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Swedish Environmental Emissions Data

Revision of Methodology and Estimated Emissions of Fluorinated Greenhouse Gases in Sweden

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SMED is short for Swedish Environmental Emissions Data, which is a collaboration between IVL Swedish Environmental Research Institute, SCB Statistics Sweden, SLU Swedish University of Agricultural Sciences, and SMHI Swedish Meteorological and Hydrological Institute. The work co-operation within SMED commenced during 2001 with the long-term aim of acquiring and developing expertise within emission statistics. Through a long-term contract for the Swedish Environmental Protection Agency extending until 2014, SMED is heavily involved in all work related to Sweden's international reporting obligations on emissions to air and water, waste and hazardous substances. A central objective of the SMED collaboration is to develop and operate national emission databases and offer related services to clients such as national, regional and local governmental authorities, air and water quality management districts, as well as industry. For more information visit SMED's website www.smed.se.

Summary

In the year 2000 the first emission inventory of fluorinated greenhouse gases (HFCs, PFCs and SF_6) was compiled for Sweden. During the following years additional information has become available, indicating that an update of the way of utilizing background data, and of the calculation methodology was necessary.

Activity data used for calculating emissions from the categories stationary refrigeration (HFCs and PFCs) and electrical insulation (SF_6) have been revised in cooperation with Product Register staff at the Swedish Chemicals Inspectorate. Furthermore, national calculation methodologies for emissions from semi-conductor manufacture and from foam blowing were studied in relation to the descriptions in IPCC Good Practice Guidance (2000). The result from these comparisons was that the methodology for calculating emissions from semi-conductor manufacture was revised according to the Tier 1 methodology given in IPCC Good Practice Guidance, while the national method for calculating emissions from foam blowing was retained.

Due to improved information during the course of the work, revisions of emission calculations were also made for mobile air conditioning and for metered dose inhalers. Additionally, from the improved information on fluorinated substances followed that the reporting of potential emissions, where previously only 1995 to 2003 were covered, could be made complete for the whole time series, 1990-2004.

The various improvements introduced into the calculations have together resulted in increased emissions estimates of fluorinated greenhouse gases in Sweden. The increases are substantial, approximately 30-40% in later years, calculated as CO_2-equivalents. The largest single contributing factor to this increase in actual emissions is the use of the improved statistics from the Product Register as complementary input data for stationary refrigeration and air conditioning equipment.

Even though several essential improvements were made during the course of the project, some issues remain to be solved. These especially apply to the circumstances concerning decommissioning of products. There are also still some uncertainties associated with the quantification of exported amounts of chemicals from Sweden.

Swedish Summary

År 2000 genomfördes och sammanställdes den första emissionsinventeringen av fluorerade växthusgaser (HFCer, PFCer och SF_6) i Sverige. Under de följande årens arbete har efter hand ny och kompletterande information och kunskap blivit tillgänglig. Denna information indikerade att en uppdatering var nödvändig avseende det sätt som bakgrundsdata användes i beräkningarna av emissioner. I vissa fall var också en översyn av beräkningsmetoderna nödvändig.

Genom samarbete med personal vid Produktregistret vid Kemikalieinspektionen har inom detta projekt aktivitetsdata för kategorierna stationär kyla och luftkonditionering (HFCer och PFCer) samt för elektrisk isolering (SF_6) uppdaterats och förbättrats. Dessutom har de nationella metoderna för beräkning av emissioner av fluorerade gaser från halvledartillverkning och från plasttillverkning jämförts med de metoder som anges i IPCC Good Practice Guidance (2000). Resultatet från dessa jämförelser var att beräkningsmetoden för emissioner från halvledartillverkning har ändrats och sker nu i enlighet med Tier 1 enligt Good Practice Guidance. Den nationella beräkningsmetoden för emissioner från plasttillverkning har däremot behållits.

Till följd av ny information som framkom under arbetets gång, har förändringar av emissionsberäkningar även genomförts för luftkonditionering i mobila källor samt från medicinska inhalatorer. Den uppdaterade och generellt förbättrade information som blev tillgänglig avseende fluorerade växthusgaser medgav dessutom att beräkningar av potentiella emissioner kunde genomföras för hela tidsserien 1990-2004. Tidigare har potentiella emissioner endast rapporterats från och med 1995.

De olika förbättringar som införts i beräkningarna har sammantaget resulterat i en kraftig ökning av de beräknade verkliga emissionerna av fluorerade växthusgaser från Sverige. Ökningen är i storleksordningen 30-40% för senare år, räknat som CO_2-ekvivalenter. Den största enskilda orsaken till ökningen är de uppdaterade aktivitetsdata från Produktregistret som använts för beräkningar av emissioner från stationär kyla och luftkonditionering.

Trots att flera viktiga förbättringar införts i beräkningarna under projektets gång, återstår fortfarande några frågor som bör utredas vidare. Detta gäller främst hanteringen vid skrotning av produkter som innehåller fluorerade gaser. Vissa osäkerheter återstår också avseende kvantiteter och kvantifiering av exporterade mängder fluorerade gaser från landet.

Contents

1 Introduction

1.1 Background

In 2000 IVL, on assignment from the Swedish Environmental Protection Agency, conducted the first national estimate of emissions of fluorinated greenhouse gases (HFCs, PFCs and SF_6) in Sweden for the time period 1990-1999 (IVL B-1428). An excel-based model was developed in order to calculate actual emissions and accumulated amounts in society. IVL has also conducted a study concerning projections of future emissions of fluorinated greenhouse gases as a background report to the Third National Communications (NV 5168).

In September 2003 the Swedish Environmental Protection Agency presented a governmental assignment on fluorinated greenhouse gases (Åtgärder för en begränsad användning av fluorerade växthusgaser, Swedish EPA reports 5311 and 5312). The governmental assignment was performed as a result of the EU commission "Proposal for a Regulation of the European Parliament and of the Council on certain Fluorinated Greenhouse Gases" (COM(2003) 492 final), but also based on additional measures proposed by the Swedish EPA. In preparing that report, the Swedish EPA obtained additional and partly new information from different end user applications. After this, IVL was again assigned to perform a study, updating the scenarios for future emissions of fluorinated gases, based on the EU-proposal and the additional measures proposed by the Swedish EPA. The results were presented in March 2004 (IVL report U 952).

During the work with the assignments following the original inventory in 2000, as well as the annual work with compiling data for the national submissions of emission data to the UNFCCC, it has become evident that there is a need for methodological update to improve the quality of reported data and also to make inventory work and reporting more efficient. The excel-based model needs to be developed to better comply with the annual background data available, and to better support the production of the information required to be reported in the UNFCCC CRF[1]-system.

1.2 Aim of the project

The overall aim of the project is to improve the reporting of emissions of fluorinated greenhouse gases by:

- utilizing best available data sources and calculation methodologies in order to improve the accuracy and completeness of the inventory

- establishing methods to include available background data into the methodology, in a way that facilitates annual extension and updating of the inventory in a consistent manner

[1] CRF, Common Reporting Format

- recalculating the whole time series from 1990 in a consistent manner for sources where background data and/or calculation methods are revised
- adapting the present calculation model to better support the reporting requirements
- developing and extending the model with functions to minimize the manual handling of data

2 International emission reporting requirements and guidelines

On a yearly basis Sweden is obliged to report national air emissions of several pollutants to UNFCCC (United Nations Framework Convention on Climate Change) and to the European Union's Mechanism for Monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol.

Reporting follows the revised 1996 IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse gas Inventories (IPCC Guidelines), IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse gas inventories (IPCC Good Practice Guidance), and UNFCCC Reporting Guidelines on annual inventories (FCCC/CP/2002/8).

3 The Excel model

3.1 Structure

The model consists of an excel file with:

- 22 sheets, one sheet for each sub-source considered where all input data from 1990 until present are registered, and where calculations of accumulated amounts and actual emissions occur,
- one summary sheet where emissions for each year from 1990 are transferred from the sub-source sheets and are summarized by year, substance and source,
- one sheet where background information such as GWP-values are automatically taken into the calculations in the summary sheet.

The individual sub-source sheets may look slightly different as far as the input data cells are concerned. These have been adapted to suit the actual input data available and needed for the calculations. However, for all sub-sources calculations are made concerning annual accumulated bank and actual emissions by substance. Where appropriate, also imported and exported amounts in products are calculated.

3.2 Input data and calculated data

Every sub-source sheet has input cells for each year where the production, import and export of the source are entered. For each year an expected lifetime, leakage factors and a minimum content factor is given. Each sub-source then has its specific composition of

use of species of HFC, PFC and SF_6, which are calculated separately. For each component the leakage in each year is calculated taking into account the leakage from production and the leakage from the accumulated bank. The leakage factor specified for each year's products is used for the calculation of leakage from the accumulated amount in subsequent years, until minimum content or the expected lifetime is reached.

Changes in accumulated amounts each year resulting from additional amounts of HFC, PFC and SF_6 imported and used within the country, as well as the decline in accumulated stock caused by exports or emissions from operating systems, have been taken into consideration.

Most calculations is made with standard worksheet functions in excel. But to simplify the worksheets some VBA functions have been written. These are:

Function **get_emission** (SheetName, ColName, RowName)

Used in the summary sheet to collect results on actual emissions from the detailed sub-source sheets.

Function **accumulated_minus_leakage** (year_range, cond_range, _

year, sum_range, leakage_range, min_content)

Calculates the sum of each years additions of HFC, PFC and SF_6, minus the leakage, taking into account the different leakage factors for each year and the minimum content in each equipment.

Function **leakage_per_year** (year_range, cond_range, _

year, sum_range, leakage_range, min_content)

Calculates the sum of the leakage of the accumulated bank.

3.3 What has to be calculated outside the model

The model does not fully support the calculation of all data required to be reported in the CRF tables. Data that have to be calculated separately or have to be extracted from the model sub-source sheets for further handling are:

- Potential emissions
- Emission trends
- Data to be included in CRF background tables 2(II).Fs1 and 2(II).Fs2.

4 Scope of the project

- Possible revisions of calculation methods. The national methods for estimating emissions from semi-conductor manufacture and from XPS production have been identified not to be performed according to Good Practice Guidance. Comparative calculations were made between the national methods and the GPG methods.

- Revision of data on used amounts of fluorinated greenhouse gases in Sweden. A new, consistent, extraction of data from the Product Register for the available time period, 1995-2003, showed that the previous, annual information had not been extracted in a consistent way.

- Adjustment of input data for refrigeration and air conditioning sources, and for electrical insulation, was made based on the new, consistent information from the Product Register.

- Adjustments in the calculation model, where some sub-sources were aggregated and some where disaggregated, to better comply with reporting requirements and with available input data.

- Development of the excel model to better support the reporting system.

- Recalculation of the time series of emissions of fluorinated greenhouse gases 1990-2003.

5 Revision of calculation methods

5.1 Emissions from semi-conductor manufacture

Semiconductor manufacture has in recent years occurred on a commercial scale at only one facility in Sweden. Previously one more facility was located in Sweden, but production was moved abroad. During 2004 the production in the only facility left was also closed down.

Information concerning the annually used amounts of various fluorinated substances has been provided by the company, and as far possible been compared to information from the Product Register at the Swedish Chemicals Inspectorate. The company has estimated emissions based on information from the European Electronic Components Industry (EECA) - European Semiconductor Industry Association (ESIA).[2] According to ESIA it is estimated that 73% (1990-2000) and 70% (2001-2003) of the used amount of HFCs and PFCs is emitted during production. The rest of the chemicals are consumed during the etching processes. The company also used SF_6, and this is assumed to be 100% emitted. This method of calculating emissions from semiconductor manufacture was used in the Swedish reporting to UNFCCC until submission 2005,

[2] http://www.eeca.org/esia.html

covering the emission years 1990-2003. The method is however not in line with the IPCC Good Practice Guidance[3] in three important aspects. According to the IPCC Good Practice Guidance, the share of chemical destroyed in the process is substance specific and varies from 20-70% (Table 5.1) and there is also a formation of CF_4 (PFC-14) from C_2F_6 (PFC-116) and from C_3F_8 (PFC-218) in the process. In the Good Practice Guidance Tier 1 method there is also an assumption that 10% of the purchased chemical remains in the shipping container and does not enter into the process. These facts were not considered in the national method previously used.

According to the Tier 1 method in IPCC Good Practice Guidance the formulae to be used in the calculations of emissions are:

Emissions of $FC_i = (1\text{-}h)*(FC_i*(1\text{-}C_i))$ *(GPG eq. 3.31)*

Emissions of CF_4 for $FC_i = (1\text{-}h)*(B_i*FC_i)$ *(GPG eq 3.32)*

where:
FC_i = Sales/purchase of individual gas
h = Fraction of gas remaining in shipping container after use (default value = 0.1)
C_i = Use rate of gas (fraction destroyed or transformed in process)
B_i = kg CF_4 created per kg of gas i

Table 5.1 Default factors for the Tier 1 method (IPCC Good Practice Guidance, table 3.15).

	CF_4	C_2F_6	CHF_3	C_3F_8	c-C_4F_8	NF_3	SF_6
	PFC-14	PFC-116	HFC-23	PFC-218			
1-C_i	0.8	0.7	0.3	0.4	0.3	0.2	0.5
B_i	NA	0.1	NA	0.2	NA	NA	NA

The substances used in the process at the Swedish facility are HFC-23 (CHF_3), PFC-14 (CF_4), PFC-116 (C_2F_6), c-C_4F_8, NF_3 and SF_6. NF_3 and c-C_4F_8 have only been used in very small amounts (a few kg/year).

A comparative calculation between the national method and the IPCC Good Practice Guidance Tier 1 method was made (Figure 5.1). The comparison shows that the Tier 1 method results in somewhat lower emission estimates than the actual reporting from the companies according to the previous national method. In addition to the revised method, a correction in input data for year 2000, where previously a too low estimate of the used amount of C_2F_6 was adjusted, shows in the comparison.

[3] IPCC (2000). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.

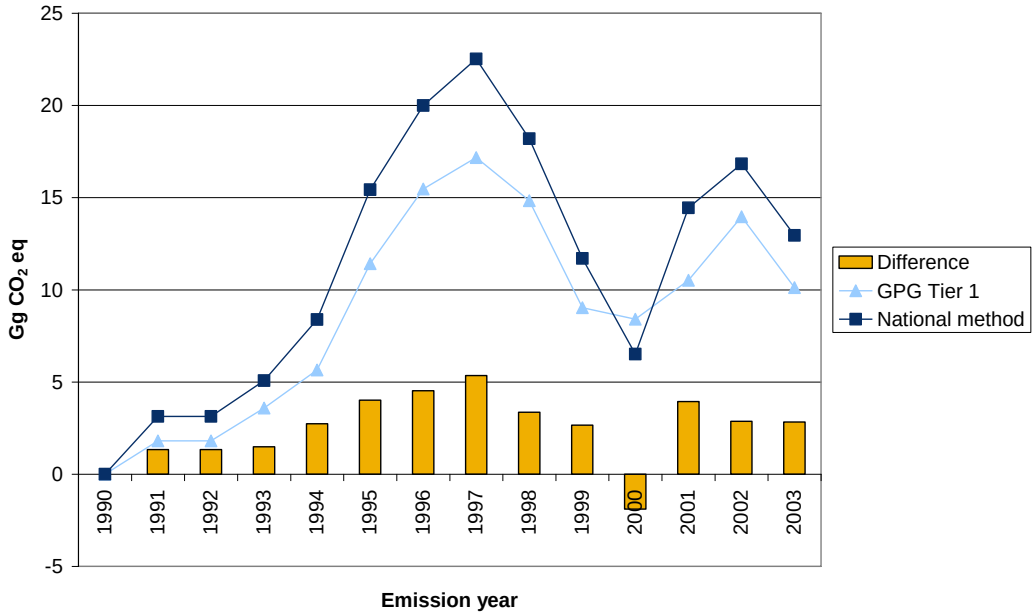

Figure 5.1 Emission of fluorinated gases (Gg CO_2 equivalents) from semiconductor manufacture as calculated with the previous national method (submission 2005) and according to Tier 1 GPG.

Due to a previously unclear end-use of C_3F_8 (PFC-218), all C_3F_8 reported as imported in the Product Register at the Swedish Chemicals Inspectorate used to be allocated to semi-conductor manufacture. This has however been corrected, and from submission 2006 all C_3F_8 is allocated to be used in refrigerant mixtures.

The actually reported emission from semiconductor manufacture in submission 2005, including the erroneously allocated C_3F_8, is presented in Figure 5.2 and Table 5.2. In Table 5.3 the calculated emissions of individual substances are presented.

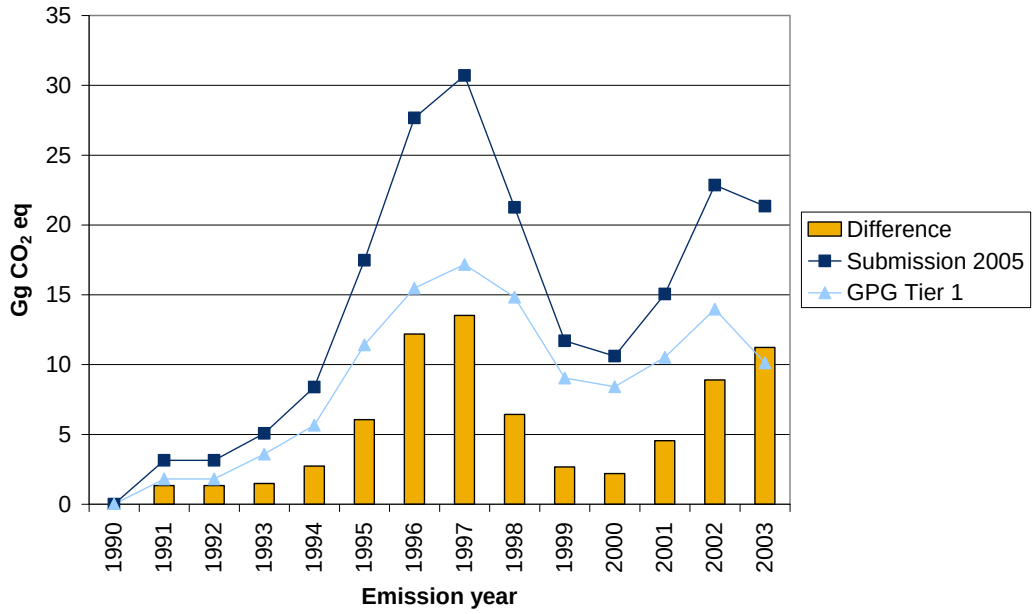

Figure 5.2 Comparison of the Good Practice Guidance Tier 1 method and reported emissions in submission 2005 (including C_3F_8 and uncorrected data for C_2F_6 for 2000).

Table 5.2 Calculated emissions (Gg CO_2 equivalents) from semiconductor manufacture in submission 2005 (including and excluding PFC-218), and calculated according to Tier 1. Change (%) from actually submitted data in sub 2005 (incl C_3F_8) and the Tier 1 calculations.

	Submission 2005		Tier 1	Submission 2005 - Tier 1
	incl PFC-218	*excl PFC-218*		
Year	Gg CO_2 eq	*Gg CO_2 eq*	Gg CO_2 eq	% change
1990	0.0	*0.0*	0.0	0
1991	3.1	*3.1*	1.8	-42
1992	3.1	*3.1*	1.8	-42
1993	5.1	*5.1*	3.6	-29
1994	8.4	*8.4*	5.7	-33
1995	17.5	*15.4*	11.4	-35
1996	27.7	*20.0*	15.5	-44
1997	30.7	*22.5*	17.2	-44
1998	21.3	*18.2*	14.8	-30
1999	11.7	*11.7*	9.0	-23
2000	10.6	*6.5*	8.4	-21
2001	15.1	*14.4*	10.5	-30
2002	22.9	*16.8*	14.0	-39
2003	21.3	*13.0*	10.1	-53

Table 5.3 Calculated emissions (ton) of individual fluorinated gases from semi-conductor manufacture as reported in submission 2005 (previous national method) and as calculated using the Tier 1 method.

	Submission 2005						Tier 1			
	ton						ton			
Year	HFC-23	PFC-14	PFC-116	SF_6	PFC-218		HFC-23	PFC-14	PFC-116	SF_6
1990	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
1991	0.04	0.08	0.03	0.08	0.00		0.02	0.08	0.03	0.03
1992	0.04	0.08	0.03	0.08	0.00		0.02	0.08	0.03	0.03
1993	0.05	0.09	0.23	0.08	0.00		0.02	0.12	0.19	0.03
1994	0.08	0.21	0.27	0.15	0.00		0.03	0.24	0.23	0.07
1995	0.08	0.35	0.72	0.23	0.29		0.03	0.44	0.62	0.10
1996	0.13	0.55	1.02	0.23	1.10		0.05	0.67	0.88	0.10
1997	0.10	0.62	1.08	0.31	1.17		0.04	0.74	0.94	0.14
1998	0.11	0.59	1.02	0.16	0.44		0.04	0.71	0.88	0.07
1999	0.04	0.12	0.74	0.15	0.00		0.02	0.21	0.64	0.07
2000	0.04	0.37	0.00	0.15	0.58		0.02	0.42	0.42*	0.07
2001	0.07	0.39	0.52	0.26	0.09		0.03	0.47	0.47	0.12
2002	0.08	0.52	0.90	0.18	0.86		0.03	0.65	0.81	0.08
2003	0.03	0.31	0.63	0.20	1.20		0.01	0.40	0.57	0.09

* corrected input data

From Table 5.3 it is obvious that the resulting emissions in ton/substance become lower for all substances except for CF_4 when calculating according to Tier 1 than according to the previous method. This is not surprising considering the Tier 1 inclusion of a remaining fraction in the container, the equal or higher fraction of gas destroyed in the process, as well as the inclusion of the formation of CF_4 in the process.

In submission 2006 to the UNFCCC the data will be revised and recalculated according to the GPG Tier 1 method.

5.2 Emissions from XPS foam

Emission estimates are based on the production and use of XPS foam in Sweden. Data is obtained from the producer on the used amount of HFC-134a and HFC-152a, emissions at production as well as the exported amount of chemicals in products each year. The use of HFCs in this application started in 1996. The company has also provided algorithms to calculate leakage of HFC-134a and HFC-152a during the product lifetime.

The current calculation method provided by the company, used for reporting of emissions, has been compared to the Tier 2 method given in the IPCC Good Practice Guidance (2000). A preliminary comparison has also been made with the suggested method from the First Order Draft of the 2006 Guidelines, although these do not yet exist in their final version.

The basis for the calculation is the amount of HFC-134a and HFC-152a that is introduced into products used in Sweden, and subsequently leached from the products. Beside annual losses from products over time, the reported Swedish emissions in the CRF tables contain emissions from manufacturing, which are reported separately by the company. All comparisons presented below only refer to annual losses from products and does not include manufacturing losses.

In the national model, changes in accumulated amounts each year resulting from additional amounts of HFC in new products, as well as the annual decline in accumulated stock caused by emissions from operating systems, are taken into consideration. In order to calculate leakage according to the national method, the specific amount of HFC-134a and HFC-152a introduced in a particular year follows the decline in leakage according to Table 5.4 and Figure 5.3, where the leakage factors for the first 15 years are presented. The factors used in the national method were provided by the manufacturing company. According to the information provided by the manufacturing company, HFC-134a remains in products for a very long time (>50 years), while all HFC-152a is emitted during the first 10 years. The default factors from IPCC Good Practice Guidance and from the First Order Draft of the 2006 Guidelines are presented as comparison. These methods do not distinguish between HFC-species in suggested leakage rates.

Table 5.4 Leakage factor used in the national method compared to Good Practice Guidance default factors from GPG Table 3.18.

	National method		GPG table 3.18	1:st Draft 2006 GL
Year	Leakage factor	Leakage factor	Leakage factor	
	HFC-134a	HFC-152a	GPG: HFC	2006 GL: HFC
1	0.095	0.659	0.40	0.25
2	0.039	0.198	0.03	0.0075
3	0.030	0.083	0.03	0.0075
4	0.025	0.035	0.03	0.0075
5	0.022	0.015	0.03	0.0075
6	0.020	0.006	0.03	0.0075
7	0.019	0.003	0.03	0.0075
8	0.017	0.001	0.03	0.0075
9	0.016	0.001	0.03	0.0075
10	0.015	0.000	0.03	0.0075
11	0.015	0	0.03	0.0075
12	0.014	0	0.03	0.0075
13	0.013	0	0.03	0.0075
14	0.013	0	0.03	0.0075
15	0.012	0	0.03	0.0075

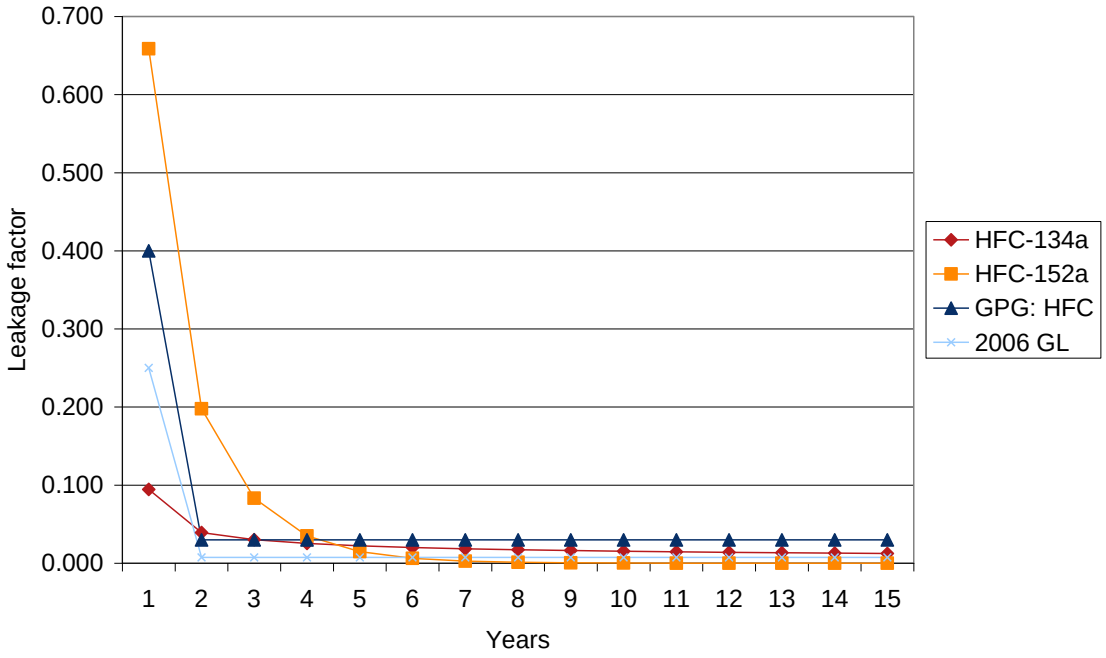

Figure 5.3 Leakage factors for HFC (GPG= IPCC Good Practice Guidance and 2006 GL= First draft of 2006 Guidelines) and individual HFC species according to the present national method.

The calculated emissions according to the national method, the GPG Tier 2 method and First Order Draft 2006 Guidelines are presented in Figure 5.4 and Table 5.5. The GPG Tier 2 default method results in a lower rate of emissions when calculated as emitted tons of HFC, and the draft 2006 Guidelines method results in an even lower rate of emissions. When calculating emissions as CO_2 equivalents, using the annual amount of HFC-134a and HFC-152a, respectively that remains in products in Sweden, the result is the opposite (Figure 5.4). The national method in this case results in lower emissions

than the GPG-method, due to the differing GWP-values of HFC-134a (1300) and HFC-152a (140). The suggested method from the First Order Draft of the 2006 Guidelines result in emissions estimates approximately equivalent to or somewhat higher than the national method for the first years, but lower during the later years.

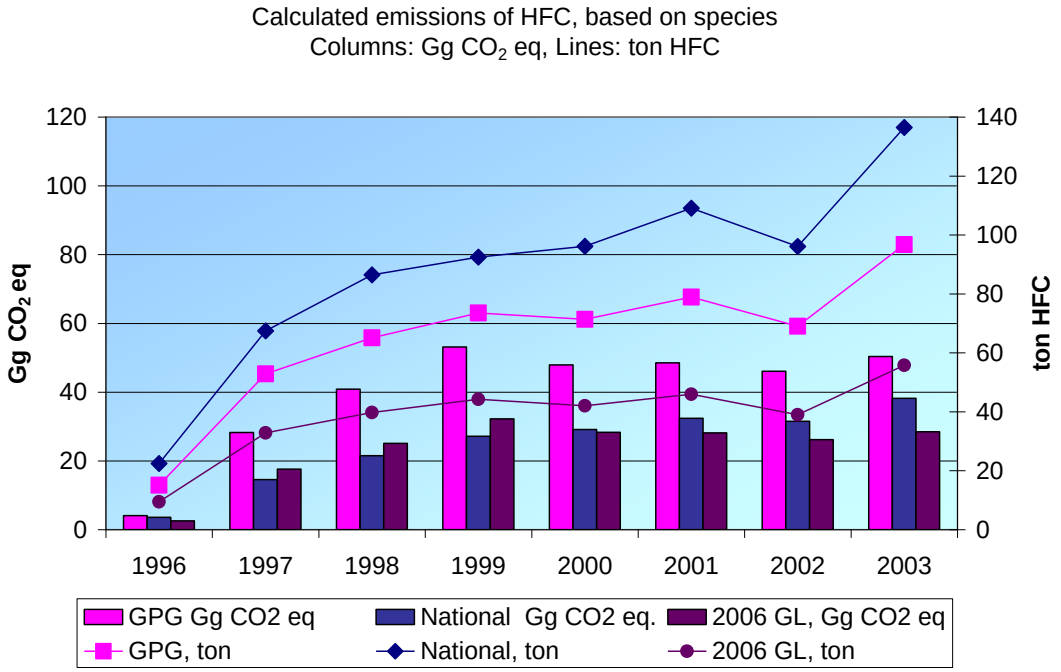

Figure 5.4 Estimated emissions of HFCs (ton and Gg CO_2 eq) from products in Sweden using national method, Tier 2 according to GPG and draft 2006 GL.

Table 5.5 Estimated emissions of HFCs (Gg CO_2 eq) from products in Sweden using national method, Tier 2 according to GPG and draft 2006 GL.

Emissions	National method		GPG (2000)		Draft 2006 GL		Sum of emissions, Gg CO_2 eq		
Gg CO_2 eq	HFC-134a	HFC-152a	HFC-134a	HFC-152a	HFC-134a	HFC-152a	National method	GPG	2006 GL
1996	1	3	2	2	1	1	4	4	3
1997	6	9	23	5	15	3	15	28	18
1998	11	11	36	5	22	3	22	41	25
1999	16	11	48	5	29	3	27	53	32
2000	18	12	42	5	25	3	29	48	28
2001	19	13	42	7	24	4	32	48	28
2002	20	11	41	5	23	3	32	46	26
2003	21	17	41	9	23	5	38	50	28
Sum	**111**	**87**	**276**	**43**	**163**	**26**	**198**	**319**	**189**

The ratio of HFC-134a to HFC-152a in products in Sweden has not been constant over the years. This means that since expected leakage rates are very different for the two chemicals, the resulting annual emissions from products vary according to chemical composition and product age in the national method. HFC in this application was not used before 1996 in Sweden.

Table 5.6. Calculated total emissions of HFC-134a and HFC-152a from products in Sweden according to the national method and according to Good Practice Guidance Tier 2 method.

Year	Emissions of HFC-134a and HFC-152a according to national method (Mg)	Emissions of total HFC according to Good Practice Guidance Tier 2 method (Mg)
1996	22.5	15.1
1997	67.4	52.8
1998	86.5	65.1
1999	92.5	73.5
2000	96.1	71.4
2001	109.1	78.9
2002	96.1	69.0
2003	136.4	96.7
Sum 1995-2003	**706.5**	**522.6**

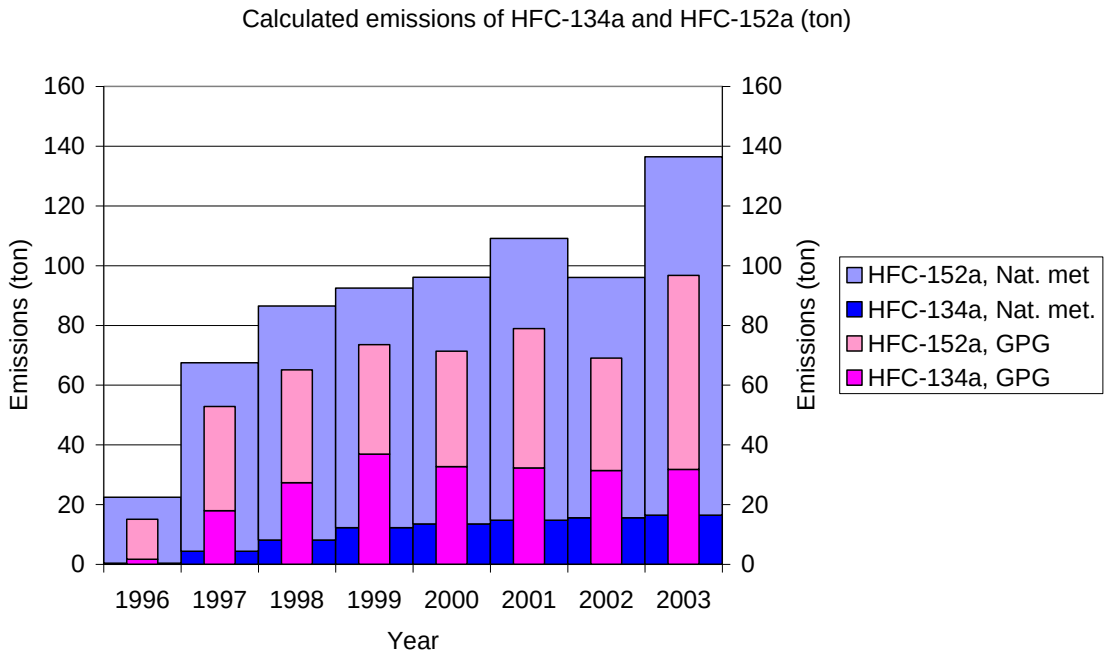

Figure 5.5 Estimated emissions of individual HFC-species (ton) by the national method and the GPG Tier 2 method.

Since the product life time of XPS-foam is very long, several decades, the total amounts of emitted chemical will however in the long run be comparable. The differences due to the different calculation methods lie primarily in estimates of how quickly the chemical is expected to be leached from the product.

From the above presented comparisons, it was decided to continue using the national method in the Swedish reporting to UNFCCC. The reasoning behind the decision is twofold; the national method is species specific, which has a considerable influence on the results, and secondly, due to the substantial change in recommended default leakage factors from the Good Practice Guidance (2000) and the first order draft of 2006 Guidelines it was considered to be better to wait for the final version of the 2006 Guidelines before taking a final decision on possible change of methods.

6 Revision of input data

6.1 Aggregation of sources in stationary refrigeration and air conditioning

To submission 2005 seven different sub-sources were accounted for in stationary refrigeration and air conditioning. All these sources were however not possible to update separately based on the annually available input data and other information. It was thus concluded that in order to make best use of available information and resources, some of these sources should be aggregated in the calculations. In the new version of the model three sub-sources in stationary refrigeration and air conditioning are treated separately in the calculation: domestic and household refrigeration, residential heat pumps, and "other stationary refrigeration".

6.2 Data from the Swedish Product Register

Data on fluorinated gases are available in the Swedish Product Register from 1995 and onwards. When studying the previous annual information from the Product Register as time series, some instances of unexplainable variations in the data occur. For some years there has also been diverging information when comparing data obtained directly from end-users and data from the Product Register, e.g. much less, or more, of a chemical was extracted from the Product Register than was reported from end-users.

A thorough scrutinising and comparison of inventory data with data from the Product Register was made by inventory experts and by Product Register staff, in order to trace possible discrepancies and missing data, either in the inventory or in the Product Register.

During this work it was discovered that data previously extracted from the Product Register had not been consistent over the years due to some erroneous coding of entries. Previously extracted data and a new, consistent extraction of time series data from the Product Register are shown in Table 6.1. Generally, the newly extracted data show that larger amounts of fluorinated substances have been imported into the country than was previously known.

Even though the new, improved time series on imported amounts of chemical from the Product Register show less inter-annual variations, there are still instances of inexplicable variations in data. These variations, with no known real reason, can be seen from the data itself (e.g. for HFC-134a for 1999-2002, where the amounts are 636, 953, 428 and 638 tons respectively). One explanation could be that substances imported and reported one year is stored and actually used in subsequent years. Information from importers and end-users show that the consumption has been smoother than reflected in the data. Thus, based on information obtained from other sources than the Product Register, such as importers and end-users, the data from the Product Register on annually imported amounts was adjusted. Adjustments were made both taking information on actually consumed amounts and other background information, such as general development of a specific application etc., into account. Data was also extrapolated to cover the years before 1995, where no data are available from the Product Register. In general, care was taken not to alter the total amount of the individual chemical species imported over the years, according to the Product Register.

The main action taken was to redistribute the substances more reasonably between years.

If there were clear indications that there had been an under-reporting to the Product Register, or if information was confidential, which is the case for some of the HFC- and PFC-species used in relatively small amounts, the information obtained from end-users substituted the data from the Product Register.

The adjusted time series of total import of individual chemicals are presented in Table 6.2.

Table 6.1 Imported amounts in bulk (ton) of fluorinated chemicals according to previous and updated information from the Product Register. C=reported as confidential from the Product Register.

Import in bulk (ton), previous information from the Product Register													
Year	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-143a	HFC-152a	HFC-227ea	HFC-365	Other HFC	CF4	C2F6	C3F8	SF6
1995	0	1.5	58.4	312.3	56.4	6.3	0	0	0	0	0	0.4	29.5
1996	0.3	4.9	44.0	304.4	34.5	4.3	0	0	0	0	0	1.5	28.8
1997	0	7.8	75.7	552.6	53.9	17.9	0	0	0	0.2	0	1.6	39.6
1998	0.2	22.3	133.4	818.0	91.7	6.0	0	0	0	0.8	1.5	0.6	89.7
1999	0	20.5	134.7	742.1	110.4	32.0	0	0	0	0.5	1.2	0	0
2000	0	2.4	43.5	420.0	33.1	2.6	0	0	0	0	0	0.8	26.8
2001	0	19.6	125.9	460.3	99.5	218.5	0	0	0	1.2	0.9	0.1	80.1
2002	0	65.8	303.5	655.2	178.5	335.4	0	0	2.3	1.6	1.1	1.2	46.6
2003	0	27.1	106.9	585.3	67.9	185.2	0	0	1.1	0	0	0	45.7

Import in bulk (ton), updated information from the Product Register													
Year	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-143a	HFC-152a	HFC-227ea	HFC-365	Other HFC	CF4	C2F6	C3F8	SF6
1995	0	8.6	77.8	865.9	74.4	65.4	0	0	0	0	0	0.4	27.1
1996	0.3	10.5	44.7	614.0	41.0	41.4	0	0	0	0	0	1.5	26.9
1997	0	14.8	61.6	805.7	47.4	15.6	0	0	0	0.2	0	1.6	36.5
1998	0.4	18.4	84.1	676.7	57.1	27.4	0	0	0	0.8	1.5	0.6	54.8
1999	1.2	19.2	94.5	635.5	58.8	24.8	0	0	0.3	0.5	1.2	0	49.5
2000	0.5	21.2	113.2	953.0	63.6	173.1	0	0	0.7	0.5	0	0.8	38.7
2001	C	19.4	98.5	428.4	66.5	217.9	0	0	C	1.2	0.9	0.1	49.4
2002	C	32.2	129.8	638.4	69.7	167.0	C	C	C	0.4	0.1	1.2	46.6
2003	C	27.1	106.8	611.8	67.9	256.7	C	C	C	C	C	C	45.7

Table 6.2 Adjusted time series on import in bulk (ton) based on data from the Product Register and additional sources of information.

Adjusted data on import in bulk (ton) used in submission 2006													
Year	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-143a	HFC-152a	HFC-227ea	HFC-365	Other HFC	CF4	C2F6	C3F8	SF6
1990	0	0	0	21.5	0	0	0	0	0	0	0	0	26.4
1991	0.1	0	0	30.9	0	0	0	0	0	0.1	0.0	0	26.4
1992	0.1	0	0	32.4	0	0	0	0	0	0.1	0.0	0	26.4
1993	0.1	0.9	11.7	129.9	11.2	21.8	0	0	0	0.1	0.3	0	26.3
1994	0.2	1.3	27.2	303.1	26.0	21.8	0	0	0	0.3	0.4	0	26.5
1995	0.2	6.5	38.9	433.0	37.2	21.8	0	0	0	0.5	1.0	0.4	31.5
1996	0.3	10.5	44.7	614.0	41.0	92.1	0	0	0	0.8	1.4	1.5	31.8
1997	0.2	14.8	61.6	635.5	47.4	233.0	0	0	0	0.8	1.5	1.6	38.8
1998	0.4	18.4	84.1	676.7	57.1	207.4	0	0	0	0.8	1.4	0.6	43.8
1999	0.5	19.2	94.5	805.7	58.8	174.8	0	0	0.3	0.2	1.0	0.7	47.6
2000	0.5	21.2	113.2	739.2	63.6	191.9	0	0	0.7	0.5	0.7	0.8	47.3
2001	0.6	19.4	98.5	642.3	66.5	217.9	1.3	0	0.1	0.6	0.7	0.1	42.8
2002	0.9	32.2	129.8	638.4	69.7	167.0	1.2	0.1	0.1	0.7	1.3	1.2	43.3
2003	0.9	27.1	106.8	611.8	67.9	256.7	1.6	0.3	0.3	0.4	0.9	1.7	47.9

6.3 Adjustment of input data for refrigeration and air conditioning sources

Due to some very large changes in data from the Product Register between the previous extracts and the new consistent time series, it was necessary to reassess earlier assumptions concerning the amount of fluorinated substances that annually have been consumed in the refrigeration and air conditioning sector.

Comparison between the information on refrigerant-related imported amounts of fluorinated gases from the Product Register and calculations made in the model, based on assumptions and information from other sources, indicated that there were imported amounts to the country that were not accounted for in the calculations. In order to account for these volumes of fluorinated substances, the amount of imported and used chemical in Sweden, derived from the adjusted time series, was assumed to be the correct data. From these adjusted data, the amounts of chemicals already accounted for in other applications, treated separately in the calculations, were subtracted. The resulting remainder of all refrigerant-related HFCs and PFCs from the Product Register that, according to the calculations in the model, are not accounted for elsewhere, were allocated as input data in the sub source "other stationary refrigeration". The chemicals concerned are HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a and PFC-218 (C_3F_8).

Recalculations of actual emissions from CRF 2.F.1, Refrigeration and air conditioning equipment, based on this methodology is presented and compared to the reported emissions from submission 2005 in Figure 6.1 and Table 6.3. By changing method, and thereby accounting more completely for fluorinated substances entering the country, actual emissions from this source increased by 50-65% for later years.

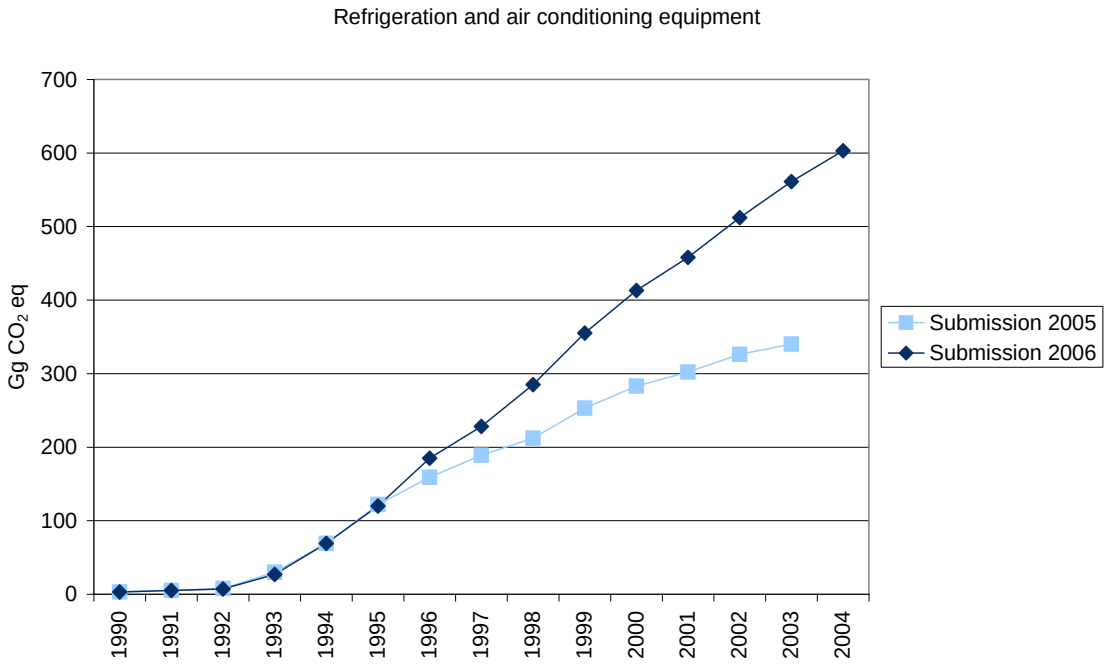

Figure 6.1 Estimated actual emissions of fluorinated gases from CRF 2.F.1, Refrigeration and air conditioning equipment, as reported in submission 2005 and the recalculated time series, Gg CO_2 equivalents.

Table 6.3 Estimated emissions from CRF 2.F.1 in submission 2005 and as recalculated time series, Gg CO_2 equivalents.

	2F1, Refrigeration and air conditioning equipment, Gg CO_2 equivalents	
Year	Submission 2005	Recalculated time series
1990	3	3
1991	5	5
1992	8	7
1993	30	27
1994	69	69
1995	122	120
1996	159	185
1997	189	228
1998	212	285
1999	253	355
2000	283	413
2001	302	458
2002	326	512
2003	340	561
2004		603

6.4 Adjustment of input data for SF_6

In accordance with the methodology for deriving amounts of refrigerant chemicals not accounted for in earlier submission, the same procedure was adopted for SF_6. When thus comparing the amounts of SF_6 accounted for in various applications with the adjusted time series based on consistent data from the Product Register, a rather large

annual volume of SF_6 remained unallocated. Sources of SF_6 emissions that are covered in the model calculations are the use in semi-conductor manufacture, in production of sound-proof windows, in magnesium foundries, in the production of gas-insulated switchgear, and as insulation in electrical equipment. Information from the Product Register did not indicate that any areas of use have not been covered and are missing from the calculations.

For all sources, except as insulation in electrical equipment, the levels of annual SF_6 consumption is comparatively easy to estimate with some confidence, since there are few end-users. It was thus concluded that the amounts of SF_6 not already accounted for elsewhere, most reasonably should be allocated to the electrical equipment source. However, even though information concerning SF_6 in electrical equipment is more difficult to judge concerning completeness, indications from end-users are that the difference between imported amounts according to the Product Register, and those already accounted for in the model, seems too large to annually be consumed for electrical insulation. One explanation to the difference could be that there is an under-reporting of exported SF_6 to the Product Register, in which no export at all of SF_6 is registered.

Since the question of the remaining amount of SF_6 at present could not be unambiguously solved, the unaccounted SF_6 from the Product Register was in the present recalculations allocated to be used as electrical insulation. The results of the recalculation, compared to the actual emissions in submission 2005 from CRF 2.F.8, Electrical equipment, are presented in Figure 6.2 and Table 6.4.

The rather jumpy and decreasing time series of emissions is explained by that emissions from both SF_6 used as insulation, and from the production of gas insulated switchgear, (the larger contribution during the first part of the time period) are included in the CRF-code.

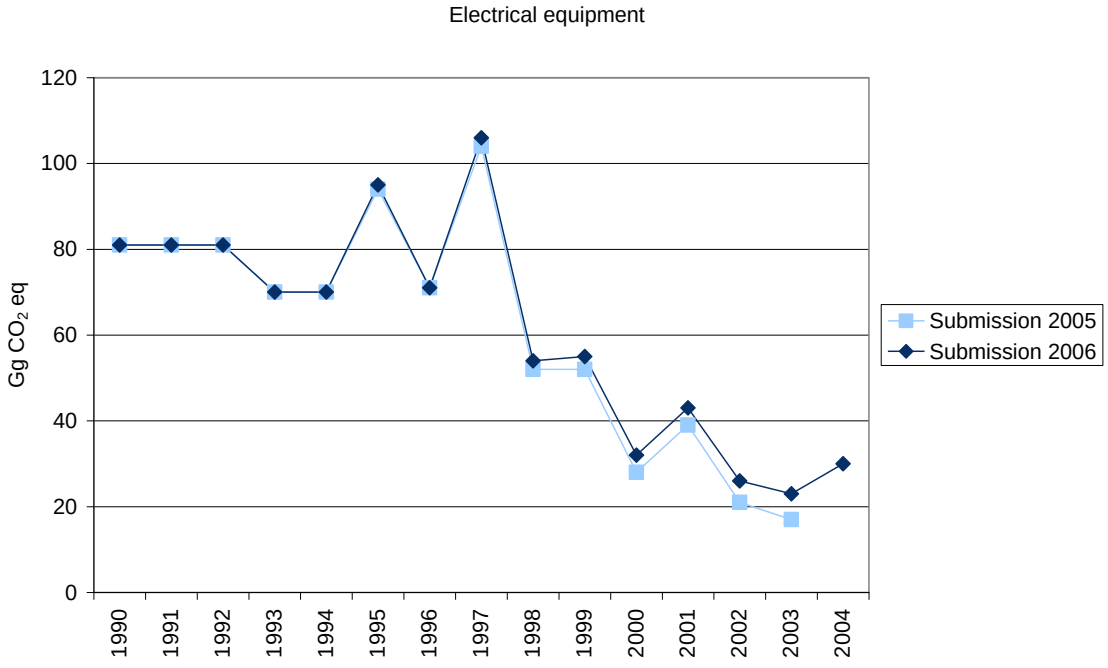

Figure 6.2 Estimated actual emissions of SF_6 from CRF 2.F.8, Electrical equipment as reported in submission 2005 and recalculated time series, Gg CO_2 equivalents.

Table 6.4 Estimated emissions of SF_6 from CRF 2.F.8 in submission 2005 and recalculated time series, Gg CO_2 equivalents.

	2.F.8 Electrical equipment, Gg CO_2 equivalents	
Year	Submission 2005	Recalculated time series
1990	81	81
1991	81	81
1992	81	81
1993	70	70
1994	70	70
1995	94	95
1996	71	71
1997	104	106
1998	52	54
1999	52	55
2000	28	32
2001	39	43
2002	21	26
2003	17	23

7 Development of new functionality in the model

Most of the information necessary for a complete reporting of fluorinated greenhouse gases according to the guidelines is already present as background data in the model. The model, however, needed to be developed with definitions and functions to select the necessary information from each source and combine and present it in an appropriate way. As the model until now only efficiently supported the compilation of annual actual emissions, this development in particular applies to the information in the background tables in the CRF reporting system.

New definitions relating to the reporting requirements were developed and included in all source specific data sheets. These cover all required data in the CRF background tables, such as the amounts of chemical filled in new manufactured products, accumulated stock and remaining amounts at decommissioning, as well as the emission factors for production, during use and at decommissioning.

Some adjustment and development relating to specific sources and calculation sheets were also made:

- an aggregation of sources in the group of stationary refrigeration and air conditioning, with previously seven separate sources/sheets were aggregated into three calculation sheets.
- the calculation method for semiconductor manufacture was revised, and is now in accordance with the Good Practice Guidance Tier 1 method.
- the calculations for metered dose inhalers and technical (other) aerosols were split on two separate sheets.

- the calculations of emissions of SF_6 from electrical equipment was split on two separate sheets, one for emissions from manufacture of gas insulated switchgear and one for electrical insulation.

- a harmonisation of the presentation of columns and calculations in the different sheets/sources in the model was also made, since source specific improvements and changes over time had made the calculation sheets develop along different lines.

- sheets for registering and adjustment of import and export data from the Product Register were added to the model. This enables the automatic calculation of volumes of chemicals not already accounted for in the model (as described for stationary refrigeration and for electrical insulation above).

The model before did not support the reporting of potential emissions regarding import and export of chemicals in bulk. The sheets for registering and adjustment of import and export data from the Product Register also enables a compilation of the import and export in bulk as a basis for the reporting of potential emissions in the CRF-system.

A functionality to include all necessary information from the model, for the purpose of being able to create one export file with all necessary data for reporting in the CRF-system was developed. This is done automatically by creating a file for export of data into the national database system (which is under development), which in turn will create the XML-files that are to be reported to the UNFCCC.

8 Recalculated time series

Several sources of emissions of fluorinated greenhouse gases were recalculated due to improved information and methodological changes during the course of this project. In addition to anticipated recalculations, some other sources were also updated since new and better information became available. Table 8.1 summarizes the changes introduced into the calculations.

Table 8.1 Summary of changes in CRF 2F, Consumption of halocarbons and SF_6, to submission 2006.

CRF code	Source	Change due to
2.F.P	Potential emissions, import and export in bulk	Recalculated (and extrapolated) for the entire time period due to improved background information from the Product Register
2.F.1	Stationary refrigeration and air conditioning equipment	Adjusted installed amounts for the entire time series due to improved background information from the Product Register
2.F.1	Mobile air conditioning	The number of new vehicles have been updated for the entire time series since improved statistics has become available
2.F.1	Mobile air conditioning, cars	HFC-134a from disposable containers for servicing of AC-equipment has been added
2.F.4	Metered dose inhalers	Improved statistics on activity data provided by the Swedish Medical Products Agency and the Swedish retailer for medical products, Apoteket
2.F.7	Semiconductor manufacture	Estimation methodology was changed from a national method to the Tier 1 method according to Good Practice Guidance
2.F.8	Electrical equipment	Adjusted installed amounts for the time period 1995-2003 due to improved background information from the Product register

The results of the methodological changes and other improvements are that calculated actual emissions of fluorinated greenhouse gases, as reported in CRF 2F, has increased substantially in submission 2006 compared to submission 2005 (Figure 8.1 and Table 8.2). The increases between the two submissions in estimated actual emissions for the years 2000-2003 are 30-40%, calculated as CO_2 equivalents. The largest single contributing factor to this increase is the use of the improved statistics from the Product Register as complementary input data for stationary refrigeration and air conditioning equipment in CRF 2F1.

The estimated changes in actual emissions arise from the recalculation in the individual source categories (change/year in Gg CO_2 eq for later years):

- 2.F.1., Refrigeration and air conditioning equipment (+ 150-200)
- 2.F.4., Aerosols and Metered Dose Inhalers (- 3-4)
- 2.F.7., Semiconductor manufacture (- 10)
- 2.F.8., Electrical equipment (+ 5)

For the sources 2.F.2, Foam blowing, 2.F.3, Fire extinguishers and 2.F.9, Other, no changes were introduced and the time series for these were thus not recalculated. The changes in estimated emissions from individual sources are presented in Figure 8.2 - Figure 8.5 and in Table 8.3, while the estimated emissions from sources with unchanged time series are presented in Figure 8.6 and Table 8.4.

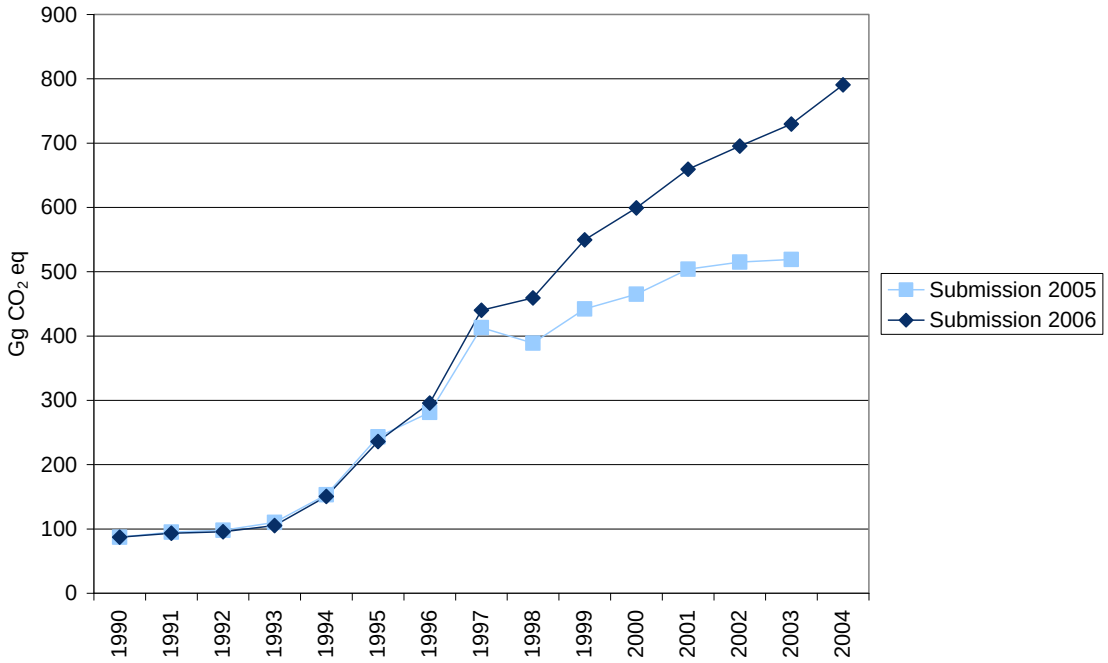

Figure 8.1 Reported actual emissions from CRF 2F, Consumption of halocarbons and SF_6, in submission 2005 and recalculated time series in submission 2006.

Table 8.2 Reported actual emissions from CRF 2F, Consumption of halocarbons and SF_6, in submission 2005 and recalculated time series in submission 2006.

	2F, actual emissions, Gg CO_2 equivalents		
Year	Submission 2005	Recalculated time series	%change
1990	87	87	0
1991	95	93	-2
1992	98	95	-3
1993	110	105	-4
1994	153	150	-2
1995	243	236	-3
1996	281	296	5
1997	413	440	7
1998	389	459	18
1999	442	550	24
2000	465	599	29
2001	504	659	31
2002	515	695	35
2003	519	729	41
2004	-	791	

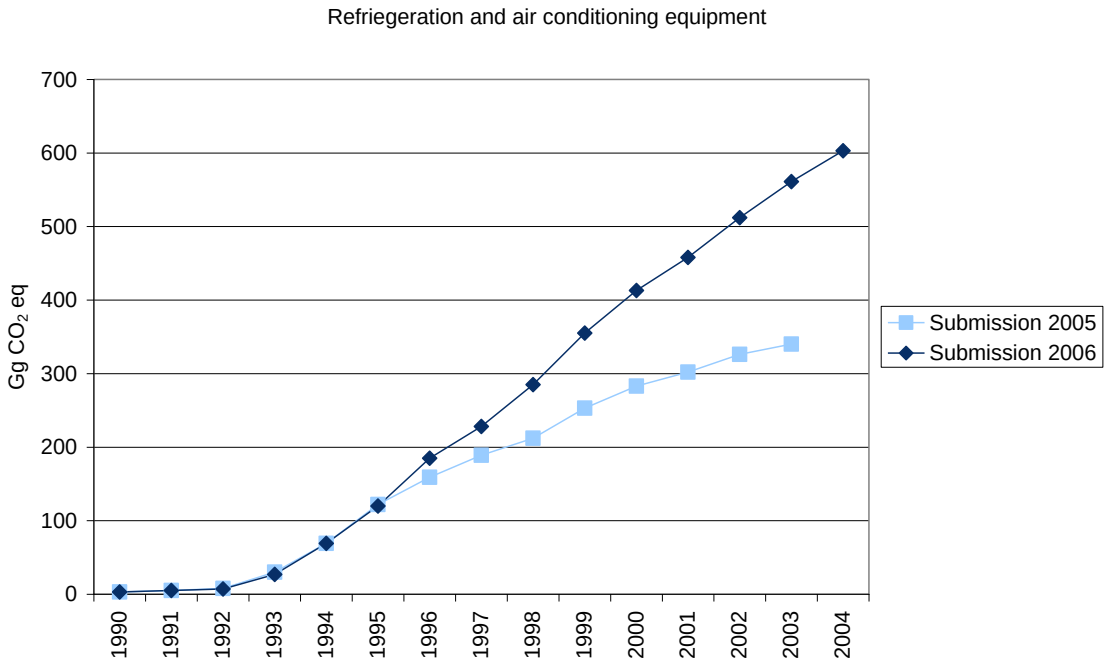

Figure 8.2 Refrigeration and air conditioning equipment, CRF 2F1, comparison of submission 2005 and recalculated time series to submission 2006.

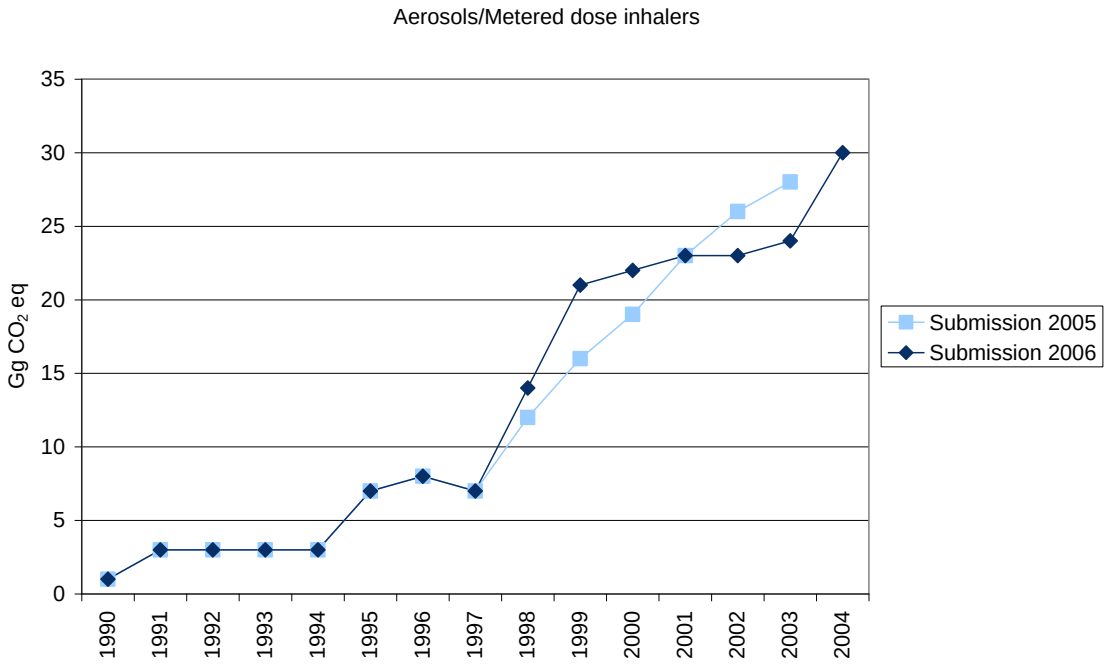

Figure 8.3 Aerosols/ Metered dose inhalers, CRF 2F4, comparison of submission 2005 and recalculated time series to submission 2006.

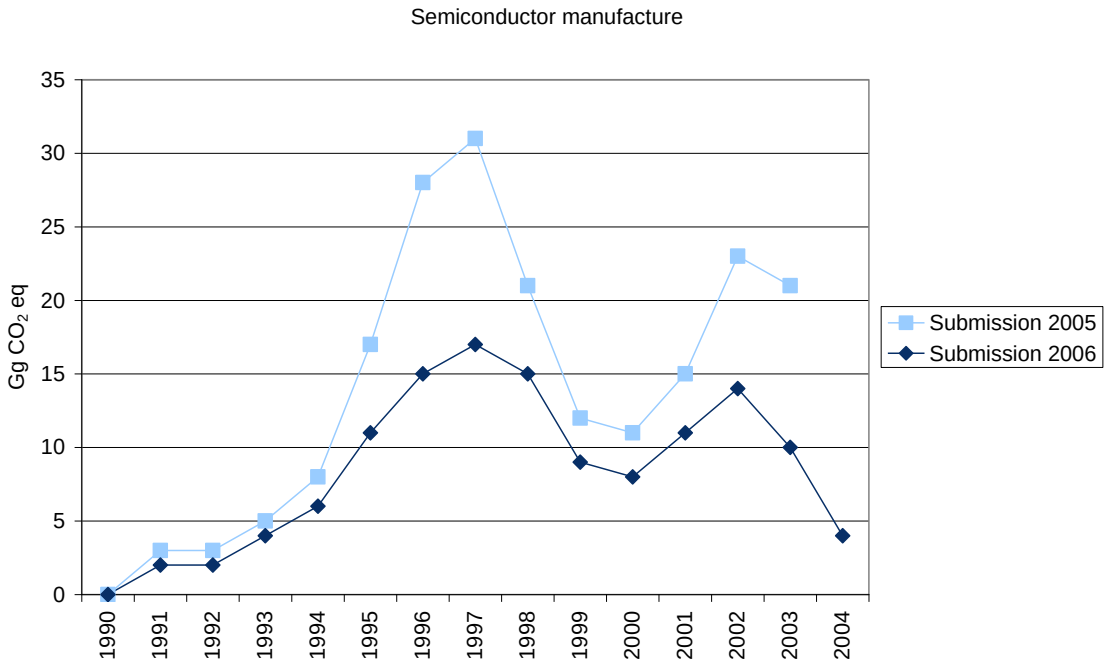

Figure 8.4 Semiconductor manufacture, CRF 2F7, comparison of submission 2005 and recalculated time series to submission 2006.

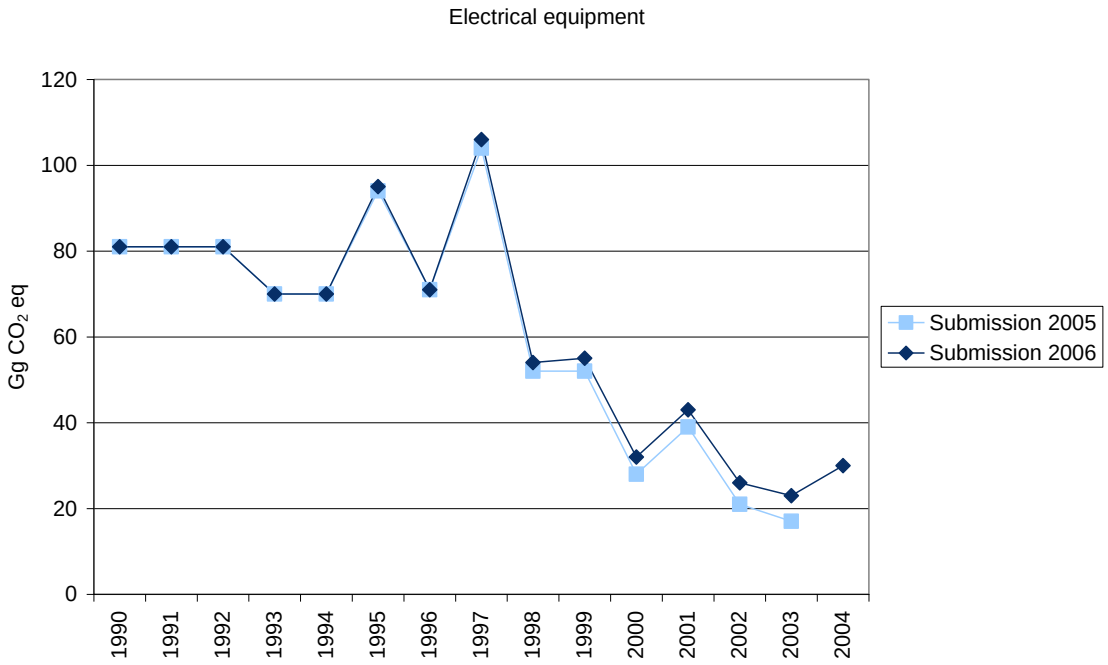

Figure 8.5 Electrical equipment, CRF 2F8, comparison of submission 2005 and recalculated time series to submission 2006.

Table 8.3 Comparison of recalculated time series, submissions 2005 and 2006, Gg CO_2 equivalents.

2F1	Refrigeration and AC		
	Submission 2005	Submission 2006	% change
1990	3	3	0
1991	5	5	0
1992	8	7	-13
1993	30	27	-10
1994	69	69	0
1995	122	120	-2
1996	159	185	16
1997	189	228	21
1998	212	285	34
1999	253	355	40
2000	283	413	46
2001	302	458	52
2002	326	512	57
2003	340	561	65
2004	-	603	

2F4	Aerosols/ Metered Dose Inhalers		
	Submission 2005	Submission 2006	% change
1990	1	1	0
1991	3	3	0
1992	3	3	0
1993	3	3	0
1994	3	3	0
1995	7	7	0
1996	8	8	0
1997	7	7	0
1998	12	14	17
1999	16	21	31
2000	19	22	16
2001	23	23	0
2002	26	23	-12
2003	28	24	-14
2004	-	30	

2F7	Semiconductor manufacture		
	Submission 2005	Submission 2006	% change
1990	0	0	0
1991	3	2	-33
1992	3	2	-33
1993	5	4	-20
1994	8	6	-25
1995	17	11	-35
1996	28	15	-46
1997	31	17	-45
1998	21	15	-29
1999	12	9	-25
2000	11	8	-27
2001	15	11	-27
2002	23	14	-39
2003	21	10	-52
2004	-	4	

2F8	Electrical Equipment		
	Submission 2005	Submission 2006	% change
1990	81	81	0
1991	81	81	0
1992	81	81	0
1993	70	70	0
1994	70	70	0
1995	94	95	1
1996	71	71	0
1997	104	106	2
1998	52	54	4
1999	52	55	6
2000	28	32	14
2001	39	43	10
2002	21	26	24
2003	17	23	35
2004	-	30	

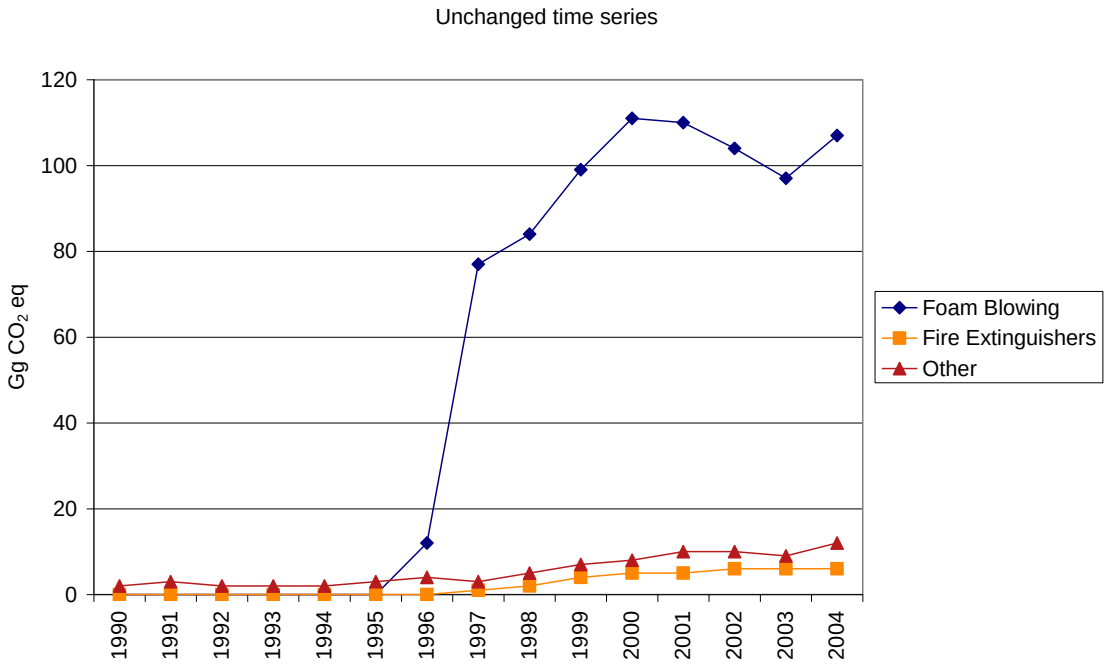

Figure 8.6 Unchanged time series of emissions of fluorinated gases to submission 2006.

Table 8.4 Unchanged time series of emissions of fluorinated gases to submission 2006, Gg CO_2 equivalents.

	2F2	2F3	2F9
	Foam Blowing	Fire Extinguishers	Other
1990	0	0	2
1991	0	0	3
1992	0	0	2
1993	0	0	2
1994	0	0	2
1995	0	0	3
1996	12	0	4
1997	77	1	3
1998	84	2	5
1999	99	4	7
2000	111	5	8
2001	110	5	10
2002	104	6	10
2003	97	6	9
2004	107	6	12

9 Discussion and conclusions

One of the most important results from the project is that the annually available information from the Product Register at the Swedish Chemicals inspectorate is now used at its full potential in the calculations of emissions of fluorinated greenhouse gases in Sweden. This was not the case in the previous calculations, where the data from the Product Register was mainly used for the reporting of potential emissions, and as a general comparison of estimated levels of consumed chemicals. From this inclusion of additional and complementary input data into the calculations follows that the completeness in the inventory has improved.

Improvements were also made for some individual source categories. A methodological change was introduced for calculations of emissions from semiconductor manufacture, which is now in accordance with Good Practice Guidance Tier 1. For other sources, as discussed above, improvements in input data resulted in recalculations of the whole time series 1990-2003. The calculation method for emissions of HFC from XPS (Foam blowing) was studied, but it was decided that the national method should be used until the final version of the IPCC 2006 Guidelines is published, since there are indications that the methodological guidance might change compared to the presently available guidelines.

The various improvements introduced into the calculations have together resulted in increased emission estimates of fluorinated greenhouse gases in Sweden. The increases are substantial compared to submission 2005, approximately 30-40% in later years, calculated as CO_2-equivalents. The largest single contributing factor to this increase is the use of the improved statistics from the Product Register as complementary input data for refrigeration and air conditioning equipment in CRF 2F1.

Even though several essential improvements were made during the course of the project, some issues remain to be solved. This especially applies to the circumstances concerning decommissioning of products. Since the consumption of fluorinated gases did not become important until the mid 1990´s for most sources, the estimated life time of early equipment is starting to be reached. This means that decommissioning of products with accumulated amounts of chemicals installed is just starting to occur on a larger scale. The decommissioning practices and possible destruction or recovery of chemicals are not well known and need further study.

There are also some uncertainties associated with the quantification of exported amounts of chemicals from the country. Errors in these estimates will have a direct influence on the calculated consumption and estimated emissions, which, if there is an underreporting of exports, become too high. An additional effort to estimate the accurate extent of exports of fluorinated chemicals would increase the accuracy of the emissions estimates.

The adjustments and introduction of new functionality in the model has resulted in a more accurate, efficient and safe handling of data and calculations. Less manual operations are needed which reduces the risk of introducing unintentional manual errors.

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