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# Danish consumption and emission of F-gases

## Year 2017

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# Foreword

On behalf of the Danish Environmental Protection Agency (Danish EPA), Provice has conducted the emission calculation and reporting of Danish emission of F-gases. The emission calculation is provided in continuation of previous years emission calculations /32/ and references herein.

The emission calculations of F-gases are extrapolated to 2030 in compliance with the revised methods from IPCC.

Danish EPA and Department of Environmental Science, Aarhus University, and Provice assess the F-gas emission calculation and reporting. Further, the draft report is sent to central stakeholders for comments and general information. The assessment group consist of:

- Mikkel Aamand Sørensen, Danish EPA
- Ole-Kenneth Nielsen, Department of Environmental Science, Aarhus University
- Tomas Sander Poulsen, Provice ApS
- Kim Valbum, AKB
- Nikolaj Stubkjær Nilsen, Confederation of Danish Industries (DI)

The objective of the project was to quantify the Danish consumption and actual emissions of F-gases (HFCs, PFCs, and $SF_6$) for 2017.

The emission calculation is partly conducted to fulfil Denmark's international obligations to provide data and information on F-gas emissions, and partly to asses the Danish trend in consumption and emissions of HFCs, PFCs, and $SF_6$. Examples of previous reporting of Danish emissions is given in reference /18, 19, 21, 23, 24, 26, 28, 31/, and most recently, in reference /32/.

The so-called F-gases are potent greenhouse gases and cause an increase in the ability of the atmosphere to retain surplus heat radiated from the earth. Consequently, the temperature of the earth's surface and lower atmosphere is rising and this leads to climate changes. There are several ozone-depleting substances that also have a strong greenhouse effect. These substances are regulated under the Montreal Protocol.

The potential effect of different greenhouse gases varies from substance to substance. This potential is expressed by a GWP value (Global Warming Potential). F-gases (HFCs, PFCs and $SF_6$) that do not have an ozone-depleting effect, but have high GWP values are regulated by the Kyoto Protocol under the United Nation Climate Change Convention, and in the EU regulation.

# Summary

## 1.1 Full compliance with IPCC requirements

A number of new requirements to F-gas emission calculation have recently been introduced by United Nations Intergovernmental Panel for Climate Change (IPCC). The requirements comprise new F-gases, new emission factors for certain F-gases, new application areas and changes in product lifetime. Since 2015, the emission calculation has been in compliance with the new revised IPCC methodologies.

In 2017, a reduction of the emission factors for 2.F.1.f stationary A/C is introduced. From 2010 and forward, the emission factor is reduced from 10% to 3% in operation. This change is introduced to meet the later data for leakage rates from stationary A/C, which indicate levels of 1-3%. Further the new emission factor is in same range to the emission factor uses by the other Nordic countries (between 2-6%). The revision and update has changed the historical emissions from 2010 and forth.

Also, in 2017, a separate subcategory for heat pumps is introduced with consumption starting from 2009. It provides a more accurate picture of consumption and emissions related to HFC-407C and HFC-410A.

Finally, the reference years for calculating *emission from stock* are changed according to the IPCC guidance. Year T1 for emission from stock is now same year as product is placed on the market instead of the year after product is placed on the market.

The revision comprises the full time period 1995-2030 and assures consistency in the methodology as outlined in IPCC's guidance.

Appendix 3 describes the specific emission factors, etc. used for emission calculations.

## 1.2 Danish consumption and emission of F-gases

### 1.2.1 Import

*HFCs*
Overall, there has been a decrease in consumption of all refrigerants.

The total bulk import reported by importers (minus re-export) of pure HFCs and HFC blends is 268,3 tonnes. Compared to 2016, where the import was 304,1 tonnes, the total import has decreased with 12 % and approx. 36 tonnes. The recent years have a clear decreasing trend.

The main decrease of bulk import of HFC's is caused by a 14% decrease in imported HFC 134a and 81% decrease of imported HFC-507. Thus, there was a 18% increase of HFC-404A and a 12% increase of HFC-410A.

The bulk import of HFC-134a decreased with 20,5 tonnes compared to 2016. The bulk import was 124,4 tonnes HFC-134a.

The import of HFC-404A has increased approx. 12.1 tonnes compared to 2016. The total consumption was 80,2 tonnes in 2017. There is not found an explanation for the increase. More new installations of commercial refrigeration systems are based on $CO_2$ or other alternative refrigerants and the legal requirements favouring low GWP alternatives, should logically lead to a decrease.

The import of HFC-410A has increased from 19,7 to 22,1 tonnes. HFC-410A is used in various heat pumps and the increased import is probably related to more service of installed heat pumps.

The import of HFC-407C was 30,9 tonnes in 2017, which is a decrease of 6,6 tonnes compared to 2016. HFC-407C is a substitute refrigerant for HCFC-22 in refrigerators and former refrigerant in heat pumps.

The import of HFC-507A has decreased significantly with 8 tonnes compared to 2016. The total import was 2,6 tonnes in 2017.

*$SF_6$*

The overall consumption of $SF_6$ in 2017 was 2,7 tonnes. This is an increase of approx. 0,4 tonnes compared to 2016. Consumption of $SF_6$ derives mainly from use for power switches in high-voltage power systems. Only a very small amount is used for research, laboratories, and optics fibre production

*PFCs*

The consumption of PFCs was limited to 0,15 tonnes PFC-14 in 2017. In previous years the PFC consumption has only been related to etching in optics fibre production and as a part of the refrigeration blend HFC-413A (contains 9% perflourpropan). Also in 2017 a small amount of PFC-14 was reported for production of low temperature freezer appliances (minus 60 degree). According to the Danish regulation of f-gases, this use requires a grant of exemption.

*GWP*

The EU F-gas Regulation includes the provision for the phase down of the quantities of F-gases (and blends) placed on the EU market by producers and importers. By 2030, the GWP target is a reduction to 21% with 2015 as reference year.

The Danish GWP development in F-gases placed on the Danish market is as following:

| | HFC/PFC | SF6 | SUM |
|---|---|---|---|
| **2017** | 620.689 | 62.837 | 683.525 |
| **2016** | 670.894 | 70.110 | 741.004 |
| **2015** | 656.914 | 33.516 | 690.430 |

**TABLE 1**
**GWP OF F-GASES PLACED ON DK MARKET, TONNES**

### 1.2.2 Emission

The GWP-weighted actual emissions of HFCs, PFCs, and $SF_6$ in 2017 were 482.000 tonnes $CO_2$ equivalents. The emissions have decreased with 126.000 $CO_2$ equivalents compared to 2016, where the corresponding emissions were 608.000 tonnes $CO_2$ equivalents as seen in table 3.

The total emissions in 2017 have a decrease for HFCs, PFCs and $SF_6$ compared to 2016.

The F-gas emission accounts for approx. 1-1.5% of the total national GWP emission from all sources.

In the table below, consumption, actual emissions and stock in products are summarised.

| Source | Substance | Consumption and imports, DK, tonnes | Stock, tonnes | Actual emis-sions, tonnes | GWP contribution, CO2 eqv. tonnes | GWP contribution in total, CO2 eqv. tonnes |
|---|---|---|---|---|---|---|
| Refrigerants for commercial stationary refrigerators and A/C systems | HFC-134a | 72,5 | 258,7 | 30,7 | 43.849 | |
| | HFC-404A | 75,6 | 336,6 | 44,5 | 174.499 | |
| | HFC-401A | 0,0 | 0,0 | 0,0 | 0 | |
| | HFC-402A | 0,0 | 0,0 | 0,0 | 0 | |
| | HFC-407C | 30,9 | 520,0 | 12,7 | 30.207 | |
| | HFC-507 | 2,6 | 54,7 | 6,5 | 26.072 | |
| | Other HFCs | 30,1 | 418,0 | 13,3 | 27.835 | |
| | PFC | 0,0 | 0,0 | 0,0 | 0 | |
| | All substances | | | | | 302.461 |
| Refridgerants in household fridges/freezers | | | | | | |
| | HFC-134a | 3,8 | 238,2 | 2,2 | 3.211 | |
| | HFC-404a | 1,8 | 36,5 | 0,4 | 1.569 | |
| | PFC-14 | 0,0 | 0,2 | 0,0 | 7 | |
| Insulationfoam in household fridges/freezers | HFC-134 | 0,0 | 21,0 | 0,1 | 87 | |
| | HFC-152 | 0,0 | 0,0 | 0,0 | 0 | |
| | All substances | | | | | 4.875 |
| Refrigerants for mobile A/C systems | HFC-134a | 43,0 | 164,3 | 43,0 | 61.433 | 61.433 |
| Refrigerated vans and lorries | HFC-134a | 0,1 | 0,3 | 0,1 | 164 | |
| | HFC-404A | 2,8 | 22,9 | 4,9 | 19.407 | |
| | HFC-402A | 0,0 | 0,0 | 0,0 | 0 | |
| | All substances | | | | | 19.572 |
| Aerosol sprays etc. | HFC-134a | 5,0 | 0,0 | 6,0 | 8.580 | 8.580 |
| Thermostates | HFC-152a | 0,0 | 80,3 | 5,7 | 710 | 710 |
| MDI | HFC-134a | 0,0 | 0,0 | 5,5 | 7.826 | 7.826 |
| System foam | HFC-134a | 0,0 | 0,0 | 0,0 | 0 | |
| | HFC-152a | 0,0 | 0,0 | 0,0 | 0 | |
| | HFC-365 | 0,0 | 0,0 | 0,0 | 0 | |
| Liquid cleaners | PFC | 0,0 | 0,0 | 0,0 | 0 | |
| Fibre optics | PFC-14 | 0,1 | 0,0 | 0,1 | 1.086 | |
| | PFC-318 | 0,0 | 0,0 | 0,0 | 0 | |
| | HFC-23 | 0,0 | 0,0 | 0,0 | 0 | |
| | All substances | | | | | 1.086 |
| Double glazing | SF6 | 0,0 | 6,5 | 2,5 | 57.635 | 57.635 |
| High-voltage power switches | SF6 | 2,6 | 97,3 | 0,6 | 13.806 | 13.806 |
| Laboratories | SF6 | 0,2 | 0,0 | 0,2 | 4.013 | 4.013 |
| Total | HFCs | 268,3 | 2.151,6 | 175,7 | 405.449 | |
| | PFCs | 0,2 | 0,2 | 0,1 | 1.094 | |
| | SF6 | 2,8 | 103,7 | 3,3 | 75.454 | |
| GWP contribution | Total | | 2.255,5 | 179,1 | 481.996 | 481.996 |

**TABLE 2**
**CONSUMPTION, ACTUAL EMISSIONS, STOCK, ACTUAL EMISSION AND GWP CONTRIBUTION FROM F-GASES, TONNES**

In Figure 1, the relative contributions of HFCs, PFCs, and $SF_6$ to the total emission in $CO_2$-equivalents are shown for application areas for 2017.

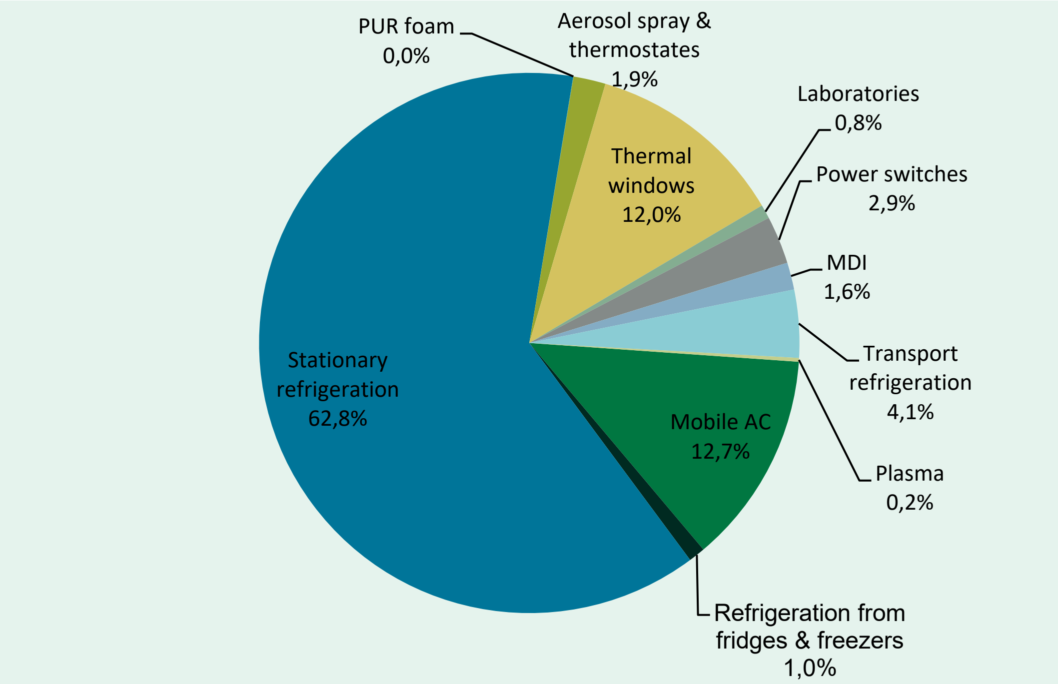


**FIGURE 1**
**RELATIVE DISTRIBUTION OF GWP EMISSIONS BY APPLIACTION AREA, 2017**

The figure shows the emissions from refrigerants used in commercial stationary refrigerators account for the largest GWP contribution. This source covers 62,8 per cent of the total actual emission of F-gases in 2017. The main contribution is from HFC-404A that accounts for 174.500 tonnes $CO_2$-equivalents, which is 36,2 per cent of the total F-gas emissions in 2017.

The second-largest source for GWP contribution occurs from mobile A/C (MAC), accounting for 61.000 tonnes $CO_2$-equivalents, which is 12,7 per cent.

The third-largest source accounting for 12 per cent for GWP contribution is from $SF_6$ released from stock in double glazed windows.

Emissions of HFC-134a from stock in insulating foam in fridges and freezers contribute with 0 per cent and emissions of HFC-134a and HFC-404A from transport refrigeration contribute with 4,1 per cent of the total GWP contribution.

The total HFC's contribution is estimated to comprise 84.1 per cent of the overall GWP contribution in 2017, emissions of $SF_6$ is 15,7 per cent and emissions of PFCs contribute with less than 0,2 per cent.

*HFCs*
Actual emissions of HFCs have been calculated to 405.449 tonnes $CO_2$ equivalents. In 2016, emissions were 503.576 tonnes $CO_2$ equivalents. It is a decrease of 98.127 tonnes $CO_2$ equivalents. Even though there are several sources with a smaller increase of emissions, there is a total net decrease because of lower consumption and emission from commercial refrigeration stock of HFC-404A.

*$SF_6$*
Actual emissions have been calculated to a GWP contribution of 75.454 tonnes $CO_2$ equivalents. In 2016, emissions were 104.172 tonnes $CO_2$ equivalents. The decrease occurs from reduced stock emissions from windows.

*PFCs*
The emission of PFCs origins from stock emission from commercial refrigeration containing HFC-413A (contains 9 per cent Perflourpropan). The total GWP-weighted PFC emission is 1.094 tonnes $CO_2$ equivalents.

### 1.2.3 Trends in total GWP contribution from F-gases

The figure below shows the trend in Danish GWP contributions from HFCs, PFCs, and $SF_6$ for 1992-2017. The differences from the present calculations of the total GWP value compared with earlier calculation methods are illustrated in the figure.

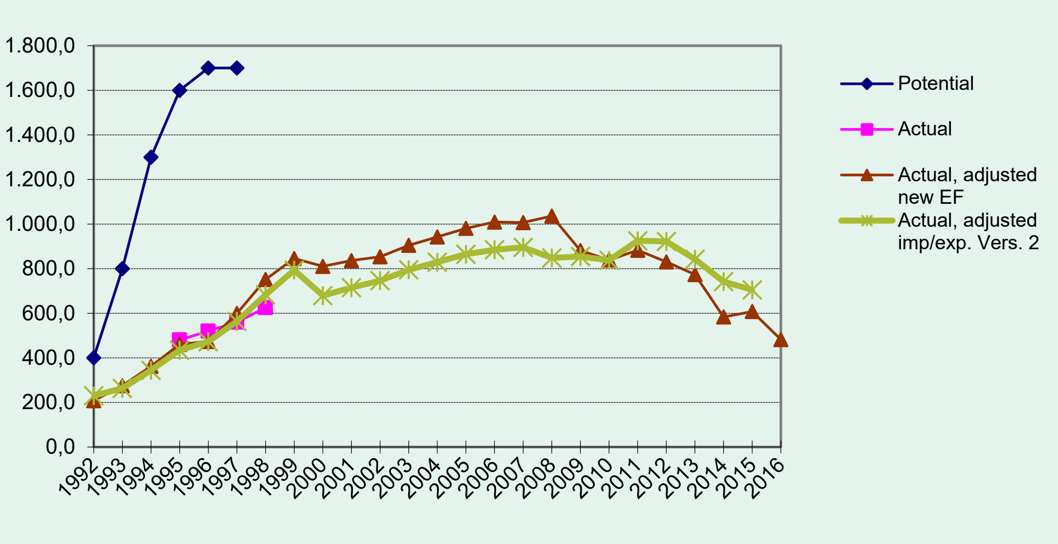


**FIGURE 2**
**GWP-WEIGHTED POTENTIAL, ACTUAL AND, ADJUSTED ACTUAL EMISSIONS 1992-2016, 1.000 TONNES $CO_2$ EQUIVALENTS**

The figure shows that the GWP emission has increased from 1992-2008 and peaked in 2012, where it display a decreasing trend from 2013 onwards.

The 2017 emission calculation and figure 2 is revised with a reduced emission factor for 2.F.1.b – stationary A/C from 10% leakage rate to 3% leakage rate from 2010. It impacts the figures from 2010 and onwards. The reduced emission factor corresponds now with the emission factor level used by the other Nordic countries where the emission factors range from 1-6%. The decision of implementing the new reduced emission factor from 2010 is based on expert judgement of when the technologies improved and next generation units were introduced to the market.

Further there are made a methodological revision. The reference years for calculating *emission from stock* are changed according to the IPCC guidance. Year T1 for emission from stock is now same year as product is placed on the market instead of the year after product is placed on the market. The impact influent on the calculation of emission form operation, because stock reference over lifetime had changed.

Development in the GWP contribution for the period can also be seen in Table 3 below.

| Year | Potential | Actual | Actual, adjusted imp/exp. Vers. 2 | Actual, adjusted new EF |
|---|---|---|---|---|
| 1992 | 400,0 | | | |
| 1993 | 800,0 | | 230,3 | 207,9 |
| 1994 | 1.300,0 | | 263,2 | 275,4 |
| 1995 | 1.600,0 | 480,0 | 344,1 | 362,3 |
| 1996 | 1.700,0 | 520,0 | 434,7 | 460,5 |
| 1997 | 1.700,0 | 560,0 | 472,5 | 473,3 |
| 1998 | | 625,0 | 563,7 | 599,3 |
| 1999 | | | 682,8 | 751,4 |
| 2000 | | | 793,3 | 845,6 |
| 2001 | | | 679,0 | 810,3 |
| 2002 | | | 715,0 | 836,1 |
| 2003 | | | 746,0 | 853,3 |
| 2004 | | | 795,0 | 904,8 |
| 2005 | | | 829,0 | 942,3 |
| 2006 | | | 865,0 | 980,7 |
| 2007 | | | 884,4 | 1.009,1 |
| 2008 | | | 895,7 | 1.006,9 |
| 2009 | | | 848,4 | 1.035,8 |
| 2010 | | | 854,4 | 881,4 |
| 2011 | | | 837,7 | 838,7 |
| 2012 | | | 925,2 | 882,9 |
| 2013 | | | 922,4 | 830,4 |
| 2014 | | | 842,7 | 773,6 |
| 2015 | | | 742,0 | 583,4 |
| 2016 | | | 705,0 | 607,8 |
| 2017 | | | | 482,0 |

**TABLE 3**
**TOTAL GWP-CONTRIBUTION FROM HFC'S, PFC'S, $SF_6$, 1992-2017 DETERMINED ACCORDING TO THE FOUR DIFFERENT METHODS OF CALCULATION APPLIED DURING THIS PERIOD, 1 000 TONNES $CO_2$ EQUIVALENTS.**

The table 4 below shows the time series 1993-2017 and the 2017-2030 projections of F-gases as GWP contributions.

The emission projections are determined by assuming a 'steady state' consumption using 2017 as the reference year and the cut-off dates for the phasing-out of specific substances, cf. the Statutory Order regulating certain industrial greenhouse gases /30/.

The calculated GWP contribution expresses actual emissions, adjusted for imports and exports.

| Year | HFC-134a | HFC-152a | HFC-404A | HFC-401A | HFC-402A | HFC-407C | HFC-507 | HFC-23 | Other HFCs | PFCs | SF6 | Total pr year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 106,3 | 3,7 | - | - | - | - | - | - | - | - | 97,8 | 207,9 |
| 1994 | 148,7 | 5,7 | 2,8 | - | 0,2 | - | - | - | - | 0,1 | 118,0 | 275,4 |
| 1995 | 228,8 | 5,4 | 21,8 | - | 1,5 | - | - | - | 0,4 | 0,6 | 103,8 | 362,3 |
| 1996 | 318,2 | 4,0 | 69,1 | - | 4,6 | - | - | - | 3,5 | 2,1 | 59,2 | 460,5 |
| 1997 | 272,0 | 1,9 | 107,3 | 0,0 | 8,3 | 0,4 | 0,5 | - | 7,2 | 5,2 | 70,5 | 473,3 |
| 1998 | 332,6 | 1,2 | 170,4 | 0,0 | 9,5 | 2,9 | 3,7 | - | 9,8 | 11,5 | 57,6 | 599,3 |
| 1999 | 381,6 | 4,7 | 249,6 | 0,1 | 10,8 | 6,2 | 7,3 | - | 12,4 | 15,7 | 62,9 | 751,4 |
| 2000 | 397,7 | 2,0 | 313,2 | 0,1 | 11,9 | 12,8 | 11,4 | - | 17,0 | 22,6 | 56,8 | 845,6 |
| 2001 | 398,5 | 1,6 | 284,1 | 0,1 | 11,6 | 19,4 | 18,4 | - | 20,1 | 27,9 | 28,6 | 810,3 |
| 2002 | 399,8 | 1,6 | 307,1 | 0,1 | 10,3 | 25,9 | 18,2 | - | 21,2 | 28,0 | 24,0 | 836,1 |
| 2003 | 359,6 | 0,2 | 348,4 | 0,1 | 8,2 | 39,3 | 21,8 | - | 20,8 | 24,6 | 30,1 | 853,3 |
| 2004 | 370,7 | 0,8 | 375,9 | 0,1 | 7,8 | 52,7 | 23,4 | - | 21,5 | 20,5 | 31,5 | 904,8 |
| 2005 | 353,9 | 0,2 | 430,3 | 0,1 | 6,8 | 64,3 | 25,0 | - | 22,3 | 18,8 | 20,7 | 942,3 |
| 2006 | 349,2 | 0,4 | 451,4 | 0,1 | 6,1 | 69,0 | 24,7 | 1,2 | 23,1 | 21,2 | 34,4 | 980,7 |
| 2007 | 353,2 | 0,5 | 472,8 | 0,1 | 5,5 | 74,1 | 24,9 | 3,6 | 24,2 | 21,2 | 29,1 | 1.009,1 |
| 2008 | 332,7 | 0,6 | 485,0 | 0,0 | 6,2 | 76,4 | 26,4 | 1,8 | 29,0 | 18,4 | 30,4 | 1.006,9 |
| 2009 | 325,2 | 0,6 | 506,0 | 0,0 | 6,4 | 83,2 | 24,8 | 3,6 | 31,2 | 19,5 | 35,3 | 1.035,8 |
| 2010 | 311,4 | 0,7 | 447,8 | 0,0 | 1,1 | 27,5 | 25,2 | 5,3 | 8,4 | 17,1 | 37,0 | 881,4 |
| 2011 | 267,9 | 0,6 | 406,6 | 0,1 | - | 30,6 | 29,8 | 5,3 | 8,4 | 11,9 | 77,5 | 838,7 |
| 2012 | 289,8 | 0,7 | 388,1 | - | - | 33,1 | 27,3 | 1,8 | 9,2 | 3,4 | 129,5 | 882,9 |
| 2013 | 239,9 | 0,9 | 364,6 | - | - | 35,2 | 26,3 | - | 10,0 | 3,7 | 149,9 | 830,4 |
| 2014 | 210,1 | 0,7 | 320,7 | - | - | 34,7 | 34,9 | 2,1 | 13,7 | 2,7 | 154,0 | 773,6 |
| 2015 | 148,7 | 0,8 | 237,8 | - | - | 33,8 | 23,1 | - | 17,8 | 0,0 | 121,4 | 583,4 |
| 2016 | 166,3 | 0,8 | 250,6 | - | - | 33,0 | 30,6 | - | 22,2 | 0,0 | 104,2 | 607,8 |
| 2017 | **125,1** | **0,7** | **195,5** | **-** | **-** | **30,2** | **26,1** | **-** | **27,8** | **1,1** | **75,5** | **482,0** |
| 2018 | 136,9 | 0,7 | 230,6 | - | - | 27,1 | 24,0 | - | 32,7 | 0,0 | 75,7 | 527,8 |
| 2019 | 116,0 | 0,7 | 130,9 | - | - | 29,4 | 21,4 | - | 36,4 | 0,0 | 74,5 | 409,3 |
| 2020 | 119,1 | 0,6 | 125,4 | - | - | 26,0 | 22,9 | - | 40,2 | 0,0 | 50,5 | 384,7 |
| 2021 | 92,2 | 0,6 | 93,1 | - | - | 24,4 | 26,6 | - | 40,2 | 0,0 | 20,0 | 297,1 |
| 2022 | 92,0 | 0,5 | 93,7 | - | - | 23,7 | 23,2 | - | 38,8 | 0,0 | 18,9 | 290,9 |
| 2023 | 95,0 | 0,4 | 103,0 | - | - | 19,0 | 24,0 | - | 38,2 | 0,0 | 19,2 | 298,9 |
| 2024 | 89,2 | 0,4 | 108,5 | - | - | 12,5 | 24,5 | - | 50,3 | 0,0 | 19,4 | 304,8 |
| 2025 | 92,7 | 0,3 | 114,3 | - | - | 11,1 | 21,6 | - | 43,4 | 0,0 | 19,6 | 303,1 |
| 2026 | 89,7 | 0,3 | 112,0 | - | - | 9,6 | 23,7 | - | 40,1 | 0,0 | 19,8 | 295,2 |
| 2027 | 81,5 | 0,2 | 106,5 | - | - | 8,2 | 24,2 | - | 40,9 | 0,0 | 20,0 | 281,6 |
| 2028 | 76,8 | 0,1 | 103,9 | - | - | 6,7 | 18,2 | - | 35,5 | 0,0 | 20,2 | 261,4 |
| 2029 | 76,8 | 0,1 | 97,5 | - | - | 5,5 | 7,1 | - | 29,4 | 0,0 | 20,4 | 236,8 |
| 2030 | 76,8 | 0,0 | 83,1 | - | - | 4,8 | 2,3 | - | 23,7 | 0,0 | 20,7 | 211,4 |
| Sum | 8.422,8 | 45,8 | 8.709,4 | 0,9 | 116,7 | 992,6 | 717,6 | 24,6 | 871,3 | 297,9 | 2.138,4 | 22.337,9 |

**TABLE 4**
**TOTAL GWP-EMISSION FROM HFC'S, PFC'S $SF_6$, 1993-2030, 1 000 TONNES $CO_2$ EQUIVALENTS.**

The future scenario for the F-gas emission 2018-2030 is based on a steady-state scenario and indicates a clear reduction. The estimated increase in 2018 is in particular related to decomissioning emissions of medium and large refrigeration containing HFC-134a or HFC-404A.

# 2. Methodology

The emission calculation is made in accordance with the IPCC guidelines (Intergovernmental Panel on Climate Change) /4/, and following the method applied in previous years calculations.

The methodology includes calculation of the actual emissions of HFCs, PFCs, and $SF_6$. In this calculation of actual emissions, the release from stock of greenhouse gases in equipment and in products has been taken into account, and adjustments have been made for imports and exports of the greenhouse gases in products.

Appendix 3 describes the specific emission factors, etc.

## 2.1 Scope and definition

The emission calculation of the actual emissions of HFCs, PFCs and $SF_6$ has over years become increasingly more comprehensive and accurate along with the development of internationally approved guidelines (IPCC Guidelines) and guidance (IPCC Good Practice Guidance /22/) and the provision of increasingly detailed data.

The evaluation of the actual emissions includes quantification and calculation of any imports and exports of HFCs, PFCs, and $SF_6$ in products, and it includes substances in stock. This is in accordance with the latest and most accurate method of calculation (Tier 2) among the options provided for in the IPCC Guidelines /4/.

*Estimation of Consumption and emissions*

The calculation of consumption, emissions and stock was carried out on the basis of information from five sources:

- Importers, agency enterprises, wholesalers, and suppliers
- Consuming enterprises, and trade and industry associations
- Danish Environmental Protection Agency
- Official trade statistics
- Previous evaluations of HFCs, PFCs and $SF_6$ /32/.

Basis information for the present emission calculation is collected through questionnaire surveys combined with follow up telephone interviews of stakeholders relevant for F-gas consumption and emissions.

The result of the project is primarily based on the information received from enterprise and importer respondents and information from KMO and Danish EPA is used as a supplement to verify parts of the collected data.

The information collected from importers and suppliers is compared with information from consumer enterprises in order to monitor any discrepancies between purchase and sales information and to identify application of the use of substances. In some cases, the use of individual substances was estimated on the basis of two sources, since the majority of the consuming enterprises were known. In cases where not all enterprise end-users had specified the application area for substances, the consumption of individual substances was estimated on the basis of the information provided by importers, suppliers, and any trade and industry-related associations.

There may be inconsistencies between the information provided by suppliers and enterprise end-users. This is partly due to imports from other EU countries, changes in inventories of substances, or a lack of correlation between the quantities sold and the quantities consumed. It is also partly due to a certain amount of uncertainty in the method of calculation used by enterprises. However, sales and consumption information has been harmonised.

The estimated average degree of uncertainty in the report's consumption figures (quantities sold and bought) is about 10-15 per cent, and slightly greater for data regarding application areas. The degree of uncertainty in the calculation of actual emissions is estimated at 20-25 per cent, depending on import/export information for the specific products.

The calculation of F-gas emission is based on a calculation of *actual emissions*.

Actual emissions are emissions in the relevant year, accounting for the time lapse between consumption and emissions. Actual emissions include Danish emissions from production, from products during their lifetimes, and from the disposal of products. Actual emissions for the specific areas of application are determined on basis of the following approaches:

*Tier 2 “Top-down” analysis*
In the Tier 2 Top-down analysis, emissions are determined on the basis of information on consumption in the various areas of application and calculated or estimated emissions in the area of application (emission factors).

*Calculating consumption for refilling mobile A/C (MAC)*
The method for calculating the consumption of refrigerant related to MAC is based on collection of data from all Danish importers of HFC-134a supplying refrigerants to refilling in mobile A/C systems installed in vehicles. While these importers only operate in the MAC refrigeration market the import data can be isolated to consumption of refrigerants to MAC. Therefore the following methodology can be applied corresponding to the Tier 2 top down approach:

Consumption/Sale from MAC refrigerant importers in year X = refilled stock = actual emission from MAC in Denmark in year X.

*Tier 2 “Bottom-up” analysis*.
In the Bottom-up analysis, the estimated emissions for a specific application area are based on information from producers using substances in production and in products; information on imports and exports of products; information on the technological developments within the application areas; information on the average amount of greenhouse gases contained in products; and information on the lifetime of products and actual emissions during their use and disposal.

Tier 2 bottom-up analyses were carried out within selected areas over a number of years. The analysis quantified the stock and, in some cases, Danish emission factors. Detailed analyses were carried out for commercial refrigerators, mobile A/C systems, fridges, freezers, and $SF_6$ power switches. Analysis were evaluated in separate reports /2, 11, 16/.

Bottom-up comprises:

- Screening of the market for products in which greenhouse gases are used.
- Defining the average content of greenhouse gases per product unit.
- Defining the lifetime and the disposal emissions of products.
- Identifying technological characteristics and trends of significance for emissions of greenhouse gases.
- Calculating imports and exports on the basis of defined key figures, Statistics Denmark's foreign trade statistics, and information from relevant industries.

Results from this analysis have been expanded in the present evaluation of actual emissions.

As far as possible, the consumption and emissions of greenhouse gases have been evaluated individually, even though consumption of certain HFCs has been very limited. This was done to ensure transparency and consistency in time in the calculation of the sum of HFCs as their GWP value. However, it was necessary to operate with a category for "Other HFCs", as not all importers and suppliers have detailed records of sales of individual substances.

Uncertainty varies from substance to substance. Uncertainty is highest for HFC-134a due to its widespread application in products imported and exported. The largest uncertainty in the analysis of substances by application areas is assessed to concern the breakdown of consumption of HFC-404A and HFC-134a between commercial stationary refrigerators and mobile A/C systems. This breakdown is significant for the short-term (about 5 years) emissions calculations, but will balance in the long term. This is because the breakdown is only significant for the rate at which emissions are released.

Appendix 3 shows an overview of all application areas included with descriptions of the bases of calculation.

In Appendix 1, the table shows the F-gases covered by the Kyoto Protocol under the Climate Change Convention, including their chemical formulas and new revised GWP values (Global Warming Potential).

## 2.2 IPCC requirements to emission factors, application areas and new F-gases

The new revised emission factors from IPCC for a number of F-gases were fully implemented in the 2013 emission calculation and applied for the 2016 calculation as well. The change in emission factors are revised for the full time period 1992-2030 to assure consistency in the methodology as outlined in IPCC’s guidance.

According to the IPCC guidance, new application areas has been identified by IPCC. The application areas are:

- TFT flat panel displays (not occurring)
- Photovoltaics (not occurring)
- Heat transfer fluid (not occurring)
- Military applications (investigated further)
- Accelerators (not occurring)
- Soundproof windows (already included in DK calculation)
- Adiabatic properties - shoes and tyres (already included in DK calculation)
- Closed cell foam (already included in DK calculation)
- Hard cell foam (already included in DK calculation)

The new application areas were assessed in relation to the Danish context, and one new application area – “Military Appliances” was relevant to investigate further to determine, whether new consumption- and emission areas should be included in the F-gas emission calculation. The conclusion is, that there is no new use of F-gases from “Military Appliances” and it is therefore not relevant to include this area in the F-gas calculation.

Further, a number of new F-gases has to be included in the emission calculation. The new F-gases are $NF_3$, and new HFC's and PFC's. Starting from the 2013 calculation, all new F-gases has been included. The new HFC's were already included in previous calculations, and the new PFC's are not used in DK. According to $NF_3$, a particular survey among relevant importers, has been conducted and no import or stocks of $NF_3$ has been identified.

## 2.3 Explanation of terminology

The following terms and abbreviations are used throughout this report:

- *Enterprise end-user:* A producer that uses greenhouse F-gases in connection with production processes in the enterprise.
- *Emission factor:* The factor used in the calculation of emissions from a product or a production process.
- *Consumption:* Consumption includes the quantities of substances reported in Denmark in the year in question via imports from wholesalers and information from Danish producers.
- *Importer:* Enterprises in Denmark that sell the relevant substances on the Danish market.
- *KMO:* The Danish Refrigeration Installers' Environmental Scheme
- *Stock:* The amount of substance contained in equipment and products in use in Denmark.

# 3. F-gas import and consumption

## 3.1 Assessment of new F-gases

From 2013 it is required by IPCC to include a number of new F-gases in the emission calculation. These new F-gases have therefore been screened to determine whether the substances are used as bulk or imported in products in Denmark.

### 3.1.1 $NF_3$

Nitrogen trifluoride ($NF_3$) is used in the plasma etching of silicon wafers. Today $NF_3$ is predominantly employed in the cleaning of chambers in the high volume production of liquid crystal displays and silicon-based thin film solar cells. $NF_3$ has been considered as an environmentally preferable substitute for $SF_6$ or PFC. $NF_3$ is also used in hydrogen fluoride and deuterium fluoride lasers, which are types of chemical lasers. Since 1992, when less than 100 tons were produced, production has grown to an estimated 8.000 tons in 2010 and is projected to increase significantly.

All national importers of F-gases have been requested to provide information about eventual import of new F-gases. None has imported NF3 in 2017 or in any previous year.

NF3 is therefore considered non-existing in Denmark.

### 3.1.2 New HFC's

The new HFC's are:

- HFC-152
- HFC-161
- HFC-236cb
- HFC-236ea
- HFC-245fa
- HFC-365mfc

No import of HFC-245fa has been registered. No importers confirm import of any other of these HFC's in 2017. Previously, a minor amount of HFC-245fa has been imported as refrigerant some years back and also HFC-365mfc was imported for a few years as foam blowing agent before it was banned in 2006 due to the Danish legislation of phasing out F-gases in a.o. foam blowing. These two F-gases have already been included in the previous emission calculations.

### 3.1.3 New PFC's

The new PFC's are:

- Perfluorodecalin – PFC-9-1-18 ($C_{10}F_{18}$)
- Perfluorocyclopropane (c-$C_3F_6$)

No importers confirm import of these PFC's in 2016 or any previous years.

## 3.2 Import of substances

An overall picture of the trends in imports of greenhouse gases is given in Table 4, based on information from importers for the years 1992-2017.

### 3.2.1 HFC's

HFCs were imported by nine enterprises in 2017. Eight companies import for resale and one company is manufacturer importing directly from another EU country.

The total bulk import (minus re-export) of pure HFCs and HFC blends is 268,3 tonnes. Compared to 2016, where the import was 304,1 tonnes, total bulk import has decreased with 35,8 tonnes. The import has decreased for HFC-134a and HFC-407C, compared to 2015.

The bulk import of HFC-134a is 124,4 tonnes in 2017 and has decreased with 20,6 tonnes compared to 2016. The bulk import of HFC-407C is 30,9 tonnes in 2017 and has decreased with 6,7 tonnes compared to 2016.

Import of HFC-404A has increased with 12,1 tonnes in 2017 compared to 2016, with a total import of 80,2 tonnes in 2017. The main consumption of HFC 404A is in commercial refrigeration systems of which 75,6 tonnes was used in 2017. The increase breaks with the trend during the later years with a stable reduction in consumption of 5-10 tonnes HFC-404A per year. The reason for an increase might be explained in importers expectations to rising market prices in near future as a consequence of the f-gas regulation and reduced quotes.

The consumption of HFC-404A refrigerant in transport refrigeration systems has decreased to 2,8 tonnes in 2017 which correspond to a 100% decrease compared to 2016 consumption.

The consumption of HFC-404A for household fridge/freezers was 1,8 tonnes in 2017.

The third largest HFC import is HFC-407C with an import of 30,9 tonnes in 2017. The import was 37,6 tonnes in 2016, so there has been a decrease of 6,7 tonnes since the previous year. HFC-407C is used in heat pumps and is a substitute refrigerant for HCFC-22 in commercial refrigeration systems. Since 2009, the import of HFC-407C has been stable at a level of approx. 35-45 tonnes. Most old HCFC-22 appliances are replaced now, so consumption of HFC-407C is mainly related to fillings in heat pumps.

The import of HFC-507 in 2017 was 2,6 tonnes, which is a substantial decrease of 11,1 tonnes compared to 2016. HFC-507 is mainly used as a drop in refrigerant on older systems.

The import of HFC-410A has increased from 19,7 to 22,1 tonnes. HFC-410A is used in heat pumps and the increased consumption is probable a consequence of more service and refilling of existing heat pump stock.

Import of HFC-152a was 0 tonnes in 2017. This is the first year where no consumptions are reported. HFC-152a is mainly used in thermostats.

The import of the category 'Other HFCs' has decreased from 16,1 tonnes in 2016 to 8 tonnes in 2017. All substances registered in the category 'Other HFCs' are used exclusively for medium and large commercial refrigerators.

Summarizing, the imports of HFC-134a, HFC-407C, HFC-507 and 'Other HFCs have decreased in 2017 compared to the previous year. No HFC-152a was imported. HFC-404A and HFC-410A have increased with 18%, and 12% respectively.

With regard import of HFC's in products, two categories are reported:

- HFC-134a in medical doze inhalers (MDI)
- HFC-410A in heat pumps

In 2017 the import of HCF-134a in MDIs was estimated to be 5,47 tonnes.

The import of HFC-410A in heat pumps is estimated to 61,3 tonnes. The estimate is based on approx. 44.000 units of air-air and air-water heat pumps sold in DK in 2017.

### 3.2.2 Sulphur hexafluoride

Six importers reported that they have imported and sold 2,8 tonnes of sulphur hexafluoride in 2017, which is a decrease of 0,3 tonnes since 2016. Sulphur hexafluoride is mainly used in power switches, but very small amounts are also used as an agent for plasma erosion in production of optical fibres, microchips and in laboratories for analytical purposes, particle accelerators and radiotherapy equipment.

### 3.2.3 Perfluorinated hydrocarbons

There is reported import of PFC-14 (Trifluoromethan - $CF_4$) of approx. 150 kg. in 2017. PFC-14 is used as low temperature refrigerant in stand alone commercial applications.

The table below contains an overview of the bulk import of all F-gases since 1992.

| Year / Substance | HFC-134a | HFC-152a | HFC-401A | HFC-402A | HFC-404a | HFC-407C | HFC-507 | HFC-410A | HFC-413a | HFC-417A | Other HFCs[1] | All HFCs | SF6 | PFCs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1992 | 20,0 | 4,0 | | | - | | | | | | - | 24,0 | 15,0 | - |
| 1994 | 524,0 | 51,0 | | | 36,0 | | | | | | 1,0 | 612,0 | 21,0 | - |
| 1995 | 565,0 | 47,0 | | | 119,0 | | | | | | 14,0 | 745,0 | 17,0 | 1,5 |
| 1996 | 740,0 | 32,0 | | | 110,0 | | | | | | 20,0 | 902,0 | 11,0 | 3,0 |
| 1997 | 700,0 | 15,0 | | | 110,0 | | | | | | 65,0 | 890,0 | 13,0 | 8,0 |
| 1998 | 884,0 | 14,0 | 15,0 | 10,0 | 146,0 | 17,0 | 10,0 | | | | 15,0 | 1.111,0 | 9,0 | |
| 1999 | 644,6 | 35,8 | 15,0 | 10,0 | 193,7 | 40,0 | 10,0 | | | | 29,2 | 978,3 | 12,1 | 7,9 |
| 2000 | 711,1 | 16,4 | 9,5 | 4,2 | 193,1 | 44,7 | 23,8 | | | | 24,1 | 1.027,0 | 9,0 | 6,9 |
| 2001 | 472,8 | 11,1 | 4,1 | 0,8 | 126,2 | 40,3 | 2,2 | | | | 18,4 | 675,9 | 4,7 | 3,7 |
| 2002 | 401,6 | 11,9 | - | - | 188,7 | 89,1 | 14,4 | | | | 7,5 | 713,2 | 1,4 | 2,0 |
| 2003 | 241,2 | 3,3 | 0,2 | 1,7 | 145,0 | 96,8 | 9,2 | | | | 13,0 | 510,4 | 2,2 | 0,5 |
| 2004 | 306,5 | 11,0 | - | - | 252,6 | 101,3 | 10,6 | 2,6 | 7,2 | 6,0 | 4,4 | 702,2 | 2,3 | 0,3 |
| 2005 | 235,4 | 5,5 | - | - | 162,4 | 61,6 | 5,4 | 3,1 | 5,0 | 1,3 | 5,1 | 484,8 | 3,6 | 0,5 |
| 2006 | 280,7 | 11,6 | - | - | 176,4 | 70,6 | 6,1 | 7,7 | | 0,9 | 4,8 | 558,8 | 4,2 | - |
| 2007 | 160,7 | 13,0 | - | - | 129,9 | 50,5 | 11,4 | 12,8 | 1,0 | 2,1 | 21,0 | 402,4 | 5,4 | 0,7 |
| 2008 | 164,5 | 15,0 | - | - | 114,1 | 76,8 | 1,8 | 16,9 | 0,7 | 0,7 | 8,9 | 399,4 | 5,9 | 68,9 |
| 2009 | 175,3 | 12,0 | - | - | 106,9 | 49,3 | 7,0 | 12,1 | - | - | 0,6 | 363,2 | 4,3 | 0,9 |
| 2010 | 160,6 | 15,0 | - | - | 103,6 | 42,4 | 9,1 | 16,0 | - | 1,0 | 5,4 | 352,9 | 3,8 | 0,9 |
| 2011 | 180,5 | 8,0 | - | - | 105,0 | 42,8 | 6,1 | 15,5 | - | 2,0 | 13,0 | 372,9 | 3,1 | 0,9 |
| 2012 | 171,7 | 13,0 | - | - | 99,5 | 42,7 | 12,1 | 21,5 | - | 1,0 | 3,5 | 365,1 | 2,6 | 0,5 |
| 2013 | 154,5 | 22,6 | - | - | 91,5 | 43,8 | 20,5 | 20,6 | - | 1,0 | 13,0 | 367,3 | 3,6 | 0,5 |
| 2014 | 139,4 | 5,8 | - | - | 84,5 | 37,2 | 22,9 | 18,9 | 1,0 | - | 27,8 | 337,6 | 2,0 | 0,1 |
| 2015 | 115,9 | 7,0 | - | - | 76,6 | 27,9 | 13,3 | 20,9 | - | - | 21,0 | 282,6 | 1,5 | 0,3 |
| 2016 | 145,0 | 4,0 | - | - | 68,1 | 37,6 | 13,7 | 19,7 | - | - | 16,1 | 304,1 | 3,1 | 0,0 |
| 2017 | 124,4 | - | - | - | 80,2 | 30,9 | 2,6 | 22,1 | - | - | 8,0 | 268,3 | 2,8 | 0,2 |

**TABLE 5**
**DEVELOPMENTS IN BULK IMPORTS OF F-GASES, TONNES**

1) The category 'Other HFCs' includes all HFC's not explicated separately.

## 3.3 Consumption by categories

The assessment of consumption divided into categories is estimated on basis of information from importers and producers, and on sales reports to the Danish Refrigeration Installers' Environmental Scheme (KMO). Table 5 below shows consumption distributed according to application.

| Substance / Use | Insulation foam | Foam systems | Soft foam | Other applications | Stand-alone commercial applications | Medium and large commercial refrigerators | Transport refrigeration | Mobile A/C | Stationary A/C | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **HFC-134a** | 0 | 0 | 0 | 5,0 | 3,8 | 62,5 | 0,1 | 43,0 | 10,0 | **124,4** |
| **HFC-152a** | 0 | 0 | 0 | 0,0 | 0 | 0 | 0 | 0 | 0 | **0,0** |
| **HFC-401A** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **HFC-402A** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **HFC-404a** | 0 | 0 | 0 | 0 | 1,8 | 75,6 | 2,8 | 0 | 0 | **80,2** |
| **HFC-407C** | 0 | 0 | 0 | 0 | 0 | 0,0 | 0 | 0 | 30,9 | **30,9** |
| **HFC-507** | 0 | 0 | 0 | 0 | 0 | 2,6 | 0 | 0 | 0 | **2,6** |
| **HFC-410A** | 0 | 0 | 0 | 0 | 0 | 22,1 | 0 | 0 | 0 | **22,1** |
| **HFC-413a** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **HFC-417A** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **Other HFCs[1]** | 0 | 0 | 0 | 0 | 0 | 8,0 | 0 | 0 | 0 | **8,0** |
| **All HFCs** | **0** | **0** | **0** | **5,0** | **5,6** | **170,9** | **2,9** | **43,0** | **40,9** | **268,3** |

**TABLE 6**
**CONSUMPTION OF HFC DISTRIBUTED ON CATEGORIES, TONNES**

### 3.3.1 Consumption of HFC refrigerant

The total consumption of HFC refrigerants is decreasing. For HFC-134a, HFC-407C, 152a, HFC-507- and 'Other HFCs' the consumption in 2017 has declined compared to the past several years.

The decreasing level of refrigerants in commercial refrigeration systems is in particular a consequence of National Danish rules where establishment of new HFC installations after 1st of January 2007 was banned /30/.

The use of HFCs as refrigerant in commercial refrigeration and stationary A/C systems is covering 80,4 per cent of the total consumption in 2016. The most commonly used refrigerants in commercial refrigeration are still HFC-404A and HFC-134a.

The consumption of HFC-134a as a refrigerant in fridges/freezers was 3,8 per cent of the total consumption in 2017. Most producers have substituted to alternative refrigerants or moved production facilities to other countries.

The consumption of refrigerants in mobile A/C covers 16,3 per cent of the total consumption.

The consumption of refrigerants in vans and lorries for transport refrigeration covers approx. 1,1 per cent of the total consumption.

Consumption by application area is based on information from producers and importers, who report sales of substances from refrigerator installers and automobile workshops, etc. (only when drawing-off is more than one kg).

The consumption of refrigerants for household fridges and freezers is calculated on the basis of information from enterprise end-users.

The consumption of refrigerants in commercial, stationary A/C systems and MAC are estimated using data and information from importers.

The table below shows the consumption by weight of refrigerants according to sub categories.

| Substance / Application | Fridges /freezers | Commercial refrigerators and StationaryA/C systems | Mobile A/C systems | Refrigerated vans and trucks | Total | Percent |
|---|---|---|---|---|---|---|
| 134a | 3,8 | 72,5 | 43,0 | 0,1 | 119,4 | 45,4 |
| 401A | - | - | - | - | 0,0 | 0,0 |
| 402A | - | - | - | - | 0,0 | 0,0 |
| 404A | 1,8 | 75,6 | - | 2,8 | 80,2 | 30,5 |
| 407C | - | 30,9 | - | - | 30,9 | 11,8 |
| 410A | - | 22,1 | - | - | 22,1 | 8,4 |
| 507 | - | 2,6 | - | - | 2,6 | 1,0 |
| Others | - | 8,0 | - | - | 8,0 | 3,0 |
| Total | 5,6 | 211,8 | 43,0 | 2,9 | 263,3 | 100,0 |
| Percent | 2,1 | 80,4 | 16,3 | 1,1 | 100,0 | |

**TABLE 7**
**CONSUMPTION OF HFC AS REFRIGERANTS ACCORDING TO SUB CATEGORIES**

### 3.3.2 Consumption of HFC as foam blowing agent and as propellant

In 2017, the uses of HFCs as propellants in aerosols for specific industrial purposes were about 6 tonnes. This production is specifically approved by DEPA's grant of exemptions and production. The use for this specific industrial purpose had been stable for many years.

It is estimated that in 2017, the consumption of HFC-134a in MDIs was 5,5 tonnes.

As in previous years, there have been no reports of consumption of HFCs for chemical production, fire-extinguishing equipment, or other application areas apart from those mentioned.

### 3.3.3 Consumption of $SF_6$

The overall consumption of $SF_6$ in 2017 was 2,8 tonnes. Consumption of $SF_6$ is used for power switches in high-voltage power systems, plasma erosion and laboratories, including research laboratories (particle accelerators) and medical services such as radiotherapy and electronic microscopes. The registered suppliers of $SF_6$ provide gas to all mentioned areas as mentioned above and it is checked through contact to consumers that no parallel import occurs (including military). The registered import from suppliers is therefore valid to determine the actual $SF_6$ consumption.

Consumption of $SF_6$ in production of double glazed thermal windows has been banned since 1$^{st}$ of January 2003 /30/.

| Application area | DK consumption, tonnes |
|---|---|
| Power switches in high-voltage plants | 2,58 |
| Plasma erosion | 0,10 |
| Laboratories | 0,08 |
| Total | **2,76** |

**TABLE 8**
**CONSUMPTION OF SF6 BY SUB CATEGORIES, TONNES**

### 3.3.4 Consumption of PFCs

Only one PFC has been recorded in 2017, which is PFC-14. The import of PFC-14 was 161 kg and was used in production of fibre optics as for extreme low-temperature refrigerant in stand-alone commercial appliances for laboratories, where no other alternatives are suitable.

# 4. Emission of F-gases

This section reports the actual emissions of the greenhouse F-gases HFCs, PFCs, and $SF_6$ for 2017. All emissions are calculated as *actual* emissions according to IPCC's tier 2 methodologies. In this year emission calculation, stationary heat pumps are introduced as a new sub category.

The emission calculation is based on the revised GWP values as stated in the IPCC guidance (ref. to appendix 1).

The calculation is based on the reports on consumption of these substances analysed by application areas (section 3.2). For relevant product groups, adjustments have been made for imports and exports of the substances in products (see also chapter two for principal description of methodology). The specific emission calculation refers to appendix 4 which shows the particular emission factors, calculation method and assumptions, determination of IPPC Tier method etc., in relation to calculation of emissions from individual substance and application areas /4, 16/.

The total GWP-weighted actual emission of HFCs, PFCs, and $SF_6$ in 2017 is calculated to 481 996 tonnes $CO_2$ equivalents. The corresponding emissions in 2016 were approx. 607.755 thousand tonnes $CO_2$ equivalents. The emission reduction is approx. 20 per cent.

The consumption and GWP contribution for HFCs, PFCs, and $SF_6$ for this year and last years are shown in the table below.

| | 2016 | | 2017 | |
|---|---|---|---|---|
| Substance group | Consumption and imports, DK, tonnes | GWP contribution, CO2 eqv. tonnes | Consumption and imports, DK, tonnes | GWP contribution, CO2 eqv. tonnes |
| HFCs | 289 | 503.576 | 268 | 405.449 |
| PFCs | 0,3 | 8 | 0,2 | 1.094 |
| SF6 | 1,5 | 104.172 | 2,8 | 75.454 |
| Total | | 607.755 | | 481.996 |

**TABLE 9**
CONSUMPTION AND GWP CONTRIBUTION BY SUBSTANCE GROUP, TONNES

### 4.1.1 Emissions of HFCs from refrigerants

As required in the IPCC guidance for calculation of emission of F-gases a distinction is made between:

- 2.F.1.b - Fridges and freezers for household use and retailers etc. **(Stand alone Commercial Applications)**
- 2.F.1.a - Commercial refrigeration (in industry and retail) and stationary air conditioning systems (**Medium and large Commercial Refrigeration + Industrial refrigeration + Residential and commercial A/C)**
- 2.F.1.e - Mobile air conditioning systems (in cars, trucks, bus, trains etc.)
- 2.F.1.d - Mobile refrigeration systems (in vans and lorries)

Actual emissions from these sources occur in connection with:

- *Filling* of refrigerants (emission is 0,5 percent to 2 per cent of refilled amount depending on application area).

- *Continual release* during the operational lifetime. An assumed average value which account operational leakage including release occurring as a result of accident and damage (depending on application area, the average yearly emission differ from 3 percent to 30 percent).

Release resulting from *disposal* of items and equipment in the applications is not calculated as a contribution to the total f-gas emissions in Denmark because Danish legislation ensures that management and treatment of refrigerants prevent uncontrolled emissions. Thus, disposal in Denmark is stated as an activity in the calculations where zero emission occurs and this principal statement is used in order to reduce stock (the quantity of substances contained in a product after end life time).

Appendix 3 shows the specific emission factors used in the calculations.

*Commercial refrigeration and stationary A/C systems*

Commercial refrigeration, used e.g. in retail, supermarket, restaurants etc. or in industry, and stationary A/C systems, also used by retailers and industry, as well in offices, constitute the largest source of emissions. The most commonly used refrigerants in this product group are HFC-134a, HFC-404A, HFC-407C and HFC-507, where HFC-404A stands for the majority of the emissions in 2016.

In addition, use of the refrigerants HFC-408A, HFC-409A and HFC-410A is less common, and HFC-401A and HFC-402A are phased out in Denmark as they contain ozone-depleting substances.

It is not relevant to adjust for imports and exports of HFCs in stationary commercial refrigeration and stationary A/C systems since filling of refrigerants only will take place on site when the units are installed.

The table below shows the consumption, stock and actual emission for the main HFC substances used in Danish commercial refrigeration systems. Emissions for HFCs have been converted to $CO_2$ equivalents in order to take into account the different GWP values of the substances and emissions for 2020 and 2030 in a future scenario are also shown.

| Substance | Consumption 2017 | Stock 2017 | Actual emissions 2017 | GWP-contribution 2017 | GWP-contribution 2020 | GWP-contribution 2030 |
|---|---|---|---|---|---|---|
| HFC-134a | 72,5 | 258,7 | 30,7 | 43.849 | 40.994 | 0 |
| HFC-404A | 75,6 | 336,6 | 44,5 | 174.499 | 71.997 | 71.997 |
| HFC-407C | 30,9 | 520,0 | 12,7 | 30.207 | 10.778 | 0 |
| HFC-507 | 2,6 | 54,7 | 6,5 | 26.072 | 2.332 | 26.556 |
| Other HFCs 1) | 30,1 | 418,0 | 13,3 | 27.835 | 5.752 | 16.552 |
| All | | | | 302.461 | 131.852 | 115.104 |

**TABLE 10**
**CONSUMPTION, STOCK AND ACTUAL EMISSIONS AND GWP CONTRIBUTION FROM COMMERCIAL REFRIGERATION; GWP CONTRIBUTION FOR 2017, 2020 AND 2030, TONNES**

1) The category "other" in 2017 is calculated based on an assumption that average GWP value is similar to HFC-410A).

As the table indicates, the emissions from commercial refrigeration will continue for several years with a steady state consumption scenario even though there are no installations of new HFC refrigeration systems as a result of the statutory order, which do not allow construction of new installations (larger than 10 kg HFC) after 1st of January 2007.

In the trend analysis, the total emission from this sector is estimated to have a reduction of approx. 56 per cent in year 2020.

*Refrigerators/freezers*

Actual emissions from refrigerants in refrigerators and freezers are determined on the basis of consumption adjusted for imports and exports of HFCs. The calculation assumes that the refrigerant is removed and treated upon disposal so that no emission occurs (see appendix 3).

When adjusting for imports and exports, the estimates of imports/exports in Environmental Project no. 523 are used /2/. In this case, exports are assumed to comprise 50% of the consumption pr. year. The calculation is made on the basis of Statistics Denmark's foreign trade statistics /3/ of average figures of the amount of HFC-134a in a standard fridge/freezer manufactured in 1999. These values have not been updated.

The table below shows actual emissions from refrigerators/freezers in 2017, 2020 and 2030.

| | HFC-134a | | | HFC-404A | | |
|---|---|---|---|---|---|---|
| | 2017 | 2020 | 2030 | 2017 | 2020 | 2030 |
| Consumption | 3,8 | 3,8 | 1,9 | 1,8 | 1,8 | 0,9 |
| Emissions during production | 0,1 | 0,1 | 0,0 | 0,0 | 0,0 | 0,0 |
| Export | 1,9 | 1,9 | 1,0 | 0,0 | 0,0 | 0,0 |
| Stock | 240,4 | 121,2 | 20,1 | 36,5 | 28,5 | 15,8 |
| Emission from stock | 2,2 | 1,1 | 0,2 | 0,4 | 0,3 | 0,2 |
| Emissison from destruction | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Actual emission | 2,2 | 1,1 | 0,2 | 0,4 | 0,3 | 0,2 |
| GWP contribution, 1000 tonnes CO2 equivalents | 3,2 | 1,6 | 0,3 | **1,6** | **1,2** | **0,7** |

**TABLE 11**
**EMISSIONS OF REFRIGERANTS FROM REFRIGERATORS/FREEZERS 2017, 2020 AND 2030, TONNES**

Total emissions of HFC-134a and HFC-404A refrigerants from refrigerators/freezers in 2017 were estimated to 4.781 tonnes of $CO_2$ equivalents. In the future scenario of actual emissions, it is estimated that the total emissions in 2020 will decrease to 2.100 tonnes $CO_2$ equivalents and in 2030 decrease to 1.000 tonnes of $CO_2$ equivalents caused by a decreasing stock.

*Mobile A/C*

Emissions from mobile A/C systems are mainly due to leakage and accident damage.

Starting from 2009, the refilled and consumed amount of HFC-134a is calculated based on a Tier 2 top-down approach were the importers of HFC-134a for mobile A/C systems are isolated. The consumption of HFC-134a for mobile A/C systems is used solely for refilling. Car manufacturers outside DK carry out initial filling. With the new approach it is possible to reduce uncertainties in determining the actual consumption of refrigerants for refilling in vehicles in Denmark. Actual emissions from mobile A/C are stated in the table below.

| | 2017 | 2020 | 2030 |
|---|---|---|---|
| Consumption to refilling | 43,0 | 43,0 | 43,0 |
| Actual emissions | 43,0 | 43,0 | 43,0 |
| GWP contribution, 1000 tonnes CO2 equivalents | **61,4** | **61,4** | **61,4** |

**TABLE 12**
**ACTUAL EMISSIONS OF HFC-134A FROM MOBILE A/C, 2017, 2020 AND 2030, TONNES**

*Vans and lorries with transport refrigeration system*

There are an estimated 5.500 – 6.000 refrigerator vans and lorries in Denmark /16/. These require an average filling of about 8 kg (HFC-134a, HFC-404A). Actual emissions from mobile refrigeration systems in vans and lorries in 2017 are stated in the table below.

| | HFC-134a | | | HFC-404A | | |
|---|---|---|---|---|---|---|
| | 2017 | 2020 | 2030 | 2017 | 2020 | 2030 |
| Consumption | 0,1 | 0,1 | 0,1 | 2,8 | 2,8 | 2,8 |
| Emissions from filling | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Emissions from stock | 0,1 | 0,0 | 0,0 | 4,7 | 2,8 | 2,6 |
| Stock | 0,3 | 0,1 | 0,2 | 25,7 | 16,7 | 15,5 |
| Actual emissions | 0,1 | 0,0 | 0,0 | 4,9 | 3,1 | 2,7 |
| GWP contribution, 1000 tonnes CO2 equivalents | 0,2 | 0,0 | 0,1 | 19,4 | 12,0 | 10,4 |

**TABLE 13**
**CALCULATION PARAMETERS AND ACTUAL EMISSIONS OF HFC-134A AND HFC-404A FROM VANS AND LORRIES WITH TRANSPORT REFRIGERATION SYSTEM FOR 2017, 2020 AND 2030 TONNES**

The total actual emission from mobile refrigeration systems in vans and lorries were estimated to 19.572 tonnes of $CO_2$ equivalents in 2017.

### 4.1.2 Emissions of HFCs from PUR foam products and propellants

IPCC's default calculation methods have been applied in the calculation of emissions of HFCs used in Polyurethan (PUR) foam plastic products, depending on the type of product:

1) Hard PUR foam plastics (closed cell)

2) Soft PUR foam plastics (open cell)

3) Polyether foam (closed cell)

The calculation methods are summarized in the table below and in appendix four.

| | Hard PUR foam | Soft PUR foam | Polyether foam |
|---|---|---|---|
| Released during production, % | 10% | 100% | 15% |
| Annual loss, % | 4,5% | - | 4,5% |
| Lifetime, years | 15 | - | 1-10 |

**TABLE 14**
**EMISSION FACTORS IN THE CALCULATION OF EMISSIONS FROM FOAM PLASTIC PRODUCTS**

*Insulation foam*

There is no longer production of HFC based hard PUR insulation foam in Denmark. This production has been banned in statutory order since 1st of January 2006 /30/.

The import of HFC-134a in products with PUR insulation foam, e.g. household fridges and freezers, is considered to be 0 in 2017. The calculation of actual emissions are therefore only from existing stock of household fridges and freezers.

Actual emissions of HFC-134a from insulating foam are summarised in the table below.

| | 2017 | 2020 |
|---|---|---|
| Consumption, HFC 134a | 0,0 | 0,0 |
| Emission from production | 0,0 | 0,0 |
| Export | 0,0 | 0,0 |
| Stock | 21,0 | 0,0 |
| Emission from stock | 0,1 | 0,0 |
| Actual emissions | 0,1 | 0,0 |
| GWP contribution, 1000 tonnes CO2 equivalents | 0,1 | 0,0 |

**TABLE 15**
**CALCULATION PARAMETERS AND EMISSIONS OF HFC-134A FROM INSULATING FOAM FOR 2017, 2020 TONNES**

In the projection scenario, it is estimated that the stock will be reduced significantly as a result of the phase-out of HFC-134a as blowing agent and from 2019 there will be no more calculated actual emissions from this source.

*Aerosol sprays*
Emission of HFC-134A from aerosol sprays for industrial purpose is calculated due to the IPCC default. The consumption is divided as an average of 50% for previous year and 50% in actual year /4/.

Total emission from this area amounts in 2017 to 6 tonnes of HFC-134a corresponding to 8.580 tonnes $CO_2$ equivalents. Compared with 2016, emission estimates have decreased by approx. 600 tonnes $CO_2$ equivalents.

*Medical Dose Inhalers (MDI)*
Until 2015, calculation of emission from MDIs has been based on yearly statistics from Danish Medicines Agency. Since 2015 the Danish Medicines Agency has altered their database and so the extracted data on MDI has a different format. For this reason, the data is no longer comparable to data from previous years. The estimated consumption and use of HFC-134a in 2017 is therefor estimated to be similar 2016 – 5,5 tonnes.

The emission of HFC-134a from medical metered dose inhalers is estimated as 100% of the consumption in the year of application. A survey has determined that HFC 134a has been fully introduced in all MDIs on the Danish market since 2007. The average content is 72 mg/pr. dose.

A time-series of the emission of HFC-134a from MDI has been included in the F-gas inventory since the application was registered in 1998.

*Optical fibre production*
Both HFC and PFC were usually used for technical purposes in Danish optics fibre production. HFC-23 is used as a protection and cleaning gas in the production process. The emission factor is therefore defined as 100% release during production. Thus, HFC-23 was not used in 2017, 2016 as well for 2015 and 2013. It indicates that HFC-23 probably is substituted with other substances not containing f-gasses.

### 4.1.3 Emissions of sulphur hexafluoride
The actual emission of $SF_6$ in 2017 has been calculated to 3,3 tonnes, equivalent to a GWP contribution of 75.454 tonnes $CO_2$ equivalents.

Emissions derive from three sources - power switches, double-glazed windows and laboratories.

*Double-glazed windows*

Use of $SF_6$ in double-glazed windows was phased out in 2002, however, there are still emissions from stock in existing double-glazed windows in Danish buildings. The stock is estimated from consumption data from Danish producers of double-glazed windows 1992-2002 and lifetime for double-glazed windows are determined to 20 years.

Emissions from double glazed windows are calculated on following factors:

- 15 per cent emission from production
- 1 per cent gradual emission from stock pr. year
- 80 per cent emission when disposal after 20 years

| | 2017 | 2020 | 2030 |
|---|---|---|---|
| Consumption | 0,0 | 0,0 | 0,0 |
| Emissions from production | 0,0 | 0,0 | 0,0 |
| Release from fitted double-glazed windows | 0,1 | 0,0 | 0,0 |
| Exports | 0,0 | 0,0 | 0,0 |
| Disposal emissions | 2,5 | 1,4 | 0,0 |
| Stock | 6,5 | 0,1 | 0,0 |
| Actual emissions | 2,5 | 1,4 | 0,0 |
| GWP contribution, 1000 tonnes CO2 equivalents | 57,6 | 32,0 | 0,0 |

**TABLE 16**
**CALCULATION PARAMETERS AND EMISSIONS OF $SF_6$ FROM DOUBLE-GLAZED WINDOWS FOR 2017, 2020 AND 2030, TONNES**

The future scenario for GWP contribution from double-glazed windows in 2020 shows a decrease to 32.000 tonnes $CO_2$ equivalents to be compared with 57.600 tonnes of $CO_2$ equivalents in 2017. The last emissions occur in 2021.

*Power switches in high-voltage transmission stations*
Power switches are filled or refilled with $SF_6$, either for new installation or during service and repair. Filling is usually carried out on new installations and a smaller proportion of the consumption of $SF_6$ is due to refilling /11/.

Emissions from power switches in high-voltage transmission systems are calculated due to the processes involved in the following way:

- release of 5 per cent on filling with new gas (average figure covering normal operation and failure/accidents)
- gradual release of 0.5 per cent from the stock (average figure covering normal operation and failure/accidents)

These figures are determined in a report of Danish $SF_6$ use in high-voltage power switches /11/.

No emissions are assumed to result from disposal since the used $SF_6$ is drawn off from the power switches and re-used internally by the concerned or appropriate disposed through waste collection scheme.

The table below shows the amounts involved in the processes leading to emissions and calculated actual emissions from $SF_6$ power switches.

| | 2017 | 2020 | 2030 |
|---|---|---|---|
| **Consumption** | 2,6 | 2,6 | 2,6 |
| **Service emissions** | 0,1 | 0,1 | 0,1 |
| **Emissions from stock** | 0,5 | 0,5 | 0,6 |
| **Stock** | 97,3 | 103,1 | 122,1 |
| **Actual emissions** | 0,6 | 0,6 | 0,7 |
| **GWP contribution, 1000 tonnes CO2 equivalents** | 13,8 | 14,5 | 16,6 |

**TABLE 17**
**CALCULATION PARAMETERS AND EMISSIONS OF $SF_6$ FROM POWER SWITCHES IN HIGH-VOLTAGE PLANTS 2017, 2020, AND 2030, TONNES**

The trend is a slightly stable consumption of $SF_6$ and consequently a minor contribution to stock.

*Laboratory purposes*
Consumption of $SF_6$ in laboratories covers following purposes:

- Plasma erosion in connection with the manufacture of microchips in clean-room laboratories
- Analytical purposes to a limited extend
- Particle accelerators
- Radiotherapy
- Electronic microscopes

The emission is calculated to approx. 0,2 tonnes $SF_6$ in 2017. The emission is 100% release during consumption and estimated to 4.000 tonnes of $CO_2$ equivalents. Aarhus University/DTU is the only entity in Denmark using $SF_6$ in particle accelerators and electronic microscopes.

### 4.1.4 Emissions of perfluorinated hydrocarbons

*Commercial refrigerators*
There is no longer PFC emission from commercial refrigerators.

*Optical fibre production*
The PFCs are used as a protection and cleaning gas in the production process. The emission factor is therefore determined as 100% release during production. This sector has previous used both PFC-14 and PFC-318 for technical purpose in optics fibre production. However PFC-318 has not been used in 2013, 2015, 2016 and either in 2017. There has been registered a small use of PFC-14 for optical fibre production in 2017. The emission is 1.100 tonnes $CO_2$ equivalents.

*Low temperature stand alone laboratory freezers*
PFC-14 is used for specialized -60 degree low-temperature freezers for laboratory purposes. Use of PFC-14 for this purpose has been registered for the first time in Denmark in 2015. The consumption of PFC-14 for laboratory freezers was 11 kg in 2017 and the emission is below triviality limit.

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# Appendix 1 GWP values for F-gases

Table 1.a

F-gases relevant for Denmark, their chemical formulas and Global Warming Potential (GWP) values used for reporting to the UN Climate Convention and the Kyoto Protocol (values from IPCC new revised GWP values to be implemented no later than 2015)

| Substance / Blend | Chemical formula | GWP value |
|---|---|---|
| HFC-23 | CHF3 | 14 800 |
| HFC-32 | $CH_2FH_2$ | 675 |
| HFC-41 | CH3F | 92 |
| HFC-125 | $C_2HF5$ | 3 500 |
| HFC-134 | C2H2F4 | 1 100 |
| HFC-134a | $CF_3CFH_2$ | 1 430 |
| HFC-143 | CHF2CH2F | 353 |
| HFC-143a | CF3CH3 | 4 470 |
| HFC-152 | CH2FCH2F | 53 |
| HFC-152a | $CF_2HCH_3$ | 124 |
| HFC-161 | CH3CH2F | 12 |
| HFC-227ea | $C_3HF_7$ | 3 220 |
| HFC-236cb | CH2FCF2CF3 | 1 340 |
| HFC.236ea | CHF2CHFCF3 | 1 370 |
| HFC-365mfc | CH3CF2CH2CF3 | 794 |
| HFC-245ca | C3H3F5 | 693 |
| HFC-245fa | CHF2CH2CF3 | 1 030 |
| HFC-404A[(1)] | Blend | 3 922 |
| HFC-401A[(2)] | Blend | 18 |
| HFC-402A[(3)] | Blend | 2 100 |
| HFC-407C[(4)] | Blend | 1 774 |
| HFC-408A[(5)] | Blend | 1 030 |
| HFC-409A[(6)] | Blend | 0 |
| HFC-410A[(7)] | Blend | 2 088 |
| HFC-507[(8)] | Blend | 3 985 |
| Sulphurhexafluoride | $SF_6$ | 22 800 |
| PFC-14 | $CF_4$ | 7 390 |
| PFC-116 | C2F6 | 12 200 |
| PFC-218 | C3F8 | 8 830 |
| PFC-3-1-10 | C4F10 | 8 860 |
| PFC-318 | c-C4F8 | 10 300 |
| PFC-4-1-12 | C5F12 | 9 160 |
| PFC-5-1-14 | C6-F14 | 9 300 |
| PFC-9-1-18b | C10F18 | 7 500 |
| Perfluorocyclopropanec | | 17 340 |
| Nitrogen Trifluoride | NF3 | 17 200 |

(1) Mixture consisting of 52 % HFC-143a, 44 % HFC-125 and 4 % HFC-134a.

(2) Mixture consisting of 53 % HCFC-22, 13 % HFC-152a and 34 % HCFC-124.

(3) Mixture consisting of 38 % HCFC-22, 60 % HFC-125 and 2 % propane.

(4) Mixture consisting of 25 % HFC-125, 52 % HFC-134a, and 23 % HFC-32.

(5) Mixture consisting of 46 % HFC-143a and 7 % HFC-125.

(6) A HCFC mixture consisting entirely of HCFCs, where the GWP - in accordance with the climate convention guidelines - is 0, since the mixture does not contain greenhouse gases. The real GWP value is 1,440.

(7) Mixture consisting of 50 % HFC-32 and 50 % HFC-125

(8) Mixture consisting of 50 % HFC-125, 50 % HFC-143a.

# Appendix 2 Assesment of Good Practice Guidance compliance in DK F-gas calculation

*The Danish F-gas emissions are calculated for the historical years up to 2010. The time series of emissions are calculated using Good practice principles and the series goes back to 1993, but are to be considered complete from the year 1995.*

## Key Source Categories

F-gases are determined as a key source category. The contribution of F-gases to national greenhouse gas emission is approx. 1.3 % of total emission excl LULUCF in the most recent historical years of the inventories.

## Future trend scenarios

A trend scenario is elaborated until 2020. The scenario is bases on a “steady state” trend but with an inclusion of dates for phase out of determined substances as stated in legal acts.

## Methodology

In the following the relevant decision trees from the GPG (Good Practice Guidance) chapter 3 are investigated with respect to the Danish F-gas calculations compliance with GPG.

For the Danish calculation of F-gases it is basically a Tier 2 bottom up approach which is used, while data is reported from identified importers and users of F-gasses in DK. As for verification using import/export data a Tier 2 top down approach is applied. In an annex 3 to the F-gas emission report (Environmental Protection Agency), there is a specification of the applied approach for each sub source category.

*Emission factors*

Consumption data of F-gases are provided by suppliers and/or producers. Emission factors are primarily defaults from GPG which are assessed to be applicable in a national context.

In case of commercial refrigerants and Mobile Air Condition (MAC), emission are defined as similar to consumption in year X. Comsumption are determined from data directly from suppliers.

In case of PUR foam blowing of shoe and use of system foam EF are stated by the producer. Because of the relative low consumption from PUR foam blowing of shoes and system foam a certain uncertainty is assessed as acceptable.

*Import/export data*

Import/export data for sub category sources where import/export are relevant (fridge/freezers for household) are quantified on estimates from import/export statistic of products + default values of amount of gas in product. The estimates are transparent and described in the annex referred to above.

Import/export data for system foam and commercial refrigerators and stationary air condition are specified in the reporting from importers and users.

*Consistency*
The time series are consistent as regards methodology. No potential emission estimates are included as emissions in the time series and same emission factors are used for all years.

*Reporting and documentation*
The national inventories for F-gases are provided on a yearly basis and documented in a yearly report (Environmental Protection Agency).

Detailed data from importers and users and calculations are available and archived in electronic version. The report contains summaries of EF used and information on sources, Further details on methodology and EF are included in annex to the report.

Activity data are described in a spread sheet for the current year. The spread sheet contains the current year as well as the years back. The current version is used with spreadsheet for data for the current year linking to the Danish inventory databases and for the CRF format. In case of changes to the previous reported data this is work out in spreadsheet versions accordingly and reported with explanations as required in the CRF format.

## Source specific QA/QC and verification

*Comparison of emissions estimates using different approaches*
Inventory agencies should use the Tier 1 potential emissions method for a check on the Tier 2 actual emission estimates. Inventory agencies may consider developing accounting models that can reconcile potential and actual emissions estimates and may improve determination of emission factors over time.

This comparison has been carried out in 1995-1997 and for all three years it shows a difference of approx. factor 3 higher emissions by using potential emission estimates.

Inventory agencies should compare bottom-up estimates with the top-down Tier 2 approach, since bottom-up emission factors have the highest associated uncertainty. This technique will also minimise the possibility that certain end-uses are not accounted for in the bottom-up approach.

This exercise has been partly conducted since data from importers (top down) are assessed against data from users (bottom up) to ensure, that import and consumption are more or less equal. The consumption reported from users are always adjusted to the import of substances, which are the most exact data we have.

The uncertainty due to this is, if not all importers are identified because new imported are introduced to the DK market.

*National activity data check*
For the Tier 2a (bottom-up) method, inventory agencies should evaluate the QA/QC procedures associated with estimating equipment and product inventories to ensure that they meet the general procedures outlined in the QA/QC plan and that representative sampling procedures were used.

No QA/QC plan specifically for the F-gas calculation is developed. However, QC procedures were carried out as described below.

The spread sheets containing activity data has incorporated several data-control mechanisms, which ensure, that data estimates do not contain calculation failures. A very comprehensive QC procedure on the data in the model for the whole time-series has for this submission been carried out in connection to the process which provided (1) data for the CRF background Tables 2(II).F. for the years (1993)-2002 and (2) provided data for potential emissions in CRF Tables 2(I). This procedure consisted of a check of the input data for the model for each substance. As regards the HFCs this checking was done according to their trade names. Conversion was made to the HFCs substances used in the CRF tables etc. A QC was that emission of the substances could be calculated and checked comparing results from the substances as trade names and as the "no-mixture" substances used in the CRF.

*Emission factors check*
Emission factors used for the Tier 2a (bottom-up) method should be based on country-specific studies. Inventory agencies should compare these factors with the default values. They should determine if the country-specific values are reasonable, given similarities or differences between the national source category and the source represented by the defaults. Any differences between country specific factors and default factors should be explained and documented.

Country specific emission factors are explained and documented for MAC and commercial refrigerants and SF6 in electric equipment. Separate studies has been carried out and reported. For other sub source categories, the country specific emission factor is assessed to by the same as the IPCC default emission factors.

*Emission check*
Since the F-gas inventory is developed and made available in full in spread sheets, where HFCs data are for trade names, special procedures are performed to check the full possible correctness of the transformation to the CRF-format through Acces databases.

## Uncertainties

In general uncertainty in inventories will arise through at least three different processes:

A. Uncertainties from definitions (e.g. meaning incomplete, unclear, or faulty definition of an emission or uptake);
B. Uncertainties from natural variability of the process that produces an emission or uptake;
C. Uncertainties resulting from the assessment of the process or quantity, including, depending on the method used,: (i) uncertainties from measuring; (ii) uncertainties from sampling; (iii) uncertainties from reference data that may be incompletely described; and (iv) uncertainties from expert judgement.

Uncertainties due to poor definitions are not expected as an issue in the F-gas inventory. The definitions of chemicals, the factors, sub source categories in industries etc. are well defined.

Uncertainties from natural variability are probably occurring in a short term time period, while estimating emissions in individual years. But in a long time period – 10-15 years, these variabilities levels out in the total emission, because input data (consumption of F-gases) are known and are valid data and has no natural variability due to the chemicals stabile nature.

Uncertainties that arise due to imperfect measurement and assessment are probably an issue for:

emission from MAC (HFC-134a)
emission from commercial refrigerants (HFC-134a)

lead to inexact values of the specific consumption of F-gases.

The uncertainty varies from substance to substance. Uncertainty is greatest for HFC-134a due to a widespread application in products that are imported and exported. The greatest uncertainty in the areas of application is expected to arise from consumption of HFC-404a and HFC-134a in commercial refrigerators and mobile refrigerators. The uncertainty on year to year data is influenced by the uncertainty on the rates at which the substances are released. This results in significant differences in the emission determinations in the short term (approx. five years), differences that balances in the long term.

In connection to the work on the Danish National Inventory report general uncertainty estimates for F-gases has been worked out to make the uncertainties for the Danish inventories complete. Refer this report given in the reference list in the main report

Further improvement of uncertainty analysis with respect to the calculation of F-gas emissions are to be considered in future calculations.

# Appendix 3 Specification of methods and assumptions

Specification of methods and assumptions for determination of emissions for 1990-2016 as well as projections of GWP in accordance with *IPCC Good Practise Guidance and Uncertainty Management in National Greenhouse Gas Inventory*

| ID | Source | Substance | Methods | Emission factor | Remarks | Projection assumptions |
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| | OF SUBSTITUTES FOR OZONE-DEPLETING SUBSTANCES (ODS SUBSTITUTES) | | | | | |
| | *Refrigerant* | | | | | |
| K1 | Household fridges and freezers (**Stand-alone commercial applications)** | HFC-134a | Tier 2 top-down approach:<br>- information on refrigerant consumption provided by reports from the main producers of household fridges and freezers in DK. information on refrigerant consumption provided by reports from the main producers of household fridges and freezers in DK, accounting for no less than an estimated 95% of the market.<br>Tier 2 bottom-up approach: | **OK according to new IPCC values**<br>- release on filling = 2% (IPCC default – 0,5-3%)<br>1 % release from stock per year (IPCC default – 1-10%)<br>Lifetime = 15 years (IPCC default 10-15 years))<br>Recovery: 100% .Up to and including 2000, the quantity remaining upon disposal was included as | Stock determined in 1998 for the period 1990-1998 based on information on consumption from Danish producers and estimates based on import/export statistics and average quantity of HFC contained in refrigerant and foam per unit (source: /2/).<br>For the updating of stock, import/export data from 1998 is used, as well as information on annual HFC consumption by | From 2001, net exports of refrigerants in household fridges are assumed to account for 50 per cent of consumption.<br>The consumption in the projection is not influenced by new phasing-out regulations.<br>The effect of charges on HFCs is expected |

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| | | | - information on imports and exports of refrigerants in products based on the average quantity contained per unit and Danish statistics. | emissions (IPCC default). Legislation in Denmark ensures drawing-off of refrigerant, and consequently, the IPCC default is misleading in the Danish context. (IPCC default 0-80% of initial charge) | Danish producers. 1998 import/export data is = net exports of 141 tonnes HFC-134a refrigerant + net exports of 1.6 tonnes HFC-134a in foam (note: DK's largest exporter does not use HFC for foam moulding, therefore the export of HFC in foam is less than the export of refrigerants). | to give an annual reduction in consumption of 5 per cent in the period 2001-2005. |
| K2 | Commercial stationary refrigerators in retail stores, industry, etc., and stationary A/C systems in buildings etc. **(medium and large commercial refrigerants)** | HFC-134a, HFC-404a, HFC-401a, HFC-402a, HFC-407C, HFC-507A, other HFCs, PFCs ($C_3F_8$) | Tier 2 top-down approach:<br>- information on refrigerant consumption was provided by importers/suppliers of refrigerants for commercial refrigerators in DK.<br>- information on distribution of refrigerant consumption at different sites is estimated using information from user enterprises, the KMO and estimates from suppliers. | 1.5% on refilling (DK default) (IPCC default 0,5-3%)<br>1990-2009: 10% release from operation and accidents (DK default).<br>2010-2030: 3% release from operation and accidents<br>Recovery: 88,5%<br>In the case of re-use it is assumed release occurs during the cleaning process equivalent to 2%. It is *good practice* not to account for any re-use since the original is accounted for in sales and imports.<br>(IPCC default for lifetime - 15years) | An intrapolation has been conducted for HFC-134a, year 1995. The intrapolation is the average of 1996/1997. Intrapolation is found necessary becaouse 1995 are reference year and the consumption this year was 0 due to lack of data.<br>In 2001/2002 an assessment was made of the national Danish leakage rate from commercial plants. This assessment was carried out by COWI for the Danish EPA. This result has led to a decrease in the leakage rates for filling, operation and disposal in compliance with IPCC guidelines /16/. | From 2007, the consumption of refrigerants merely represents the amount used for refilling existing systems (stock). It is assumed that the consumption of refrigerants for refilling stock will be reduced by 15 per cent in 2007 and will then diminish by 5 per cent per year until 2014. |

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| K3 | Refrigerated vans and lorries | HFC-134a, HFC-404a | Tier 2 top-down approach<br>- information on refrigerant consumption in refrigerated vans and lorries is based on consumption information from refrigerated transport companies as well as data from the KMO. | 0.5% on refilling (DK default)<br>17% from operation annually (DK default, same as IPCC)<br>2% in reuse (DK default)<br>Lifetime = 6-8 years<br>Recovery: 88,5% | In 2001/2002 an assessment was made of the national Danish leakage rate from refrigerated vans and lorries. This assessment was carried out by COWI for the Danish EPA. This result has led to a decrease in the leakage rates for filling and disposal in compliance with IPCC guidelines. The leakage rate for operation is still 17% in compliance with IPCC guidelines /16/. | The tax effect has not been included, since refrigerated vans and lorries are exempt from taxes.<br>Stock is defined as 7.7 tonnes (HFC-134a) and 23.2 tonnes HFC-404A in 2000 /16/.<br>Consumption has been projected as steady state compared to 2001. |
| K4 | Mobile A/C systems | HFC-134a | Tier 2 top-down approach used for gathering of import/sales data from importers that supplies the Danish market with refrigerants to mobile A/C systems. | Consumption = refilling in mobil A/C = emission.<br>Recovery: 88,5% until 2011<br>After 2011, emissions = consumption to service. | | The projection is based on a steady state stock. |
| | *Foam production* | | | | | |
| S1 | Foam in household fridges and freezers (closed cell) | HFC-134a | Tier 2 top-down + bottom-up approach:<br>- information on refrigerant consumption provided by reports from the main producers of household fridges and freezers in DK. information on refrigerant consumption provided by reports from the main producers of household fridges and freezers in | 10% release in foam production (IPCC default)<br>4.5% release from stock per year (IPCC default)<br>Lifetime = 15 years (DK default)<br>Recovery: 100% | Stock of HFC in foam determined in 1998 for the period 1990-1998 based on information from Danish producers and estimates based on import/export statistics and average quantity of HFC contained | |

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| | | | DK, accounting for no less than an estimated 95% of the market. | 33% remaining upon disposal which is destroyed in incineration and thereby is not released as emissions (DK default). | in refrigerant and foam per unit /2/.<br>For the updating of stock, import/export data from 1998 is used, as well as information on annual HFC consumption by Danish producers. 1998 import/export data is = net exports of 141 tonnes HFC-134a refrigerant + net exports of 1.6 tonnes HFC-134a in foam (note: DK's largest exporter does not use HFC for foam moulding, therefore the export of HFC in foam is less than the export of refrigerants). | |
| S2 | Soft foam (open cell) | HFC-134a<br>HFC-152a<br>Other HFCs (HFC-365) | Tier 2<br>- information on foam blowing agents for soft foam is derived from reports provided by the main producer in Denmark, which still employs HFC in foaming processes. This producer is thought to represent approx. 80% of the Danish soft foam consumption. | Emissions = 100% of the HFCs sold in the current year (IPCC default) | | |
| S3 | Joint filler (open cell) | HFC-134a<br>HFC-152a | Tier 2 top-down approach.<br>- There are no longer any Danish producers of joint filler employing HFC as a foaming agent. Emissions are due to previous | Emissions = 100% of imported quantity contained in joint filler in the current year (IPCC default). | The estimated imports in 1998 by a joint filler producer were 10 tonnes HFC-134a and 1 tonne HFC-152a. | |

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| | | | estimates by producers of imported joint filler products. | | This estimate was based on the assumption that there is an average of 100 g HFC-134a and 25 g HFC-152a per tin of joint filler imported. | |
| S4 | Foaming of polyether (for shoe soles) | HFC-134a<br>HFC-152a | Tier 2 top-down approach<br>Information regarding consumption is identical to the consumption reported by producer in 1999 + an estimate of imports/exports of HFC in shoe soles, 1998.<br>Tier 2 bottom-up approach:<br>Imports of HFCs contained in shoes are based on the average amount per shoe and on Danish statistics. | Emission (Danish default):<br>- Production = 15 %<br>- Use = 4.5 %<br>- Lifetime = 3 years<br>- Disposal = 71.5%, destroyed in incineration and thereby not released as emissions. | The calculation of the HFC stock in shoe soles is based on the following assumptions: it is assumed that 5% of all shoes with plastic, rubber and leather soles contain polyether containing 8 g of HFC-134a per shoe.<br>Net export with the same consumption in Danish production is 0.3 tonnes HFC-134a. | |
| S5 | System foam (for panels, insulation, etc.) | HFC-134a<br>HFC-152a<br>Other HFCs (HFC-365) | Bottom-up Tier 2 approach on the basis of information from enterprises | Emissions = 0. HFC is used as a component in semi-manufactured goods and emissions first occur when the goods are put into use. | All system foam produced in Denmark is exported, therefore emissions can only occur in the country where the goods are put into use. | |
| | *Aerosols* | | | | | |

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| D1 | Aerosol sprays (industrial products) | HFC-134a | Tier 2.<br>- information on propellant consumption is derived from reports on consumption from the only major producers of HFC-containing aerosol sprays in Denmark. The importers are estimated to account for 100% of Danish consumption. | Emissions = 50% of the HFC sold to this area of application in the current year and 50% of the consumption in the second year (IPCC default for top-down data) | Top-down data.<br>Estimates of imports/exports are based on the producer's assessment of imports equivalent to 20% of Danish production in the current year. Exports are quantified by the producer. | |
| D2 | MDI (metered dose inhalers) | HFC-134a | Tier 2 bottom-up approach<br>- information on consumption is based on data from the national medical trade statistic concerning total sale of MDI in Denmark. Data from producers concerning product content of HFC-134a is used to calculate amount used pr. year. A unit factor of 72 mg HFC-134a/pr. dose are used for the calculation.<br>The estimate for 2016 is based on 2015, due to change in the format of the national medical trade statistics. A reduction of 10 per cent is added to numbers from 2015, to create consistency with the decrease seen throughout previous years. | Emissions = 100 % HFC used in these products are assumed to be consumed the same year. | HFC is used in MDI as a subsidiary for effective inhale of the medicine. It is assumed that 100 % of the subsidiary emits. | |
| | *Solvents* | | | | | |
| R1 | Liquid cleaners | PFC ($C_3F_8$ Perfluorpropane) | Tier 2.<br>- information on consumption of PFC in liquid cleaners is derived from two importers' sales reports. This is thought to represent | Emissions = 50% of the HFC sold to this area of application in the cur- | | Top-down data<br>Phasing-out cf. Statutory Order 1/9 2002. It is assumed that the |

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| | | | 100% of the Danish consumption of PFCs in liquid cleaners. | rent year and 50% of the consumption in the second year (IPCC good practice for top-down data) | | consumption is equally distributed over all months. |
| | *Others* | | | | | |
| O1 | Fibre Optics production | PFC-14<br>PFC-318<br>HFC-227ea | Tier 2.<br>- information on consumption of PFC in production of fibre optics is derived from importers' sales report with specific information on the amount used for production of fibre optics.. This is thought to represent 100% of the Danish consumption of PFC-14 and PFC-318 for that purpose | Emission = 100% in the production year = year for consumption | This is a new consumption area which are added for first time in 2006 emission calculation. | It is considered that consumption will be steady state in projection estimated. |
| | EMISSIONS OF $SF_6$ FROM ELECTRICAL EQUIPMENT AND OTHER SOURCES | | | | | |
| | Insulation gas in double glazing | $SF_6$ | Tier 2<br>- information on consumption of SF6 in double glazing is derived from importers' sales reports to the application area. The importers account for 100% of the Danish sales of $SF_6$ for double glazing. In addition, the largest producer of windows in Denmark has provided consumption data, with which import information is compared. | Emission (DK-default):<br>- 15% during production of double glazing.<br>- 1 % per year during the lifetime of the window<br>- Lifetime = 20 years | | Emissions data and lifetimes are based on information from the window producers and industry experts in Denmark /2/.<br>The stock is determined on the basis of consumption infor- |

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| | | | | - Disposal - 80% of the filled content of double glazing in the production year.<br>- Net exports = 50% of the consumption in the current year | | mation provided by importers back to 1990. The first Danish consumption was registered in 1991.<br>In the projection of emissions, it is assumed that the consumption of $SF_6$ in Danish window production was phased out in 2003, after which emissions only arise from stock. |
| | Insulation gas in high-voltage power switches | $SF_6$ | Tier 3c country-level mass-balance approach<br>- information on consumption of $SF_6$ in high-voltage power switches is derived from importers' sales reports (gas or gas-containing products). The importers account for 100% of the Danish sales of $SF_6$.<br>The electricity sector also provides information on the installation of new plant and thus whether the stock is increasing. | Emission (Danish default):<br>- release on filling = 5%<br>- loss / release in operation = 0.5 % per year<br>- release upon disposal = 0% | | There is one supplier (Siemens) that imports its own gas for filling in Denmark.<br>Suppliers (AAB, Siemens, Alstom) report on new installations.<br>The stock in 2000 was 57.6 tonnes of $SF_6$, which covers power switches of all sizes in production and transmission plants. The |

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| | | | | | | stock has been evaluated on the basis of a questionnaire survey in 1999 which encompassed the entire Danish electricity sector /11/. |
| | Shock-absorbing gas in Nike Air training footwear | $SF_6$ | Tier 2 - top-down approach<br>Importer has estimated imports to Denmark of $SF_6$ in training footwear. | Lifetime training footwear = 5 years | | Importer/wholesaler reports that imports for the period 1990-1998 amounted to approx. 1 tonne, equivalent to emissions of 0.11 tonnes per year in the period 1995-2003. For the period 1999-2005, the importer estimated imports to represent approx. 1/3, corresponding to 0.037 tonnes per year in the period 2004-2010. |

**Danish consumption and emission of F-gases**

The so-called F-gases are potent greenhouse gases and cause an increase in the ability of the atmosphere to retain surplus heat radiated from the earth. Consequently the temperature of the earth's surface and lower atmosphere is rising and this leads to climate changes. The potential effect of different greenhouse gases varies from substance to substance. This potential is expressed by a GWP value (Global Warming Potential).

The objective of this project was to quantify the Danish consumption and actual emissions of F-gases (HFCs, PFCs, and $SF_6$) on a yearly basis. Furthermore is future-emissions of F-gases extrapolated until 2030.

The emission calculation is partly conducted to fulfil Denmark's international obligations to provide data and information on F-gas emissions, and partly to assess the Danish trend in consumption and emissions of HFCs, PFCs, and $SF_6$.

A number of new requirements to F-gas emission calculation has recently been introduced by United Nations Intergovernmental Panel for Climate Change (IPCC). The requirements comprises new F-gases, new emission factors for certain F-gases, new application areas and changes in product lifetime.

The emission calculation are in compliance with the most recent revised IPCC methodologies.

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