative. Since the data on waste from manufacturing are uncertain at this detailed level, a trend adjustment is performed to fit the trend in landfilled biodegradable 'other material' from manufacturing with the overall trend in landfilled biodegradable waste in Norway. The factor 0.5 applied on 'other combustible' is chosen as a medium value, due to absence of information. Other substances in the landfilled 'other materials' are assumed entirely mineral or non-degradable. (Heie 1998 and Skullerud, Frøyen et.al. 2010)

Contaminated soils are assumed not to develop methane in landfills. The same applies to waste used as cover material, due to excess oxygen availability. No biodegradable hazardous waste is landfilled in Norway. No organic waste is imported for landfilling.

Linear interpolation of the amount of waste deposited has been applied for the period 1985 to 1995.

#### *Industrial disposal sites*

Historical data for industrial waste for years before 1970 are made by extrapolation, using the same trend as for municipal waste. After 1970, literature studies and information from the industrial waste study from the years 1993, 1996, 1999 and 2003 have been used. Linear interpolation is used for the years where data are missing.

Data from each landfill site with methane recovery units are compiled by the county governors and reported to the Norwegian Environment Agency. These data are imported into the national model for calculating methane from landfills.

#### 7.2.1.4. Emission factors

The emission factors used in the Norwegian model are the IPCC default values for Northern Europe. Table 7.1 shows some of the variables used in the calculations of methane emissions from solid waste disposals.

**Table 7.1. Variables used in the calculations of methane from landfills**

Variables	Description	Type of waste				
		Food waste	Paper	Wood	Textiles	Sewage sludge
$t_{1/2}$	Half-life time	3.7 years	11.6 years	23.1 years	11.6 years	3.7 years
DOC		0.15 Mg/Mg	0.40 Mg/Mg	0.43 Mg/Mg	0.24 Mg/Mg	0.05 Mg/Mg
DOC <sub>f</sub>	Part of DOC dissimilating	0.5	0.5	0.5	0.5	0.5
Ox.	Methane oxidized in top layer	0.1	0.1	0.1	0.1	0.1
F.	Part of methane in generated landfill gas	0.5	0.5	0.5	0.5	0.5

Source: IPCC 2006.

#### 7.2.1.5. Uncertainties

The amount of different waste materials is considered to be known within  $\pm 20$  per cent. The emission factors used are considered to have the uncertainty range  $\pm 30$  per cent. More information about the uncertainty estimates for this source is given in Appendix D.

The importance of the uncertainties in calculations of methane from landfills will decrease with decreased source contribution and improved IPCC default parameter values, but most likely it will still remain among the main uncertainties in the Norwegian GHG inventory.

The methodology Statistics Norway/the Norwegian Environment Agency use to calculate methane emissions from landfills is identical for the whole time series. The quality of the activity data used in the model has been improved in the last years. This is also the case regarding the data for recovered methane.

#### 7.2.1.6. Completeness

Major missing emission sources are not likely.

#### 7.2.1.7. Source specific QA/QC

Internal checks of time series for all emission sources are made every year when an emission calculation for a new year is performed.

Internal checks of time series of waste data, methane recovered at landfill sites and calculated methane emissions from the model are carried out and corrections are made if any kind of errors are found. If there is a change in the trend of methane recovered from a landfill site, the site is contacted to identify a plausible explanation. Corrections are made if there is no plausible explanation of the change.

### 7.2.2. Unmanaged waste disposal sites

IPCC 6A2

NFR 6A2

Last update: 01.09.2005

In Norway landfilling of solid waste has been regulated and controlled for some decades, and unmanaged landfills are from before 1970. Furthermore, the methane emissions for all years have been calculated from the total amounts of landfilled materials. Therefore Norway does not separately report emissions from unauthorized/unmanaged SWDSs.

### 7.3. Waste water handling

*IPCC 6B, Key category for N<sub>2</sub>O*

*NFR 6B*

*Last update: 10.02.2014*

The Norwegian waste water treatment system is characterised by few big and advanced waste water treatment plants (WWTPs) and many smaller WWTPs. In 2012, 62 per cent of Norway's population were connected to high-grade treatment plants – biological and/or chemical treatment. Furthermore, 19 per cent of the population were connected to mechanical or other types of treatment, 16 per cent of the population were connected to small wastewater facilities (less than 50 pe) and the remaining 4 per cent had direct discharges. The wastewater facilities in Norway with a capacity of more than 50 population equivalents (pe) treated waste water from 80 per cent of the population,

The source category 6B includes estimation of the emission of CH<sub>4</sub> and N<sub>2</sub>O from waste water handling; i.e. wastewater collection and treatment. CH<sub>4</sub> is produced during anaerobic conditions and treatment processes, while N<sub>2</sub>O may be emitted as a bi-product from nitrification and denitrification processes under anaerobic as well as aerobic conditions.

No distinction between emissions from industrial and municipal WWTPs is made, as Norwegian industries to a great extent are coupled to the municipal sewer system. Waste water streams from households and industries are therefore mixed in the sewer system prior to further treatment at centralised WWTPs.

It should be mentioned that no activity data are available for industrial WWTPs. Therefore, the emissions from industries having separate waste water treatment are unknown and accordingly not included in the Norwegian inventory for category 6B Waste water handling.

Waste water treatment facilities in the Norwegian industry:

- *Oil refining*: There are two oil refineries both with facilities for cleaning waste water for total organic carbon (TOC). Aerob treatment of waste water.
- *Pharmaceutical industry*: Most plants are coupled to the municipal sewage system.
- *Pulp and paper industry*: Energy recovery from waste water treatment in pulp and paper industry is included in the inventory. Some plants report burning of sludge for energy use, while other plants recover methane, and burn CH<sub>4</sub>-gas for energy use. These emissions are included in energy combustion for *Manufacturing Industries and construction: 1A2d Pulp, paper and print*.
- *Chemical industry*: It will be investigated whether emissions from this industry occur.

#### 7.3.1. Method

*CH<sub>4</sub>*

Emissions of methane from domestic waste water and from water consumption in food processing industries (breweries, dairies and slaughterhouses) are included in the inventory.

No activity data are available for industrial WWTPs. Emissions of methane from other industries are not calculated. CH<sub>4</sub> from domestic sludge is calculated together with the waste water emissions.

Emissions of methane from domestic waste water are calculated according to the IPCC default methodology:

$$(7.10) \quad E_i = N_i * D * B_0 * MCF$$

*E*: Emissions of methane  
*N*: Population in Norway  
*D*: Organic load in biochemical oxygen demand (kg BOD/1000 persons/year)  
*B<sub>0</sub>*: Maximum methane-producing capacity (kg CH<sub>4</sub>/kg DC)  
*MCF*: Methane conversion factor  
*i*: Year

Emissions of methane from water consumption in each food processing industry are calculated using the same equation as for domestic water, except that COD is estimated based on water consumption multiplied with mg COD/litre wastewater.

$$(7.11) \quad E_i = W_i * COD_i * B_0 * MCF$$

*E*: Emissions of methane  
*W*: Water consumption/economic turnover (mill. NOK)  
*COD*: Organic load in chemical oxygen demand (kg COD/unit waste water)  
*B<sub>0</sub>*: Maximum methane-producing capacity (kg CH<sub>4</sub>/kg DC)  
*MCF*: Methane conversion factor  
*i*: Industry

### *N<sub>2</sub>O*

For this source emissions of nitrous oxide from domestic and commercial waste water have been calculated. N<sub>2</sub>O emissions from the part of the population and the part of the industry connected to large waste water treatment plants (>50 pe) have been estimated, and N<sub>2</sub>O emissions from human sewage which is not treated in sewage treatment plants are estimated. Emissions of N<sub>2</sub>O from industries with their own waste water treatment plants are not estimated.

N<sub>2</sub>O emissions from the part of the population and the part of the industry connected to large treatment plants (>50 pe) are calculated from nitrification/denitrification that occurs in the pipelines and the N<sub>2</sub>O emissions that occur as a by-product in biological nitrogen-removal plants. This is assumed to be a more precise method than the recommended IPCC method that is based on the annual per capita protein intake. The N<sub>2</sub>O from sewage sludge applied on fields is included under Agriculture in chapter 6 and under Other waste (6D).

For the part of the population connected to treatment plants (> 50 pe), the N<sub>2</sub>O emissions are estimated like this:

N<sub>2</sub>O emissions from pipelines:

$$N_2O_{(S)} = N_{\text{supplied to pipelines}} \times 0.01 \times 1.57$$

For the part of the population that is connected to large treatment plants the N<sub>2</sub>O emissions are calculated by multiplying the total amount of nitrate supplied to the pipelines by the IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg sewage-N produced. Conversion factor of N<sub>2</sub>O-N to N<sub>2</sub>O is 1.57

N<sub>2</sub>O emissions in biological nitrogen removal plants:

$$N_2O_{(S)} = N_{\text{removed}} \times 0.02 \times 1.57$$

It is assumed that 2 per cent of the nitrogen removed from plants will form N<sub>2</sub>O. This country-specific emission factor is given in Norwegian pollution control

authority (1992), and the assumption is based on measurements in plants and comparisons with factors used in Sweden. The amount of N removed is multiplied with 0.02 and then multiplied with the factor of 1.57 for conversion of N-removed to N<sub>2</sub>O-N

For the part of the population that is not connected to large treatment plants, the N<sub>2</sub>O emissions are estimated as recommended by the IPCC review team. The IPCC method based on the annual per capita protein intake is being used. Emissions of N<sub>2</sub>O from the part of the population not connected to large waste water plants (> 50 pe) are estimated by Tier 1 method, using the equation:

$$N_2O_{(s)} = \text{Protein} \times \text{Frac}_{NPR} \times NR_{PEOPLE} \times EF_6$$

N<sub>2</sub>O<sub>(s)</sub>: N<sub>2</sub>O emissions from human sewage (kg N<sub>2</sub>O -N/ yr)

Protein: annual per capita protein intake (kg/person/yr)

NR<sub>PEOPLE</sub>: number of people not connected to treatment plants

EF<sub>6</sub>: emission factor (default 0.01 (0.002-0.12) kg N<sub>2</sub>O -N/kg sewage- N produced)

Frac<sub>NPR</sub>: fraction of nitrogen in protein (default = 0.16 kg N/kg protein)

### 7.3.2. Activity data

#### CH<sub>4</sub>

Data for the number of people in Norway are taken from Statistics Norway's population statistics. The IPCC default value of 18 250 kg BOD/1000 persons/year is used for D, the degradable organic component in the waste, for all years.

Industrial wastewater from breweries, dairies and slaughterhouses are to a great extent coupled to the municipal sewer system. Emissions of methane from industries with their own wastewater treatment plants are not calculated due to lack of activity data. The emissions are assumed to be small, because the plants are mainly aerobic.

Norway estimates emissions of CH<sub>4</sub> from food processing industries. The estimations are based on water consumption, in NACE 15 (SIC2002, which now has been replaced by NACE 10/11 in SIC2007) for the year 2004 (Stave 2006) and information from the national accounts on gross values from industry (NACE 15 (SIC2002) or NACE 10/11 (SIC2007)) in constant 2000 prices for the period 1990 to 2011.

Data for the economic turnover in million NOK for each industry are taken from Statistics Norway's national accounts on gross values from industry (NACE 10/11 (SIC2007)).

#### N<sub>2</sub>O

A yearly estimate for the amount of nitrate supplied to the pipelines is obtained from Statistics Norway's waste water statistics. These figures are used for estimating N<sub>2</sub>O emissions from the part of the population and the part of industry connected to large waste water treatment plants.

Data on the amount of nitrogen that is removed in the biological step in the actual waste water plants is obtained from Statistics Norway's waste water statistics. An overview of plants that remove nitrogen is given by the Norwegian Environment Agency.

Data on the number of people in Norway connected to waste water treatment plants are obtained from Statistics Norway's waste water statistics:

<https://www.ssb.no/en/statistikbanken>. See Table 05273 and Table 05272. We know the number of inhabitants connected to large treatment plants (>50 pe) for the years after 1990, and the number of inhabitants connected to small treatment

plants (<50 pe) for the years after 2002. We have also received the percentage connected for 1990, which were 75 per cent. For the years between 1990 and 2002 the percentage connected has been interpolated.

### 7.3.3. Emission factors

#### *CH<sub>4</sub>*

The IPCC emission factor for B<sub>0</sub> of 0.6 kg CH<sub>4</sub>/kg DC is used. The methane conversion factor (MCF) is, according to good practice, given by the fraction of BOD that will ultimately degrade anaerobically. Country-specific MCF factors are estimated by Statistics Norway for the years after 2000, based on the part of the population connected to tanks with anaerobic conditions. Information on the part of the population connected to tanks with anaerobic conditions is taken from Statistics Norway's waste water statistics, and corresponds to the fraction of the waste water plants that are categorized as "Sealed tank", "Sealed tank for black water" and partly the category "Separate toilet system". These are the treatment methods assumed to be anaerobic and hence emit CH<sub>4</sub>. The MCF factor is about 0.01 (1 per cent) for the years after 2000. We assume that in 1990, 2 per cent of the population was connected to anaerobic treatment systems for waste water and that the share gradually has decreased until 2000. From our best knowledge, we therefore assume that the MCF factor of 0.02 is reflecting the condition in 1990 and that the factor for 1990 is consistent with the calculated factors for the years after 2000.

**Table 7.2. The methane conversion factor (MCF) for the periode 1990-2012**

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
MCF .....	0.02	0.019	0.018	0.017	0.016	0.015	0.014	0.014	0.013	0.012	0.011	0.010
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
MCF .....	0.009	0.008	0.009	0.009	0.009	0.009	0.010	0.008	0.008	0.009	0.008	

Emissions from water consumption in food processing industries are calculated using the average MCF factor (0.01) for wastewater. The IPCC emission factor for B<sub>0</sub> of 0.6 kg CH<sub>4</sub>/kg DC is used. The COD factors for the different groups are taken from IPCC 2006 and some are average factors made by Statistics Norway, based on the water consumption and gross values from industry in 2004. We know the water consumption per economic turnover. The same factor is used for all years for the different products (table 7.3). Table 7.3 also shows the default COD factors for the different products. COD factors for manufacture of animal feeds and dry general food products are the average of all the others.

**Table 7.3. The developed water consumption coefficients and chemical oxygen demand. m<sup>3</sup>/million NOK and mg/l**

	m <sup>3</sup> /million NOK	COD mg/l
Manufacture of meat products and cooking oil ..	125	2.9
Manufacture of fish products .....	476	2.5
Manufacture of fruit, vegetables and grain mill products .....	499	5.2
Manufacture of dairy products .....	314	1.5
Manufacture of animal feeds .....	154	2.72
Manufacture of dry general food products .....	170	2.72
Manufacture of beverages .....	317	1.5

Source: IPCC (2006) and Statistics Norway

#### *N<sub>2</sub>O*

For the part of the population and the part of the industry that are connected to large treatment plants, the N<sub>2</sub>O emissions are calculated by multiplying the total amount of nitrate supplied to the pipelines by the IPCC default emission factor of 0.01 kg N<sub>2</sub>O-N/kg sewage-N produced. Conversion factor of N<sub>2</sub>O-N to N<sub>2</sub>O is 1.57.

N<sub>2</sub>O emissions also occur as a by-product in biological nitrogen removal plants. It is assumed that 2 per cent of the nitrogen removed from plants will form N<sub>2</sub>O (country-specific emission factor). Based on measurements at an early stage of the development of the process at one large waste water treatment plant, it was hypothesized that the performance of this plant is much better than this (i.e. a lower percentage of processed N emitted as N<sub>2</sub>O). During 2011 the emissions were tested by measuring N<sub>2</sub>O emissions at various spots within the treatment plant, as well as the concentrations of N<sub>2</sub>O in the liquid phase throughout, including the exit water. The results verified that the performance of this process with respect to N<sub>2</sub>O emission is much better than the emission factor used for this treatment plant. On the average, the emissions of N<sub>2</sub>O -N to air from the entire plant (through the chimney) amount to 0.2 per cent of the processed N. If the N<sub>2</sub>O lost as dissolved N<sub>2</sub>O in the exit water is included, the percentage increases to 0.3 (Bakken 2012). For this treatment plant it is assumed that 0.3 per cent of the nitrogen removed from the plant will form N<sub>2</sub>O. This emission factor has been used for all years since 1996, which is when the nitrification and denitrification reactors were fully operational.

The amount of N removed at the plants is multiplied with 0.02 (0.003 for one plant) and then multiplied with the factor of 1.57 for conversion of N-removed to N<sub>2</sub>O-N.

For the part of the population that is not connected to large treatment plants, the emission factors are as follows: The IPCC emission factors for EF<sub>6</sub> of 0.01kg N<sub>2</sub>O/kg sewage -N produced are used, and the fraction of nitrogen in protein, Frac<sub>NPR</sub>, is 0.16 kg N/kg protein.

Protein is annual per capita protein intake (kg/person/yr).

A report from the Directorate for Health and Social Affairs estimates the amount of daily per capita protein intake for Norway for 1997 (Johansson and Solvoll 1999). There has not been done any other survey like this, where the daily per capita protein intake for Norway has been estimated.

In 1997 the daily per capita protein intake for Norway was 86 grammes, which gives 31.39 kilos per year. For the years 1990, 1995, 2000, 2003, 2004, 2005, 2006, 2007, 2009 and 2010 the Directorate for Health and Social Affairs has estimated the potential protein intake for the population (Directorate for Health and Social Affairs 2012).

The estimation is based on the equation:  
Potential protein intake = production + import - export

This estimation does not reflect that the actual consumption is lower because not everything is eaten. Parts of the food end up as waste and so on. Norway uses an estimated protein intake of 31.39 kilos per person for 1997 and the trend in potential protein intake when making the time series. Statistics Norway has estimated the intermediate years by interpolation. This is based on recommendations from the Directorate for Health and Social Affairs (Johansson, pers. comm<sup>21</sup>). This is shown in table 7.4

<sup>21</sup> Johansson, L. (2005): Personal information by telephone, Directorate for Health and Social Affairs.

**Table 7.4 Potential protein intake, and estimated protein intake. g/person/day, kg/person/year. 1990-2012**

Year	Potential protein intake g/person/day	kg/person/year	Index 1997 =100	Estimated protein intake kg/person/year
1990 ....	<b>94</b>	34.3	100.5	31.6
1991 ....	93.8	34.2	100.3	31.5
1992 ....	93.6	34.2	100.1	31.4
1993 ....	93.4	34.1	99.9	31.6
1994 ....	93.2	34.0	99.7	31.3
1995 ....	<b>93</b>	33.9	99.5	31.2
1996 ....	93.3	34.0	99.7	31.3
<b>1997</b> ....	93.5	34.1	100	<b>31.39</b>
1998 ....	93.8	34.2	100.3	31.5
1999 ....	<b>94</b>	34.3	100.5	31.6
2000 ....	<b>95</b>	34.7	101.6	31.9
2001 ....	96	35.0	102.7	32.2
2002 ....	97	35.4	103.7	32.6
2003 ....	<b>98</b>	35.8	104.8	32.9
2004 ....	<b>101</b>	36.9	108.0	33.9
2005 ....	<b>100</b>	36.5	107.0	33.6
2006 ....	<b>102</b>	37.2	109.1	34.2
2007 ....	<b>112</b>	40.9	119.8	37.6
2008 ....	111	40.5	118.7	37.3
2009 ....	<b>110</b>	40.2	117.6	36.9
2010 ....	<b>100</b>	33,5	107.0	33.6
2011 <sup>1</sup> ...	100	36.5	107.0	33.6
2012 <sup>1</sup> ...	100	36.5	107.0	33.6

Numbers in bold in column 2 are from the Directorate for Health and Social Affairs, (2012)

<sup>1</sup>Estimates for 2011 are also used for 2011 and 2012, due to lack of newer data.

#### 7.3.4. Uncertainties

Uncertainty estimates for this source are given in Appendix D.

#### 7.3.5. Completeness

Major missing emission components are not likely.

#### 7.3.6. Source specific QA/QC

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### 7.4. Waste incineration

*IPCC 1A1a, 1A2d and 6C*

*NFR 1A1a, 1A2d and 6C*

*Last update: 22.05.2013*

#### 7.4.1. Description

Emissions from waste incineration in district heating plants are reported under energy (IPCC 1A1a), as the energy is utilised, and therefore described in section 3.2.2. In 2012, there were 12 waste incineration plants where household waste was incinerated. In addition, some incineration plants burn waste other than household waste, mainly wooden waste, paper, pasteboard and cardboard. These emissions are reported and described under energy (IPCC 1A2d). Waste, other than household waste, is also used as energy source in some manufacturing industries. These emissions are reported and described in the relevant subsectors under 1A2. Flaring off-shore and in refineries is included under sector 1B2c. Flaring in chemical industry is included under sector 2B5. In this chapter, the focus will be on waste reported in IPCC sector 6C. This includes emissions from flaring, except flaring from energy sectors, and emissions from cremation and hospital waste until 2005. CO<sub>2</sub> emissions from cremations of human bodies are biogenic.



### 7.4.2. Method

Emissions from flaring of landfill gas are estimated. However, CO<sub>2</sub> emissions from flaring of landfill gas are not included in the inventory, as these are considered as being of biogenic origin. The emissions are estimated by multiplying the amount of gas flared with the emission factors shown in table 7.6.

Emissions from cremation and hospital waste are estimated by emission factors multiplied with activity data. For hospital waste, the emissions of lead, cadmium and mercury used in the model are reported to the Norwegian Environment Agency. Emissions of arsenic, chromium and copper were only reported by two hospitals to the Norwegian Environment Agency for the year 1999. A country specific emission factor is made for each component. This factor is based on the ratio between reported emission figures for 1999 and the quantities of waste burned in 1999. This factor is then multiplied with the amount of waste burned at other hospitals for the years 1995 -2005. Around 1995 more control device systems were installed at waste incineration plants as a result of stricter emission requirements. It is assumed that this also applied to incineration of hospital waste. For the years before 1995 it is assumed that the emissions were higher. The emission standards for particulate matter from waste incineration changed from 100 to 30 mg/Nm<sub>3</sub>. It was assumed that emissions of lead, cadmium, copper and chromium follow the same pattern as particulate matter. It is believed, however, that arsenic is more like properties of mercury, and we assume that emissions of arsenic have been reduced in the same way as mercury. Emissions of mercury were regulated from 0.1 to 0.05 mg/Nm<sub>3</sub> from 1994/1995. It is therefore assumed that emissions of arsenic before 1995 were twice as large as after 1995. Emissions of particulate matter are reported for all hospitals for the period 1990-1999. Since 2000, emissions from some of the hospitals are estimated based on EF and the amount of waste incinerated. Since 2006 all hospital waste is incinerated at waste incineration plants.

### 7.4.3. Activity data

#### *Landfill gas*

The total amount of landfill gas extracted each year is reported by landfill owners to the Norwegian Environment Agency. Statistics Norway subtracts the amount utilized for district heating and thermal power, which is given by the energy statistics in Statistics Norway. Information on the amount flared is given by the Norwegian Environment Agency. Emissions from landfill gas flared is included under 6C. Emissions from landfill gas used for district heating and used in other sectors are reported in the relevant subsectors under 1A1 and 1A4.

**Table 7.5. Amount of landfill gas flared and used for energy purposes. Tonnes. 1990-2012**

Year	6C. Flared	1A1a district heating	1A4a, Other sectors, commercial /institutional
1990 .....	<b>879</b>	0	67
1991 .....	2 483	0	189
1992 .....	4 103	0	1 109
1993 .....	4 893	0	1 322
1994 .....	5 304	0	1 433
1995 .....	<b>5 951</b>	208	2 472
1996 .....	6 869	350	2 853
<b>1997</b> .....	9 309	224	2 016
1998 .....	13 505	201	2 925
1999 .....	16 222	2 420	3 513
2000 .....	<b>12 459</b>	3 654	2 698
2001 .....	11 674	3 235	5 672
2002 .....	11 769	121	10 270
2003 .....	<b>11 183</b>	121	10 199
2004 .....	<b>10 550</b>	174	9 739
2005 .....	8 995	187	13 925
2006 .....	8 093	177	12 528
2007 .....	10 419	1 767	10 558
2008 .....	10 351	3 061	8 483
2009 .....	9 870	4 752	6 041
2010 .....	8 283	4 077	7 056
2011 .....	6 965	3 428	5 933
2012* .....	3 004	8 539	2 559

*Hospital waste*

The amount of hospital waste was reported to Statistics Norway for the years 1998 and 1999. For the period 1990-1997 the average for 1998 and 1999 has been used. After 1999 there has been no collection of hospital waste data. Due to the lack of better information, the waste amount for 1999 has been used to calculate the emissions for subsequent years. The hospital incinerators have gradually been closed down, mainly due to new emission limits. Since 2006, no hospital incinerators have been in operation. Today hospital waste is incinerated in incinerators for municipal waste and emissions are included under 1A1a.

*Cremation*

The incineration of human bodies is a common practice that is performed on an increasing part of the annually deceased. The number of cremated bodies is gathered by the Ministry of Culture and published in Statistics Norway's Statistical Yearbook. The average body weight is assumed to be 60 kg.

#### 7.4.4. Emission factors

**Table 7.6. Emission factors for flare of landfill gas, cremation and hospital waste incineration**

Component	Flare landfill gas kg/tonnes	Cremation Tonnes/body	Hospital waste Tonnes/tonnes
SO <sub>2</sub>	0.02	0.00001813	0.0014
CO <sub>2</sub>	0	0	0.3
CO	0.04	0.000735	0.0028
NO <sub>x</sub>	0.17	0.0000441	0.0014
Particles PM <sub>10</sub>	0.14	2.54E-08	0.0005
TSP			0.0005
PM <sub>2.5</sub>			0.0005
NM VOC	0	0.0000637	0.0007
CH <sub>4</sub>	0.37	0.00001176	0.00023
N <sub>2</sub> O	0.0015	0.0000147	0.000035
		kg/body	mg/tonne
Pb	NA	1.86E-08	Plant-specific emission factors
Cd	NA	3.11E-09	Plant-specific emission factors
Hg	NA	0.005	Reported
Cu	NA	7.70E-09	2594.6*
Cr	NA	8.44E-09	1272.4*
As	NA	1.10E-08	4705.6
Dioxins	NA	9.99E-09	0.29685
PAH	NA	0.0343	2.5
PAH-4	NA	0.01127	0.04
PAH-Ospar	NA	0.00049	0.9

NA=Not Applicable.

\* Country specific emission factor used for the years after 1995. Emission factors for the years 1990 to 1994 can be given on request.

#### 7.4.5. Uncertainties

Uncertainty estimates for greenhouse gases and long-range transboundary air pollutants are given in Appendix D.

##### 7.4.5.1. Activity data

No new data on amounts of hospital waste have been reported since 1999. The amount of hospital waste the subsequent years may vary from the data reported in 1998 and 1999. Since 2006, no hospital incinerators have been in operation.

##### 7.4.5.2. Emission factors

If the composition of the hospital waste is different to the waste the emission factors are based on, the calculated emissions will be incorrect. Combustion engineering and processes also influence the emissions. These uncertainties have not been calculated.

#### 7.4.6. Source specific QA/QC

There is no source specific QA/QC procedure for this sector. See section 1.5 for the description of the general QA/QC procedure.

### 7.5. Other emission sources from the waste sector

*IPCC -*

*NFR 6D*

*Last update: 21.09.2012*

#### 7.5.1. Description

This category is a catchall for the waste sector. Emissions in this category could stem from accidental fires, sludge spreading, compost production and biogas production. In the Norwegian inventory, emissions from sewage sludge applied on fields other than agricultural soils, accidental car fires, house fires, emissions from recovering processes in the waste trade and emissions from combustion of hazardous waste are included in this category.

## 7.5.2. Method

### 7.5.2.1. Sewage sludge applied on fields

*N<sub>2</sub>O and NH<sub>3</sub>*

Emissions of N<sub>2</sub>O and NH<sub>3</sub> are calculated for sewage sludge applied on fields other than agricultural soils.

*N<sub>2</sub>O*

Emissions are calculated by multiplying the amount of nitrat in the sewage sludge applied with the IPCC default emission factor.

*NH<sub>3</sub>*

To calculate NH<sub>3</sub> emissions from sewage sludge, the fraction of N in manure lost as NH<sub>3</sub> is used (fracgasm). The loss equals to total N in sewage sludge multiplied by fracgasm. See 6.4.2.

### 7.5.2.2. Car and house fires

*Particles, heavy metals and POPs*

Emissions of particles and dioxins are calculated for car fires and house fires. In addition, heavy metals are calculated for house fires. Emissions are calculated by multiplying the annual number of car and house fires with emission factors. Four types of buildings are separated with different emission factors: detached houses, undetached houses, apartment buildings and industrial buildings.

### 7.5.2.3. Waste trade

*NH<sub>3</sub>, particles, heavy metals and POPs*

Emissions from recovering processes in the waste trade include emissions of NH<sub>3</sub>, particles, heavy metals and PAH. The emission figures are reported annually by the actual plants to the Norwegian Environment Agency.

## 7.5.3. Activity data

### 7.5.3.1. Sewage sludge applied on fields

Statistics Norway's waste water statistics annually gives values for the amount of sewage sludge and the fraction of the sewage sludge that is applied on fields.

**Table 7.7. Amount of sewage sludge. Tonnes (dry matter). 1990-2012**

	Total	Parks and green spaces	Delivered producer of fertiliser	Cover on landfills	Other use	Use unknown
1990 .....	20 405		..			..
1991 .....	25 963		..			..
1992 .....	29 557		..			..
1993 .....	31 129		..			..
1994 .....	31 129	3 370	..	14 809	12 950	..
1995 .....	31 174	6 270	..	11 064	13 840	..
1996 .....	29 761	8 640	..	10 680	10 441	..
1997 .....	40 066	8 217	..	16 515	15 334	..
1998 .....	37 918	9 601	..	13 049	15 268	..
1999 .....	42 771	10 671	..	12 233	19 867	..
2000 .....	44 638	10 093	..	16 456	18 089	..
2001 .....	43 776	10 533	..	4 217	12 812	16 214
2002 .....	49 646	8 995	5 714	6 160	28 776	..
2003 .....	55 205	13 871	3 507	9 236	14 978	13 613
2004 .....	44 334	6 770	7 117	10 244	14 373	5 829
2005 .....	46 095	10 203	10 647	6 569	4 900	13 776
2006 .....	47 371	12 924	11 784	5 064	5 629	11 971
2007 .....	34 392	12 408	6 121	7 491	8 372	0
2008 .....	40 310	15 647	7 387	10 384	5 749	1 143
2009 .....	47 458	7 562	18 092	10 956	5 218	5 630
2010 .....	46 672	11 209	12 535	7 030	10 234	5 664
2011 .....	47 057	10 063	17 855	15 594	3 250	295
2012 .....	50 503	13 869	18 426	17 111	657	440

.. Data not available

### 7.5.3.2. Car and house fires

Data on the number of car and house fires are provided annually by the Directorate for Civil Protection and Emergency Planning. These figures only include fires reported to the fire service.

## 7.5.4. Emission factors

### 7.5.4.1. Sewage sludge applied on fields

The N-content in the sludge is given in Statistics Norway (2001), and the same value of 2.82 per cent is used for all years.

### 7.5.4.2. Car fires

The emission factor for particles is given by EPA (2002). EPA recommends the factor of 0.9 kg/car for combustion of wrecked cars without car tyres, and a factor for combustion of car tyres of 1.4 kg/car. This results in an overall emission factor of 2.3 kg/car. The emission factor for emission of dioxins from car fires is found in Hansen (2000).

### 7.5.4.3. House fires

It is difficult to estimate the amount of material burned in a house fire. In Finstad *et al.* (2002b) a calculation was made that has been used to scale the chosen emission factors, to reflect how much of the building that is lost in a fire. This scaling calculation is based on the amount of damage estimated in monetary value, and value on how much of the building and the furniture that is burned. The emission factors used for particles in the inventory are given by scaling the emission factors used for combustion of fuelwood in the households (Haakonsen and Kvingedal 2001). The emission factors for heavy metals are given by scaling the emission factors for combustion of wood waste in the industry (EPA 2002). For dioxins, OSPAR (Norwegian pollution control authority 2001) gives the emission factor of 170 µg I-TEQ per tonne burned material. The scaled emission factors used for the different building types are given in table 7.8.

**Table 7.8. Emission factors used for car fires and house fires, unit/fire**

	Car	Detached house	Undetached house	Apartment building	Industrial building
TSP (tonnes)	0.0023	0.14382	0.06162	0.04378	0.02723
PM <sub>10</sub> (tonnes)	0.0023	0.14382	0.06162	0.04378	0.02723
PM <sub>2.5</sub> (tonnes)	0.0023	0.14382	0.06162	0.04378	0.02723
Pb (kg)		0.00042	0.00018	0.00013	8E-05
Cd (kg)		0.00085	0.00036	0.00026	0.00016
Hg (kg)		0.00085	0.00036	0.00026	0.00016
As (kg)		0.00135	0.00058	0.00041	0.00025
Cr (kg)		0.00129	0.00055	0.00039	0.00024
Cu (kg)		0.00299	0.00128	0.00091	0.00057
Dioxins (mg)	0.047	1.43817	0.61621	0.43779	0.27234

## 8. Areas for further improvement

### 8.1. Overview

There are several areas where improvement actions are needed to improve the Norwegian emission inventory system. In this chapter the main issues are listed. For greenhouse gases the yearly international review identifies areas where the Norwegian inventory needs improvements to be consistent with the IPCC Guidelines. The long-range transboundary air pollutants reported to UNECE also undergo a yearly international review.

### 8.2. General

- In 2015, the estimation of greenhouse gas emissions will follow the revised UNFCCC reporting guidelines. This will cause several changes in the present estimation methods.
- Many of the emission factors used in the inventory are relatively old, some over 10 years, and they need to be analysed. Some of them also lack good documentation and source references. Work has begun to go through all emission factors, register digitally those that have sufficiently documentation and flag those that do not for future revision. This work need to be continued.

### 8.3. Energy

- The energy statistics used as input to the Norwegian emission inventory need to be improved for some sectors. For use of petroleum products, Statistics Norway's sales statistics for petroleum products are used. The division between sectors in the sales statistics is not as detailed as the one needed in the energy statistics. A number of different methods are being used to distribute the energy use of the different energy products on actual sectors. Some are based on very old assumptions and surveys that need to be updated.

### 8.4. Agriculture

- The national models for estimating  $\text{NH}_3$ ,  $\text{N}_2\text{O}$  and  $\text{CH}_4$  from manure need to be better documented.
- New available activity data on manure storage and management will be available in 2014 and need to be implemented.

### 8.5. Waste

- Fossil carbon content in incinerated waste is estimated based on old standard factors. As waste composition varies among nations and over time, updated factors based on national composition data would pose an improvement. An estimation of such updated factors, based on local waste characterization studies, is in progress.

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*In this inventory, SFT is the former Norwegian abbreviation for the Climate and Pollution Agency, which early in 2010 changed its name from the Norwegian Pollution Control Authority. From 1 July 2013, the Climate and Pollution Agency was, together with the Directorate for Nature Management, merged into the Norwegian Environment Agency.*

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## Appendix A Abbreviations

### Pollutants

GHG	Greenhouse gases
CO <sub>2</sub>	Carbon dioxide
CH <sub>4</sub>	Methane
N <sub>2</sub> O	Nitrous oxide
PFCs	Perfluorocarbons
HFCs	Hydrofluorocarbons
SF <sub>6</sub>	Sulphur hexafluoride
SO <sub>2</sub>	Sulphur dioxide
NO <sub>x</sub>	Nitrogen oxides
NH <sub>3</sub>	Ammonia
CO	Carbon monoxide
(NM)VOC	(Non-methane) volatile organic compounds
TSP	Total suspended particulates
HM	Heavy metals
Pb	Lead
Cd	Cadmium
Hg	Mercury
As	Arsenic
Cr	Chromium
Cu	Copper
POPs	Persistent organic pollutants

### Other

BOD	Biological oxygen demand
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CRB	Crop residue burned
CRF	Common Reporting Format
DOC	Degradable organic carbon
EEA	European Environment Agency
EPA	U.S. Environmental protection agency
EU ETS	European Union Emissions Trading System
GIS	Gas-insulated switchgear
Forurensning	Register at the Norwegian Environment Agency with data and information on point sources
IAI	International Aluminium Institute
IPCC	Intergovernmental Panel on Climate Change
Jordforsk	Norwegian Centre for Soil and Environmental research
Klif	The Climate and Pollution Agency. From 1 July 2013: The Norwegian Environment Agency
LPG	Liquid Petroleum Gas
LTO	Landing Take off
NFR	Nomenclature For Reporting
Skog + Landskap	Norwegian Forest and Landscape Institute (until 2006 Norwegian Institute of Land Inventory NIJOS)
NILF	Norwegian Agricultural Economics Research Institute
NILU	Norwegian Institute for Air Research
NIVA	Norwegian Institute for Water Research
NPD	Norwegian Petroleum Directorate
NPRA	Norwegian Public Roads Administration
OECD	Organisation for Economic Co-operation and Development
OLF	Norwegian Oil Industry Association
OSPAR	The Oslo and Paris Convention
PRODCOM	PRODUCTS of the European COMMUNITY
QA/QC	Quality Assurance and Quality Control
RVP	Reid vapour pressure
SACS	Saline aquifer carbon dioxide storage project
SFT	Norwegian Pollution Control Authority. From 2010: The Climate and Pollution Agency. From 1 July 2013: The Norwegian Environment Agency
SINTEF	The Foundation for Scientific and Industrial Research
SPS	Specific wear of studded tyres
SWDS	Solid waste disposal sites
TNO	Institute of Environmental and Energy Technology
UNECE	United nations - Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VPU	Vapour recovery units

## Appendix B Emission factors

In the calculations the numbers are used with the highest available accuracy. In this tables though, they are only shown rounded off, which in some cases can lead to the result that the exceptions looks the same as the general factors.

For road traffic this general view of the emission factors only includes last years factors and not all time series.

In the tables for stationary combustion, dotted cells indicate combinations of fuel and source without consumption.

A description of the sector codes used in the tables is given in Appendix F.

### CO<sub>2</sub>, SO<sub>2</sub> and heavy metals - Stationary and mobile combustion

**Table B1. General emission factors for CO<sub>2</sub>, SO<sub>2</sub> and heavy metals**

	CO <sub>2</sub> tonne/tonne <sup>2</sup>	SO <sub>2</sub> <sup>1</sup> kg/tonne <sup>2</sup>	Pb g/tonne <sup>2</sup>	Cd g/tonne <sup>2</sup>	Hg g/tonne <sup>2</sup>	As g/tonne <sup>2</sup>	Cr g/tonne <sup>2</sup>	Cu g/tonne <sup>2</sup>
Coal .....	2.52	16 <sup>3</sup>	0.2 <sup>3</sup>	0.003 <sup>3</sup>	0.05 <sup>3</sup>	0.089 <sup>3</sup>	0.065 <sup>3</sup>	0.087 <sup>3</sup>
Coke .....	3.19	18	0.2 <sup>3</sup>	0.003 <sup>3</sup>	0.05 <sup>3</sup>	0.089 <sup>3</sup>	0.065 <sup>3</sup>	0.087 <sup>3</sup>
Petrol coke .....	3.59	18	0.2	0.003	0.05	0.089	0.065	0.087
Motor gasoline .....	3.13	<b>0.01</b>	<b>0.03</b> <sup>4</sup>	0.01	0,0084	0.05	0.05	1.7
Aviation gasoline .....	3.13	0.4	675.7	0.01	0	0.05	0.05	1.7
Kerosene (heating) .....	3.15	<b>0.326</b>	0.07	0.01	0.03	0.05	0.04	0.05
Jet kerosene .....	3.15	<b>0.294</b>	0.07	0.01	0.03	0.05	0.05	0.05
Auto diesel .....	3.17 <sup>5</sup>	<b>0.015</b> <sup>6</sup>	0.1	0.01	0,0023	0.05	0.05	1.7
Marine gas oil/diesel .....	3.17	<b>1.038</b>	0.1	0.01	0.05	0.05	0.04	0.05
Light fuel oils .....	3.17	<b>0.658</b>	0.1	0.01	0.05	0.05	0.04	0.05
Heavy distillate .....	3.17	<b>4.295</b>	0.1	0.01	0.05	0.05	0.04	0.05
Heavy fuel oil .....	3.2	<b>17.5</b> <sup>7</sup>	1	0.1	0.2	0.057	1.35	0.53
Natural gas (1000 Sm <sup>3</sup> ) .....	1.99/ <b>2.34</b> <sup>8</sup>	0	0.00025	0.002	0.001	0.004	0.021	0.016
LPG .....	3	0	0	0	0	0.004	0.021	0.016
Refinery gas .....	2.8	0	0	0	0	0.004	0.021	0.016
Blast furnace gas .....	1.571	0	0	0	0	0.004	0.021	0.016
Fuel gas .....	2.5	0	0	0	0	0.004	0.021	0.016
Landfill gas .....	0	0.019	0	0	0	0.004	0.021	0.016
Biogas .....	0	0	0.000294	0.001998	0.001175	0.004466	0.024679	0.018803
Fuel wood .....	0	0.2	0.05	0.1	0.010244	0.159	0.152	0.354
Wood waste .....	0	0.37	0.05	0.1	0.010244	0.159	0.152	0.354
Black liquor .....	0	0.37	0.05	0.1	0.010244	0.159	0.152	0.354
Municipal waste .....	<b>0.5417</b> <sup>9</sup>	1.4	<b>0.00304</b>	<b>0.00015</b>	<b>0.00016</b>	0.022	0.001	0.000985
Special waste .....	3.2	9.2	14	0.6	0.2	1	31	25

<sup>1</sup> Applies to 2012 for petroleum products; the factors change yearly, in accordance with changes in the sulphur content in the products.

<sup>2</sup> For natural gas: 1000 Sm<sup>3</sup>.

<sup>3</sup> Exceptions: Direct-fired furnaces in cement production = 9.1 and small stoves in households = 20.

<sup>4</sup> From 1997 - considerably higher earlier years. Earlier used factors are not shown in this Appendix.

<sup>5</sup> From 2006 the emission factor has been corrected for use of bio diesel, which not causes emissions of CO<sub>2</sub>: 2006: 3.159, 2007: 3.114, 2008: 3.029, 2009: 3.007, 2010: 2.992, 2011: 3.006, 2012: 2.989.

<sup>6</sup> Applies to road traffic. Weighted average of duty-free and dutiable auto diesel.

<sup>7</sup> Stationary combustion.

<sup>8</sup> Respectively dry gas (domestic use) and rich gas (continental shelf).

<sup>9</sup> From 1996. For earlier years: 0.251.

Numbers in italics have exceptions for some sectors, see table B2 and B5. Bold numbers are different for different years, see table B3, B4 and B5.

Source: Norwegian Petroleum Industry Association, Rosland (1987), SFT (Norwegian pollution control authority 1990), SFT (Sandgren *et al.* 1996), Finstad *et al.* (2001) and Finstad *et al.* (2003).

**Table B2. Exceptions from the general emission factors for heavy metals: Solid fuels in small stoves (households)**

	Pb g/tonne	Cd g/tonne	Hg g/tonne	As g/tonne	Cr g/tonne	Cu g/tonne
Coal .....	2.5	0.15	0.3	1.2	0.9	1.2
Coke .....	2.5	0.15	0.3	1.2	0.9	1.2

**Table B3. Time series for variable emission factors for SO<sub>2</sub> (kg/tonne)**

Years	V11	V13	V14	V15			V17	V18	V19	V20	V20	
	Motor gasoline	Kerosene (heating)	Jet kerosene	Auto diesel			Marine gas oil/diesel	Light fuel oils	Heavy distillate	Heavy fuel oil (LS-oil)	Heavy fuel oil (NS-oil)	
	General	General	General	General	M.1A3B.1 Passenger cars	M.1A3B.2 Light duty vehicles	M.1A3B.3 Heavy duty vehicles	General	General	General	General	General
1980	1	0.2	0.2	6.6	.	.	.	6.6	6.6	15	19	46
1987	0.7	0.4	0.4	4.4	.	.	.	4.4	4.4	9	19	44
1989	0.6	0.4	0.4	3.4	.	.	.	3.4	3.4	7.6	18.2	40
1990	0.6	0.3	0.3	3.2	.	.	.	3.2	3.2	6	17	39.4
1991	0.6	0.38	0.38	2.8	.	.	.	2.8	2.8	4.6	16.8	43.6
1992	0.6	0.32	0.32	2.6	.	.	.	2.6	2.6	4.4	16.4	42.6
1993	0.6	0.42	0.42	2.2	.	.	.	2.2	2.2	4.4	16.2	45.8
1994	0.6	0.36	0.36	1.4	.	.	.	1.4	1.4	4.2	14.2	44.8
1995	0.24	0.46	0.46	1.4	.	.	.	1.4	1.4	4.6	11.8	43.4
1996	0.22	0.46	0.5	1.2	.	.	.	1.2	1.2	3.8	12.6	46.6
1997	0.16	0.46	0.46	1.2	.	.	.	1.2	1.2	3.8	12.6	47.2
1998	0.16	0.42	0.42	0.8	.	.	.	1.8	1.8	4.2	12.4	42.8
1999	0.22	0.32	0.32	0.6	.	.	.	1.6	1.6	4.4	12.8	39
2000	0.18	0.36	0.36	1.4	0.1174	0.1174	0.1174	1.8	1.8	4.6	14.4	31
2001	0.18	0.46	0.46	0.8	0.0885	0.0885	0.0885	1.8	1.8	4.8	13.2	44.4
2002	0.2	0.32	0.32	0.6	0.0708	0.0708	0.0708	1.6	1.2	4.8	12	43.8
2003	0.1	0.3	0.3	0.8	0.0748	0.0748	0.0748	2	0.8	4.6	14	44.2
2004	0.06	0.3	0.3	0.8	0.0748	0.0748	0.0748	1.8	0.8	5	14.2	44.2
2005	0.01	0.28	0.28	0.8	0.0278	0.0278	0.0278	1.8	0.8	4.6	13.6	39.2
2006	0.01	0.27	0.27	1.38	0.0393	0.0393	0.0393	2	1.38	4.44	10.4	26.2
2007	0.01	0.296	0.296	0.73	0.0244	0.0244	0.0244	1.53	0.73	4.17	17.8	20
2008	0.01	0.286	0.286	0.786	0.0285	0.0285	0.0285	1.562	0.986	3.098	17.5	28.5
2009	0.01	0.302	0.371	0.016	0.016	0.016	0.016	1.069	0.949	4.31	17.4	27.8
2010	0.01	0.324	0.294	0.015	0.015	0.015	0.015	1.184	0.978	4.31	17.5	28
2011	0.01	0.334	0.296	0.015	0.015	0.015	0.015	1.196	0.984	4.32	17.8	28.4
2012	0.01	0.326	0.294	0.015	0.015	0.015	0.015	1.038	0.658	4.295	17.5	27.4

**Table B4. Time series for variable emission factors for heavy metals, stationary combustion. g/tonne**

Sector	Source	Fuel	1990-1991			1992-		
			Pb	Cd	Hg	Pb	Cd	Hg
General	S.03	V51	0.0085	0.00047	0.00035	0.00304	0.00015	0.00016

**Table B5. Exceptions with time series for variable emission factors for natural gas combusted by oil exploration, tonne CO<sub>2</sub>/1000 Sm<sup>3</sup> natural gas**

Sector	Source	Fuel	Component	1990-1994	1995	1996	1997	1998	1999	2000	2001	2002*
				230600.1	S.02	V31	CO <sub>2</sub>	2.34	2.29	2.3	2.3	2.31
230600.1	S.1B2C	V31	CO <sub>2</sub>	2.34	2.42	2.34	2.34	2.34	2.48	2.52	2.42	2.47

\*For the years after 2002 reported emissions are used



Aviation - CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NMVOC, CO, particles and PAH

Table B6. General emission factors for aviation

Source	Fuel	CH <sub>4</sub> kg/ tonne	N <sub>2</sub> O kg/ tonne	NO <sub>x</sub> kg/ tonne	NMVOC kg/ tonne	CO kg/ NH <sub>3</sub> kg/ tonne tonne	TSP, PM <sub>10</sub> , PM <sub>2.5</sub> kg/tonne	PAH g/ tonne	PAH- OSPAR g/tonne	PAH-4 g/tonne	Dioxins ug/tonne	
M.1A3A.111 Jet/turboprop 0-100 m	V14 Jet kerosene	<b>0.185</b>	0.1	<i>6.854</i>	<i>1.668</i>	<i>18.764</i>	0	0.025	<i>0.54</i>	0.02	0.005	0.06
M.1A3A.112 Jet/turboprop 100-1000 m	V14 Jet kerosene	<b>0.030</b>	0.1	<i>13.208</i>	<i>0.273</i>	<i>2.036</i>	0	0.025	<i>0.32</i>	<i>0.02</i>	<i>0.005</i>	0.06
M.1A3A.12 Jet/turboprop cruise	V14 Jet kerosene	0	0.1	<i>12.106</i>	<i>0.569</i>	<i>3.080</i>	0	0.007	<i>0.29</i>	<i>0.02</i>	<i>0.005</i>	0.06
M.1A3A.211 Helicopter 0-100 m	V14 Jet kerosene	3.2	0.1	6.67	28.8	36.6	0	0.025	<i>0.54</i>	0.02	<i>0.005</i>	0.06
M.1A3A.212 Helikopter 100-1000 m	V14 Jet kerosene	3.2	0.1	6.67	28.8	36.6	0	0.025	<i>0.32</i>	<i>0.02</i>	<i>0.005</i>	0.06
M.1A3A.22 Helicopter cruise	V14 Jet kerosene	0	0.1	6.67	32	36.6	0	0.007	<i>0.29</i>	<i>0.02</i>	<i>0.005</i>	0.06
M.1A3A.311 Small aircrafts 0-100 m	V12 Aviation gasoline	3.61	0.1	0	32.5	898.7	0	0.025	<i>0.54</i>	0.02	<i>0.005</i>	2
M.1A3A.312 Small aircrafts 100-1000 m	V12 Aviation gasoline	1.55	0.1	3.617	13.95	932.5	0	0.025	<i>0.32</i>	<i>0.02</i>	<i>0.005</i>	2
M.1A3A.32 Small aircrafts cruise	V12 Aviation gasoline	0	0.1	2.92	19.48	926	0	0.007	<i>0.29</i>	<i>0.02</i>	<i>0.005</i>	2

Numbers in italics have exceptions for some sectors, see table B7, and bold numbers are different for different years, see table B8.  
Source: IPCC (2000), Finstad *et al.* (2001) and Finstad *et al.* (2002a).

Table B7. Exceptions from the general factors for aviation

Component	Emission factor	Fuel	Source	Sectors
CH <sub>4</sub>	0.35	V14	Jet kerosene	M.1A3A.111-112, M1A3A.211-212 248422
NO <sub>x</sub>	13.51	V14	Jet kerosene	M.1A3A.111, M1A3A.211 248422
NO <sub>x</sub>	13.29	V14	Jet kerosene	M.1A3A.112, M1A3A.212 248422
NO <sub>x</sub>	11.7	V14	Jet kerosene	M.1A3A.12, M.1A3A.22 248422
NMVOC	7.43	V14	Jet kerosene	M.1A3A.111, M1A3A.211 248422
NMVOC	7.36	V14	Jet kerosene	M.1A3A.112, M1A3A.212 248422
NMVOC	4.3	V14	Jet kerosene	M.1A3A.12, M.1A3A.22 248422
CO	23.67	V14	Jet kerosene	M.1A3A.111, M1A3A.211 248422
CO	23.15	V14	Jet kerosene	M.1A3A.112, M1A3A.212 248422
CO	20.9	V14	Jet kerosene	M.1A3A.12, M.1A3A.22 248422
PAH	0.18	V12, 14	Aviation gasoline, jet kerosene	M.1A3A.111, M1A3A.211, M1A3A.311 235100.2N
PAH	0.05	V12, 14	Aviation gasoline, jet kerosene	M.1A3A.112, M1A3A.212, M1A3A.312 235100.2N
PAH	0.1	V12, 14	Aviation gasoline, jet kerosene	M.1A3A.12, M.1A3A.22, M.1A3A.32 235100.2N
PAH-OSPAR, PAH-4	0	V12, 14	Aviation gasoline, jet kerosene	M.1A3A.112, M.1A3A.12, M1A3A.212, M.1A3A.22, M1A3A.312, M.1A3A.32 235100.2N

Table B8. Time series for variable emission factors for aviation. Factors for 1989, 1995, and 2000 are calculated as given in the table. Factors for 1990-1994 and 1996-1999 are calculated by linear interpolation. Factors before 1989 and after 2000 are kept constant

Sector	Source	Fuel	CH <sub>4</sub>			NO <sub>x</sub>			NMVOC			CO		
			1989	1995	2000	1989	1995	2000	1989	1995	2000	1989	1995	2000
General	M.1A3A.111	V14	0.156	0.201	0.185	6.026	7.2	6.854	1.402	1.8	1.668	11.105	17.5	18.764
	M.1A3A.112	V14	0.026	0.033	0.030	11.611	13.904	13.208	0.230	0.297	0.273	1.205	1.895	2.036
	M.1A3A.12	V14	0	0	0	10.663	12.061	12.106	1.022	0.660	0.569	3.450	3.268	3.080
235100.2N	M.1A3A.111	V14	0.157	0.336	0.393	6.725	8.118	7.689	1.410	3.025	3.534	11.557	17.213	18.954
	M.1A3A.112	V14	0.026	0.055	0.067	12.960	15.643	15.619	0.231	0.495	0.605	1.254	1.868	2.978
	M.1A3A.12	V14	0	0	0	10.663	11.572	11.333	1.022	3.505	0.502	3.450	6.293	1.701
665100.2	M.1A3A.111	V14	0.157	0.336	0.393	6.725	8.118	7.689	1.410	3.025	3.534	11.557	17.213	18.954
	M.1A3A.112	V14	0.026	0.055	0.067	12.960	15.643	15.619	0.231	0.495	0.605	1.254	1.868	2.978
665100.2	M.1A3A.12	V14	0	0	0	10.663	11.572	11.333	1.022	3.505	0.502	3.450	6.293	1.701

**Road traffic - CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NMVOC, CO, NH<sub>3</sub>, particles and PAH****Table B9. General emission factors for road traffic**

Source	Fuel	CH <sub>4</sub> kg/tonne	N <sub>2</sub> O kg/tonne	NO <sub>x</sub> kg/tonne	NMVOC kg/tonne	CO kg/tonne	NH <sub>3</sub> kg/tonne	TSP, PM <sub>10</sub> kg/tonne	PM <sub>2.5</sub> kg/tonne	PAH g/tonne	PAH- OSPAR g/tonne	PAH-4 g/tonne	Dioxins ug/tonne
M.1A3B.1 Passenger car	V11 Motor gasoline	<b>0.454</b>	<b>0.056</b>	<b>5.485</b>	<b>7.767</b>	<b>50.630</b>	<b>1.277</b>	<b>0.051</b>	<b>0.051</b>	<b>1.000</b>	<b>0.446</b>	<b>0.126</b>	<b>0.1</b>
	V15 Auto diesel	<b>0.017</b>	<b>0.086</b>	<b>9.093</b>	<b>0.692</b>	<b>3.762</b>	<b>0.020</b>	<b>0.414</b>	<b>0.393</b>	4.367	2.383	0.447	0.1
	V31 Natural gas	0.261	0.0255	0.871	0.0653	1.69	0	0.122	0.122	0.015	0.00085	0	0.05
	V32 LPG	0	<b>0.047</b>	<b>1.926</b>	0	<b>11.599</b>	0	<b>0.037</b>	<b>0.037</b>	0	0	0	0.06
M.1A3B.2 Other light duty cars	V11 Motor gasoline	<b>0.667</b>	<b>0.116</b>	<b>7.637</b>	<b>11.613</b>	<b>120.312</b>	<b>0.997</b>	<b>0.096</b>	<b>0.096</b>	<b>1.000</b>	<b>0.446</b>	<b>0.126</b>	<b>0.1</b>
	V15 Auto diesel	<b>0.016</b>	<b>0.062</b>	<b>11.257</b>	<b>0.645</b>	<b>4.060</b>	<b>0.014</b>	<b>0.860</b>	<b>0.817</b>	4.367	2.383	0.447	0.1
M.1A3B.3 Heavy duty vehicles	V11 Motor gasoline	<b>0.583</b>	<b>0.044</b>	<b>28.311</b>	<b>16.982</b>	<b>22.539</b>	<b>0.019</b>	0	0	1.995	0.997	0.21	<b>0.1</b>
	V15 Auto diesel	<b>0.013</b>	<b>0.065</b>	<b>17.509</b>	<b>0.519</b>	<b>5.254</b>	<b>0.009</b>	<b>0.300</b>	<b>0.285</b>	<b>3.563</b>	<b>1.782</b>	<b>0.428</b>	<b>0.1</b>
	V31 Natural gas	0	0	<b>34.003</b>	0	<b>5.884</b>	<b>0.008</b>	<b>0.140</b>	<b>0.140</b>	0.015	0.00085	0	0.05
	V37 Bio gas	0	0	<b>34.003</b>	0	<b>5.884</b>	<b>0.008</b>	<b>0.140</b>	<b>0.140</b>	0.015	0.00085	0	0.05
M.1A3B.41 Moped	V11 Motor gasoline	<b>20.856</b>	<b>0.053</b>	<b>3.192</b>	<b>119.340</b>	<b>206.822</b>	<b>0.053</b>	0	0	2	0.53	0.08	<b>0.1</b>
M.1A3B.42 Motorcycle	V11 Motor gasoline	<b>1.245</b>	<b>0.059</b>	<b>4.491</b>	<b>21.532</b>	<b>218.435</b>	<b>0.059</b>	0	0	2	0.53	0.08	<b>0.1</b>

Bold numbers are different for different years, but only the 2012 data are shown in this Appendix, except for CH<sub>4</sub> (table B10) and N<sub>2</sub>O (table B11).

Source: Results from Statistics Norway's use of HBEFA (INFRAS 2009) and Finstad *et al.* (2001).

**Table B10. Average CH<sub>4</sub> emission factors for road traffic including cold start emissions and evaporation, g CH<sub>4</sub>/ kg fuel**

	V11 Motor gasoline					V15 Auto diesel		
	Passenger car	Other light duty cars	Heavy duty vehicles	Moped	Motorcycle	Passenger car	Other light duty cars	Heavy duty vehicles
1980 .....	2.024	2.282	0.587	13.285	3.815	0.119	0.109	0.116
1987 .....	2.021	2.273	0.592	13.417	3.853	0.109	0.099	0.100
1989 .....	1.961	2.239	0.584	13.234	3.622	0.118	0.108	0.108
1990 .....	1.863	2.178	0.570	12.901	3.360	0.111	0.101	0.083
1991 .....	1.821	2.184	0.574	12.988	3.106	0.107	0.099	0.082
1992 .....	1.772	2.150	0.575	13.015	2.870	0.098	0.093	0.078
1993 .....	1.721	2.080	0.577	13.055	2.615	0.078	0.077	0.068
1994 .....	1.660	1.996	0.578	13.092	2.412	0.086	0.089	0.074
1995 .....	1.592	1.888	0.581	13.153	2.253	0.083	0.085	0.071
1996 .....	1.450	1.730	0.572	12.949	2.016	0.079	0.080	0.066
1997 .....	1.392	1.674	0.588	13.303	1.952	0.081	0.082	0.066
1998 .....	1.264	1.512	0.571	12.929	1.684	0.077	0.074	0.056
1999 .....	1.164	1.410	0.568	12.871	1.594	0.074	0.070	0.052
2000 .....	1.106	1.347	0.583	13.209	1.542	0.070	0.067	0.049
2001 .....	0.976	1.176	0.559	12.682	1.428	0.060	0.058	0.043
2002 .....	0.890	1.077	0.558	12.662	1.398	0.053	0.053	0.040
2003 .....	0.804	0.996	0.552	13.142	1.408	0.048	0.049	0.038
2004 .....	0.719	0.917	0.544	14.292	1.426	0.042	0.044	0.035
2005 .....	0.682	0.896	0.568	16.233	1.522	0.038	0.041	0.034
2006 .....	0.628	0.844	0.574	17.502	1.505	0.033	0.036	0.032
2007 .....	0.601	0.814	0.590	18.939	1.475	0.029	0.032	0.029
2008 .....	0.564	0.768	0.591	19.745	1.370	0.025	0.027	0.026
2009 .....	0.532	0.730	0.588	20.220	1.324	0.022	0.023	0.022
2010 .....	0.497	0.690	0.578	20.289	1.270	0.019	0.020	0.017
2011 .....	0.480	0.686	0.585	20.895	1.265	0.018	0.018	0.015
2012 .....	0.454	0.667	0.583	20.856	1.245	0.017	0.016	0.013

Source: Results from Statistics Norway's use of HBEFA (INFRAS 2009)

**Table B11. Average N<sub>2</sub>O emission factors for road traffic including cold start emissions and evaporation, g N<sub>2</sub>O/ kg fuel**

	V11 Motor gasoline					V15 Auto diesel		Heavy duty vehicles
	Passenger car	Other light duty cars	Heavy duty vehicles	Moped	Motorcycle	Passenger car	Other light duty cars	
1980 .....	0.086	0.116	0.045	0.053	0.058	0	0	0.032
1987 .....	0.095	0.114	0.045	0.054	0.059	0	0	0.029
1989 .....	0.098	0.112	0.045	0.053	0.058	0	0	0.031
1990 .....	0.099	0.109	0.043	0.052	0.057	0	0	0.029
1991 .....	0.105	0.109	0.044	0.052	0.057	0	0	0.028
1992 .....	0.110	0.111	0.044	0.052	0.058	0	0	0.026
1993 .....	0.117	0.117	0.044	0.052	0.058	0	0	0.022
1994 .....	0.125	0.123	0.044	0.053	0.058	0	0	0.025
1995 .....	0.135	0.134	0.044	0.053	0.058	0.003	0.005	0.026
1996 .....	0.146	0.143	0.044	0.052	0.057	0.009	0.012	0.026
1997 .....	0.155	0.158	0.045	0.053	0.059	0.018	0.020	0.029
1998 .....	0.153	0.161	0.044	0.052	0.057	0.027	0.026	0.028
1999 .....	0.154	0.168	0.043	0.052	0.057	0.036	0.034	0.028
2000 .....	0.160	0.180	0.045	0.053	0.059	0.045	0.041	0.029
2001 .....	0.156	0.188	0.043	0.051	0.057	0.049	0.043	0.027
2002 .....	0.156	0.204	0.043	0.051	0.057	0.056	0.046	0.026
2003 .....	0.152	0.179	0.042	0.050	0.056	0.061	0.049	0.025
2004 .....	0.147	0.178	0.042	0.050	0.056	0.065	0.052	0.024
2005 .....	0.087	0.168	0.043	0.052	0.058	0.072	0.057	0.024
2006 .....	0.083	0.165	0.044	0.052	0.059	0.076	0.060	0.023
2007 .....	0.081	0.164	0.045	0.054	0.060	0.082	0.064	0.025
2008 .....	0.077	0.155	0.045	0.054	0.060	0.086	0.065	0.028
2009 .....	0.073	0.146	0.045	0.053	0.060	0.086	0.064	0.033
2010 .....	0.067	0.132	0.044	0.052	0.059	0.082	0.061	0.042
2011 .....	0.062	0.126	0.045	0.053	0.059	0.084	0.061	0.056
2012 .....	0.056	0.116	0.044	0.053	0.059	0.086	0.062	0.065

Source: Results from Statistics Norway's use of HBEFA (INFRAS 2009)

**Navigation - CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NMVOC, CO, particles and POPs****Table B12. General emission factors for navigation**

	CH <sub>4</sub> kg/ tonne	N <sub>2</sub> O kg/ tonne	NO <sub>x</sub> kg/ tonne	NMVOC kg/tonne	CO kg/ tonne	NH <sub>3</sub> kg/ tonne	TSP, PM <sub>10</sub> kg/ tonne	PM <sub>2.5</sub> kg/ tonne	PAH g/ tonne	PAH- OSPAR g/tonne	PAH-4 g/ tonne	Dioxins ug/ tonne
V17 Marine gas oil/diesel, V18 Light fuel oils	<i>0.23</i>	<i>0.08</i>	<b>33.31</b>	2.4	2.9	0	1.6	1.5	1.6	0.26	0.04	4
V19 Heavy distillate, V20 Heavy fuel oil	<i>0.23</i>	<i>0.08</i>	<b>33.31</b>	2.4	2.9	0	5.4	5.1	1.6	0.26	0.04	4
V31 Natural gas (1000 Sm <sup>3</sup> )	<b>46.83</b>	0	4.0	0.814	2.143	0	0.032	0.032	0.015	0.00085	0	0.05

Numbers in italics have exceptions for some sectors, see table B13, and bold numbers are different for different years, see table B14-B16.

Source: Flugsrud and Rypdal (1996), Tornsjo (2001), Finstad *et al.* (2001), Finstad *et al.* (2002b), Finstad *et al.* (2003), Bremnes Nielsen and Stenersen (2010).

**Table B13. Exceptions from the general factors for navigation**

Component	Emission factor (kg/tonne)		Fuel	Sector
CH <sub>4</sub>	0.8	V17	Marine gas oil/diesel	230600.1 -230600.3
CH <sub>4</sub>	1.9	V20	Heavy fuel oil	230600.1 -230600.3
N <sub>2</sub> O	0.02	V17	Marine gas oil/diesel	230600.1 -230600.3
NO <sub>x</sub>	<b>43.16</b>	V17, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	230310.N
NO <sub>x</sub>	54	V17, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, Heavy fuel oil	230600.1 -230600.3
NO <sub>x</sub>	<b>47.23</b>	V17, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	248422
NMVOC	<b>1.4</b>	V17, 18, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	230310.N
NMVOC	<b>2.3</b>	V17, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	248422
NMVOC	5	V17	Marine gas oil/diesel, light fuel oils	230600.1 -230600.3
NMVOC	<b>5</b>	V19, 20	Heavy distillate, heavy fuel oil	230600.1 -230600.3
CO	7.9	V17, 18, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	230310.N
CO	<b>1.6</b>	V17, 18, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	230600.1
CO	7	V17, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	230600.1 -230600.3
CO	2.3	V17, 19, 20	Marine gas oil/diesel, light fuel oils, heavy distillate, heavy fuel oil	248422

**Table B14. Time series for variable emission factors for navigation. NO<sub>x</sub>**

Sector	Fuel	1980-1999	1980-1986	1987	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
General	V17-20		57.33	56.99	56.90	56.85	56.80	56.89	56.77	56.82	56.68	57.23	57.47	57.41	56.82
			2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
General	V17-20		57.82	57.96	57.18	56.80	56.51	55.90	55.55	54.61	51.52	48.03	44.00	38.90	33.31
230310.N	V17, 19, 20	52.11	52.12	52.01	51.90	51.80	51.69	51.58	51.48	50.93	49.90	47.41	45.17	43.64	43.16
248422	V17, 19, 20	50.17	49.82	49.60	49.39	49.17	48.95	48.74	48.52	48.31	48.09	47.88	47.66	47.44	47.23

Source: (Flugsrud et al. 2010)

**Table B15. Time series for variable emission factors for navigation. CH<sub>4</sub>**

Sector	Fuel	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
General	V31	31.43	31.43	31.43	49.99	52.71	54.55	54.43	36.81	38.83	41.65	42.73	40.50	46.83

**Table B16. Time series for variable emission factors for navigation. NMVOC and CO**

Sector	Fuel	NMVOC						CO			
		1980-1990	1980-1997	1980-1998	1991-	1998-	1999-	1980-1997	1998-		
General	V17-20									3.1	2.9
230310.N	V17-20			1.5					1.4		
230600.1	V17-20									2	1.6
230600.1,230910	V19,20	6.4					5				
230600.1,230910	V 20										
248422	V17-20		2.2					2.3			

## Other mobile sources including railways - CH<sub>4</sub>, N<sub>2</sub>O, NO<sub>x</sub>, NMVOC, CO, NH<sub>3</sub>, particles and POPs

**Table B17. General emission factors for other mobile sources**

		CH <sub>4</sub> kg/ tonne	N <sub>2</sub> O kg/ tonne	NO <sub>x</sub> kg/ tonne	NMVOC kg/ tonne	CO kg/ tonne	NH <sub>3</sub> kg/ tonne	TSP, PM <sub>10</sub> kg/ tonne	PM <sub>2.5</sub> kg/ tonne	PAH g/ tonne	PAH- OSPA R g/tonne	PAH-4 g/ tonne	Dioxins ug/ tonne
M.1A3C	V01 Coal	0.28	0.04	3	1.1	3	0	1.6/1.14	0.82	0.46	0.16	0.024	1.6
Railway	V15 Auto diesel	0.18	1.2	47	4	11	0.007	3.8	3.8	3.3	0.53	0.08	0.1
M.1A3E.21	V11 Motor gasoline	5.1	0.02	6	240	415	0	8	8	2	0.53	0.08	<b>0.1</b>
Small boats 2 stroke	V11 Motor gasoline	1.7	0.08	12	40	1 000	0	1	1	2	0.53	0.08	<b>0.1</b>
M.1A3E.22	V15 Auto diesel	0.18	0.03	54	27	25	0	4	4	3.3	0.53	0.08	0.1
Small boats 4 stroke													
M.1A3E.31	V11 Motor gasoline	6	0.02	<b>2<sup>1</sup></b>	500	700	0	8	8	2	0.53	0.08	<b>0.1</b>
Motorized equipment 2 stroke	V11 Motor gasoline	2.2	0.07	10	110	1 200	0	1	1	2	0.53	0.08	<b>0.1</b>
	V15 Auto diesel	0.17	1.3	<b>21.9</b>	6	15	0.005	4	3.8	3.3	0.53	0.08	0.1
M.1A3E.32	V18 Light fuel oils	0.17	1.3	50	6	15	0.005	7.1	6.75	3.3	0.53	0.08	0.1
Motorized equipment 4t													

M.1A3E.1 Snow scooter has the same emission factors as M.1A3B.41 Moped, see table B9.

Bold numbers are different for different years.

<sup>1</sup>Before 1995 the emission factor was 1.3.

Numbers in italics have exceptions for some sectors, see table B18–B19.

Sources: Bang (1993), SFT (Bang *et al.* 1999), Finstad *et al.* (2001), Finstad *et al.* (2002b), Finstad *et al.* (2003), Winther and Nielsen (2006), EEA (2013).

**Table B18. Exceptions from the general factors for greenhouse gases and precursors for other mobile sources**

Component	Emission factor (kg/tonne)	Fuel	Source	Sectors	
CH <sub>4</sub>	6.2	V11	Motor gasoline	M.1A3E.31 Motorized equipment 2 stroke	230100
CH <sub>4</sub>	3.7	V11	Motor gasoline	M.1A3E.32 Motorized equipment 4 stroke	230100
CH <sub>4</sub>	7.7	V11	Motor gasoline	M.1A3E.31 Motorized equipment 2 stroke	230210
CH <sub>4</sub>	8.1	V11	Motor gasoline	M.1A3E.31 Motorized equipment 2 stroke	330000
CH <sub>4</sub>	5.5	V11	Motor gasoline	M.1A3E.32 Motorized equipment 4 stroke	330000
CH <sub>4</sub>	0.18	V15	Auto diesel	M.1A3E.32 Motorized equipment 4 stroke	330000
N <sub>2</sub> O	0.08	V11	Motor gasoline	M.1A3E.32 Motorized equipment 4 stroke	230500-233320
NO <sub>x</sub>	<b>23.4</b>	V15	Auto diesel	M.1A3E.32 Motorized equipment 4 stroke	230100
NO <sub>x</sub>	<b>15.0</b>	V15	Auto diesel	M.1A3E.32 Motorized equipment 4 stroke	230210
NO <sub>x</sub>	54	V18	Light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230100
NO <sub>x</sub>	52	V18	Light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230210
NO <sub>x</sub>	47	V18	Light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230710-230892, 234910
NO <sub>x</sub>	48	V18	Light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	232360, 248422
NO <sub>x</sub>	46	V18	Light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	234110-234120
NMVOC	7.2	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230100
NMVOC	5.7	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230210
NMVOC	4	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230710-230892, 234910
NMVOC	4.8	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	232360, 248422
NMVOC	3.8	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	234110-234120
CO	25	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230100
CO	20	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230210
CO	11	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230710-230892, 234910
CO	17	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	234110-234120
CO	18	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	248422

Bold numbers are different for different years, see table B20.

**Table B19. Exceptions from the general factors for other pollutants for other mobile sources**

Component	Emission factor (kg/tonne)	Fuel	Source	Sectors	
TSP, PM <sub>10</sub>	7.1	V15	Auto diesel	M.1A3E.32 Motorized equipment 4 stroke	230100-230210
TSP, PM <sub>10</sub>	3.8	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230710-230892, 234910
TSP, PM <sub>10</sub>	4.2	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	232360
TSP, PM <sub>10</sub>	5.3	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	234110-234120
TSP, PM <sub>10</sub>	5.4	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	248422
PM <sub>2.5</sub>	6.75	V15	Auto diesel	M.1A3E.32 Motorized equipment 4 stroke	230100-230210
PM <sub>2.5</sub>	3.61	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	230710-230892, 234910
PM <sub>2.5</sub>	3.99	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	232360
PM <sub>2.5</sub>	5.04	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	234110-234120
PM <sub>2.5</sub>	5.13	V15, 18	Auto diesel, light fuel oils	M.1A3E.32 Motorized equipment 4 stroke	248422

**Table B20. Time series for NO<sub>x</sub> emission factors for use of auto diesel in motorized equipment 4t**

Sector	1980	1987	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
General	38.8	39.4	39.9	40.2	41.0	41.7	42.3	42.9	43.4	43.9	44.3	44.5	43.6	42.6	41.2
230100	30.1	31.2	32.2	32.7	33.6	34.2	34.9	35.6	36.6	38.3	39.3	40.0	40.7	41.3	41.8
230210	31.2	34.0	36.2	37.2	38.4	40.1	41.3	42.5	43.7	44.5	45.4	46.0	45.7	45.4	44.8

Sector	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
General	39.7	37.7	35.7	34.0	32.2	29.9	27.6	26.1	24.6	23.3	21.9
230100	40.8	39.3	37.9	36.3	34.4	32.3	30.3	28.4	26.8	25.0	23.4
230210	42.3	38.7	35.5	32.0	28.1	24.4	22.0	19.5	17.7	16.2	15.0

Source: Winther and Nielsen (2006). Data for 2005 and later are extrapolations.

**Table B21. Time series for variable emission factors for other mobile sources**

Fuel	Component	1980-1990	1991	1992	1993	1994	1995	1996	1997-
V11 Gasoline	Dioxins	1.32	1.11	0.95	0.69	0.25	0.23	0.11	0.1

## CH<sub>4</sub> - Stationary combustion

**Table B22. General emission factors, kg CH<sub>4</sub>/tonne fuel**

Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood briquettes	V04 Charcoal	V31 Natural gas (1 000 Sm <sup>3</sup> )	V33 Refinery gas
S.01 Direct-fired furnaces ...	0.028	0	0	.	.	.	.	.	.	0.05	0.054
S.02 Gas turbines ....	.	.	.	.	.	.	.	.	.	0.91	.
S.03 Boilers .....	0.28	0.28	0.28	.	0.25	0.25	0.25	0.25	.	0.2	0.24
S.04 Small stoves .....	8.4	8.4	.	5.3	.	.	5.3	.	8.4	.	.
S.1B2C Flares .....	.	.	.	.	.	.	.	.	.	0.24	0.28

	V34 Blast fur- nace gas	V36 Landfill gas	V35 Fuel gas	V32 LPG	V13 Kerosene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy distillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
S.01 Direct-fired furnaces	0.054	.	0.05	.	.	0.016	.	0.04	0.04	.	0.04
S.02 Gas turbines	.	0.24	.	.	.	0	.	.	.	.	.
S.03 Boilers	0.24	0.24	0.24	0.17	0.17	0.4	0.4	0.4	0.4	0.23	0.4
S.04 Small stoves	.	.	.	0.24	0.3	.	0.4	0.4	.	.	.
S.1B2C Flares	.	0.37	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B23.

Source: IPCC (1997a), SFT (Sandgren *et al.* 1996), SINTEF (Karlsvik 1995) and OLF (The Norwegian oil industry association 1994).

**Table B23. Exceptions from the general factors for CH<sub>4</sub>, stationary combustion (kg CH<sub>4</sub>/tonne fuel)**

Emission factor	Fuel	Source	Sectors
0	V31, 35	Natural gas (1000 Sm <sup>3</sup> ), fuel gas	S.01 Direct fired furnaces
0.085	V31	Natural gas (1000 Sm <sup>3</sup> )	S.01 Direct fired furnaces
0.03	V01	Coal	S.03 Boilers
0.1	V17, 18, 19, 20, 52	Fuel oils incl. spesial waste	S.03 Boilers
0.0425	V31	Natural gas (1000 Sm <sup>3</sup> )	S.03 Boilers
0	V34	Blast furnace gas	S.03 Boilers
1	V33	Refinery gas	S.02 Gas turbines

**N<sub>2</sub>O - Stationary combustion****Table B24. General emission factors. kg N<sub>2</sub>O/tonne fuel**

Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood briquettes	V04 Char- coal	V31 Natural gas (1000 Sm <sup>3</sup> )	V33 Refinery gas
S.01 Direct-fired furnaces ...	0	0	0	.	.	.	.	.	.	0.02	0.024
S.02 Gas turbines .....	.	.	.	.	.	.	.	.	.	0.019	.
S.03 Boilers .....	0.04	0.04	0.04	.	0,07	0,07	0.07	0.07	.	0.004	0.005
S.04 Small stoves .....	0.04	0.04	.	0.032	.	.	0.032	.	0.04	.	.
S.1B2C Flares .....	.	.	.	.	.	.	.	.	.	0.02	0.024
	V34 Blast furn- ace gas	V36 Landfill gas	V35 Fuel gas	V32 LPG	V13 Kero- sene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy distillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
S.01 Direct-fired furnaces	0.024	0.024	0.024	.	.	0.03	.	0.03	0.03	.	0.03
S.02 Gas turbines	.	0.005	.	.	.	0.024	.	.	.	.	.
S.03 Boilers	0.005	0.005	0.005	0.03	0.03	0.03	0.03	0.03	0.03	0.035	0.03
S.04 Small stoves	.	.	.	0.03	0.03	.	0.03	0.03	.	.	.
S.1B2C Flares	.	0.002	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B25.

Source: IPCC (1997a), SFT (Sandgren *et al.* 1996) and OLF (The Norwegian oil industry association 1994).

**Table B25. Exceptions from the general factors for N<sub>2</sub>O. Stationary combustion (kg N<sub>2</sub>O/1000 Sm<sup>3</sup> natural gas)**

Emission factor	Fuel	Source	Sectors
0.017	V31	Natural gas	S.01 Direct-fired furnaces
0.023	V33	Refinery gas	S.02 Gas turbines

**NO<sub>x</sub> - Stationary combustion****Table B26. General emission factors. kg NO<sub>x</sub>/tonne fuel**

Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood bri- quettes	V04 Char- coal	V31 Natural gas (1000 Sm <sup>3</sup> )	V33 Refinery gas
S.01 Direct-fired furnaces ...	16	20	20	.	.	.	.	.	.	5.95	5.4
S.02 Gas turbines ....	.	.	.	.	.	.	.	.	.	6.27	.
S.03 Boilers .....	3	3	3.4	.	0.9	0.9	1.3	1.3	.	2.55	3
S.04 Small stoves .....	3	3	.	<b>0.985</b>	.	.	1.1	.	1.4	.	.
S.1B2C Flares .....	.	.	.	.	.	.	.	.	.	12	7

	V34 Blast furn- ace gas	V36 Landfill gas	V35 Fuel gas	V32 LPG	V13 Kerosene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy distillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
S.01 Direct-fired furnaces	5.4	.	5.4	.	.	70	.	5	5	.	5
S.02 Gas turbines	.	.	.	.	.	16	.	.	.	.	.
S.03 Boilers	3	0.01	3	2.3	3	2.5	2.5	2.5	4.2	1.365	4.2
S.04 Small stoves	.	.	.	2.3	2.5	.	2.5	2.5	.	.	.
S.1B2C Flares	.	0.17	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B27, and bold numbers are different for different years, see table B28.

Source: Rosland (1987). Fuel wood factor based on data from annual surveys on use of fuel wood in households.

**Table B27. Exceptions from the general factors for NO<sub>x</sub>. Stationary combustion. kg NO<sub>x</sub> /tonne fuel**

Emission factor	Fuel	Source	Sectors
24	V19, 20, 52	Heavy distillate, heavy fuel oil, special waste	S.01 Direct-fired furnaces 231910.2, 232350
6.13	V31	Natural gas (1000 Sm <sup>3</sup> )	S.01 Direct-fired furnaces 232014
9.5	V19, 20	Heavy distillate, heavy fuel oil	S.01 Direct-fired furnaces 232360
<b>8.681</b>	V31	Natural gas (1000 Sm <sup>3</sup> )	S.02 Gas turbines 230600.1
1.4	V31	Natural gas (1000 Sm <sup>3</sup> )	S.1B2C Flares 230600.1
3	V17, 18, 19	Fuel oils	S.03 Boilers 230500-233320
4.5	V01	Coal	S.03 Boilers 230500-233320
3.4	V02	Coke	S.03 Boilers 230500-233320
5	V20, 52	Heavy fuel oil, special waste	S.03 Boilers 230500-233320
2.9	V35	Fuel gas	S.03 Boilers 232011-232050, 232411-232442
0.01	V34	Blast furnace gas	S.03 Boilers 233510-233530
6.27	V33	Refinery gas	S.02 Gas turbines 233511
1.4	V01, 02	Coal, coke	S.04 Small stoves 330000



**Table B28. Time series for variable emission factors for NO<sub>x</sub>. Stationary combustion. kg NO<sub>x</sub>/tonne fuel**

Sector	Source	Fuel	1980-1990	1991	1992-1994	1995	1996-1998	1999-2004	2005	2006	2007	2008	2009	2010	2011	2012
General	S.04	V41	0.982	0.981	0.982	0.981	0.982	0.981	0.985	0.984	0.987	0.988	0.987	0.988	0.986	0.985

Sector	Source	Fuel	1980-1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000-
230600.1	S.02	V31	8.223	8.172	8.234	8.444	8.617	8.874	9.128	9.185	9.528	9.087	8.681

**NM VOC - Stationary combustion****Table B29. General emission factors. kg NMVOC/tonne fuel**

Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood bri- quettes	V04 Char coal gas (1000 Sm <sup>3</sup> )	V31 Natural gas (1000 Sm <sup>3</sup> )	V33 Re finery gas
S.01 Direct-fired furnaces .....	0	0	0	.	.	.	.	.	.	0	0.1
S.02 Gas turbines .....	.	.	.	.	.	.	.	.	.	0.24	.
S.03 Boilers .....	1.1	0.6	0.6	.	1.30	.	1.3	1.3	.	0.085	0.1
S.04 Small stoves .....	1.1	0.6	.	7.0	.	.	6.501	.	10	.	.
S.1B2C Flares .	.	.	.	.	.	.	.	.	.	0.06	13.5

	V34 Blast furnace gas	V36 Landfill gas	V35 Fuel gas	V32 LPG	V13 Kero sene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy distillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
S.01 Direct-fired furnaces	0	.	0	.	.	5	.	0.3	0.3	.	0.3
S.02 Gas turbines	.	.	.	.	.	0.03	.	.	.	.	.
S.03 Boilers	0.1	0	0.1	0.1	0.4	0.4	0.4	0.4	0.3	0.7	0.3
S.04 Small stoves	.	.	.	0.1	0.4	.	0.4	0.4	.	.	.
S.1B2C Flares	.	0	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B30.

Source: Rosland (1987) and SFT (Sandgren *et al.* 1996).

**Table B30. Exceptions from the general factors for NMVOC. Stationary combustion. kg NMVOC/tonne fuel**

Emission factor	Fuel	Source	Sectors
0	V 19, 20, 52	Heavy distillate, heavy fuel oil, special waste	S.01 Direct-fired furnaces 231910.2, 232350
0.1	V34	Blast furnace gas	S.01 Direct-fired furnaces 231910.2
0.085034	V31	Natural gas (1000 Sm <sup>3</sup> )	S.01 Direct-fired furnaces 232014
0.9	V19, 20	Heavy distillate, heavy fuel oil	S.01 Direct-fired furnaces 232360
0.8	V01	Coal	S.03 Boilers 230500-233320
0	V32, 34, 35, 42	LPG, blast furnace gas, fuel gas, wood waste	S.03 Boilers 230500-233320, 231711, 232011-232050, 233510-233530
0.6	V17, 18, 19	Fuel oils	S.03 Boilers 330000
10	V01	Coal	S.04 Small stoves 330000
0.6	V13	Kerosene (heating)	S.04 Small stoves 330000

## CO - Stationary combustion

Table B31. General emission factors. kg CO/tonne fuel

Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood briquettes	V04 Char coal	V31 Natural gas (1000 Sm <sup>3</sup> )	V33 Re finery gas
S.01 Direct-fired furnaces ...	0	0	0	.	.	.	.	.	.	0	0
S.02 Gas turbines ....	.	.	.	.	.	.	.	.	.	1.7	.
S.03 Boilers .....	3	3	3	.	15	0	15	15	.	0	0
S.04 Small stoves .....	3	3	.	<b>99.2</b>	.	.	2.6	.	100	.	.
S.1B2C Flares .....	.	.	.	.	.	.	.	.	.	1.5	0
	V34 Blast furn- ace gas	V36 Landfill gas	V35 Fuel gas	V32 LPG	V13 Kero sene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy distillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
S.01 Direct-fired furnaces ...	0	.	0	.	.	5	.	0.2	0.2	.	0.2
S.02 Gas turbines ....	.	.	.	.	.	0.7	.	.	.	.	.
S.03 Boilers .....	0	0	0	0.5	2	2	2	2	0.4	2.8	0.4
S.04 Small stoves	.	.	.	0.5	2	.	2	2	.	.	.
S.1B2C Flares	.	0.04	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B32, and bold numbers are different for different years, see table B33.

Table B32. Exceptions from the general factors for CO. Stationary combustion. kg CO/tonne fuel

Emission factor	Fuel	Source	Sectors
0	V 19, 20, 52	Heavy distillate, heavy fuel oil, special waste	S.01 Direct-fired furnaces 231910.2, 232350, 232360
0.01	V34	Blast furnace gas	S.01 Direct-fired furnaces 231910.2
0.2	V20, 52	Heavy fuel oil, special waste	S.03 Boilers 230500-233320
0	V32, 42	LPG, wood waste	S.03 Boilers 230500-233320, 231711
6.5	V17, 18, 19	Fuel oils	S.03 Boilers 330000
100	V01, 02	Coal, coke	S.04 Small stoves 330000
6.5	V13	Kerosene (heating)	S.04 Small stoves 330000
1.7	V31	Natural gas (1000 Sm <sup>3</sup> )	S.1B2C Flares 231922

Table B33. Time series for variable emission factors for CO. Stationary combustion. kg CO/tonne fuel

Sector	Source	Fuel	1980- 1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
General	S.04	V41	149.1	148.4	146.3	142.6	137.6	131.0	122.2	111.5	115.5	111.9	110.6	107.9	105.0
Sector	Source	Fuel	2010	2011	2012										
General	S.04	V41	103.3	101.2	99.2										

NH<sub>3</sub> - Stationary combustionTable B34. General emission factors. kg NH<sub>3</sub>/tonne fuel

Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood bri- quettes	V04 Char- coal	V31 Natural gas (1000 Sm <sup>3</sup> )	V33 Re- finery gas	V34 Blast furn- ace gas	V36 Land- fill gas	V35 Fuel gas	V32 LPG	V13 Kero- sene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy dis- tillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
S.04 Small stoves	.	.	0.066	.	.	0.066	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
All other sources	0	0	0	.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

## Particulate matter - Stationary combustion

Table B35. General emission factors. kg particle component/tonne fuel

Com- ponent	Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood briquettes	V04 Char coal	V31 Natural gas (1000 Sm <sup>3</sup> )	V33 Refinery gas
	S.01 Direct-fired											
TSP ....	furnaces	1.6	1.6	1.6	.	.	.	.	.	.	0.122	0.144
	S.02 Gas											
TSP ....	turbines	.	.	.	.	.	.	.	.	.	0.122	.
	S.03											
TSP ....	Boilers	1.6	1.6	1.6	.	2.69	0	2.69	2.69	.	0.122	0.144
	S.04 Small											
TSP ....	stoves	4.2	2.85	3.5	<b>17.65</b>	.	.	1.1	.	2.4	.	.
	S.1B2C											
TSP ....	Flares	.	.	.	.	.	.	.	.	.	0.002	0.144
	S.01 Direct-fired											
PM <sub>10</sub> ...	furnaces	1.14	1.14	1.14	.	.	.	.	.	.	0.122	0.144
	S.02 Gas											
PM <sub>10</sub> ...	turbines	.	.	.	.	.	.	.	.	.	0.122	.
	S.03											
PM <sub>10</sub> ...	Boilers	1.14	1.14	1.14	.	2.52	0	2.52	2.52	.	0.122	0.144
	S.04 Small											
PM <sub>10</sub> ...	stoves	2.8	1.71	2.1	<b>17.29</b>	.	.	1.1	.	2.4	.	.
	S.1B2C											
PM <sub>10</sub> ...	Flares	.	.	.	.	.	.	.	.	.	0.002	0.144
	S.01 Direct-fired											
PM <sub>2.5</sub> ..	furnaces	0.82	0.82	0.82	.	.	.	.	.	.	0.122	0.144
	S.02 Gas											
PM <sub>2.5</sub> ..	turbines	.	.	.	.	.	.	.	.	.	0.122	.
	S.03											
PM <sub>2.5</sub> ..	Boilers	0.82	0.82	0.82	.	2.52	0	2.52	2.52	.	0.122	0.144
	S.04 Small											
PM <sub>2.5</sub> ..	stoves	0.86	0.86	1.5	<b>16.77</b>	.	.	1.1	.	2.4	.	.
	S.1B2C											
PM <sub>2.5</sub> ..	Flares	.	.	.	.	.	.	.	.	.	0.002	0.144
	V34 Blast furnace gas		V36 Landfill gas	V35 Fuel gas	V32 LPG	V13 Kerosene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy distillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
	S.01 Direct-fired											
TSP ....	furnaces	0.144	.	0.144	.	.	0.286	.	*	*	.	5.68
	S.02 Gas											
TSP ....	turbines	.	.	.	.	.	0.286	.	.	.	.	.
	S.03											
TSP ....	Boilers	0.144	0.144	0.144	0.136	0.296	0.286	0.286	*	*	0.05	5.68
	S.04 Small											
TSP ....	stoves	.	.	.	0.136	0.3	.	0.3	.	.	.	.
	S.1B2C											
TSP ....	Flares	.	0.144	.	.	.	.	.	.	.	.	.
	S.01 Direct-fired											
PM <sub>10</sub> ...	furnaces	0.144	.	0.144	.	.	0.143	.	*	*	.	4.87
	S.02 Gas											
PM <sub>10</sub> ...	turbines	.	.	.	.	.	0.143	.	.	.	.	.
	S.03											
PM <sub>10</sub> ...	Boilers	0.144	0.144	0.144	0.136	0.148	0.143	0.15	*	*	0.05	4.87
	S.04 Small											
PM <sub>10</sub> ...	stoves	.	.	.	0.136	0.16	.	0.155	.	.	.	.
	S.1B2C											
PM <sub>10</sub> ...	Flares	.	0.144	.	.	.	.	.	.	.	.	.
	S.01 Direct-fired											
PM <sub>2.5</sub> ..	furnaces	0.144	.	0.144	.	.	0.036	.	*	*	.	3.2
	S.02 Gas											
PM <sub>2.5</sub> ..	turbines	.	.	.	.	.	0.036	.	.	.	.	.
	S.03											
PM <sub>2.5</sub> ..	Boilers	0.144	0.144	0.144	0.136	0.037	0.12	0.12	*	*	0.05	3.2
	S.04 Small											
PM <sub>2.5</sub> ..	stoves	.	.	.	0.136	0.12	.	0.119	.	.	.	.
	S.1B2C											
PM <sub>2.5</sub> ..	Flares	.	0.144	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B37, and bold numbers are different for different years, see table B38.

\* General emission factors for all sources for heavy distillate and heavy fuel oil are given in table B36 for all years.

Source: Finstad *et al.* (2003). Fuel wood factor based on data from annual surveys on use of fuel wood in households

**Table B36. General particle emission factors for heavy distillate and heavy fuel oil for all sources. Factors dependent on sulphur content. kg particle component /tonne fuel**

Fuel	Com-ponent	1990	1991	1992	1993	1994	1995	1996-1997	1998	1999	2000-
V19	TSP	0.803	0.714	0.701	0.701	0.688	0.714	0.663	0.688	0.701	0.714
	PM <sub>10</sub>	0.690	0.614	0.603	0.603	0.592	0.614	0.570	0.592	0.603	0.614
	PM <sub>2.5</sub>	0.450	0.400	0.393	0.393	0.385	0.400	0.371	0.385	0.393	0.400
	TSP	1.350	1.339	1.316	1.304	1.190	1.053	1.098	1.087	1.110	1.201
V20	PM <sub>10</sub>	1.161	1.151	1.131	1.121	1.023	0.905	0.944	0.934	0.954	1.033
	PM <sub>2.5</sub>	0.761	0.754	0.741	0.735	0.671	0.593	0.619	0.613	0.625	0.677

Source: Finstad *et al.* (2003).**Table B37. Exceptions from the general factors for particles. Stationary combustion**

Emission factor (kg TSP/tonne)	Emission factor (kg PM <sub>10</sub> /tonne)	Emission factor (kg PM <sub>2.5</sub> /tonne)	Fuel	Source	Sectors
4.06	2.4	1.4	V52	Special waste	S.01 Direct-fired furnaces 230500-233320
5.45	3.54	1.45	V01	Coal	S.01 Direct-fired furnaces 233530
4.2	2.8	0.86	V01	Coal	S.03 Boilers 230100
.	0.143 (V18)	0.036 (V17, 18)	V17, 18	Light fuel oils	S.03 Boilers 230500-233320
4.06	2.4	1.4	V52	Special waste	S.03 Boilers 230500-233320
5.45	3.54	1.45	V01	Coal	S.03 Boilers 233530
0.5	0.5	0.5	V51	Municipal waste	S.03 Boilers 253800
0.3	0.155	0.119	V13	Kerosene (heating)	S.04 Small stoves 330000

**Table B38. Time series for variable emission factors for particles. Stationary combustion. kg particle component /tonne fuel**

Component	Source	Fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
TSP .....	S.04	V41	22.24	22.24	22.24	22.25	22.26	22.25	22.26	22.27	22.24	22.05	21.68	21.22
PM <sub>10</sub> .....	S.04	V41	21.80	21.80	21.80	21.80	21.81	21.81	21.81	21.83	21.79	21.61	21.25	20.79
PM <sub>2.5</sub> .....	S.04	V41	21.13	21.13	21.13	21.14	21.15	21.14	21.15	21.16	21.12	20.95	20.60	20.16
			2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
TSP .....	S.04	V41	20.62	19.82	18.85	19.10	18.80	18.66	18.41	18.16	17.96	17.78	17.65	
PM <sub>10</sub> .....	S.04	V41	20.21	19.42	18.47	18.72	18.42	18.29	18.04	17.79	17.60	17.43	17.29	
PM <sub>2.5</sub> .....	S.04	V41	19.59	18.83	17.91	18.15	17.86	17.73	17.49	17.25	17.06	16.89	16.77	

## POPs (Persistent Organic Pollutants) - Stationary combustion

Table B39. General emission factors for PAH

Component	Source	V01 Coal	V02 Coke	V03 Petrol coke	V41 Fuel wood	V42 Wood waste	V43 Black liquor	V44 Wood pellets	V45 Wood briquettes	V04 Charcoal	V31 Natural gas (1000 Sm <sup>3</sup> )	V33 Refinery gas
PAH	S.01 Direct- fired furn- aces	0.17	0.17	0.17	.	0.018	0.018	.	.	.	0.015	0.018
PAH	S.02 Gas turbines	.	.	.	.	.	.	.	.	.	0.015	.
PAH	S.03 Boilers	0.46	0.46	0.46	.	0.018	0.018	0.16	0.16	.	0.015	0.018
PAH	S.04 Small stoves	39.9	27.8	27.8	<b>24.48</b>	.	.	38.8	.	39.9	.	.
PAH	S.1B2C Flares	.	.	.	.	.	.	.	.	.	0.015	0.018
PAH	M.1A3C Railroad	0.46.	.	.	.	.	.	.	.	.	.	.
PAH- OSPAR	S.01 Direct- fired furnaces	0.02	0.02	0.02	.	.	.	.	.	.	9E-04	0.001
PAH- OSPAR	S.02 Gas turbines	.	.	.	.	.	.	.	.	.	9E-04	.
PAH- OSPAR	S.03 Boilers	0.16	0.16	0.16	.	0.061	0.061	0.061	0.061	.	9E-04	0.001
PAH- OSPAR	S.04 Small stoves	18	13.4	13.4	<b>3.97</b>	.	.	6.8	.	18	.	.
PAH- OSPAR	S.1B2C Flares	.	.	.	.	.	.	.	.	.	9E-04	0.001
PAH- OSPAR	M.1A3C Railroad	0.16.	.	.	.	.	.	.	.	.	.	.
PAH-4	S.01 Direct- fired furnaces	0	0	0	.	.	.	.	.	.	0	0
PAH-4	S.02 Gas turbines	.	.	.	.	.	.	.	.	.	0	.
PAH-4	S.03 Boilers	0.024	0.024	0.024	.	0.016	0.016	0.016	0.016	.	0	0
PAH-4	S.04 Small stoves	2.6	0.4	0.4	<b>1.37</b>	.	.	2.5	.	2.6	.	.
PAH-4	S.1B2C Flares	.	.	.	.	.	.	.	.	.	0	0
PAH-4	M.1A3C Railroad	0.024.	.	.	.	.	.	.	.	.	.	.

**Table B39 (cont.). General emission factors for PAH**

Component	Source	V34 Blast furnace gas	V36 Landfill gas	V35 Fuel gas	V32 LPG	V13 Kero- sene (heating)	V17 Marine gas oil/ diesel	V18 Light fuel oils	V19 Heavy distillate	V20 Heavy fuel oil	V51 Municipal waste	V52 Special waste
PAH	S.01 Direct- fired furn- g/tonne ...aces	0.018	.	0.018	.	.	1.6	.	0.015	0.015	.	0.015
PAH	S.02 Gas g/tonne ...turbines	.	.	.	.	.	1.6	.	.	.	.	.
PAH	S.03 g/tonne ...Boilers	0	0.018	0.018	0.018	0.007	<i>0.01</i>	<i>0.01</i>	0.015	0.015	2.5	0.015
PAH	S.04 Small g/tonne ...stoves	.	.	.	0.039	0.039	.	1.01	.	.	.	.
PAH	S.1B2C g/tonne ...Flares	.	0.018	.	.	.	.	.	.	.	.	.
PAH	M.1A3C g/tonne ...Railroad	.	.	.	.	.	.	.	.	.	.	.
PAH- OSPAP	S.01 Direct- fired g/tonne ...furnaces	0.001	.	0.001	.	.	0.26	.	0.004	0.004	.	0.004
PAH- OSPAP	S.02 Gas g/tonne ...turbines	.	.	.	.	.	0.26	.	.	.	.	.
PAH- OSPAP	S.03 g/tonne ...Boilers	0.001	0	0.001	0.001	8E-04	<i>0</i>	<i>0</i>	0.004	0.004	<i>0.7</i>	0.004
PAH- OSPAP	S.04 Small g/tonne ...stoves	.	.	.	0.007	0.007	.	0.57	.	.	.	.
PAH- OSPAP	S.1B2C g/tonne ...Flares	.	0	.	.	.	.	.	.	.	.	.
PAH- OSPAP	M.1A3C g/tonne ...Railroad	.	.	.	.	.	.	.	.	.	.	.
PAH-4	S.01 Direct- fired g/tonne ...furnaces	0	.	0	.	.	0.04	.	4E-04	4E-04	.	4E-04
PAH-4	S.02 Gas g/tonne ...turbines	.	.	.	.	.	0.04	.	.	.	.	.
PAH-4	S.03 g/tonne ...Boilers	0	0	0	0	1E-04	1E-04	1E-04	4E-04	4E-04	<i>0.03</i>	4E-04
PAH-4	S.04 Small g/tonne ...stoves	.	.	.	0	0	.	0.003	.	.	.	.
PAH-4	S.1B2C g/tonne ...Flares	.	0	.	.	.	.	.	.	.	.	.
PAH-4	M.1A3C g/tonne ...Railroad	.	.	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B42, and bold numbers are different for different years, see tables B40 and B43.

Source: Finstad *et al.* (2001). Fuel wood factor based on data from annual surveys on use of fuel wood in households

**Table B40. Time series for variable emission factors for PAH<sup>1</sup>. Stationary combustion (g component /tonne fuel)**

Component	Source	Fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
PAH	S.04	V41	50.70	50.70	50.71	50.71	50.71	50.70	50.70	50.71	50.37	49.26	47.34	44.68
PAH-OSPAP	S.04	V41	8.03	8.03	8.03	8.03	8.03	8.02	8.03	8.03	7.97	7.80	7.50	7.09
PAH-4	S.04	V41	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.69	2.63	2.54	2.40
			2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	
PAH	S.04	V41	41.26	36.72	31.22	32.94	31.13	30.28	28.78	27.35	26.37	25.41	24.48	
PAH-OSPAP	S.04	V41	6.56	5.84	4.97	5.29	5.00	4.89	4.67	4.44	4.30	4.13	3.97	
PAH-4	S.04	V41	2.22	1.98	1.68	1.81	1.71	1.68	1.61	1.53	1.49	1.42	1.37	

**Table B41. General emission factors for dioxins**

Com- ponent	Source	V01	V02	V03	V41	V42	V43	V44	V45	V04	V31	V33
		Coal	Coke	Petrol coke	Fuel wood	Wood waste	Black liquor	Wood pellets	Wood bri- quettes	Char- coal	Natural gas (1000 Sm <sup>3</sup> )	Refinery gas
Dioxins	S.01 Direct- fired furnaces	1.6	1.6	1.6	.	.	.	.	.	.	0.05	0
Dioxins	S.02 Gas turbines	.	.	.	.	.	.	.	.	.	0.05	.
Dioxins	S.03 Boilers	1.6	1.6	1.6	.	1	1	1	1	.	0.05	0
Dioxins	S.04 Small stoves	10	10	10	5.9	.	.	5.9	.	10	.	.
Dioxins	S.1B2C Flares	.	.	.	.	.	.	.	.	.	0.05	0
		V34	V36	V35	V32	V13	V17	V18	V19	V20	V51	V52
		Blast furn- ace gas	Landfill gas	Fuel gas	LPG	Kerosene (heating)	Marine gas oil/ diesel	Light fuel oils	Heavy distillate	Heavy fuel oil	Municipal waste	Special waste
Dioxins	S.01 Direct- fired furnaces	0	.	0	.	.	4	.	0.1	0.1	.	4
Dioxins	S.02 Gas turbines	.	.	.	.	.	4	.	.	.	.	.
Dioxins	S.03 Boilers	0	0	1	0.06	0.1	0.1	0.1	0.1	0.1	0.02	4
Dioxins	S.04 Small stoves	.	.	.	0.06	0.06	.	0.2	.	.	.	.
Dioxins	S.1B2C Flares	.	0	.	.	.	.	.	.	.	.	.

Numbers in italics have exceptions for some sectors, see table B42.

Source: Finstad *et al.* (2002b).

**Table B42. Exceptions from the general factors for POPs. Stationary combustion**

Emission factor (g PAH/tonne)	Emission factor (g PAH-OSPAR/tonne)	Emission factor (g PAH-4/tonne)	Emission factor (ug dioxin/tonne)	Fuel	Source	Sectors
0.0008	0.0005	.	.	V17, 18 Fuel oils	S.03 Boilers	230500-233320
.	.	0.2	.	V18, 19 Heavy distillate, heavy fuel oil	S.03 Boilers	330000
<b>0.75</b>	<b>0.2</b>	<b>0.01</b>	.	V51 Municipal waste	S.03 Boilers	233530

**Table B43. Time series for variable emission factors for PAH. Stationary combustion**

Sector	Source	Fuel	1980-1994				1995-	
			Emission factor (g PAH/tonne)	Emission factor (g PAH-OSPAR/tonne)	Emission factor (g PAH-4/tonne)	Emission factor (g PAH/tonne)	Emission factor (g PAH-OSPAR/tonne)	Emission factor (g PAH-4/tonne)
General	S.03	V51	2.5	0.7	0.03	0.75	0.2	0.01

Source: NILU/NIVA (Norwegian institute for air research and Norwegian institute for water research 1995)/ Karlsson *et al.* (1992).

## Appendix C Activity data and emission figures

StatBank Norway is a service operated by Statistics Norway where you may select scope and content of each table, and then may export the result in various formats to your own PC. For air emissions you may find data on different pollutants distributed by source, energy product and industry.

StatBank is found at: <http://ssb.no/en/statistikbanken>

Reported air emission data for Norway are given at the website of the European Environment Agency. They may be accessed through the European Environment Information and Observation Network (EIONET) at <http://acm.eionet.europa.eu/databases/#ae>. The data are provided as downloadable csv or mdb files.

Reported data for greenhouse gases may also be obtained from the UN Climate Convention at [http://unfccc.int/national\\_reports/annex\\_i\\_ghg\\_inventories/items/2715.php](http://unfccc.int/national_reports/annex_i_ghg_inventories/items/2715.php). The data are provided as downloadable Excel spreadsheets in the Common Reporting Format (one file per year).



## Appendix D Uncertainty estimates for single sources

### Greenhouse gases

The national greenhouse gas (GHG) emission inventory is compiled from estimates based on emission factors and activity data and direct measurements by plants. All these data and parameters will contribute to the overall inventory uncertainty. The uncertainties and probability distributions of the inventory input parameters have been assessed based on available data and expert judgements. Finally, the level and trend uncertainties of the national GHG emission inventory have been estimated using Monte Carlo simulation. The methods used in the analysis correspond to an IPCC Tier 2 method, as described in (IPCC 2000). Analyses have been made both excluding and including the sector LULUCF (land use, land-use change and forestry).

The uncertainty analysis performed in 2011 (Flugsrud and Hoem 2011) was an update of the uncertainty analyses performed for the greenhouse gas inventory in 2006 and 2000. The report *Uncertainties in the Norwegian Greenhouse Gas Emission Inventory* (Rypdal and Zhang (2000)) includes more detailed documentation of the analysis method used in all analyses. In this note we mainly focus on the changes since the last analysis in 2006. This includes new methodology for several source categories as well as revised uncertainty estimates.

During the project we have been in contact with experts, and have collected information about uncertainty from them. There has been a focus on the sources where methodological changes have been made since the last uncertainty analysis was performed in 2006. For the industries included in the emission trading system, new information from the reports about uncertainty in activity data and CO<sub>2</sub> emission factor has been used. This has improved the quality of the uncertainty estimates for the energy and manufacturing sectors.

The results show that the uncertainty in the calculated greenhouse gas emissions for 2009 is  $\pm 5$  per cent. The uncertainty estimate is lower now than earlier analyses have shown. This is partly due to a considerable work made to improve the calculation methodology. It is also partly the uncertainty estimates themselves that have been improved.

### Level of the analysis

The uncertainty analysis is performed at the most detailed level of IPCC source categories (IPCC 2000). For some sources even a more detailed separation is made, e.g. where different pollutants from a source sector have to be connected to different activity measures, as for example for the source category 6B Waste water, or to be able to consider dependencies between only parts of the source groups, which for example is the case for the source categories 4D1 Direct soil emissions and 4D3 Indirect soil emissions. Energy carriers have been grouped into five main types; solid, gaseous, liquid, waste and bio energy. The allocation in groups has been made using international definitions based on the type of the original energy carrier, e.g. refinery gas and fuel gas is placed in "liquid" and CO gas is placed in "solid". This is a change from the preceding analysis, when all these three gases were allocated to "gaseous" fuels. This change affects the allocation of emissions on sources with different uncertainty estimates. The definitions of sources have also been changed to some extent since the preceding analysis, and this also affects the results of the uncertainty analysis. The most important changes are:

- Emissions from mobile installations in oil and gas exploration have been moved from "Mobile combustion-Coastal traffic" to "Stationary combustion-Oil and gas extraction".
- Emissions from district heating and electricity production are now placed in a new category called Energy supply.
- There are some minor adjustments in limitation and also some changes of names and order.

In table D3, source category level used in the study is listed.

For some emission sources a separation into activity and emission factors is not possible due to lack of information. Examples are estimates based on measurements, emissions reported by plants (in the cases when the plants have reported only emissions and not activity data and emission factor used), and emissions that are aggregated from sources with diverse methods (for example emissions from 2C5 Other metal production). These emissions have been assigned activity equal to 1, and emission factor to be equal to the estimated value. This is possible since the total uncertainty estimate is independent of scale for activity and emission factor<sup>22</sup>. Emissions from landfills, HFCs and some other sources have been transferred into the form of emission factor

<sup>22</sup> We may state the activity in any given unit, as long as the emission factor is stated in the corresponding unit. Examples: tonnes and kg/tonne, Gg and kg/Gg, or, as in this case, unit value and total emissions in kg.

multiplied with activity rate, in spite of the fact that the estimates are based on more complex estimation models (e.g. taking time lag into account and using several activity data and emission factors).

### **Uncertainties in input parameters**

#### **Emission estimates**

In the analysis emission estimates for the different source categories (table D3) for the years 1990 and 2009 are taken from the Norwegian emission inventory.

The emission estimates used in the analysis come from the national GHG emission inventory and are based on Norwegian measurements, literature data or statistical surveys. Some data are based on expert judgements.

#### **Standard deviation and probability density**

The probability densities used in this study have been divided into four types of model shapes:

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

For low uncertainties all the distributions 2-4 above approach the normal distribution. For large uncertainties the normal distribution may lead to negative values. To avoid this, the distributions are, when necessary, truncated at 0, which means that there is a given probability of the value 0. The lognormal distribution and beta distribution are both asymmetrical distributions, giving a heavier tail of probabilities towards higher values. These two distributions are very similar in shape for low to medium size uncertainties. For higher uncertainties the beta distribution is more flat and the peak in the distribution is more close to the mean value. The beta distribution is, however, only defined for variables taking values between 0 and 1.

The densities were used in the following way: Normal or lognormal distributions were used for most of the categories. Normal distribution was used for uncertainties up to 30 per cent, while lognormal distribution was used for higher uncertainties. Normal distribution was also used for carbon balances that were in principle a difference between larger gains and losses that likely were normally distributed with lower uncertainties. These carbon balances might take both positive and negative values. Beta distribution and truncated normal distribution were used only in a few special cases. Beta distribution was used for N<sub>2</sub>O emissions from combustion. Truncated normal distribution was used for CH<sub>4</sub> emissions from stationary combustion of liquid fuels, and from flaring.

The uncertainties and densities given in the following sections are based on information for 2009. However, they were also used for 1990 and for the trend analysis. In reality, due to improved methods, the quality of the 2009 data inventory is higher than that of the 1990 data for several categories. Thus, the analysis may underestimate the uncertainty in 1990 emissions and in the trend. The CO<sub>2</sub> emissions are likely most affected by this problem.

#### **Activity data**

The assessed standard deviations and corresponding probability densities are summarised in table D1.

Table D1. Summary of standard deviation and probability density of activity data

IPCC Source category	Pollutant source	Standard deviation ( $2\sigma$ ), per cent <sup>1</sup>	Density shape	Source/ comment
1A1, 1A2	Coal/coke - general	5	Normal	Expert judgement industry, Norcem (2006)
1A1B	Coal/coke – petroleum refining	1.1	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2A	Coal/coke - iron and steel	4.1	Normal	Emission trading scheme (Klif 2011), Expert judgement industry, Norcem (2006)
1A2F	Coal/coke - other	0.8	Normal	Emission trading scheme (Klif 2011), Expert judgement industry, Norcem (2006)
1A4B	Coal/coke - residential	20	Normal	Expert judgement, Rypdal and Zhang (2000)
1A4C	Coal/coke - agriculture	30	Normal	Expert judgement, Statistics Norway
1A1, 1A2, 1A4	Wood	30	Lognormal	Expert judgement, Rypdal and Zhang (2000)
1A1A	Gas – public electricity and heat production	0.8	Normal	Emission trading scheme (Klif 2011), Expert judgement, Statistics Norway
1A2	Gas - general	4	Normal	Norwegian Petroleum Directorate, Rypdal and Zhang (2000)
1A1C	Gas - manufacture of solid fuels and other energy industries	0.2	Normal	Emission trading scheme (Klif 2011), NPD (2006)
1A2C	Gas - chemicals	1.7	Normal	Emission trading scheme (Klif 2011), Norwegian Petroleum Directorate, Rypdal and Zhang (2000)
1A2D	Gas - pulp, paper, print	1.7	Normal	Emission trading scheme (Klif 2011), Norwegian Petroleum Directorate, Rypdal and Zhang (2000)
1A4A	Gas - commercial/institutional	10	Normal	Expert judgement, Statistics Norway
1A4B, 1A4C	Gas - residential, agriculture/forestry/fishing	30	Normal	Expert judgement, Statistics Norway
1A1, 1A2	Oil - general	3	Normal	Spread in data, Rypdal and Zhang (2000)
1A1B	Oil - petroleum refining	1.1	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A1C	Oil – manufacture of solid fuels and other energy industries	1.8	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2A	Oil - iron and steel	0.5	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2C	Oil - chemicals	14.4	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2D	Oil – pulp, paper, print	0.7	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2F	Oil - other	2.6	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A4A	Oil - commercial/institutional	20	Normal	Expert judgement, Statistics Norway
1A4B	Oil - residential	9.5	Normal	Emission trading scheme (Klif 2011), Expert judgement, Statistics Norway
1A4C	Oil - agriculture/forestry	10	Normal	Expert judgement, Statistics Norway
1A1A	Waste – general	5	Normal	Expert judgement, Rypdal and Zhang (2000)
1A2F	Waste - other manufacturing	3.2	Normal	Emission trading scheme (Klif 2011), Expert judgement, Rypdal and Zhang (2000)
1A4A	Waste - commercial/institutional	30	Lognormal	Expert judgement, Rypdal and Zhang (2000)
1A3A, 1A3E	Transport fuel - civil aviation, motorized equipment and pipeline	20	Normal	Expert judgement, Rypdal and Zhang (2000)
1A3B	Transport fuel - road	5	Normal	Expert judgement, Statistics Norway
1A3C	Transport fuel - railway	5	Normal	Expert judgement, Statistics Norway
1A3D	Transport fuel - navigation	20	Normal	Expert judgement, Statistics Norway
1A5A, 1A5B	Military fuel - stationary and mobile	5	Normal	Expert judgement, Statistics Norway
1B1A, 1B2B	Coal mining, extraction of natural gas	3	Normal	Expert judgement, Rypdal and Zhang (2000)
1B2A	Extraction of oil - transport, refining/storage	3	Normal	Expert judgement, Rypdal and Zhang (2000)
1B2A	Extraction of oil - distribution gasoline	5	Normal	Expert judgement, Rypdal and Zhang (2000)
1B2C	Venting	-	-	See emission factor
1B2C	Flaring	1.4	Normal	Emission trading scheme (Klif 2011), Expert judgement, Rypdal and Zhang (2000)
1B2C	Well testing	30	Normal	Expert judgement, Rypdal and Zhang (2000)
2A1	Cement production	0.4	Normal	Emission trading scheme (Klif 2011)
2A2	Lime production	0.4	Normal	Emission trading scheme (Klif 2011)
2A3	Limestone and dolomite use	14.1	Normal	Emission trading scheme (Klif 2011)
2A7	Other mineral production	0.1	Normal	Emission trading scheme (Klif 2011)
2B1	Ammonia production	3	Normal	Expert judgement industry, Yara (2006)
2B2	Nitric acid production	-	-	See emission factor
2B4	Carbide production - SiC	3	Normal	Expert judgement industry, St. Gobain and Orkla Exolon (2006)
2B4	Carbide production - CaC	3	Normal	Expert judgement, Rypdal and Zhang (2000)

2B5	Methanol and plastic production	9.0	Normal	Emission trading scheme (Klif 2011)
2C1	Iron and steel production	1.23	Normal	Expert judgement industry, Tinfos (2006)
2C2	Ferroalloys production	-	-	See emission factor
2C3	Aluminium production	3	Normal	Expert judgement industry, Norsk Hydro (2006a)
2C4	SF <sub>6</sub> used in Al and Mg foundries	-	-	See emission factor
2C5	Mg production	0.25	Normal	Expert judgement industry, Norsk Hydro (2006b)
2C5	Ni production, anodes	10	Normal	Expert judgement, Statistics Norway
2D1	Pulp and paper	0.9	Normal	Emission trading scheme (Klif 2011)
2D2	Carbonic acid, bio protein	10	Normal	Expert judgement, Statistics Norway
2F	Consumption of halocarbons and SF <sub>6</sub>	-	-	See emission factor
3A, 3B, 3C, 3D	Solvent and other product use - CO <sub>2</sub>	-	-	See emission factor
3D	Use of N <sub>2</sub> O in anaesthesia and as propellant - N <sub>2</sub> O	-	-	See emission factor
4A	Enteric fermentation	5	Normal	Expert judgement, Statistics Norway (2006a), Division for agricultural statistics
4B1-9, 4B13	Manure management - CH <sub>4</sub>	5	Normal	Expert judgement, Statistics Norway (2006a), Division for agricultural statistics
4B11-12	Manure management - N <sub>2</sub> O	24	Normal	Expert judgement <sup>2</sup> , Statistics Norway (2006a), Statistics Norway (2006b), and Statistics Norway (2006c)
4D1	Direct soil emission - fertiliser	5	Normal	SFT (1999a)
4D1	Direct soil emission - manure	20	Normal	Rypdal and Zhang (2000)
4D1	Direct soil emission - other	64	Lognormal	Expert judgement <sup>3</sup> , Statistics Norway and Rypdal and Zhang (2000)
4D1	Direct soil emission - organic soil	Fac2	Lognormal	Expert judgement, Statistics Norway
4D2	Animal production	22	Normal	Expert judgement <sup>4</sup> , Statistics Norway
4D3	Indirect soil emission - deposition	30	Lognormal	SFT (1999a)
4D3	Indirect soil emission - leakage	70	Lognormal	SFT (1999a)
4F1	Agricultural residue burning	10	Normal	Expert judgement, Statistics Norway
5A1	Forest Land remaining Forest Land, - general	-	-	See emission factor
5A1	Forest Land remaining Forest Land - wildfires	20	Normal	Expert judgement, Statistics Norway
5A2	Land converted to Forest Land	-	-	See emission factor
5B1	Cropland remaining Cropland - general	-	-	See emission factor
5B1	Cropland remaining Cropland - liming	5	Normal	Expert judgement, Statistics Norway
5B2	Land converted to Cropland	-	-	See emission factor
5C1	Grassland remaining Grassland	-	-	See emission factor
5C2	Cropland converted to Grassland	-	-	See emission factor
5D1	Wetlands remaining Wetlands	-	-	See emission factor
5D2	Land converted to Wetland	-	-	See emission factor
5E2	Land converted to Settlements	-	-	See emission factor
5F2	Land converted to Other land	-	-	See emission factor
5G	Other; Liming of lakes and rivers	5	Normal	Expert judgement, Statistics Norway
6A	Solid waste disposal	20	Normal	Expert judgement, Statistics Norway (2010) and SFT (2006a)
6B	Waste water treatment - CH <sub>4</sub>	1	Lognormal	Expert judgement, Statistics Norway
6B	Waste water treatment - N <sub>2</sub> O pipeline and plant	25	Normal	Expert judgement, Statistics Norway (2006e)
6B	Waste water treatment - N <sub>2</sub> O, not connected	30	Normal	Expert judgement, Statistics Norway (2011)
6C	Waste incineration	30	Normal	Expert judgement, Statistics Norway

<sup>1</sup> Strongly skewed distributions are characterised as fac.3 etc, indicating that 2σ is a factor 3 below and above the mean.

<sup>2</sup> Population 5% (Statistics Norway 2006a), Nex 15% (Statistics Norway 2006b), distribution AWMS 10% (Statistics Norway 2006c), distribution pasture/ storage 15% (Statistics Norway 2006b)

<sup>3</sup> N fixation 40% and crop residues 50% (Rypdal and Zhang 2000)

<sup>4</sup> Population 5% (Statistics Norway 2006a), Nex 15% (Statistics Norway 2006b, distribution pasture/ storage 15% (Statistics Norway 2006b)

### Emission factors

The assigned values and probability densities are shown in table D2.

**Table D2. Summary of standard deviation and probability density of emission factors**

IPCC Source category	Pollutant source	Gas	(2 $\sigma$ ). per cent <sup>1</sup>	Density shape	Source/ comment
1A1, 1A2B, 1A2D, 1A2E, 1A4	Coal/coke - general	CO2	7	Normal	Spread in data, Rypdal and Zhang (2000)
1A1B	Coal/coke – petroleum refining	CO2	0.9	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2A	Coal/coke – iron and steel	CO2	16.0	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2F	Coal/coke - other	CO2	2.0	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2, 1A4	Gas - general	CO2	3.5	Normal	IPCC (2006), expert judgement, Statistics Norway
1A1A	Gas – public electricity and heat prod	CO2	0.6	Normal	Emission trading scheme (Klif 2011), Norwegian Petroleum Directorate, Rypdal and Zhand (2000)
1A1C	Gas – Manufacture of solid fuels and other energy	CO2	2.6	Normal	Emission trading scheme (Klif 2011), Norwegian Petroleum Directorate, Rypdal and Zhand (2000)
1A2C	Gas - Chemicals	CO2	1.6	Normal	Emission trading scheme (Klif 2011), Norwegian Petroleum Directorate, Rypdal and Zhand (2000)
1A1, 1A2, 1A4	Oil - general	CO2	3	Normal	Spread in data, Rypdal and Zhang (2000)
1A1B	Oil – petroleum refining	CO2	0.9	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2C	Oil - Chemicals	CO2	1.1	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A2F	Oil - other	CO2	2.6	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A4B	Oil - residential	CO2	3.4	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A1, 1A4	Waste - general	CO2	30	Normal	Spread in data, Rypdal and Zhang (2000)
1A2F	Waste - other	CO2	25.2	Normal	Emission trading scheme (Klif 2011), Spread in data, Rypdal and Zhang (2000)
1A3A, 1A3B, 1A3C, 1A3D	Transport fuel	CO2	3	Normal	Spread in data, Rypdal and Zhang (2000)
1A5	Military fuel - stationary and mobile	CO2	5	Normal	Expert judgement, Statistics Norway
1A1, 1A2, 1A4	Coal/coke, wood, waste - general	CH4	Fac2	Lognormal	Spread in data, Rypdal and Zhang (2000)
1A1B	Coal/coke – petroleum refining	CH4	Fac2	Truncated N	Spread in data, Rypdal and Zhang (2000)
1A1, 1A2, 1A4, 1A5	Gas – general, military fuel – stationary and mobile	CH4	Fac2	Lognormal	Expert judgement, Statistics Norway
1A1, 1A2, 1A4	Oil - general	CH4	Fac2	Truncated N	Spread in data, Rypdal and Zhang (2000)
1A3A, 1A3C, 1A3D	Transport fuel	CH4	Fac2	Lognormal	Spread in data. Expert judgement, Rypdal and Zhang (2000)
1A3B	Transport fuel	CH4	45	Lognormal	(Gustafsson 2005)
1A1, 1A2, 1A4, 1A5	Coal/coke, wood, gas, waste – general, military fuel – stationary and mobile	N2O	Fac3	Beta	Expert judgement, Statistics Norway
1A1, 1A2, 1A4	Oil - general	N2O	Fac3	Beta	Spread in data. Expert judgement. IPCC (1997), Rypdal and Zhang (2000)
1A1B	Coal/coke – petroleum refining	N2O	Fac3	Beta	Spread in data. Expert judgement. IPCC (1997), Rypdal and Zhang (2000)
1A3A, 1A3C, 1A3D	Transport fuel	N2O	Fac3	Beta	Spread in data. Expert judgement, Rypdal and Zhang (2000)
1A3B	Transport fuel	N2O	65	Lognormal	(Gustafsson 2005)
1B1A, 1B2B	Coal mining, extraction of natural gas	CO2	Fac2	Lognormal	Expert judgement, Statistics Norway
1B2A	Extraction of oil - transport, refining/storage, distribution gasoline	CO2	40	Lognormal	Expert judgement, Statistics Norway
1B2C	Venting	CO2	Fac2	Lognormal	Expert judgement, Rypdal and Zhang (2000)
1B2C	Flaring	CO2	4.5	Normal	Emission trading scheme (Klif 2011), Rypdal and Zhang (2000)
1B2C	Well testing	CO2	7	Normal	Expert judgement, Rypdal and Zhang (2000)

1B1A, 1B2B, 1B2C	Coal mining, extraction of natural gas, venting	CH4	Fac2	Lognormal	Expert judgement, Rypdal and Zhang (2000)
1B2A	Extraction of oil - transport, refining/storage	CH4	40	Lognormal	Expert judgement, Statistics Norway
1B2C	Flaring, well testing	CH4	Fac2	Truncated N	Expert judgement, Rypdal and Zhang (2000)
1B2C	Flaring, well testing	N2O	Fac3	Beta	Expert judgement, Rypdal and Zhang (2000)
2A1	Cement production	CO2	0.6	Normal	Emission trading scheme (Klif 2011), IPCC (1997)
2A2	Lime production	CO2	0.5	Normal	Emission trading scheme (Klif 2011), Expert judgement, Statistics Norway
2A3, 2A7	Limestone and dolomite use, other mineral production	CO2	7	Normal	Expert judgement, Statistics Norway
2B1	Ammonia production	CO2	7	Normal	Expert judgement industry, Yara (2006)
2B4	Carbide production - SiC	CO2	10	Normal	Expert judgement industry, St. Gobain and Orkla Exolon (2006)
2B4	Carbide production - CaC	CO2	10	Normal	Spread in data, Rypdal and Zhang (2000)
2B5	Methanol and plastic production	CO2	0.7	Normal	Emission trading scheme (Klif 2011), Expert judgement, Statistics Norway
2B4	Carbide production - SiC	CH4	10	Normal	SFT (2006b)
2B5	Methanol and plastic production	CH4	Fac2	Lognormal	Expert judgement, Statistics Norway
2B2	Nitric acid production	N2O	6.0	Normal	Expert judgement industry, Yara (2006), Emission trading scheme (Klif 2011)
2C1	Iron and steel production	CO2	1.3	Normal	Emission trading scheme (Klif 2011), Expert judgement industry, Tinfos (2006)
2C2	Ferroalloys production	CO2	3	Normal	Expert judgement, SINTEF (2006)
2C3	Aluminium production	CO2	10	Normal	International Aluminium Institute (IAI), Norsk Hydro (2006a)
2C5	Mg production, Ni production, anodes	CO2	10	Normal	Expert judgement, Statistics Norway
2C2	Ferroalloys production	CH4	Fac2	Lognormal	Expert judgement, Statistics Norway
2C2	Ferroalloys production	N2O	10	Normal	Expert judgement, Statistics Norway
2C3	Aluminium production	PFK	20	Normal	Expert judgement industry, Norsk Hydro (2006a)
2C4	SF6 used in Al and Mg foundries	SF6	0.25	Normal	Expert judgement industry, Norsk Hydro (2006b)
2D1	Pulp and paper	CO2	10	Normal	Expert judgement, Statistics Norway
2D2	Carbonic acid, bio protein	CO2	10	Normal	Expert judgement, Statistics Norway
2F	Consumption of HFK and PFK	HFK/ PFK	50	Lognormal	Apply to HFK. Expert judgement, Statistics Norway
2F	Consumption of SF6	SF6	60	Lognormal	Expert judgement, Statistics Norway
3A, 3B,3C, 3D	Solvent and other product use	CO2	10	Normal	Expert judgement, Statistics Norway (2010)
3D	Use of N2O in anasthesia and as propellant	N2O	15	Normal	Expert judgement, Statistics Norway (2010)
A1, 4A3	Enteric fermentation - cattle and sheep	CH4	25	Normal	Expert judgement, UMB (2006)
4A4-10	Enteric fermentation - other animal	CH4	40	Normal	IPCC (2006)
4B1-9, 4B13	Manure management	CH4	25	Normal	IPCC (1997)
4B11-12	Manure management - N2O	N2O	Fac2	Lognormal	IPCC (1997)
4D1	Direct soil emission	N2O	Fac5	Lognormal	IPCC (2000)
4D2	Animal production	N2O	Fac2	Lognormal	IPCC (2000)
4D3	Indirect soil emission	N2O	Fac3	Lognormal	IPCC (1997)
4F1	Agricultural residue burning	CH4	Fac2	Lognormal	Expert judgement, Statistics Norway
4F1	Agricultural residue burning	N2O	Fac3	Beta	Expert judgement, Statistics Norway
5A1	Forest Land remaining Forest Land, Fertiliser	N2O	Fac5	Lognormal	NIJOS (2005)
5A1	Forest Land remaining Forest Land, Drainage	N2O	Fac10	Lognormal	NIJOS (2005)
5A1	Forest Land remaining Forest Land, Wildfires	CH4/ N2O	75	Lognormal	NIJOS (2005)

5A1	Forest Land remaining Forest Land, Forest inventory area, Living Biomass	CO2	15	Normal	NIJOS (2005)
5A1	Forest Land remaining Forest Land, Forest inventory area, Dead Biomass	CO2	50	Lognormal	NIJOS (2005)
5A1	Forest Land remaining Forest Land, Forest inventory area, Soils, Mineral	CO2	25	Normal	NIJOS (2005)
5A1	Forest Land remaining Forest Land, Forest inventory area, Soils, Organic	CO2	Fac10	Lognormal	NIJOS (2005)
5A2	Land converted to Forest Land, Living biomass	CO2	25	Normal	Expert judgement, Statistics Norway
5A2	Land converted to Forest Land, Soils, Mineral	CO2	50	Lognormal	Expert judgement, Statistics Norway
5B1	Cropland remaining Cropland, Liming	CO2	10	Normal	NIJOS (2005)
5B1	Cropland remaining Cropland, Horticulture, Living biomass	CO2	25	Normal	NIJOS (2005)
5B1	Cropland remaining Cropland, Reduced tillage, Soils	CO2	Fac2	Lognormal	NIJOS (2005)
5B1	Cropland remaining Cropland, Erosion of new agriculture land, Soils				
5B1	Cropland remaining Cropland, Histosols, Soils	CO2	Fac3	Lognormal	NIJOS (2005)
5B2	Land converted to Cropland, Living biomass	CO2	25	Normal	NIJOS (2005)
5B2	Land converted to Cropland, Soils, Mineral	CO2	50	Lognormal	Expert judgement, Statistics Norway
5B2	Cropland, Disturbance	N2O	Fac10	Lognormal	NIJOS (2005)
5C1	Grassland remaining Grassland, Other Grassland, Living biomass	CO2	50	Lognormal	Expert judgement, Statistics Norway
5C1	Grassland remaining Grassland, Histosols, Soils	CO2	Fac3	Lognormal	NIJOS (2005)
5C2	Cropland converted to Grassland, Horticulture, Living biomass	CO2	25	Normal	NIJOS (2005)
5D1	Wetlands remaining Wetlands, Living biomass	CO2	25	Normal	Expert judgement, Statistics Norway
5D1	Wetland remaining Wetland, Peat extraction, Soils	CO2	Fac3	Lognormal	NIJOS (2005)
5D2	Land converted to Wetland, Drainage	N2O	Fac10	Lognormal	NIJOS (2005)
5E2	Land converted to Settlements, Living biomass	CO2	50	Lognormal	NIJOS (2005)
5E2	Land converted to Settlements, Soils	CO2	50	Lognormal	Expert judgement, Statistics Norway
5F2	Land converted to Other land, Living biomass	CO2	50	Lognormal	Expert judgement, Statistics Norway
5G	Other; Liming of lakes and rivers	CO2	10	Normal	NIJOS (2005)
6A	Solid waste disposal	CH4	30	Lognormal	SFT (2006a)
6B	Waste water treatment - CH4	CH4	50	Lognormal	IPCC (2000) and expert judgement, Statistics Norway (2010) <sup>2</sup>
6B	Waste water treatment - N2O, pipeline and plant	N2O	70	Lognormal	Expert judgement, Rypdal and Zhang (2000)
6B	Waste water treatment - N2O, not connected	N2O	Fac5	Lognormal	IPCC (2006) and expert judgement, Statistics Norway (2010)
6C	Waste incineration	CO2	30	Normal	Expert judgement, Statistics Norway
6C	Waste incineration	CH4	Fac2	Lognormal	Expert judgement, Statistics Norway
6C	Waste incineration	N2O	Fac3	Lognormal	Expert judgement, Statistics Norway

<sup>1</sup> Strongly skewed distributions are characterised as *fac2*, *fac3*, *fac5* and *fac10*, indicating that  $2\sigma$  is respectively a factor 2, 3, 5 and 10 below and above the mean.

<sup>2</sup> BOD/ person 30%, Bo 30% (IPCC 2000) and MCF 25%. Dependencies between parameters

### Dependencies between parameters

Some of the input parameters (emission factors and activity data) are for various reasons not independent, that means that their values are dependent (or correlated). The problem of dependencies may be solved by appropriate aggregation of the data or explicitly by modelling. In this work we have partly designed the dataset to reduce the problem with dependencies as well as introduced a number of dependence assumptions into the model. The determination of dependencies is sometimes a difficult task and requires some understanding of the data set and the assumptions it is based on. Initial estimates with variable assumptions have shown that the assumptions on dependencies generally have little effect on the final conclusions on uncertainties. The

assumptions of dependencies of data between years are, however, crucial for the determination of trend uncertainty (Rypdal and Zhang 2000).

### ***Dependencies between activity data***

The activity data are in principle independent. However, the same activity data may be used to estimate more than one source category (e.g. in the agriculture sector). Also the same activity data are used for estimating emissions of more than one pollutant (especially in the case of energy emissions).

The cases when activity data are assumed dependent in the statistical modelling are:

- The consumption of oil products in each sector. The sum of all oil products has a lower uncertainty than the consumption in each sector. In practice, this is treated by assuming that sectors are independent, and then by scaling all uncertainties so that total uncertainty equals a specified value.
- Where the same activity data are used to estimate emissions of more than one pollutant
- The number of domestic animals. The same population data are used for estimation of a) methane from enteric fermentation, b) methane and nitrous oxide from manure management and c) nitrous oxide from agricultural soils
- For estimation of N<sub>2</sub>O from manure management, N<sub>2</sub>O from manure spreading and N<sub>2</sub>O from animal production (pasture) the following dependency estimation has been used for the activity data:
  - 70 % of emissions dependent on cattle population
  - 30 % of emissions dependent on sheep population
- For estimation of N<sub>2</sub>O from indirect soil emissions the following dependency estimation has been used for the activity data:
  - 23 % of emissions dependent on cattle population
  - 10 % of emissions dependent on sheep population
  - 67 % of emissions dependent on amount of synthetic fertiliser used

### ***Dependencies between emission factors***

Where emission factors have been assumed equal, we have treated them as dependent in the analysis.

The following assumptions have been made:

- The CO<sub>2</sub> emission factors for each fuel type are dependent
- The methane and nitrous oxide emission factors from combustion are dependent where they have been assumed equal in the emission inventory model
- In a few cases the emission factors of different pollutants are correlated. That is in cases when CO<sub>2</sub> is oxidised from methane (oil extraction, loading and coal mining).
- For all direct emissions of N<sub>2</sub>O from agricultural soils, except for N<sub>2</sub>O from cultivation of organic soil, the same emission factor is being used, and the sources are dependent.
- There is a dependency between the emission factor used for calculating emissions from cropland liming and other liming.

There are also likely dependencies between other sources in LULUCF, e.g. between the activity data in the sources *5A2 Forest remaining forest* and *5Q1 Forest drainage*. But we have no estimates for the uncertainty in activity data, and anyhow the uncertainty in the emission factors is so large that even if the activity data is given an uncertainty it will have a minimal effect on the total uncertainty estimate for the source.

### ***Dependencies between data in base year and end year***

The estimates made for 1990 and 2009 will to a large extent be based on the same data and assumptions.

#### ***Activity data***

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

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

#### ***Emission factors***

Most of the emission factors are assumed unchanged from 1990 and 2009. Those that are not are all based on the same assumptions. This implies that all the emission factors are fully correlated between the two years.



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

### **The statistical modelling**

Uncertainty analysis based on probabilistic analysis implies that uncertainties in model inputs are used to propagate uncertainties in model outputs. The result of the uncertainty estimation gives us the range and likelihood of various output values (Cullen and Frey 1999).

Having generated a data set according to the specified parametric simultaneous distribution of the data described in table D1 and table D2, we may calculate any desired output defined as a function of the data. This gives us one simulated random realisation of this output, according to its marginal distribution derived from the underlying simultaneous distribution of the data. Independent repetition of the simulation gives an independent sample of the desired output according to its marginal distribution. The size of the sample is given by the number of repeated simulations, and has nothing to do with the size of the original data set. Based on such an independent and identically distributed sample, we may use the sample mean as an estimate of the mean of the output; we may also use the sample standard deviation as an estimate of the standard deviation of the output.

### **Results of the Tier 2 Uncertainty analysis**

Results for the uncertainties in the total emissions and trends for the GHG inventory, excluding and including the LULUCF sector are given in Chapter 1.6.1.

### **Source category level used in the analysis**

Source category level used in the analysis is listed in table D3.

**Table D3. Source category level used in the analysis**

IPCC	Source Category	Pollutant source
1A1A	Public electricity and heat prod	Coal/coke combustion
1A1A	Public electricity and heat prod	Wood combustion
1A1A	Public electricity and heat prod	Gas combustion
1A1A	Public electricity and heat prod	Oil combustion
1A1A	Public electricity and heat prod	Waste combustion
1A1B	Petroleum refining	Coal/coke combustion
1A1B	Petroleum refining	Oil combustion
1A1C	Manufacture of solid fuels and other energy	Gas combustion
1A1C	Manufacture of solid fuels and other energy	Oil combustion
1A2A	Iron and steel	Coal/coke combustion
1A2A	Iron and steel	Wood combustion
1A2A	Iron and steel	Gas combustion
1A2A	Iron and steel	Oil combustion
1A2B	Non-ferrous metal	Coal/coke combustion
1A2B	Non-ferrous metal	Wood combustion
1A2B	Non-ferrous metal	Gas combustion
1A2B	Non-ferrous metal	Oil combustion
1A2C	Chemicals	Coal/coke combustion
1A2C	Chemicals	Wood combustion
1A2C	Chemicals	Gas combustion
1A2C	Chemicals	Oil combustion
1A2D	Pulp, paper, print	Coal/coke combustion
1A2D	Pulp, paper, print	Wood combustion
1A2D	Pulp, paper, print	Gas combustion
1A2D	Pulp, paper, print	Oil combustion
1A2E	Food processing, beverages, tobacco	Coal/coke combustion
1A2E	Food processing, beverages, tobacco	Wood combustion
1A2E	Food processing, beverages, tobacco	Gas combustion
1A2E	Food processing, beverages, tobacco	Oil combustion
1A2F	Other manufacturing	Coal/coke combustion
1A2F	Other manufacturing	Wood combustion
1A2F	Other manufacturing	Gas combustion
1A2F	Other manufacturing	Oil combustion
1A2F	Other manufacturing	Waste combustion
1A3A	Transport fuel - civil aviation	
1A3B	Transport fuel - road transportation	
1A3C	Transport fuel - railway	
1A3D	Transport fuel - navigation	
1A3E	Transport fuel - motorized equipment and pipeline	
1A4A	Commercial/institutional	Coal/coke combustion
1A4A	Commercial/institutional	Wood combustion
1A4A	Commercial/institutional	Gas combustion
1A4A	Commercial/institutional	Oil combustion
1A4A	Commercial/institutional	Waste combustion
1A4B	Residential	Coal/coke combustion
1A4B	Residential	Wood combustion
1A4B	Residential	Gas combustion
1A4B	Residential	Oil combustion
1A4C	Agriculture/forestry/fishing	Coal/coke combustion
1A4C	Agriculture/forestry/fishing	Wood combustion
1A4C	Agriculture/forestry/fishing	Gas combustion
1A4C	Agriculture/forestry/fishing	Oil combustion
1A5A	Military	Military fuel - stationary
1A5B	Military	Military fuel - mobile
1B1A	Coal mining, Extraction of natural gas	
1B2A	Extraction of oil - transport	
1B2A	Extraction of oil - refining/storage	
1B2A	Extraction of oil - distribution gasoline	
1B2B	Coal mining, Extraction of natural gas	
1B2C	Venting	
1B2C	Well testing	
1B2C	Flaring	
2A1	Cement production	
2A2	Lime production	

2A3	Limestone and dolomite use
2A7	Other mineral production
2B1	Ammonia production
2B2	Nitric acid production
2B4	Silicium carbide production
2B4	Calcium carbide production
2B5	Methanol and plastic production
2C1	Iron and steel production
2C2	Ferroalloys production
2C3	Aluminium production
2C4	SF6 used in Al and Mg foundries
2C5	Mg production
2C5	Ni production, anodes
2D1	Pulp and paper
2D2	Carbonic acid, bio protein
2F	Consumption of halocarbons and SF6
3A	Paint application
3B	Degreasing and dry cleaning
3C	Chemical products, Manufacture and processing
3D	Other
4A1	Enteric fermentation - cattle
4A10	Enteric fermentation - other animal
4A3	Enteric fermentation - sheep
4A4	Enteric fermentation - goat
4A6	Enteric fermentation - horse
4A8	Enteric fermentation - swine
4A9	Enteric fermentation - poultry
4B1	Manure management - CH4 -cattle
4B11	Manure management - N2O - Liquid storage
4B12	Manure management - N2O - solid storage
4B13	Manure management - CH4 - other animal
4B3	Manure management - CH4 - sheep
4B4	Manure management - CH4 -goat
4B6	Manure management - CH4- horse
4B8	Manure management - CH4- swine
4B9	Manure management - CH4- poultry
4D1	Direct soil emission - Fertiliser
4D1	Direct soil emission - Manure
4D1	Direct soil emission- Other
4D1	Direct soil emission- Organic soil
4D2	Animal production
4D3	Indirect soil emission- Deposition
4D3	Indirect soil emission - Leaching, other
4F1	Burning of straw
5A1	Forest Land remaining Forest Land, Fertiliser
5A1	Forest Land remaining Forest Land, Drainage
5A1	Forest Land remaining Forest Land, Wildfires
5A1	Forest Land remaining Forest Land, Forest inventory area, Living Biomass
5A1	Forest Land remaining Forest Land, Forest inventory area, Dead Biomass
5A1	Forest Land remaining Forest Land, Forest inventory area, Soils, Mineral
5A1	Forest Land remaining Forest Land, Forest inventory area, Soils, Organic
5A2	Land converted to Forest Land, Living biomass
5A2	Land converted to Forest Land, Soils, Mineral
5B1	Cropland remaining Cropland, Liming
5B1	Cropland remaining Cropland, Horticulture, Living biomass
5B1	Cropland remaining Cropland, Reduced tillage, Soils
5B1	Cropland remaining Cropland, Erosion of new agriculture land, Soils
5B1	Cropland remaining Cropland, Histosols, Soils
5B2	Land converted to Cropland, Living biomass
5B2	Land converted to Cropland, Soils, Mineral
5B2	Cropland, Disturbance
5C1	Grassland remaining Grassland, Other Grassland, Living biomass
5C1	Grassland remaining Grassland, Histosols, Soils

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5C2	Cropland converted to Grassland, Horticulture, Living biomass
5D1	Wetlands remaining Wetlands, Living biomass
5D1	Wetland remaining Wetland, Peat extraction, Soils
5D2	Land converted to Wetland, Drainage
5E2	Land converted to Settlements, Living biomass
5E2	Land converted to Settlements, Soils
5F2	Land converted to Other land, Living biomass
5G	Other; Liming of lakes and rivers
6A	Managed waste disposal on land
6B	Waste water -CH4
6B	Waste water - N2O pipeline
6B	Waste water - N2O plant
6B	Waste water - N2O not connected
6C	Waste incineration

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### **Long-range transboundary air pollutants**

Source for the uncertainty estimates for long-range transboundary air pollutants is Rypdal and Zhang (2001).

**Table D4. Summary of expert judgements of uncertainties in point sources**

Production type	Number of plants	Pollutant	Emission determination method and uncertainty evaluation	Assessment (average)
Pulp and paper	6	SO <sub>2</sub>	Continuous emission measurements and estimations from sulphur content of fuel. Diffuse emissions of sulphur compounds when producing sulphite pulp. The latter has a higher uncertainty than both the measured and estimated stack emissions.	± 4 %
Oil refineries	2 (3)	SO <sub>2</sub>	Continuous emission measurements and estimations from sulphur content of fuel.	± 5 %
		NO <sub>x</sub>	Based on measurements and calculations.	± 10 %
		NM VOC	Combination of point measurements and calculations. Emissions are variable with possibilities of systematic errors. Emissions from loading of products have lower uncertainty than the fugitive. Differences between the refineries due to different technology, products and operations.	± 45 %
Petrochemical industries and gas terminal	4	NO <sub>x</sub>	Annual measurements and/or calculations	± 7 %
		NM VOC	Several emission points. Difficult to measure properly and high variability. Uncertainty is in any case lower than for the refineries as mostly gas is handled (high demand for security).	± 25 %
Cement	2	SO <sub>2</sub>	Continuous measurements and annual measurements/calculations. High variability as cement plants incinerates special waste.	± 12 %
		NO <sub>x</sub>	Continuous measurements and annual measurements/calculations. High variability as cement plants incinerates special waste.	± 12 %
Ammonia and fertiliser	2	NO <sub>x</sub>	Continuous/weekly measurements.	± 7 %
		NH <sub>3</sub>	Several emission points. Several measurements performed each year. Low variability.	± 10 %
Silicon carbide (SiC)	3	SO <sub>2</sub>	Emissions are estimates based on consumption and sulphur content of coke. The sulphur content is measured independently for every delivery. There is, however, uncertainty connected to the end products and degree of oxidation and definition applied, so reporting can seem inconsistent.	± 20 %
Ferroalloys	16	SO <sub>2</sub>	Emissions are estimates based on consumption and sulphur content of coke and the sulphur in products. The sulphur content is measured independently for every delivery. The sulphur content of products are measured regularly, but shows small variability.	± 2 %
		NO <sub>x</sub>	Estimates using emission factors. Emission factors are based on measurements. Emission factors are, however, only available for some types of ferroalloys and emissions are not estimated for the others.	± 10-20 %*
Aluminium	8	SO <sub>2</sub>	Monthly measurements (covering emissions from stack and ceiling)	± 7 %
		NO <sub>x</sub>	Emissions are estimated based on emission factors (see table 4).	-
Waste incineration	8	SO <sub>2</sub>	Annual representative measurements. Variable emissions due to the waste fraction incinerated.	± 7 %
		NO <sub>x</sub>	Annual representative measurements.	± 10 %

\* Additional uncertainty due to possible incomplete reporting.

**Table D5. Summary of standard deviation and probability density of activity data**

SNAP category	Pollutant source	Important for	Standard deviation (2σ). %	Density shape	Source/Comment
01, 02, 03	Gas combustion	NO <sub>x</sub>	± 4	Normal	Directorate of oil and gas
01, 02, 03, 07, 08	Oil combustion (total)	SO <sub>2</sub> , NO <sub>x</sub>	± 3	Normal	Spread in data.
0102	Waste combustion - Energy industries	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 5	Normal	Expert judgement
0202	Coal and coke combustion - Residential	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 20	Normal	Expert judgement
090201	Waste combustion - Other sectors	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 30	Lognormal	Expert judgement
01, 02, 03	Wood combustion - All sectors	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 30	Lognormal	Expert judgement
01, 03	Coal and coke combustion-Industry	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 5	Normal	Spread in data
07, 08	Oil, road/off-road/catalytic/non-catalytic	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC, NH <sub>3</sub>	± 20	Normal	Comparisons of data
0805	Oil combustion - Aviation	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 20	Normal	Expert judgement
0804	Oil combustion - Shipping	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 10	Normal	Comparisons of data
0401	Refineries (throughput)	NMVOC	± 3	Normal	Expert judgement
040301	Aluminium production	NO <sub>x</sub>	± 3	Normal	Expert judgement
040302	Ferroalloy production	NO <sub>x</sub>	± 3	Normal	Expert judgement
040605	Bread production	NMVOC	± 30	Normal	Expert judgement
040607	Beer production	NMVOC	± 10	Normal	Expert judgement
050202	Loading of crude oil	NMVOC	± 3	Normal	Expert judgement
0505	Gasoline distribution	NMVOC	± 3	Normal	Expert judgement
0601	Solvent use	NMVOC			See emission factor
09	Waste combustion in small scale	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 50	Lognormal	Expert judgement
090201	Methane incineration (landfills)	NO <sub>x</sub> , NMVOC	± 5	Normal	Expert judgement
090204	Flaring of natural gas	NO <sub>x</sub> , NMVOC	± 4	Normal	As combustion of gas
090204	"Flaring" of crude oil	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 10	Normal	Expert judgement
090203/4	Other flaring	NO <sub>x</sub> , NMVOC	± 5	Normal	Expert judgement
090207	Incineration of hospital waste	NO <sub>x</sub> , NMVOC	± 20	Normal	Expert judgement
090901	Cremation	SO <sub>2</sub> , NO <sub>x</sub> , NMVOC	± 20	Normal	Expert judgement
10	Animal population	NH <sub>3</sub>	± 5-10	Normal	Expert judgement
10	Agricultural soils - Treatment of straw	NH <sub>3</sub>			See emission factor
1001	Agricultural soils - Fertiliser use	NH <sub>3</sub>	± 5	Normal	Agriculture authorities
1009	Agricultural soils - Manure use	NH <sub>3</sub>	± 20	Normal	Expert judgement

**Table D6 Summary of standard deviation and probability density of emission factors**

SNAP source category	Pollutant source	Standard deviation ( $2\sigma$ ). %	Density shape	Source/Comment
01, 02, 03	SO <sub>2</sub> - Oil combustion, general	± 1	Normal	Expert judgement. Oil companies
01, 02, 03	SO <sub>2</sub> - Oil combustion, heavy fuel oil	-50 - +100	Normal	Expert judgement. Oil companies
01, 03	SO <sub>2</sub> - Coal combustion	-50 - +100	Lognormal	Spread in data
01, 03	SO <sub>2</sub> - Wood combustion	-50 - +100	Lognormal	Spread in data
0804	SO <sub>2</sub> - Oil combustion, domestic shipping	± 25	Normal	Expert judgement. Oil companies
01, 02 (+03)	NO <sub>x</sub> - Combustion in area sources	± 40-50	Normal	Spread in data
0105	NO <sub>x</sub> - Combustion off-shore	± 40	Lognormal	Expert judgement
040301	NO <sub>x</sub> - Aluminium production	-50 - +100	Lognormal	Expert judgement
07	NO <sub>x</sub> - Road traffic	± 25-30	Normal	Expert judgement, spread in data
0704/0705	NO <sub>x</sub> - Motorcycles	± 40	Normal	Expert judgement, spread in data
0801-02, 0806-09	NO <sub>x</sub> - Equipment and railways	± 40	Normal	Spread in data
0804	NO <sub>x</sub> - Shipping	± 15	Normal	Spread in data
0805	NO <sub>x</sub> - Aircraft	± 20	Normal	EEA (2000)
0902	NO <sub>x</sub> - Flaring	± 40	Lognormal	Expert judgement
01, 02 (+03)	NM VOC - Combustion in area sources	± 40-50	Normal	Spread in data
0105	NM VOC - Combustion offshore	± 50	Lognormal	Expert judgement
040605/07	NM VOC- Beer and bread production	-50 - +100	Lognormal	EEA (2000)
050201	NM VOC- Oil loading onshore	± 30	Normal	Rypdal (1999), Expert judgement
050202	NM VOC- Oil loading offshore	± 40	Normal	Rypdal (1999), Expert judgement
0505	NM VOC - Gasoline distribution	± 50	Lognormal	EEA (2000)
0601	NM VOC - Solvent use	± 30	Normal	Rypdal (1995)
0701	NM VOC - Road traffic (gasoline vehicles)	± 40-50	Normal	Expert judgement, spread in data
0703	NM VOC - Road traffic (diesel vehicles)	± 20-30	Normal	Expert judgement, spread in data
0704/0705	NM VOC - Motorcycles	± 40	Normal	Expert judgement, spread in data
0801-02, 0806-09	NM VOC - Equipment and railways	± 40	Normal	Spread in data
0804	NM VOC - Shipping	± 50	Normal	Spread in data
0805	NM VOC - Aircraft	± 25	Normal	EEA (2000)
0902	NM VOC - Flaring	± 50	Lognormal	Expert judgement
07	NH <sub>3</sub> - Road traffic	Factor 3	Lognormal	Expert judgement, spread in data
1001	NH <sub>3</sub> -Agriculture, fertiliser	± 20	Normal	Expert judgement
1005	NH <sub>3</sub> -Agriculture, animal manure	± 30	Normal	Expert judgement
10	NH <sub>3</sub> -Agriculture, treatment of straw	± 5	Normal	Expert judgement



**Table D7. Uncertainty in emission level of pollutants. 1990, 1998 and 2010**

1990	$\mu$ (mean) ktonnes	Relative standard deviation ( $\sigma/\mu$ )	Uncertainty $2\sigma$ (% of mean)	Uncertainty $2\sigma$ (ktonnes)
SO <sub>2</sub>	52.7	0.02	4.0	2
NO <sub>x</sub>	219.0	0.062	12	27
NMVOC	298.4	0.09	18	54
NH <sub>3</sub>	22.9	0.104	21	5
1998	$\mu$ (mean) ktonnes	Relative standard deviation ( $\sigma/\mu$ )	Uncertainty $2\sigma$ (% of mean)	Uncertainty $2\sigma$ (ktonnes)
SO <sub>2</sub>	29.8	0.021	4.2	1
NO <sub>x</sub>	224.0	0.062	12	27
NMVOC	344.5	0.105	21	72
NH <sub>3</sub>	27.0	0.091	18	5
2010*	$\mu$ (mean) ktonnes	Relative standard deviation ( $\sigma/\mu$ )	Uncertainty $2\sigma$ (% of mean)	Uncertainty $2\sigma$ (ktonnes)
SO <sub>2</sub>	22.0	0.025	5.0	1
NO <sub>x</sub>	156.0	0.062	12	19
NMVOC	194.0	0.074	15	29
NH <sub>3</sub>	23.0	0.105	21	5

\* Projected data with uncertainties as if they were historical.

**Table D8. Uncertainties in emission trends 1990-1998 and 1990-2010**

	Absolute change ( $\mu_{2010}-\mu_{1990}$ )	% change ( $((\mu_{2010}-\mu_{1990})*100/\mu_{1990})$ )	Relative standard deviation ( $\sigma/(\mu_{2010}-\mu_{1990})$ )	Uncertainty $2\sigma$ (absolute change)	Uncertainty $2\sigma$ (%-point of change)
<b>1990-1998</b>					
SO <sub>2</sub>	-23.0	-43	-0.04	1.7	3.2
NO <sub>x</sub>	+4.8	+2	+3.00	28	13
NMVOC	+43.8	+15	+0.40	35	12
NH <sub>3</sub>	+4.1	+18	+0.22	1.8	8.0
<b>1990-2010</b>					
SO <sub>2</sub>	-30.7	-58	-0.03	1.8	3.4
NO <sub>x</sub>	-62.8	-29	-0.21	26.9	12
NMVOC	-104.9	-35	-0.18	38	13
NH <sub>3</sub>	+0.0	0	61.3	3.1	13

\* Projected values with uncertainties as if they were historical.

## Appendix E Key category analysis for GHG

This chapter outlines the Tier 2 methodologies used to find which sources are key categories in the Norwegian greenhouse gas emission inventory.

Two different methods are used for the key category analysis. First, the standard method as described in IPCC Good Practice Guidance (IPCC 2000) is used, both at the Tier 1 level and at the Tier 2 level with uncertainties. Second, a sensitivity analysis is performed using the specification of the model for the uncertainty analysis, as described in Rypdal and Zhang (2000)). The uncertainty model is presented in Annex II. The discussion focuses primarily on the standard method. The sensitivity analysis is presented as supporting data.

Key categories are identified as the emission sources that add up to 90 per cent of total uncertainty in level and/or trend. This definition of a key category is according to IPCC (IPCC 2000) which is based on Rypdal and Flugsrud (2001). A Tier 2 analysis for the LULUCF sector has also been performed. However, key categories for non-LULUCF sources are based on the analysis without LULUCF.

The key category analysis is performed at the level of IPCC source categories and each GHG from each source category is considered separately with respect to total GWP weighted emissions (HFCs and PFCs are grouped together). The advantage in using a Tier 2 rather than the Tier 1 methodology is that uncertainties are taken into account so the ranking shows where uncertainties can be reduced.

The steps taken to find key categories with respect to level and trend were the determination of uncertainties in input parameters (AD = activity data and EF = emission factors). Uncertainties of activity data and emissions factors were combined to source uncertainty by the error propagation rule  $U_{source} = \sqrt{U_{AD}^2 + U_{EF}^2}$  (IPCC (2000), equation 6.4).

The next step was the use of sensitivity analysis to identify the parameters in the inventory that most influence most the total GHG emissions in level and in trend. The standard method does not take into account correlations. This has partly been handled by aggregating sources with the same emission factors. However, sources with similar emission factors in stationary combustion, categories 1A1, 1A2, and 1A4, were treated separately as suggested in the proposed 2006 guidelines. Also, correlations due to common activity data for several pollutants have not been taken into account. This may lead to an underestimation of the uncertainty importance for such sources. In the sensitivity analysis, such correlations may be specified in the model. The sensitivity analysis also allows separate treatment of activity data and emission factors.

Compilations of the uncertainty importance elasticity lead to the estimation of uncertainty importance of each input parameter with respect to total level and trend uncertainty. Out of this we get a ranked list of parameters which add up to 90 per cent of total uncertainty in level and trend. The LULUCF key categories come in addition to this.

## Appendix F                      Economic sectors in the Norwegian emission model

The classification is an aggregated version of the one used in the national accounts. To make the standard sectors more appropriate for emission calculations, a few changes have been made, e.g. "Private households" is defined as a sector. The classification is aggregated from the Norwegian *Standard Industrial Classification*, SIC2007 (Statistics Norway 2009). The SIC is identical to the European NACE (rev. 2) classification up to the four-digit level. A national level has been introduced at the five-digit level.

The sector numbers in the model have six or, in a few cases, eight digits. The first two digits refer to the main sectors of the economy: 23 = private sector, 24 = central government, 25 = local government, 33 = private households, and 66 = foreign activity. For clarity, the two first digits are only included for the first sector listed in each main sector in the table below.

The next four digits are approximate SIC codes. The first two of these in most cases correspond to SIC at the two-digit level, but some sector numbers, particularly those used for service industries, are aggregates of several SIC divisions. The detailed relationship is shown in the following table, where the sectors are listed with the corresponding SIC codes.

For emissions from solvents and paraffin wax, figures are available at a somewhat more disaggregated sector level, but since these sectors do not reflect the general detailing level in the emission calculations, they are not included in the table below.

Sector number	SIC code	Sector name
<b>Agriculture and forestry</b>		
230100	01.01-5, 01.7	Agriculture
0160	01.6	Services related to agriculture
0210	02	Forestry and logging
<b>Fishing</b>		
0310-N	03.1	Fishing
0320	03.2	Operation of fish farms
<b>Energy sectors</b>		
0500	05	Coal mining
0600.1	06 part, 49.5	Extraction of crude petroleum and natural gas, offshore: Permanent installations
0600.2	06 part	Extraction of crude petroleum and natural gas, offshore: Moveable installations
0600.3	06 part	Extraction of crude petroleum and natural gas: Plants on shore
1910.2	19.1 part	Coking plants
1922	19.2 part	Manufacture of refined petroleum products
3510	35.12, 35.13, 35.14	Transmission, distribution and trade of electricity
3511	35.11	Production of electricity
3520	35.2	Manufacture and distribution of gas
3530	35.3	Steam and hot water supply
<b>Mining/manufacturing</b>		
0710	07.1, 07.29	Mining of ores except uranium and thorium
0721	07.21	Mining of uranium and thorium ores
0810	08 except 08.92	Quarrying and mining except ores and extraction of peat
0892	08.92	Extraction and agglomeration of peat
0910	09.1, 52.215	Service activities incidental to oil and gas extraction
0990	09.9	Service activities incidental to mining
1010	10.1	Production, processing and preserving of meat and meat products
1020	10.2	Processing and preserving of fish and fish products
1030	10.3	Processing and preserving of fruit and vegetables
1040	10.4	Manufacture of vegetable and animal oils and fats
1050	10.5	Manufacture of dairy products
1060	10.6	Manufacture of grain mill products, starches and starch products
1080	10.7, 10.8	Manufacture of other food products
1090	10.9	Manufacture of prepared animal feeds
1100	11	Manufacture of beverages
1200	12	Manufacture of tobacco products
1300	13	Manufacture of textiles and textile products
1400	14	Manufacture of wearing apparel
1500	15	Manufacture of leather, leather products and footwear
1610	16.1	Sawmilling and planing of wood, impregnation of wood
1620	16.21, 16.22, 16.24, 16.29	Manufacture of products of wood, cork, straw and plaiting materials, except furniture
1630	16.23	Manufacture of builders' supplies
1711	17.11	Manufacture of pulp
1712	17.12	Manufacture of paper and paperboard
1720	17.2	Manufacture of articles of paper and paperboard
1800	18	Printing and service activities related to printing and reproduction of recorded media
1910.1	19.1 part	Manufacture of coke oven products
1921	19.2 part	Manufacture of refined petroleum products except oil refineries
2011	20.11, 20.12, 20.13	Manufacture of basic chemicals
2014	20.14	Manufacture of other organic basic chemicals
2015	20.15	Manufacture of fertilisers and nitrogen compounds
2016	20.16, 20.17	Manufacture of plastics and synthetic rubber in primary forms
2020	20.2	Manufacture of pesticides and other agrochemical products
2030	20.3	Manufacture of paints and varnishes, printing ink and mastics
2040	20.4	Manufacture of soap and detergents and toilet preparations

Sector number	SIC code	Sector name
2050	20.5, 20.6	Manufacture of other chemical products
2100	21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
2200	22	Manufacture of rubber and plastic products
2310	23.1	Manufacture of glass and glass products
2320	23.2, 23.3, 23.4	Manufacture of refractory products, clay building materials and other porcelain and ceramic products
2350	23.5	Manufacture of cement, lime and plaster
2360	23.6, 23.7, 23.9	Manufacture of products of cement, lime and plaster and other non-metallic mineral products
2411	24.101, 24.2, 24.3	Manufacture of basic iron and steel
2412	24.102	Manufacture of ferroalloys
2440	24.4 except 24.42	Other non-ferrous metal production
2442	24.42	Aluminium production
2451	24.51, 24.52	Casting of iron and steel
2453	24.53, 24.54	Casting of light metals and other non-ferrous metals
2510	25.1, 25.2, 25.3	Manufacture of structural metal products, tanks, reservoirs and containers etc. of metal
2570	25.7	Manufacture of cutlery, tools and general hardware
2590	25.4, 25.5, 25.6, 25.9	Manufacture of other metal products
2610	26.1, 26.2	Manufacture of electronic components and computers
2630	26.3	Manufacture of communication equipment
2640	26.4	Manufacture of consumer electronics
2650	26.5, 26.6, 26.7, 26.8	Manufacture of other electronic and optical products
2750	27.5	Manufacture of domestic appliances
2790	27.1, 27.2, 27.3, 27.4, 27.9	Manufacture of other electrical apparatus and equipment
2810	28.1, 28.2	Manufacture of general-purpose machinery
2830	28.3, 28.4, 28.9	Manufacture of special-purpose machinery
2900	29	Manufacture of motor vehicles and parts and accessories for motor vehicles
3011	30.1 except 30.113 and 30.116	Building of ships and boats
3012	30.113, 30.116	Building of oil platforms
3020	30.2	Manufacture of railway and tramway locomotives and rolling stock
3030	30.3	Manufacture of aircraft and spacecraft
3090	30.4, 30.9	Manufacture of other transport equipment
3100	31	Manufacture of furniture
3210	32.1	Manufacture of jewellery, bijouterie and related articles
3290	32.2, 32.3, 32.4, 32.5, 32.9	Other manufacturing
3310	33.1	Repair of fabricated metal products, machinery and equipment
3320	33.2	Installation of industrial machinery and equipment

#### Water supply, sewerage, waste management and remediation activities

3600	36	Water collection, treatment and supply
3700	37	Sewerage
3800	38	Waste collection, treatment and disposal activities; materials recovery
3900	39	Remediation activities and other waste management services

#### Construction

4120	41.2, 42, 43	Construction
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Sector number	SIC code	Sector name
<b>Wholesale and retail trade</b>		
4700	45, 46, 47	Wholesale and retail trade, repair of motor vehicles and personal and household goods
<b>Transport etc.</b>		
4910	49.1, 49.2	Transport via railways
4932	49.32	Taxi operation
4939	49.31, 49.39	Other land passenger transport
4940	49.4	Freight transport by road
5020.N	50.101, 50.201	Ocean transport
5030	50.102, 50.109, 50.202, 50.203, 50.204, 50.3, 50.4	Inland and coastal water transport
5100.1N	51 part	Domestic air transport
5100.2N	51 part	International air transport
5222	52 except 52.215, 79	Supporting and auxiliary transport activities
5300	53, 61	Post and telecommunications
<b>Accommodation and food service activities</b>		
5500	55, 56	Accommodation, food and beverage service activities
<b>Business services</b>		
5800	58	Publishing activities
6200	62, 63, 95	Information technology services
6600	64, 65, 66	Financial and insurance activities
6810	41.1, 68	Real estate activities
7100	69-71, 73-74, 78, 80-82	Other business activities
7200	72	Research and development
7700	77	Rental and leasing activities
8500	85	Education
8600	75, 86-88	Health and social work
9300	59-60, 90-93	Recreational, cultural and sporting activities
9400	94, 99	Activities of membership organisations
9600	96	Other service activities
<b>Central government</b>		
245222	52, 79	Supporting and auxiliary transport activities
7100	69-71, 73-74, 78, 80-82	Other business activities
7200	72	Research and development
8410	84.1, 84.21, 84.23, 84.24, 84.25, 84.3	Public administration
8422	84.22	Defence
8500	85	Education
8600	75, 86-88	Health and social work
9300	59-60, 90-93	Other service activities
<b>Local government</b>		
253700	37	Sewerage
3800	38	Waste collection, treatment and disposal activities; materials recovery
6000	59-60, 90-93	Other service activities
8410	84.1, 84.21, 84.23, 84.24, 84.25, 84.3	Public administration
8500	85	Education
8600	75, 86-88	Health and social work
9600	96	Other personal service activities
<b>Private households</b>		
330000	n.a.	Private households
Foreign activities in Norway		
665020	n.a.	Foreign activities in Norway, ocean transport
665100.2	n.a.	Foreign activities in Norway, air transport

## Appendix G Source classifications used in the Norwegian emission inventory

**Table G1. Source classifications used in the national emission inventory**

### Oil and gas extraction

#### Oil and gas extraction (stationary combustion)

##### Offshore

Natural gas in turbines etc., offshore

Flaring, offshore

Diesel fixed installations

Diesel mobile installations, production

Diesel mobile installations, exploration

Well testing

##### Onshore installations

Natural gas in turbines etc., onshore installations

Flaring, onshore installations

#### Oil and gas extraction (process emissions)

##### Offshore

Cold flaring and leakage

Oil loading at sea

##### Onshore installations

Oil loading, land

Gas terminals

### Manufacturing industries and mining

#### Manufacturing industries and mining, stationary combustion

##### Wood processing

##### Oil refining

##### Chemical industries

Petrochemistry

Fertiliser

Other chemical industries

##### Mineral industry

Cement, lime and plaster

Other mineral industries

##### Metal industry

##### Other industries and mining

#### Manufacturing industries and mining, processes

##### Wood processing

##### Oil refining

##### Chemical industries

Petrochemistry

Fertiliser

Carbides

Other chemical industries

##### Mineral industry

Cement

Other mineral industries

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	Metal industry	
		Iron, steel and ferro-alloys
		Aluminium
		Other metals
		Anodes
	Other manufacturing industries and mining	
		Coal mining
		Other mining
		Fermentation (bread and beer)
		Asphalt production plants
		Other industries
Energy supply		
Heating in other industries and households		
	Heating in other industries	
		Heating in primary industries
		Heating in construction and building
		Heating in other service industries
	Heating in households	
Road traffic		
	Passenger cars	
		Passenger cars - petrol
		Passenger cars - diesel
	Light duty vehicles	
		Light duty vehicles- petrol
		Light duty vehicles - diesel
	Heavy duty vehicles	
		Heavy duty vehicles - petrol
		Heavy duty vehicles - diesel etc.
	Motorcycles and mopeds	
		Motorcycles
		Mopeds
Aviation, navigation, fishing, motorized equipment etc.		
	Railways	
	Domestic aviation	
		Domestic aviation < 1000 m
		Domestic aviation > 1000 m
	Coastal navigation	
		Navigation - Coastal traffic etc.
		Navigation - Fishing
	Other mobile combustion	
		Small boats
		Snowmobiles
		Tractors, constructions machines and other motorized equipment: diesel
		Tractors, constructions machines and other motorized equipment: petrol

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## Agriculture

- Enteric fermentation and manure
  - Enteric fermentation
  - Manure
- Fertiliser and agriculture, other
  - Fertiliser
  - Agriculture, other

## International transportation

- International navigation
- International aviation

## Other

- Landfill gas
  - Road, tyre and brake wear
    - Road wear
    - Tyre and brake wear
    - Railway contact wire abrasion
  - Products containing fluorinated gases, solvents etc.
    - Products containing fluorinated gases
    - Other products, including solvents
  - Other
    - Fires, cremations etc.
    - Gas distribution
    - Petrol distribution
    - Whitening of industrial waste
    - Waste water and waste water handling
    - Sources not mentioned elsewhere
-

## Appendix H Methane emissions from enteric fermentation in Norway's cattle and sheep population. Method description<sup>23</sup>

By Harald Volden and Silje K. Nes, Department of Animal and Aquacultural Sciences, Norwegian University of Life Sciences.

### Introduction

An important end product from the ruminal fermentation is methane (CH<sub>4</sub>), and it is well known that the ruminants are important contributors to global warming through CH<sub>4</sub> production. The Norwegian calculation of CH<sub>4</sub> emission from livestock has been based on the Tier 1 method proposed by the Intergovernmental Panel on Climate Change (IPCC). However, the amount of CH<sub>4</sub> produced from enteric fermentation is dependent on several factors, like animal species, production level, quantity and quality of feed ingested and environmental conditions. Therefore, IPCC (IPCC, 2001) has recommended to use more advanced methods when estimating CH<sub>4</sub> gas emission, which take into consideration the influencing factors described above. According to IPCC (IPCC, 2001) the method for estimating CH<sub>4</sub> emission from enteric fermentation requires three basic items:

- No. 1 The livestock population must be divided into animal subgroups, which describe animal type and production level.
- No 2. Estimate the emission factors for each subgroup in terms of kilograms of CH<sub>4</sub> per animal per year.
- No 3. Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emission, and sum across the subgroups to estimate total emission.

Earlier the Tier 1 method, which is a simplified approach based on default emission factors from the literature, has been used. However, according to IPCC (IPCC, 2001) the Tier 2 approach should be used if livestock enteric fermentation represents a large proportion of the country's total emissions or important animal subgroups data is available for more correct estimation CH<sub>4</sub> emission. In Norway detailed information of the cattle production is available from the Cow recording System (TINE BA), which gives information of dairy cow production level and feeding. The system also gives information on beef production which includes age at slaughter, carcass weight, and average daily gain. This information will give additional country-specific information and can be used to develop sophisticated models that better incorporate information of diet composition, feed quality and animal production level and intensity.

The objective of this manuscript is to describe the methods used to estimate the CH<sub>4</sub> emissions from enteric fermentation in Norwegian's cattle and sheep production.

### General emission factor development and animal subgroups

In all animal subgroups the following basic equation is used to calculate the CH<sub>4</sub> emission factor:

$$EF = (GE \cdot Y_m \cdot 365 \text{ days/yr}) / 55.65 \text{ MJ/kg CH}_4$$

Where:

EF = emission factor, kg CH<sub>4</sub>/head/yr

GE = gross energy intake, MJ/head/day

Y<sub>m</sub> = CH<sub>4</sub> conversion rate, which is the fraction of gross energy in feed converted to CH<sub>4</sub>.

This equation assumes an emission factor for an entire year (365 days). In some circumstances the animal category may be defined for a shorter period or a period longer than one year and in this case the emission factor will be estimated for the specific period (e.g., lambs living for only 143 days and for beef cattle which are slaughtered after 540 days).

The new methods of calculation require subdividing the cattle and sheep populations by animal type, physiological status (dry, lactating or pregnant) live weight and age, and table H1 describe the animal categories used in the calculations.

<sup>23</sup> The methods and data sources used for calculating numbers and life times of cattle in the emission inventory weres revised in 2012 (see chapter 6.2.3). The parts of this article that refer to these kind of data may therefore not be in accordance with the data actually used in the inventory since 2012 or the methodology connected to the use of this data.

In dairy cows additional information from the Cow Recording System concerning annual milk production and proportion of concentrate in the diet are used. The Cow Recording System also supply information about slaughter age, slaughter weight and average daily weight gain (ADG) for growing cattle, which are utilized in the calculations for growing cattle.

**Table H1. Categories of cattle and sheep used in the Norwegian calculations of methane emission from enteric fermentation. Animal numbers from 2004<sup>24</sup>**

Categories of cattle and sheep	Number of animal by year 2004
Dairy cows .....	315 224
Beef cows .....	51 802
Replacement heifers, < one year .....	156 712
Replacement heifers, > one year .....	174 568
Finisher heifers, < one year .....	3 263
Finisher heifers, > one year .....	18 410
Finisher bulls, < one year .....	13 114
Finisher bulls, > one year .....	106 308
Breeding sheep, > one year .....	878 405
Breeding sheep, < one year .....	387 860
Slaughter lamb, < one year. Jan- May .....	86 554
Slaughter lamb, < one year. Jun- Sept .....	1 010 461

The number of animals in each category is based on the official register of production subsidies. The register covers 90-100 % of the animal populations.

Calculation of methane emission from enteric fermentation in dairy cows and beef cows

To develop equations to calculate CH<sub>4</sub> emission from enteric fermentation in dairy cows the following set of equations were needed:

1. In the estimation of CH<sub>4</sub> emission we wanted to take into account the production level and diet composition. Therefore, we used 1.16 million observations from the Cow Recording System to develop standard lactation curves, which were used for calculation of standard feeding rations. The lactation curves were used to predict animal requirement for milk production through the whole lactation cycle. The lactation curve was estimated using a gamma distribution model as described by Wood *et al.* (1967). Length of the lactation period was standardised to 305 days, which gives a dry period of 60 days. The lactation curves were estimated in 500 kg intervals from 4500 to 9500 kg of milk (305 day lactation yields).
2. To calculate feed energy value (gross energy, metabolizable energy and net energy content), animal energy requirement and energy supplementation the Dutch net energy lactation system (NEL) was used (Van Es, 1975). This system has been used as the official energy system in Norway since 1992. Standard feed rations at different lactation yields (500 kg intervals) were calculated using three different forage qualities representing low, medium and high energy content (5.7, 6.1 and 6.6 MJ NEL per kg dry matter, respectively). These qualities represent a normal range in forage qualities found in the Norwegian cattle production. Four different concentrate mixtures were used in the diet formulation to complement the animal energy requirement at different production levels. The concentrate mixtures are representative of what is used in practical diet formulation in Norway.
3. To estimate total feed intake and ration forage: concentrate ratio in the dry period and trough the lactation period a NDF (Neutral Detergent Fibre) intake system was used (Volden and Kjos, 2003). In the system, effect of daily milk yield and stage of lactation are taken into account when estimating the animal NDF intake capacity (g NDF per kg live weight). Daily feed intake is calculated from the following equation:

$$\text{Intake} = \frac{\text{NDFIC}}{(\text{P})\text{NDF} + (1-\text{P})\text{NDFC}} = \frac{\text{ARNEL}}{(\text{P})\text{NEL} + (1-\text{P})\text{NELC}}$$

Where:

NDFIC = NDF intake capacity, g/kg body weight

ARNEL = Animal energy requirement, NEL per day

P = proportion of forage in the total ration

NDF = forage NDF content, g/kg DM

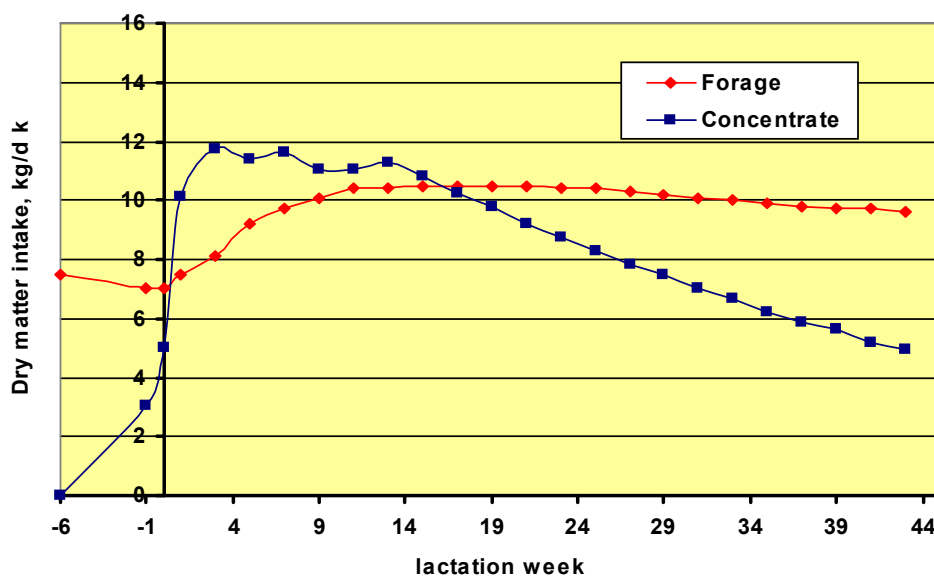
NDFC = concentrate NDF content, g/kg DM

NELF = forage NEL content, per kg DM

NELC = concentrate NEL content, per kg DM

The point where the animal NDF intake capacity and the animal requirement intersect there is a unique solution, which represent the maximum intake and where the animal requirement is met. Consequently this equation can be used to maximize forage intake and at the same time fulfill the animal requirement at a chosen production level. In the equation the lactation curve information is used to define the animal requirement at different stages of lactation and different 305 d lactation yields. Figure H1 presents an example of estimated feed intake trough the lactation cycle for a lactation yield of 7000 kg. The estimates are based on the medium forage quality.

**Figure H1. Example of estimated daily feed intake through the lactation cycle. Medium forage quality and a 305 d lactation yield of 7000 kg**



4. In Norway grass silage is the dominating winter forage, approx. 40 % of the total fed ration calculated on energy basis, and the dairy cows are normally fed indoors for a period of six to eight months. Therefore, when estimating the CH<sub>4</sub> production from enteric fermentation we wanted to use equations are based on grass silage measurements, and that take into account the effect of diet composition on CH<sub>4</sub> production. This is in accordance with the recommendations of IPCC (IPCC, 2001), which suggest to use a Tier 2 or a Tier 3 approach when estimation CH<sub>4</sub> emissions. After evaluating the literature we decided to use two equations published by Mills *et al.* (2003) and Kirchgessner *et al.* (1995). In the Mills *et al.* (2003) equation the effect of feed intake and dietary ADF and starch content are taken into account when predicting daily CH<sub>4</sub> production. The following non linear model is used:

$$\text{Methane (MJ/d)} = 45.98 - 45.98 \cdot e^{-(0.0011 \cdot \text{starch/ADF} + 0.0045) \cdot \text{ME}}$$

Where:

Starch = diet starch content, g/kg dry matter<sup>2</sup>

ADF = diet ADF content, g/kg dry matter

ME = daily intake of metabolizable energy, MJ

The advantage of this equation is that it takes into account that both the feed intake level (expressed as metabolizable energy) and the ratio between rumen easily degradable carbohydrates and fibre which has shown to affect CH<sub>4</sub> production. Test of this equation has shown that it is robust and it covers both dry cows and cows at different production levels. The second equation we used was the one described by Kirchgessner *et al.* (1995). The advantage of this equation is that it covers a wide range of cattle production (growing cattle and lactating cattle) and that it includes information about diet composition. This equation also takes into account that CH<sub>4</sub> production is affected by dietary crude fat content:

$$\text{Methane (MJ/d)} = (63 + 79 \cdot \text{CF} + 10 \cdot \text{NFE} + 26 \cdot \text{CP} - 212 \cdot \text{CFat}) \cdot 55.65$$

Where:

CF = crude fibre, kg/d  
 NFE = nitrogen free extracts, kg/d  
 CP = crude protein, kg/d  
 CFat = Crude fat, kg/d

In development of the CH<sub>4</sub> emission equations we used average values of the two equations.

The information from the four points described above were used to calculate daily total feed intake, GE intake, ME intake and Y<sub>m</sub>. Daily feed intake was calculated in 14 d intervals for the different 305 d milk yields and the three different forage qualities. From this data set we developed two multiple regression equations, which were used to calculate average daily GE intake, across stage of lactation, at different 305 d lactation yields and different concentrate proportion in the diet. The reason why we used this approach is that both these variables are available from the Cow Recording System. In the statistical analysis a Proc Mixed procedure was used with stage of lactation as a repeated measurement. GE was predicted from the following equation:

$$GE = 150.8 + 0.0205 \cdot \text{Milk}_{305} + 0.3651 \cdot \text{Concentrate\_prop}$$

Where:

GE = gross energy intake, MJ/day  
 Milk<sub>305</sub> = 305 d lactation yield,  
 Concentrate\_proportion = proportion of concentrate in the total diet. Calculated on net energy basis.

The extent to which feed energy is converted to CH<sub>4</sub> depends on several feeding and animal factors. From the dataset described above it is directly or indirectly possible to take into account several of these factors. The following equation was developed to predict Y<sub>m</sub> for dairy cows:

$$Y_m = 10.0 - 0.0002807 \cdot \text{Milk}_{305} - 0.02304 \cdot \text{Concentrate\_prop}$$

Where:

Y<sub>m</sub> = methane conversion rate, %  
 Milk<sub>305</sub> = 305 d lactation yield,  
 Concentrate\_proportion = proportion of concentrate in the total diet. Calculated on net energy basis.

From this equation it can be seen that the proportion of GE converted to CH<sub>4</sub> decrease with increased milk yield and the proportion of concentrate in the diet. Table H2 present examples of GE and Y<sub>m</sub> at different production levels and different proportions of concentrate in the diet.

**Table H2. Daily intakes of gross energy (GE) and methane conversion rate (Y<sub>m</sub>) at different milk yields (305 d yield) and concentrate proportions in the diet**

Milk yield, 305 d	Concentrate proportion, %	GE, MJ/d <sup>1</sup>	Y <sub>m</sub> , %
5000 .....	20	261	8.1
5000 .....	50	272	7.4
7000 .....	20	302	7.6
7000 .....	50	313	6.9
9000 .....	20	342	7.0
9000 .....	50	354	6.3

<sup>1</sup>Feeding in the non lactating period included.

The Y<sub>m</sub> values presented in table H2 are higher than the standard value suggested in IPCC Tier 2 (IPCC 2001), which is 6.5% for dairy cows. The discrepancies can probably be explained by differences in diet composition, which has a high proportion of forage in Norway, and the relative moderate milk yield compared to other western European countries and North America. Another reason can be differences in the scientific basis for prediction of CH<sub>4</sub> from enteric fermentation.

The same approach was used when predicting CH<sub>4</sub> production from beef cows. However, variable milk yield was not used. The lactation yield was fixed to 2500 kg and the concentrate proportion to 15%.

### Calculation of methane emission from enteric fermentation in growing and finishing cattle

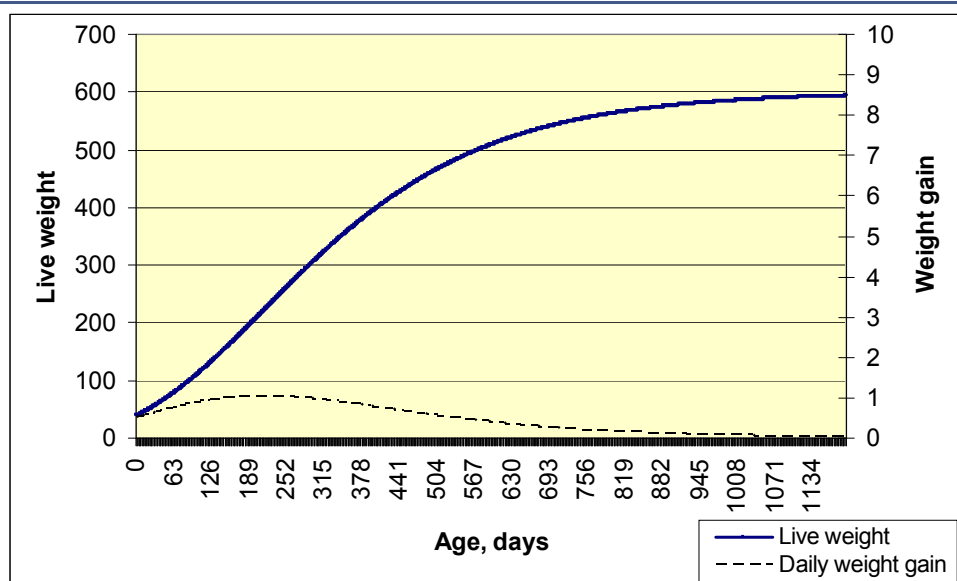
In the Norwegian Cow recording System growing and slaughter information is available for different categories of growing and finishing cattle. Approximately 90% of the growing cattle are attended to the recording system.

Information about age at slaughter, carcass weight and ADG are available. When developing equations for predicting CH<sub>4</sub> emission in growing cattle we wanted to utilize this information. Therefore, the same approach as for dairy cows was used, including development of standard feed rations, which used the same forage qualities as for the dairy cows. Beef production in Norway comes mainly from one breed (Norwegian Red Cattle), which is described as an early-maturing breed. The feed rations used in practise contain an high proportion forage, with grass silage as the dominating forage, even during the finishing period. The carcasses required by the Norwegian market are normally heavy and average weight is approximately 300 kg.

To develop equations to calculate CH<sub>4</sub> emission from enteric fermentation in growing cattle the following set of basic equations were needed:

1. To describe changes in live weight and ADG over time a Gompertz growth equation based on Norwegian slaughter data was used (F. Walland, personal communication). From the Gompertz equation (figure H2) it is possible to estimate animal live weight (LW) and ADG. This information are further used to calculate animal energy requirement for maintenance and growth.

**Figure H2. Gompertz growth function for prediction of live weight change and daily weight gain**



Animal energy requirement was estimated based on an adjusted version of the Dutch Net energy lactation system (Van Es, 1975). The following equation was used to predict daily total energy requirement (NE MJ/d) for early-maturing bulls and heifers (Berg and Matre, 2001):

$$NE = 0.2926 \cdot LW^{0.75} + 0.020 \cdot LW + 17.3 \cdot ADG - 6.57$$

Where:

NE = net energy requirement for maintenance and growth

LW = live weight, kg

ADG = average daily weight gain, kg

2. To calculate feed energy value and energy supplementation the same system as for dairy cows, the Dutch net energy lactation system (NEL), was used (Van Es, 1975). Standard feed rations at different carcass weights and slaughter ages were calculated using the three different forage qualities. The French fill unit system (INRA, 1989) was used to estimate feed intake. Tests of this system have shown good agreements to what have been observed in Norwegian growing cattle experiments (J. Berg, personal communication). Animal feed intake capacity (IC) is dependent on LWt and age at maturing. In Norway, the forage is fed ad libitum, since a maximum forage intake is generally sought, and then the minimum allowance of concentrate necessary to meet energy requirement related to the production goal provided. Therefore, the same approach as for dairy cows was used to formulate feed rations:

$$\text{Intake} = \frac{IC}{(P)FVF + (1-P)FVC} = \frac{ARNEL}{(P)NELF + (1-P)NELC}$$

Where:

IC = animal intake, intake capacity, kg per day  
 ARNEL = Animal energy requirement, NEL per day  
 P = proportion of forage in the total ration  
 FVF = forage fill value, g/kg DM  
 FVC = concentrate fill value, g/kg DM  
 NELF = forage NEL content, per kg DM  
 NELC = concentrate NEL content, per kg DM

In this formula information from the growth curve (figure H1) is used to define the animal energy requirement at different age, LW and ADG. The growth curve is also used to predict IC from the relationship between age and LW. Standard rations were calculated for slaughter ages of 14, 18 and 22 months. Within slaughter age three different carcass weights were used; 290, 320 and 350 kg. This data matrix is a representative variation of what is observed in practise in Norway. Feed rations were calculated in 30 day intervals from day 150 to slaughter.

3. Since the most commonly used feeding strategy for growing cattle is to maximise the forage intake and that grass silage is the dominating forage in beef production the same equations as used for dairy cows was used to predict CH<sub>4</sub> production. These equations are expected to be robust because different production levels (Mills *et al.*, 2003) and animal categories (Kirchgessner *et al.*, 1995).

Based on the standard feed rations, daily intake of GE, ME and Y<sub>m</sub> were predicted. From the dataset a multiple regression analysis were accomplish to develop equations that predict GE and Y<sub>m</sub> from animal characteristics available from the Cow Recording System. The analysis showed that it was necessary to develop two set of equations, one for the period when animals are younger than one year and one from one year to slaughter. The following equations were developed to predict average daily intake of GE:

From day 150 to 365 days of age:

$$GE = 102.2 + 0.3849 \cdot CAW - 6.25 \cdot SLA$$

From 366 days to slaughter:

$$GE = 118.5 + 0.375 \cdot CAW - 4.05 \cdot SLA$$

Where:

GE = gross energy, MJ/d  
 CAW = carcass weight, kg  
 SLA = months at slaughter

Equations to estimate Y<sub>m</sub>:

From day 150 to 365 days of age:

$$Y_m = 9.79 - 0.0187 \cdot CAW + 0.3155 \cdot SLA$$

From 366 days to slaughter:

$$Y_m = 9.64 - 0.0045 \cdot CAW + 0.074 \cdot SLA$$

Where:

Y<sub>m</sub> = methane conversion rate, %  
 CAW = slaughter weight, kg  
 SLA = months at slaughter

Table H3 present examples of daily GE intake and Y<sub>m</sub> at different age at slaughter and carcass weights.

**Table H3. Estimated average daily intake of gross energy (GE) and methane conversion rate  $Y_m$  (%) at different slaughter age and carcass weights**

Months at slaughter	Carcass weight	Period: 150 – 365 d		Period: 366 d - slaughter	
		GE, MJ/d	$Y_m$ , %	GE, MJ/d	$Y_m$ , %
14 .....	290	126	8.8	191	9.4
14 .....	350	149	7.7	193	9.1
22 .....	290	76	11.3	138	10.0
22 .....	350	99	10.2	161	9.7

The  $Y_m$  values presented in table H3 are higher than those presented as standard values in IPCC Tier 2 (IPCC 2001), which are 3% for feedlot cattle (90% or more concentrates in the diet) and 6,5% for other cattle. The discrepancies can probably be explained by differences in diet composition and the scientific basis for prediction of CH<sub>4</sub> from enteric fermentation.

Methane emissions from Norwegian's cattle population calculated from the developed equations are presented in table H4. To be able to compare our values to what has been suggested by IPCC, CH<sub>4</sub> emission per animal has been standardised to kg/head/year. In prediction of total CH<sub>4</sub> emission from enteric fermentation data has been corrected for animal lifetime. Our emission factors (kg CH<sub>4</sub>/head/yr) for dairy cows and beef cows are comparable to what is presented by IPCC (IPCC, 2001) for Western European cows. Our estimate is 10% higher, which are mainly due to differences in dry matter intake and the  $Y_m$  factor. The latter can be explained by a high proportion of forage in the diet and scientific basis for the equations used to predict CH<sub>4</sub> production. The same effect is found for growing cattle, which in IPCC (IPCC, 2001) is suggested to be 57 kg CH<sub>4</sub>/head/yr. Our average value, across all growing cattle categories, is 64 kg CH<sub>4</sub>/head/yr, which is 11% higher than the IPCC value suggested for Western European countries (IPCC, 2001).

**Table H4. Methane emissions from enteric fermentation in Norwegian's cattle and sheep, as determined by emission factors taken from European literature (cattle) and IPCC Tier 2 guidelines for 2006 (sheep). Animal predictions from year 2004**

Categories of cattle and sheep	GE intake, MJ/d	Methane lost, % of gross energy intake	Methane, kg per head per year <sup>12</sup>	Methane, t per year		
				1990	2000	2004
Dairy cows <sup>1</sup> .....	297	7.3	143	46 194	40 236	37 605
Beef cows <sup>2</sup> .....	208	9.0	122	1 971	6 932	6 312
Replacement heifers <sup>3</sup> .....	68	11.1	49	7 999	8 340	7 611
Finisher heifers, < one year <sup>4</sup> .....	93	10.3	63	92	163	133
Finisher heifers, > one year <sup>5</sup> .....	74	11.1	67	742	982	997
Finisher bulls, < one year <sup>6</sup> .....	104	9.8	67	335	617	543
Finisher bulls, > one year <sup>7</sup> .....	114	10.1	76	10 265	9 716	9 559
Breeding sheep, < one year <sup>8</sup> .....	51	4.5	15	3 317	4 212	2 876
Breeding sheep, > one year <sup>9</sup> .....	40	6.5	17	13 688	15 127	14 976
Slaughter lamb, < one year. Jan- May <sup>10</sup> ..	51	4.5	15	389	387	467
Slaughter lamb, < one year. Jun- Dec <sup>11</sup> ..	49	4.5	14	3 142	3 120	3 768

<sup>1</sup>dairy cows: milk yield of 6469 kg per year

<sup>2</sup>Beef cows: milk yield of 2500 kg per year

<sup>3</sup>Replacement heifers: 27 months of at calving

<sup>4</sup>Finisher heifers < one year: 7.8 months at slaughter

<sup>5</sup>Finisher heifers > one year: 23.2 months at slaughter

<sup>6</sup>Finisher bulls, < one year: 19.8 months at slaughter

<sup>8</sup>Breeding sheep, < one year:

<sup>9</sup>Breeding sheep, > one year:

<sup>10</sup>Slaughter lamb, < one year. Jan- May: 4.8 months at slaughter

<sup>11</sup>Slaughter lamb, < one year. Jun- Dec: 11 months at slaughter

<sup>12</sup>Methane in kg per head per year was calculated as follows: ((GE intake, MJ/d x methane lost as % of GE/100)/55.65 MJ/kg)\*365, where 55.65 is the energy content (MJ) of 1 kg of methane.

### Calculation of methane emission from enteric fermentation in sheep

In Norway sheep are used for meat- and not for milk production. No information system as the Cow Recording System is available for sheep. Information is restricted to number of sheep younger and older 1 year, the number of slaughtered sheep younger and older 1 year, and how many sheep younger than 1 year that are slaughtered each month throughout the year. Prediction of methane emission from sheep is therefore based on the Tier 2 method described by IPCC (IPCC, 2001). In Norway most ewes lamb in the period March to May. There is a big demand for lamb meat around Christmas, and therefore, the major part of the lambs is slaughtered in the period October to December. Lambs that don't fulfil the minimum levels for weight will be fed and slaughtered the next year together with ewe lambs that are not pregnant. On this basis the sheep population has been divided in four categories: 1) lambs under 1 year of age slaughtered in the period from June 1<sup>st</sup> to December 31<sup>st</sup>, 2) lambs under 1 year of age slaughtered in the period from January 1<sup>st</sup> to May 31<sup>st</sup>, 3) breeding sheep under 1 year of age and 4) breeding sheep over 1 year. Slaughtered lambs younger than 1 year are divided in two groups



because lambs that live longer than December will have an increased energy requirement for maintenance, activity and growth. To be able to divide the number of slaughtered lambs younger than 1 year in the two groups, the portion of slaughtered lambs for each are calculated. This calculation are based on available information of the number of slaughtered lambs younger than 1 year, and the number of lambs slaughtered each month, for two subsequent years. The number of lambs slaughtered in the period from June 1<sup>st</sup> to December 31<sup>st</sup>, and in the period from January 1<sup>st</sup> to May 31<sup>st</sup>, are added up for each year and the portion according to total number for each period and year were calculated, and an average number of the same period from the two subsequent years were used. The average portion of lambs slaughtered in June – December were found to be 0.921 and the portion slaughtered in January – May were 0.0789.

Prediction of methane emission from sheep is based on the intake of GE and the fraction of GE converted to CH<sub>4</sub> (the CH<sub>4</sub> conversion rate, Y<sub>m</sub>). The intake of GE is estimated from the net energy requirement and conversion factors from net energy to GE. According to IPCC (IPCC, 2001) the Y<sub>m</sub> for sheep over one year is 6.5 % and 4.5 % for sheep under one year.

The following equation was used to predict GE:

$$GE = [(NE_m + NE_a + NE_l + NE_p)/NEM_{ef}] + [(NE_g + NE_{wool})/NEG_{ef}] / (DE/100),$$

Where:

GE = gross energy, MJ/day

NE<sub>m</sub> = net energy for maintenance, MJ/day

NE<sub>m</sub> = C<sub>f</sub> · (bodyweight)<sup>0.75</sup>

NE<sub>a</sub> = net energy for activity, MJ/day

NE<sub>a</sub> = C<sub>a</sub> · bodyweight

NE<sub>l</sub> = net energy for unknown lactation, MJ/day

NE<sub>l</sub> = ((5 · W<sub>gwean</sub>) / 365 days) · EV<sub>milk</sub>

NE<sub>p</sub> = net energy for pregnancy, MJ/day

NE<sub>p</sub> = C<sub>pregnancy</sub> · NE<sub>m</sub>

NE<sub>g</sub> = net energy for growth, MJ/day

NE<sub>g</sub> = / (365 days/year)

NE<sub>wool</sub> = net energy for one year of wool production, MJ/day

NE<sub>wool</sub> = (EV<sub>wool</sub> · yearly wool production, kg/year) / (365 days/year)

NEM<sub>ef</sub> = the ratio of net energy available in a diet for maintenance to digestible energy consumed

NEG<sub>ef</sub> = the ratio of net energy available for growth in a diet to digestible energy consumed

DE = digestible energy in present of gross energy

Net energy for maintenance is calculated as metabolic bodyweight (bodyweight<sup>0.75</sup>) multiplied with a coefficient (C<sub>f</sub>) varying with age and sex. C<sub>f</sub> provided by IPCC (IPCC, 2001) is 0.217 for ewes over one year and 0.2496 for intact males over one year. For sheep under one year it is 0.236 for ewes and 0.2714 for intact male lambs. It is not possible to divide the number of sheep by sex, and therefore an average value of 0.2333 for sheep over one year and 0.2537 for sheep under one year has been used. Net energy for activity is calculated as bodyweight multiplied by a coefficient (C<sub>a</sub>) corresponding to the animal's feeding situation. According to IPCC (IPCC, 2001) C<sub>a</sub> for housed ewes is 0.009, sheep grazing on flat pasture 0.0107, sheep grazing on hilly pasture 0.024, and for lambs kept indoor 0.0067. The feeding situation varies during the year, and therefore an average of the first three values (0.0146) has been used for sheep over one year, and an average of the three last values (0.0138) has been used for sheep under one year. Calculation of net energy for lactation is based on the formula for unknown lactation, because sheep in Norway are used for meat production. This formula includes average daily gain for each lamb in the period from birth to weaning, (W<sub>gwean</sub>), in kg. Weaning was set at seven weeks of age, which is taken as the time when the lambs are dependent on milk for half their energy requirement, and W<sub>gwean</sub> was set to 21.5 kg. The energy required for producing 1 kg of milk (EV<sub>milk</sub>) is 4.6 MJ/kg. Net energy for lactation is calculated for breeding sheep over one year, and for two lambs for each ewe. Net energy for pregnancy is calculated from a coefficient for pregnancy, (C<sub>pregnancy</sub>), multiplied with net energy for maintenance. According to IPCC (IPCC, 2001) C<sub>pregnancy</sub> is 0.077 for one lamb, 0.126 for two lambs and 0.15 for more than two lambs. When the GE intake is calculated an average of the first two values (0.1015) is used for breeding sheep under one year, and an average of all three values (0.1177) is used for breeding sheep over one year. The formula used for calculating net energy for growth include bodyweight at the time of weaning (BW<sub>i</sub>), bodyweight at one year of age or at the time of slaughtering (BW<sub>f</sub>), average daily gain in the period from weaning to on year of age or slaughtering (W<sub>glamb</sub>), and the given factors a and b. This formula was tried out,

but the outcome was not in accordance with expected theoretical numbers, and therefore, another method was used to estimate the net energy requirement for growth. This method is based on average daily gain from birth to slaughtering and a net energy requirement of 17.3 MJ per kg gain was used. Average daily gain was calculated on the assumptions that weight at birth was 4.5 kg (Nedkvitne, 1989). Net energy for growth is calculated for both slaughtered and breeding sheep younger than 1 year. The need for net energy for wool production is calculated as the amount of wool produced during a year multiplied with the net energy content of 1 kg wool ( $EV_{\text{wool}}$ ), which is 24 MJ/kg (IPCC, 2001). The quantity of wool produced was set to 1.9 kg for sheep under one year and 4.1 kg for sheep over one year.

From the estimated net energy requirement, daily GE intake is calculated based on conversion factors from net energy to GE. Conversion ratios were derived from the Dutch net energy system (Van Es, 1975), where values of 65, 81 and 43 % were used as average conversion rates from net energy to metabolizable energy, from metabolizable energy to digestible energy and from digestible energy to GE, respectively.

For slaughtered lamb under one year, the requirements for net energy (MJ/day),  $NE_m$ ,  $NE_a$ ,  $NE_g$ , and  $NE_{\text{wool}}$ , were added up and converted into GE as described above. For these two animal sub-categories, June – December and January – May, the  $CH_4$  emission was calculated for the living period, since the lamb live shorter than one year. When calculating methane emission from lambs it is, according to IPCC (2001), assumed that lambs do not emit methane until half of their energy requirement is covered from milk, and this phase has been set to 7 weeks of age. Therefore, when calculating methane emission from lambs younger than one year, daily emission is multiplied with the age at slaughter subtracted the 7 weeks. For breeding sheep under one year the requirements for net energy (MJ/day),  $NE_m$ ,  $NE_a$ ,  $NE_g$ , and  $NE_{\text{wool}}$ , were multiplied by 365 days, and net energy for pregnancy in MJ/day were multiplied by 150 days. Then the total requirement for net energy, MJ/year, was divided by 365 to get the energy requirement in MJ/day, and then converted GE. For breeding sheep over one year calculation of total net energy requirement was done in the same way as for breeding sheep under one year. For this category of sheep net energy for unknown lactation (IPCC, 2001) was used and this was done by multiplying daily requirement by 96 days, and then divided by 365 days.

In table H4 daily GE intake and  $CH_4$  production for the different sub-categories of sheep is presented. The  $CH_4$  emission values, expressed as kg  $CH_4$ /head /year, are higher than IPCC Tier 1 values. It is likely that the IPCC Tier 1  $CH_4$  emission factors for sheep under Norwegian feeding practices and management strategies are set too low.

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## Appendix I                      QA/QC performed for GHG emissions from industrial plants included in the national GHG inventory

### Introduction

This appendix presents the methodology for the performance of QA/QC on time series from 1990 to 2004 of greenhouse gas (GHG) emissions from the largest industrial plants in Norway.

The work was carried out by Section for climate and energy at the Climate and Pollution Agency in the period from February to April 2006. The following sectors of industry were covered: Cement production, mineral fertilisers, carbide industry, production of ferroalloys, production of primary aluminium, anode manufacture, production of iron and steel, nickel production, pulp and paper manufacture, oil refineries, gas terminals, lime production, other mineral production, methanol production, plastics, other chemical industry and production of magnesium.

The goal of this work was to establish final time series of greenhouse gas emissions from 1990 to 2004 for these sectors. The main documentation from this work is contained in Excel spread sheets giving the resulting time series for each plant included in this revision, and in a documentation report "Documentation of methodology and results: QA/QC performed for GHG emissions from industrial plants included in the national GHG inventory" (Norwegian pollution control authority 2006).

There have been several changes since the methodology was described:

- The 2005 GHG inventory data from the preliminary emission trading system (2005-2007) has been used. Onwards from 2008, the GHG inventory will include data from the emissions trading scheme (2008-2012) that is linked with the EU emission trading scheme. There was a voluntary agreement between industry and authorities covering the most carbon-intensive industry not included in the trading system in 2005-2007. This has made the reporting requirements stricter than before and QC is even more detailed.
- Changes of more than 20 per cent (10 per cent for plants included in emission trading) are flagged in the Excel spread sheets for further QC in collaboration with the plant.
- The Inkosys database has been replaced by the *Forurensning* database. Data have been transferred from Inkosys to *Forurensning*.
- Based on responses from ERT, more attention is given to implied emission factors (IEF).
- New plants and a new sector (gas-fired power plants) are now included
- Several time series have been recalculated

### Method for establishing and verifying data series of emissions

The following work procedure was established to verify data series:

1. For each plant; a first time series of emission data as well as activity data were established with basis on existing sources of data (see section on data sources).
2. The first time series of emission data and activity data were presented in both a table format as well as a graphic presentation. See figure I1 and figure I2 for examples.
3. Based on the table with compiled data and the graphic presentation, it was possible to identify:
  - Lack of emission data and activity data for any year or time series.
  - Possible errors in the reported data. Possible errors were typically identified if there were discrepancies between reported activity data (consumption of raw materials, production volumes etc) and emissions, or if there were large variations in the existing time series of emissions.
4. The emission data were supplemented and/or corrected if possible by one or more of the following sources of information:
  - Supply of new data from the company
  - Supplementary data from the Climate and Pollution Agency paper archives.
  - Verification of reported emission data by new calculations based on reported activity data.
  - Calculation of missing emissions (if sufficient activity data were present).
5. A final time series of greenhouse gas emissions from 1990 to 2004 were established, and presented both as a tables and a figure. The origin of the data was documented by the use of colour codes.
6. The differences between former and new time series of emissions were identified and documented.

In the tables, colour codes were used to describe the source and type of the data. See figure I1 as an example of a data table with the explanations of the colour codes.

Figure I1. Examples of presentation in data tables and the use of colour codes

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO2 process (1000 ton)	218,0	232,6	252,0	256,0	243,6	273,0	271,9	242,0	265,4	272,7	272,5	218,0	129,1	209,0	229,5
CH4 (ton)	79,5	69	72	77	74	84	84	80	88	86	87	74	52	69	76
N2O (ton)	26,5	26	27	29	27	31	31	30	33	32	33	28	20	28	31
Activity data -whitebook(1000 ton)	69,68								84,33	85,1	84,55	70,05			
Activity data -Inkosys (1000 ton)		61	64	78,6	80,2	87,9	85,4	73,2	79,7	80,3	79,8	53,5	45,6	72,4	

Time Serie	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
total CO2 (1000 tons)	47	32	64	84	161	151	207	207	202	185	128	213	153	135	137
CO2 combustion (1000 tons)	38	23	55	75	152	143	199	198	193	177	119	205	145	127	127
CO2 process (1000 tons)	9	9	9	9	9	9	9	9	9	8	9	8	8	9	10
CH4 (ton)	2,0	2,2	2,5	0,9	7,4	7,0	9,8	9,9	9,6	8,7	5,8	10,1	7,1	6,0	6,2
N2O (ton)	0,40	0,42	0,43	0,63	1,33	1,33	1,83	1,83	1,80	1,60	1,10	1,90	1,4	1,1	1,2
Activity data white book (1000 tons)	12,2								60,5	55,4	37,2	64,1			
Activity data Inkosys (1000 tons)			17,3	7,4	48,1	45,1	62,6	63,0	60,7	55,4	35,6	64,1	45,7	39,4	41,3

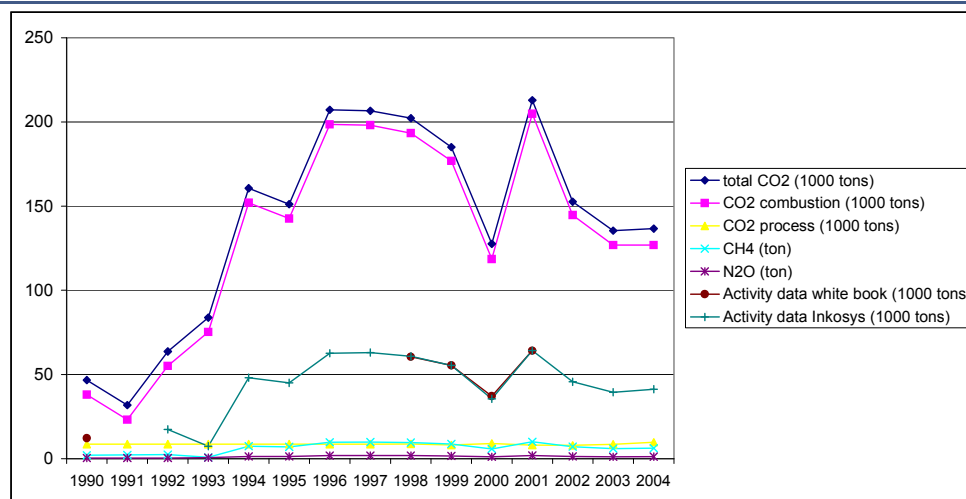
Data from:	Color code
White book on GHG	
Forurensning database	
Former time serie reported to Statistics Norway	
New, calculations by the Climate and Pollution Agency	
New, by intrapolation	
New, provided by company	

As the figure shows, there were six main sources of final data to the time series: the white book on GHG (SINTEF and Det Norske Veritas 2004), the *Forurensning* database (described in section on data sources), new data calculated by the Climate and Pollution Agency based on reported activity data, new data provided by company, and new data based on intrapolation between. Intrapolation was typically used as a method to establish data for the year 1991, if the emissions from 1990 and 1992 were given.

The emission data and the activity data were presented in graphic presentation for a visual presentation.

Figure I2 illustrates a presentation of the emissions and activity data from a pulp and paper plant.

Figure I2. Example of graphic presentation



## Data sources

### *The Forurensning database*

Data from the annual company emission reports are stored in the Climate and Pollution Agency database *Forurensning*. The database contains data from 1992, and holds emission and activity data from all companies reporting emissions to the Climate and Pollution Agency. The *Forurensning* database holds reported emissions and activity data from Norwegian companies. The companies report the data according to a manual<sup>25</sup>. In the Climate and Pollution Agency, the respective responsible officer undertakes a control of the data, before they are inserted in the database.

### *The white book on climate gases from Norwegian process industry*

The white book on climate gases from Norwegian process industry (SINTEF and Det Norske Veritas 2004) was initiated by the Federation of Norwegian Process industry (PIL), Norwegian Chemical Industrial Worker's Union (NKIF) and Norwegian Oil- and Petrochemical Worker's Union (NOPEF). The work was carried out by DNV and Sintef, who collected, compiled, controlled and verified all emissions of climate gasses from these industrial plants for the years 1990, 1998, 1999, 2000 and 2001. The method of work as well as the main results are described in the reports from this project published by Federation of Norwegian Process Industry 2003. The main data files and verification tables from this work have been made available for the Climate and Pollution Agency. The white book includes data from 60 process industry plants.

Since the emission data in this white book has gone through a thorough verification process, these emissions were assumed to be correct, unless any other information proved them incorrect. If several data sources reported different series of emissions, the data series from the white book were used.

### *The white book on climate gases from Norwegian pulp and paper industry*

The white book on climate gases from Norwegian pulp and paper industry work was initiated by the Norwegian Pulp and Paper Association, and was carried out by DNV, Sintef and the Norwegian Association of Energy Users and Suppliers. They collected, compiled, controlled and verified all emissions of climate gasses from the relevant pulp and paper plants for the years 1990, 1998, 1999, 2000 and 2001. The method of work as well as the main results are described in the reports from this project published by Norwegian Pulp and Paper Association 2003. The main data files from this work have been made available for the Climate and Pollution Agency.

Since the emission data in this white book has gone through a thorough verification process, these emissions were assumed to be correct, unless any other information proved them incorrect. If several data sources reported different series of emissions, the data series from the white book were used.

### *Other sources*

Other data sources also available for this work were:

- Annual update of the climate gas inventories based on annual reports from Norwegian industry. Reported to Statistics Norway.
- Yearly (paper) reports from industry of emission to air, water and soil (Egenrapportering).
- Applications for CO<sub>2</sub>-permits for the Norwegian emissions trading scheme.

### *Documentation of calculations and time series*

The main documentation from the work is contained in Excel spread sheets giving the resulting time series for each plant included in this revision. Each spread sheet includes emission data and activity data from the relevant data sources for each production plant. It includes the proposed time series for the relevant greenhouse gases, and states the sources for this information. Relevant information related to the QA/QC process for the specific site is noted as a comment or as a text box for each plant.

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<sup>25</sup> SFT (2004): Bedriftenes egenrapportering til forurensningsmyndighetene. Veiledning. Manual. Declaration of emissions. TA-1929/2004.

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ISBN 978-82-537-8999-6 (electronic)



**Statistisk sentralbyrå**  
Statistics Norway