Ministry of Environment of Denmark
Environmental Protection Agency

Danish consumption and emission of F-gases in 2022

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Contents

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 /36/ and references herein.

The emission calculations of F-gases are extrapolated to 2040 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 sector stakeholder for comments and general information. The assessment group consist of:

- Søren Nørby Pedersen, Danish Environmental Protection Agency
- Mikkel Aamand Sørensen, Danish Ministry of Environment
- Ole-Kenneth Nielsen, Department of Environmental Science, Aarhus University
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- Tomas Sander Poulsen, Provice ApS
- Nikolai Alstrup, KMO

The objective of the project was to quantify the Danish consumption and actual emissions of F-gases (HFCs, PFCs, and SF_6) for 2022.

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. Examples of previous reporting of Danish emissions is given in references, and most recently, in reference /36/.

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.

Overview

1.1 Full compliance with IPCC requirements

A number of updated and 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.

Overview of recent improvements

A few improvements are introduced in the emission calculation of F-gases in 2022.

The lifetime of emission of SF_6 from laboratories are changed from one year to two years through the whole time-series. This change is made as a response from the latest in-country review recommendations.

Further, also lifetime for emission of HFC-134a and HFC-227e from MDI are changed from one year to two years through the whole time-series. This change are made as a common initiative to align calculation methods between the Nordic countries. Both one year and two years are in compliance with the IPPC guidance.

According to projection, it is introduced for all commercial refrigeration categories with high GWP refrigerants, that trend is steady state until 2025, whereafter the consumption will reduce 20% pr. year

The calculation model for heat pumps is modified to accomplish the accelerating innovation and introduction towards R290 (natural refrigeration) in especially monoblock units up to 20 kW. The model is based on expert judgement from heat pump producers. it is assumed that 50% of monoblock units (air-water)up to 20 kW are R290 in actual year increasing up to 100% in 2026 because of the F-gas regulation.

Improvements from 2021 and before

The refrigerant HFC-410A in transport refrigeration is introduced as a separate category (CRF 2.F.1.d) with separate emission calculation, based on consumption data from consumers.

In 2020,10 new MDI products with HFC-134a and two new MDI products with HFC-227ea are applied for the category “medical doze inhalers” (CRF 2.F.4) for the full time series and HFC-32 in heat pumps was introduced.

In 2019, the emission factors for charge and operation of refrigerant in “stationary air-condition” (CRG 2.F.1.f) are consequently defined as 0,5% pr. charge and 10% in operation emission until 2009, and 3% operation emission from 2010 and forth.

In 2018, the group “other HFC’s” were split into five sub-groups – “HFC-410A”, “HFC-449A”, “HFC-452A” and “other HFC’s” and “HFO’s”. The sub-division is introduced for the full time series. Furthermore, the category “large and medium commercial refrigeration and stationery aircondition” for HFC-134a is divided into two categories – “medium and large commercial refrigeration (CRF 2.F.1.a)” and “stationary air-condition (CRF 2.F.1.f)” because new emission factors are applied for stationary air condition. The division is introduced for the full time series.

In 2017, a reduction of the emission factors for 2.F.1.f stationary A/C was introduced. From 2010 and onward, 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%. Furthermore, the new emission factor is in same range as 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. In 2017, a separate subcategory for heat pumps was introduced as well 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 the 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 reduction in total consumption of HFC refrigerants for almost all refrigerants.

The total bulk import reported by importers (minus re-export) of pure HFCs and HFC blends was 191.1 tonnes in 2022. Compared to 2021, where the import was 231.1 tonnes, the total import has decreased with approx. 40 tonnes, a decrease of 17%.

The bulk import of HFC-134a has decreased to 93.3 tonnes in 2022 from 116.3 tonnes in 2021. The HFC-134a consumption to maintain medium and large commercial refrigerants has decreased compared to the consumption in 2021.

The bulk import of HFC-404A has decreased by 3.7 tonnes to a total of 18.8 tonnes in 2022. In previous years, there has been a general decrease in consumption of HFC-404A. However, the rate of change converges. Hence, steady state of total import of HFC-404A is expected within the next years.

Import of HFC-410A has decreased to 33.7 tonnes in 2022, which is an increase of 16% compared to 2021. Hence, the consumption was extraordinarily high in 2021. HFC-410A is mainly used in stationary refrigeration and heat pumps.

The bulk import of HFC-407C was 19.6 tonnes for 2022 which is an increase compared to 2021 where the import was 17.5 tonnes. HFC-407C is applied in stationary air condition.

In 2022 the bulk import of HFC 507C is below 1 tonne. HFC-507A is used for medium and large commercial refrigeration.

The import of low GWP refrigerants has no increasing trend. The import of HFC-449A was 7.5 tonnes in 2022. In 2021 the import was 8.9 tonnes. The import of HFC-452A was 9.7 tonnes in 2022 which is an increase of 18% compared to 2021 with 8.2 tonnes. The use of these two substances is related to introduction as “low GWP” refrigerants, and are e.g., drop-in substitute for HFC-404A.

SF_6

The overall consumption of SF_6 in 2022 was approx. 0.8 tonnes. Consumption of SF_6 is primary related to power switches in high-voltage power systems. Only a very small amount is used for research, laboratories, and optics fibre production.

PFCs

No consumption of PFCs was reported for 2022.

GWP average for HFCs

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 of 21% with 2015 as reference year.

Table 1 below calculate the development of GWP average for HFCs placed on the Danish market. In 2021 the average GWP is reduced with 15,6% compared to 2015. The calculation approach is applied from the impact assessment of the EU F-gas directive and express the development in average GWP for HFC's. By calculation the total GWP from imported HFC's in bulk and divide total GWP with the imported HFC's in tonnes, it expresses the average GWP for all imported HFC's. The average GWP has decreased from 2,333 pr. kg. HFC to 1,882 pr. kg. HFC. A decrease of 19.3%. The reduction is close to the EU 2030 target of 21%.

TABLE 1. Development of average gwp for hfc placed on dk market, tonnes

	HFCs	Consumption, t	GWP value	%
2022	359.545	191	1.882	80,7
2021	455.034	231	1.969	84,4
2020	368.205	190	1.938	83,1
2019	405.055	202	2.005	85,9
2018	535.267	269	1.988	85,2
2017	620.689	271	2.292	98,2
2016	670.894	305	2.203	94,4
2015	656.914	282	2.333	100,0

1.2.2 Emission

The GWP-weighted actual emissions of HFCs, PFCs, and SF_6 in 2022 were 290,895 tonnes CO_2 equivalents. The emissions have decreased with 16,313 tonnes compared to 2021, where the corresponding emissions were 307,208 tonnes CO_2 equivalents. The development is stipulated in table 2.

The total 2022 emissions of F-gases have decreased for both HFCs and SF_6. The decrease is mainly caused by significant decrease of emissions of SF_6 from sound proof thermal windows because of reduced decommissioning/End of Life emission and stock emission from mobile air condition (MAC) with HFC-134a. Thus, the emissions have increased for the categories commercial refrigeration and heat pumps.

The F-gas emission accounts for approx. 1-1.5% of the total national GWP emission from all sources /31/.

In table 2 below, consumption, actual emissions and stock in products are summarised.

TABLE 2. Consumption, actual emissions, stock, actual emission and gwp contribution from f-gases, tonnes

Source	Substance	Consumption and imports, DK, tonnes	Stock, tonnes	Actual emissions, tonnes	GWP contribution, CO2 eqv. tonnes	GWP contribution in total, CO2 eqv. tonnes
Refrigerants for commercial refrigerators and A/C systems	HFC-134a	53,2	261,5	22,4	32.017	
	HFC-404A	18,6	108,9	12,2	47.835	
	HFC-407C	19,6	271,2	12,3	21.825	
	HFC-410A	32,3	251,3	9,4	19.695	
	HFC-449A	7,5	36,5	2,0	2.773	
	HFC-452A	5,6	23,5	2,2	4.800	
	HFC-507	0,1	35,5	3,9	15.735	
	Other HFCs	1,0	28,7	3,1	6.447	
	All substances					151.127
Refridgerants in domestic and special fridges/freezers	HFC-134a	0,2	62,8	0,6	805	
	HFC-404a	0,0	17,6	0,2	664	
	PFC-14	0,0	0,2	0,0	7	
	All substances					1.476
Insulationfoam in domestic fridges/freezers	HFC-134	0,0	0,0	0,0	0	
	HFC-152	0,0	0,0	0,0	0	
	All substances					0
Refrigerants for mobile A/C systems	HFC-134a	39,8		39,8	56.925	56.925
Refrigerated vans and lorries	HFC-134a	0,1	0,2	0,1	77	
	HFC-404A	0,1	7,8	1,7	6.574	
	HFC-410A	1,4	1,0	0,2	438	
	HFC-452A	4,0	9,5	1,6	3.485	
	All substances					10.575
Aerosol sprays etc.	HFC-134a	0,0	0,0	0,0	0	0
Hard Foam etc.	HFC-152a	1,0	44,9	4,3	532	532
MDI	HFC-134a	6,7	3,4	6,4	9.121	
	HFC-227ea	0,9	0,4	0,8	2.498	
	All substances					11.619
Heat pumps	HFC-407c	0,0	41,9	5,5	9.725	
	HFC-410A	38,9	432,6	15,2	31.686	
	HFC-32	114,6	212,7	6,7	4.545	
	All substances					45.956
Liquid cleaners	PFC	0,0	0,0	0,0	0	
Fibre optics	PFC-14	0,0	0,0	0,0	0	
	PFC-318	0,0	0,0	0,0	0	
	HFC-23	0,0	0,0	0,0	0	
	All substances					0
Double glazing	SF6	0,0	0,0	0,0	0	0
High-voltage power switches	SF6	0,7	101,4	0,5	12.388	12.388
Laboratories	SF6	0,0	0,0	0,0	296	296
Total	HFCs	345,8	1.639,2	142,0	278.203	
	PFCs	0,0	0,2	0,0	7	
	SF6	0,8	101,4	0,6	12.685	
GWP contribution	Total		1.740,8	142,5	290.895	290.895

It should be notified that the recieved data for consumption is considered in compliance with the Danish Statutory Order “F-gas bekendtgørelsen” (BEK nr 1013 af 13/05/2021).

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 2022.

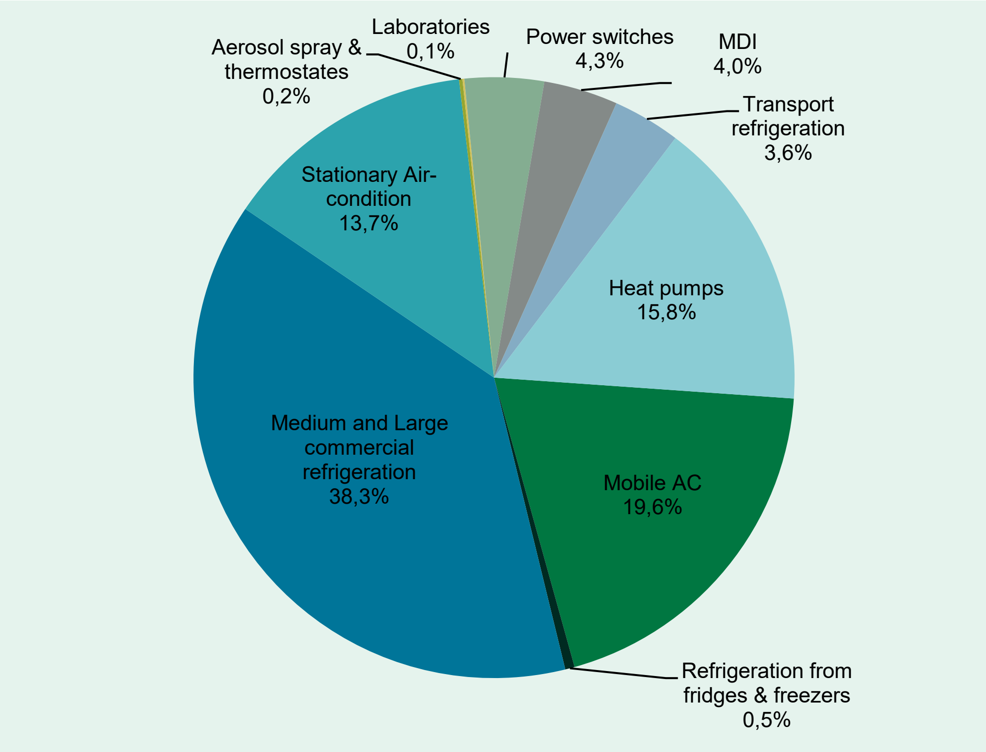

FIGURE 1. Relative distribution of gwp emissions by appliaction area

The figure determines that the emissions from refrigerants used in medium and large size commercial refrigerators account for the largest GWP contribution. This source covers 38.3% of the total actual emission of F-gases in 2022. The main contribution is from HFC-404A that accounts for 47,835 tonnes CO_2-equivalents.

The second-largest source for GWP contribution occurs from mobile A/C (MAC), accounting for 56,925 tonnes CO_2-equivalents, which constitutes for 19,6%. This is a significant decrease compared to 78,740 tonnes CO_2-equivalents in 2021.

The third-largest source is heat pumps accounting for 15.8% of the total GWP contribution, and the fourth-largest source is stationary air conditioning, which contributes with 13.7%.

The total HFCs' contribution comprises 95.6% of the overall GWP contribution in 2022, emissions of SF_6 is 4.4% and emissions of PFCs contribute with 0%.

HFCs

Actual emissions of HFCs have been calculated to 278,213 tonnes CO_2 equivalents. In 2021, emissions were approximately 292,618 tonnes CO_2 equivalents. It is a small decrease of 14,415 tonnes CO_2 equivalents.

SF_6

Actual emissions have been calculated to a GWP contribution of 12,685 tonnes CO_2 equivalents. In 2021, the emissions were 14,582 tonnes CO_2 equivalents. The decrease is small.

PFCs

The emission of PFCs origins only from old stock emission from commercial refrigeration containing HFC-413A (contains 9 per cent Perflourpropan), in 2022, there is a marginal stock left. The total GWP-weighted PFC emission was 7 tonnes CO_2 equivalents in 2022.

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 1992-2022. The differences from the present calculations of the total GWP value compared with earlier calculation methods are illustrated in the figure.

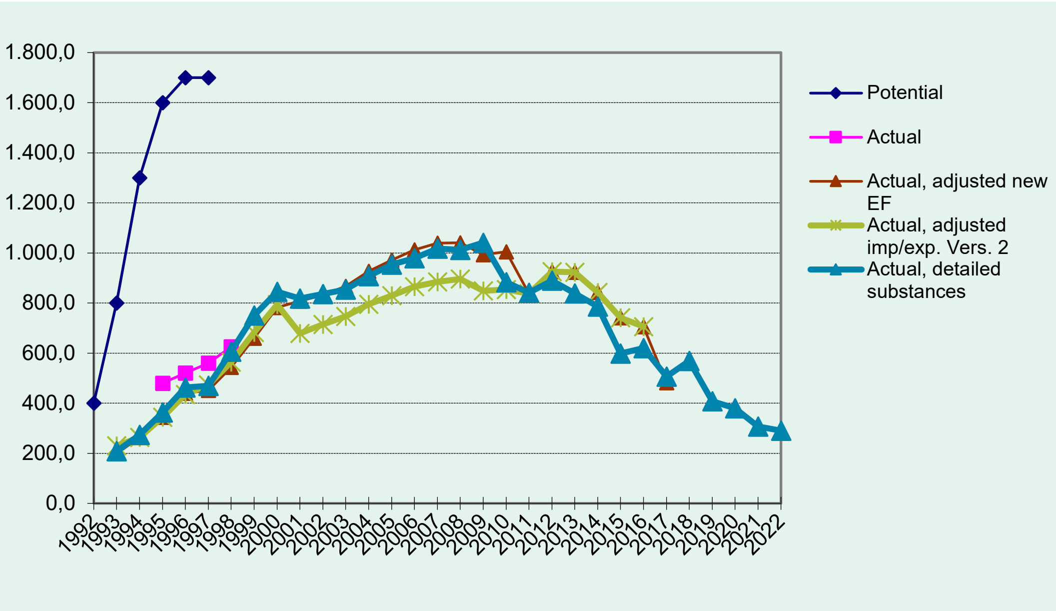

FIGURE 2. Gwp-weighted potential, actual and, adjusted actual emissions 1992-2022, 1000 tonnes co_2 equivalents

The GWP emission has increased from 1992-2008 and peaked in 2009, whereafter it indicates a significant decreasing trend from 2013 onwards.

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

TABLE 3. Total gwp-contribution from hfc's, pfc's, sf_6, 1992-2022 determined according to the four different methods of calculation applied during this period, 1000 tonnes co_2 equivalents**.**

Year	Potential	Actual	Actual, adjusted imp/exp. Vers. 2	Actual, adjusted new EF	Actual, detailed substances
1992	400,0				
1993	800,0		230,3	198,8	207,9
1994	1.300,0		263,2	262,8	274,3
1995	1.600,0	480,0	344,1	344,5	363,4
1996	1.700,0	520,0	434,7	440,1	462,8
1997	1.700,0	560,0	472,5	451,2	468,7
1998		625,0	563,7	543,6	606,1
1999			682,8	659,7	750,8
2000			793,3	782,2	845,0
2001			679,0	807,2	817,7
2002			715,0	831,5	836,5
2003			746,0	866,2	854,0
2004			795,0	926,6	908,1
2005			829,0	971,3	953,9
2006			865,0	1.012,4	979,1
2007			884,4	1.038,7	1.017,9
2008			895,7	1.040,7	1.012,7
2009			848,4	992,7	1.041,0
2010			854,4	1.004,9	883,6
2011			837,7	837,7	841,6
2012			925,2	925,2	889,6
2013			922,4	922,4	838,4
2014			842,7	842,7	786,2
2015			742,0	742,0	597,9
2016			705,0	705,0	620,1
2017				482,0	506,0
2018					568,6
2019					407,8
2020					380,2
2021					307,4
2022					290,9

The table 4 below shows the time series 1993-2022 and the 2022-2040 projections of F-gases (1,000 tonnes CO_2 equivalents).

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

TABLE 4. Total gwp-emission from hfc's, pfc's sf_6, 1993-2040, 1,000 tonnes co_2 equivalents.

Year	HFC-134a	HFC-152a	HFC-404A	HFC-401A	HFC-402A	HFC-407C	HFC-410A	HFC-449A	HFC-452A	HFC-507A	HFC-23	HFC-32	HFC-227ea	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	116,8	274,3
1995	228,8	5,4	21,8	-	1,5	-	-	-	-	-	-	-	-	0,4	0,6	104,9	363,4
1996	318,2	4,0	69,1	-	4,6	-	-	-	-	-	-	-	-	3,5	2,1	61,4	462,8
1997	272,0	1,9	107,3	0,0	8,3	0,4	-	-	-	0,5	-	-	-	7,2	5,2	66,0	468,7
1998	332,6	1,2	170,4	0,0	9,5	2,9	-	-	-	3,7	-	-	-	9,8	11,5	64,5	606,1
1999	381,1	4,7	249,6	0,1	10,8	6,2	-	-	-	7,3	-	-	-	12,4	15,7	62,9	750,8
2000	397,1	2,0	313,2	0,1	11,9	12,8	-	-	-	11,4	-	-	-	17,0	22,6	56,8	845,0
2001	397,9	1,6	284,1	0,1	11,6	19,4	0,0	-	-	18,4	10,4	-	-	20,1	27,9	26,2	817,7
2002	399,2	1,6	307,1	0,1	10,3	25,9	0,2	-	0,1	18,2	-	-	-	21,4	28,0	24,4	836,5
2003	359,1	0,2	348,4	0,1	8,2	39,3	0,8	-	0,7	21,8	-	-	-	23,3	24,6	27,5	854,0
2004	370,0	0,8	375,9	0,1	7,8	52,7	1,2	-	0,6	23,4	-	-	-	25,5	20,5	29,6	908,1
2005	352,4	0,2	430,3	0,1	6,8	64,3	1,7	-	0,6	25,0	-	-	-	26,6	18,8	27,2	953,9
2006	347,3	0,4	451,4	0,1	6,1	69,0	2,3	-	0,5	24,7	1,2	-	-	27,2	21,2	27,7	979,1
2007	351,4	0,5	472,8	0,1	5,5	74,1	3,8	-	0,6	24,9	3,6	-	-	26,7	21,2	32,7	1.017,9
2008	333,4	0,6	485,0	0,0	6,2	76,4	6,2	-	1,4	26,4	1,8	-	-	26,6	18,4	30,2	1.012,7
2009	325,6	0,6	506,0	0,0	6,4	83,2	9,0	-	1,8	24,8	3,6	-	-	28,4	19,5	32,1	1.041,0
2010	305,2	0,7	444,0	0,0	1,1	27,3	3,1	-	1,6	24,9	5,3	-	-	24,1	10,2	36,0	883,6
2011	261,7	0,6	403,2	0,1	-	33,2	4,0	-	2,1	29,6	5,3	-	-	17,7	7,7	76,3	841,6
2012	283,1	0,7	385,2	-	-	36,0	4,9	-	2,3	26,9	1,8	-	-	15,5	3,5	129,6	889,6
2013	233,5	0,9	362,4	-	-	42,4	6,1	-	2,5	25,6	-	-	-	15,5	3,7	145,7	838,4
2014	203,5	0,7	319,0	-	-	42,2	10,4	-	2,8	34,2	2,1	-	-	10,5	2,7	158,3	786,2
2015	141,0	0,8	236,4	-	-	39,6	14,0	-	3,9	22,8	-	-	0,4	10,0	0,0	129,0	597,9
2016	158,3	0,8	249,7	-	-	48,0	18,1	-	4,3	30,3	-	-	0,9	12,7	0,0	97,0	620,1
2017	118,2	0,7	194,1	-	-	45,3	22,6	-	2,5	26,3	-	-	1,3	12,7	1,1	81,1	506,0
2018	156,5	0,7	229,6	-	-	41,7	27,9	0,0	2,9	23,8	-	-	1,8	9,6	0,0	74,1	568,6
2019	108,6	0,7	122,6	-	-	35,1	34,9	0,8	5,2	17,7	-	-	2,2	7,7	1,1	71,2	407,8
2020	118,9	0,6	106,7	-	-	33,4	40,1	1,5	6,5	16,6	-	1,0	2,5	5,9	0,0	46,5	380,2
2021	115,5	0,6	63,0	-	-	27,1	46,8	2,1	8,8	17,9	-	2,1	2,4	6,3	0,0	14,7	307,4
2022	**98,9**	**0,5**	**55,1**	**-**	**-**	**31,6**	**51,8**	**2,8**	**8,3**	**15,7**	**-**	**4,5**	**2,5**	**6,4**	**0,0**	**12,7**	**290,9**
2023	104,6	0,5	55,7	-	-	21,0	53,9	3,2	8,6	14,6	-	6,9	2,8	6,0	0,0	12,8	290,4
2024	103,2	0,4	57,2	-	-	20,0	71,1	3,6	10,2	13,8	-	9,1	2,8	5,6	0,0	12,8	310,0
2025	109,7	0,3	62,4	-	-	19,0	68,2	4,0	11,5	10,2	-	11,3	2,8	6,5	0,0	12,8	318,7
2026	98,2	0,3	60,9	-	-	18,1	70,8	4,4	10,3	12,2	-	13,3	2,8	3,9	0,0	12,8	308,0
2027	83,7	0,2	56,5	-	-	17,2	75,1	4,7	9,7	11,8	-	15,3	2,8	5,2	0,0	12,9	295,0
2028	75,6	0,1	55,4	-	-	14,7	74,3	5,0	11,2	0,0	-	16,9	2,8	4,5	0,0	12,9	273,4
2029	65,9	0,1	50,8	-	-	11,9	75,1	5,3	8,7	0,0	-	18,2	2,8	0,1	0,0	12,9	251,8
2030	59,0	0,0	38,3	-	-	13,5	62,9	5,5	9,1	0,0	-	22,9	2,8	0,1	0,0	12,9	227,1
2031	50,0	0,0	41,6	-	-	11,3	67,7	5,8	10,0	0,0	-	23,0	2,8	0,1	0,0	13,0	225,2
2032	40,5	0,0	11,0	-	-	10,1	58,6	7,3	12,8	0,0	-	27,7	2,8	0,1	0,0	13,0	184,0
2033	31,3	0,0	11,5	-	-	9,4	53,8	6,6	8,5	0,0	-	25,5	2,8	0,1	0,0	13,0	162,5
2034	22,9	0,0	9,1	-	-	6,4	50,7	6,3	9,2	0,0	-	23,3	2,8	0,1	0,0	13,0	143,8
2035	21,0	0,0	8,1	-	-	6,1	50,9	5,8	9,7	0,1	-	21,1	2,8	0,1	0,0	13,0	138,8
2036	20,1	0,0	1,6	-	-	6,1	44,3	5,2	10,2	0,0	-	18,9	2,8	0,1	0,0	13,0	122,4
2037	18,4	0,0	1,3	-	-	5,6	40,7	5,1	10,3	0,0	-	16,9	2,8	0,1	0,0	13,1	114,2
2038	17,0	0,0	1,2	-	-	4,9	36,9	5,0	10,2	0,0	-	13,9	2,8	0,1	0,0	13,1	105,0
2039	15,8	0,0	1,0	-	-	4,3	33,2	4,9	10,4	0,0	-	11,5	2,8	0,1	0,0	13,1	97,1
2040	14,2	-	0,9	-	-	3,0	27,9	4,9	10,4	0,0	-	9,6	2,8	0,1	0,0	13,2	86,9
Sum	8.675,2	46,1	8.290,9	0,9	116,7	1.212,0	1.326,4	100,1	241,2	605,7	34,9	312,8	63,9	463,3	288,0	2.194,5	23.972,6

2. Methodology

The emission calculation is made in accordance with the IPCC guidelines (Intergovernmental Panel on Climate Change) /4/. In comparison to last year's calculation, some methodological adjustments have been made.

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 /22/.

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/.

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 to estimated emissions in the area of application.

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. Analyses 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 such as average content in products, Statistics Denmark's foreign trade statistics, and information from relevant industries.

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. There has been a growing trend of using new, low-GWP substances. Therefore, the recent years calculation have introduced several new, separate substances categories – HFC-32, HFC-449A, HFC-452A and HFOs. These substances were previously calculated as “Other HFCs” category, but due to the steady increase in use, import and emissions, they are now calculated separately for each of these substances. This change provide more accurate conclusions on GWP trends. This change has also entailed that the historical emissions have been changed.

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 are fully implemented. The change in emission factors is revised for the full time period 1992-2040 to assure consistency in the methodology as outlined in IPCC’s guidance.

According to the IPCC guidance, new application areas have 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 have 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 have 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 in 2015 and no import or stocks of NF_3 was identified.

The emission projections are determined by following assumptions:

- Steady state consumption using most recent year as the reference year including the cut-off dates for the phasing-out of specific substances, cf. the Statutory Order regulating certain industrial greenhouse gases /30/

- *Medium and large commercial refrigeration (2.F.1.a):* Consumption of HFC-134a, HFC-404A are steady state consumption using most recent year as the reference year until 2025. From 2026, the consumption decreases with 20% per year

- *Medium and large commercial refrigeration – low GWP refrigerants (2.F.1.a):* Consumption of HFC-449A, HFC-452A are steady state consumption using most recent year as the reference year

- *Stand-alone domestic refrigeration (2.F.1.b):* Consumption of HFC-134a is steady state consumption using most recent year as the reference year

- *Transport refrigeration (2.F.1.d):* Steady state consumption using most recent year as the reference year

- *Mobile Aircondition, MAC (2.F.1.e):* Consumption of HFC-134a is steady state consumption using most recent year as the reference year until 2025. From 2026, the consumption decreases with 20% per year. The assumption is made with reference to a graduated increased effect of the MAC Directive require only HFOs in new person cars introduced to the EU market

- *Stationary aircondition (2.F.1.f):* Consumption of HFC-134a, HFC-404A, HFC-407C, HFC-410A are steady state consumption using most recent year as the reference year until 2025. From 2026, the consumption decreases with 20% per year

- *Stationary aircondition – low GWP refrigerants (2.F.1.f):* Consumption of HFC-449A, HFC-452A are steady state consumption using most recent year as the reference year

- *Heat pumps (2.F.1.f):* The model for calculating consumption of HFC's in heat pumps are based on statistic from sold heat pumps to DK market. The projection of HFC-32 in air-air heat pumps are steady state using most recent year as reference. The projection of consumption of HFC-32 in monoblock units are based on a relative deduction of stock pr. year until 2026, where R290 are expected fully phased in as substitute for HFC-32 in monoblock units. The consumption of HFC-410 in other air-water units are steady state using most recent year as the reference year.

- *Medical Doze Inhalers and Aerosol spray (2.F.4):* Steady state consumption using most recent year as the reference year

- Switch gear (2.G.1): Steady state consumption of SF_6 using most recent year as the reference year.

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:* Quantities of substances reported in Denmark in the year in question via imports from wholesalers and information from Danish enterprise end-users.

- *Importer:* Enterprises in Denmark that import (from EU and outside EU) and sell the relevant substances on the Danish market.

- *KMO:* On behalf of the Danish Environmental Protection Agency, KMO issues HFC and SF6 gas authorizations as well as AC EU certificates for companies and individuals in the automotive industry.

- *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 from EU or outside EU. None has imported NF_3 in this year or any previous years.

NF_3 is therefore considered non-existing in Denmark.

3.1.2 HFCs from the latest IPCC Refinement

The new HFCs 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 2022. Previously, a minor amount of HFC-245fa was imported as refrigerant, 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 among others foam blowing. These two F-gases have already been included in the previous emission calculations.

3.1.3 New PFCs

The new PFCs are:

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

No importers confirm import of these PFC's in 2022 or any previous years.

3.2 Import of substances

An overall picture of the trends in imports of F- gases is given in table 4 (chapter 1), based on information from importers for the years 1992-2022.

3.2.1 HFCs

HFCs were imported by eight enterprises in 2022, either for resale or use in own production.

Overall, there has been a reduction in total consumption of HFC refrigerants for almost all refrigerants.

The total bulk import reported by importers (minus re-export) of pure HFCs and HFC blends was 191.1 tonnes in 2022. Compared to 2021, where the import was 231.1 tonnes, the total import has decreased with approx. 40 tonnes, a decrease of 17%.

The bulk import of HFC-134a has decreased to 93.3 tonnes in 2022 from 116.3 tonnes in 2021. The consumption of HFC-134a for MAC has decreased 15.3 tonnes, and HFC-134a for commercial refrigeration has increased with 12.1 tonnes.

The bulk import of HFC-404A has decreased by 3.7 tonnes to a total of 18.8 tonnes in 2022. In previous years, there has been a general decrease in consumption of HFC-404A. I smaller decrease of HFC-404A applied in commercial refrigeration is expected within the next years, because of the general introduction of low GWP refrigerants and substitution to e.g., CO_2 units.

Import of HFC-410A has decreased to 33.7 tonnes in 2022, which is an increase of 16% compared to 2021. Hence, the consumption was extraordinarily high in 2021. HFC-410A is mainly used in stationary refrigeration and heat pumps. 1,4 tonnes were used for transport refrigeration.

The bulk import of HFC-407C was 19.6 tonnes for 2022 which is an increase compared to 2021 where the import was 17.5 tonnes. HFC-407C is applied in stationary air condition. Most old HCFC-22 appliances are replaced now, so consumption of HFC-407C is mainly related to fillings in heat pumps.

In 2022 the bulk import of HFC 507C is below 1 tonne. HFC-507A is used for medium and large commercial refrigeration. HFC-507 is a drop-in refrigerant in old commercial refrigeration systems.

The import of 'Other HFCs' was 7.4 tonnes in 2022, which is a increase compared to the 2021 consumption (4.7 tonnes). The refrigerants were primary HFC-32.

The import of low GWP refrigerants has no increasing trend. The import of HFC-449A was 7.5 tonnes in 2022. In 2021 the import was 8.9 tonnes. The import of HFC-452A was 9.7 tonnes in 2022 which is an increase of 18% compared to 2021 with 8.2 tonnes.

1 tonnes of HFC-152a was imported in 2022.

With regard import of HFCs in products, two categories are calculated:

Medical Doze inhalers (MDI)

- HFC-134a
- HFC-227ea

Heat pumps

- HFC-410A
- HFC-32

In 2022, the import of HFC-134a in MDIs was calculated to be 6.7 tonnes and the import of HFC-227ea in MDI was calculated to be 0.9 tonnes.

The import of HFC-32 in air-air heat pumps in 2022 is estimated to 114.6 tonnes compared to 51.1 tonnes in 2021. The import of HFC-410A in air-water heat pumps in 2022 is estimated to 38.9 tonnes compared to 73.8 tonnes in 2021. The reduction of HFC-410A is a consequence of the introduction of R290 (natural refrigerant) in monoblock units.

3.2.2 Sulphur hexafluoride

Four importers reported an import of 0.8 tonnes of sulphur hexafluoride in 2022. It is a decrease from 1.5 tonnes compared to 2021. Sulphur hexafluoride is mainly used in power switches. A very small amount is also used in laboratories, including plasma erosion, analytical purposes, particle accelerators, radiotherapy equipment and electronic microscopes.

3.2.3 Perfluorinated hydrocarbons

No import of PFC-14 (tetrafluoromethan - CF_4) has been reported in 2022 (or 2018-2021). In 2017, the import was approx. 14 kg. PFC-14 is used as low temperature refrigerant in stand-alone commercial applications.

Table 5 below contains an overview of the bulk import of all F-gases since 1992.

TABLE 5. Development in bulk import of f-gases

Year / Substance	HFC-134a	HFC-152a	HFC-401A	HFC-402A	HFC-404a	HFC-407C	HFC-507	HFC-410A	HFC-449A	HFC-452A	Other HFCs[1]	All HFCs	SF6
1992	20,0	4,0	-	-	-	-	-	-	-	-	-	24,0	15,0
1994	524,0	51,0	-	-	36,0	-	-	-	-	-	-	611,0	21,0
1995	565,0	47,0	-	-	119,0	-	-	-	-	-	14,0	745,0	17,0
1996	740,0	32,0	-	-	110,0	-	-	-	-	-	20,0	902,0	11,0
1997	700,0	15,0	-	-	110,0	-	-	-	-	-	16,0	841,0	13,0
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	-	-	-	29,0	978,1	12,1
2000	711,1	16,4	9,5	4,2	193,1	44,7	23,8	-	-	-	24,0	1.026,8	9,0
2001	472,8	11,1	4,1	0,8	126,2	40,3	2,2	0,7	-	-	22,7	680,9	4,7
2002	401,6	11,9	-	-	188,7	89,1	14,4	2,7	-	3,3	18,9	730,6	1,4
2003	241,2	3,3	0,2	1,7	145,0	96,8	9,2	2,7	-	-	40,3	540,4	2,2
2004	306,5	11,0	-	-	252,6	101,3	10,6	2,6	-	-	25,0	709,6	2,3
2005	235,4	5,5	-	-	162,4	61,6	5,4	3,1	-	-	28,4	501,8	3,6
2006	280,7	11,6	-	-	176,4	70,6	6,1	7,7	-	-	72,4	625,4	4,2
2007	160,7	13,0	-	-	129,9	50,5	11,4	12,8	-	4,5	13,2	396,0	5,4
2008	164,5	15,0	-	-	114,1	76,8	1,8	16,9	-	2,7	175,0	566,8	5,9
2009	175,3	12,0	-	-	106,9	49,3	7,0	12,1	-	-	16,8	379,4	4,3
2010	160,6	15,0	-	-	103,6	42,4	9,1	16,0	-	3,0	3,4	353,1	3,8
2011	180,5	8,0	-	-	105,0	42,8	6,1	15,5	-	2,0	12,0	371,9	3,1
2012	171,7	13,0	-	-	99,5	42,7	12,1	21,5	-	2,0	1,5	364,1	2,6
2013	154,5	22,6	-	-	91,5	43,8	20,5	20,6	-	2,0	11,0	366,3	3,6
2014	139,4	5,8	-	-	84,5	37,2	22,9	17,5	-	7,0	28,8	343,0	2,0
2015	115,9	7,0	-	-	76,6	27,9	13,3	20,9	-	-	20,0	281,6	1,5
2016	150,4	4,0	-	-	68,1	37,6	13,7	19,7	-	-	11,0	304,6	3,1
2017	124,4	-	-	-	80,2	30,9	2,6	22,1	-	2,5	8,0	270,8	2,8
2018	139,4	-	-	-	42,6	28,2	0,4	35,3	8,4	12,3	2,7	269,2	2,0
2019	96,6	-	-	-	31,2	27,7	1,7	28,7	7,9	6,2	2,1	202,1	1,4
2020	97,4	-	-	-	24,4	17,4	1,0	28,1	9,0	8,2	4,5	190,0	1,6
2021	116,3	-	-	-	22,5	17,5	-	43,0	8,9	8,2	10,0	231,1	1,5
2022	93,3	1,0	-	-	18,8	19,6	0,1	33,7	7,5	9,7	7,4	191,1	0,8

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

3.3 Consumption by application area

The assessment of consumption divided into categories is estimated on basis of information from importers and producers. Table 6 below contains the HFC consumption data per sub-category.

TABLE 6. Netto bulk import of hfc distributed on sub sector, tonnes

Use / Substance	HFC-134a	HFC-152a	HFC-404A	HFC-407C	HFC-507A	HFC-410A	HFC-449A	HFC-452A	HFC 32 and other	Total
Insulation foam	-	-	-	-	-	-	-	-	-	-
Foam systems	-	-	-	-	-	-	-	-	-	-
Soft foam	-	-	-	-	-	-	-	-	-	-
Other applications	-	1,0	-	-	-	-	-	-	-	1,0
Stand-alone commercial applications	0,2	-	0,0	-	-	-	-	0,1	-	0,4
Medium and large commercial refrigeration	38,3	-	18,6	-	0,1	-	3,7	2,8	1,0	64,6
Transport refrigeration	0,1	-	0,1	-	-	1,4	-	4,0	-	5,6
Mobile A/C	39,8	-	-	-	-	-	-	-	-	39,8
Stationary aircondition	14,9	-	-	19,6	-	32,3	3,7	2,8	6,4	79,7
Total	93,3	1,0	18,8	19,6	0,1	33,7	7,5	9,7	7,4	191,1

3.3.1 Consumption of HFC refrigerant

The consumption of HFC refrigerants has generally increased across all categories.

The largest consumption of HFC refrigerants is related to heat pumps. Since 2015, the consumption (primarily through imported products) has increased from approx. 40 tonnes in 2015 to 160 tonnes in 2022. The used refrigerants are HFC-410A and HFC-32.

The use of HFCs as refrigerant in commercial refrigeration covers 18,8% of the total HFC refrigeration consumption in 2022. The most commonly used refrigerants in commercial refrigeration are HFC-134a and HFC-404A.

The use of HFCs as refrigerant in stationary A/C covers 21.3% of the total HFC refrigeration consumption in 2022. The most commonly used refrigerants in stationary A/C are HFC-410A and HFC-407C.

The consumption of refrigerants in mobile A/C covers 11.6% of the total consumption of HFC for refrigeration.

The consumption of refrigerants in fridges/freezers was 0.1% of the total consumption in 2022. Most producers have substituted to alternative refrigerants or moved production facilities to other countries.

The consumption of refrigerants in vans and lorries for transport refrigeration covers 1.6 % 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 manufacture 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 refrigerant bulk import and refrigerant import in products by weight of refrigerants according to application area.

TABLE 7. Comsumption of hfc refrigerant according to sub categories

HFC Substance/ Application	Fridges /freezers	Commercial refrigeration	Stationary A/C	Heat pumps	Mobile A/C	Refrigerated vans and trucks	Total	Percent
134a	0,2	38,3	14,9	-	39,8	0,1	93,3	27,2
404A	0,0	18,6	-	-	-	0,1	18,8	5,5
407C	-	-	19,6	-	-	-	19,6	5,7
410A	-	-	32,3	38,9	-	1,4	72,7	21,1
449A	-	3,7	3,7	-	-	-	7,5	2,2
452A	0,1	2,8	2,8	-	-	4,0	9,7	2,8
507A	-	0,1	-	-	-	-	0,1	0,0
Other HFC's	-	1,0	-	121,0	-	-	122,0	35,5
Total	0,4	64,6	73,3	160,0	39,8	5,6	343,6	-
Percent	0,1	18,8	21,3	46,5	11,6	1,6	-	100,0

3.3.2 Consumption of HFC as blowing agent and as propellant

Since 2019, the reported use of HFCs as propellants in aerosols for specific industrial purposes has been substituted with HFO-1234ze.

The import and consumption of Norfluran (HFC-134a) in Medical Doze Inhalers (MDI) was 6.7 tonnes and the import and consumption of Apafluran (HFC-227ea) in MDIs was 0.9 tonnes. This is an increase compared to the consumption in 2021. Since 2015, the import and consumption of HFCs in MDI has increased 65% because of extended use of MDIs with spray-function. MDIs with HFC propellant are prescribed when a patients lung capacity is not in conditions to inhale the medicine unaided.

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 SF6

The import and consumption of SF_6 in 2022 was 0.76 tonnes. Consumption of SF_6 is used for power switches in high-voltage power systems, and laboratories, including plasma erosion, analytical purposes, particle accelerators, electronic microscopes and medical services such as radiotherapy. The consumption is stipulated in the table below. 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 1st of January 2003 /30/.

TABLE 8. Consumption of sf_6 by sub categories, tonnes

Application area	DK consumption, tonnes
Power switches in high-voltage plants	0,75
Plasma erosion	0,00
Laboratories	0,02
Total	**0,76**

3.3.4 Consumption of PFCs

No import of PFCs has been reported in the period 2018-2022 and the PFCs are now assumed phased out. In 2017 a minor import of PFC-14 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 2022. All emissions are calculated as *actual* emissions according to IPCC's tier 2 methodologies.

The emission calculation is based the revised GWP values as stated in the IPCC 2019 refinement (ref. to appendix 1). The emission modelling is based on the IPCC guidance /22/ and calculated upon collected and available data as presented in chapter 2.

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 description of methodology). The specific emission calculation refers to appendix 1 and 3 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, 22/.

The total GWP-weighted actual emission of HFCs, PFCs, and SF_6 in 2022 is calculated to 290,895 tonnes CO_2 equivalents. The corresponding emissions in 2021 were approx. 307,208 tonnes CO_2 equivalents. Consequently, we can notice a decreased total emission of approx. 5% compared to 2021. The emission from heat pumps have increased. The remaining categories are more less at same level as 2021 except emissions from MAC which have decreased significant.

The consumption and GWP contribution for HFCs, PFCs, and SF_6 for this year and last years are shown in table 9 below.

TABLE 9. Total f-gas consumption and f-gas gwp èmission, tonnes

	2021		2022	
Substance group	Consumption and imports, DK, tonnes	GWP contribution, CO2 eqv. tonnes	Consumption and imports, DK, tonnes	GWP contribution, CO2 eqv. tonnes
HFCs	365	292.618	346	278.203
PFCs	0,0	7	0,0	7
SF6	1,5	14.582	0,8	12.685
Total		307.208		290.895

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 the different applications using refrigerants, the so called CRF categories:

- 2.F.1.a - Medium and large Commercial Refrigeration + Industrial refrigeration
- 2.F.1.b - Stand-alone Commercial Applications (Fridges and freezers for household use etc.)
- 2.F.1.d - Mobile refrigeration systems (in vans and lorries)
- 2.F.1.e - Mobile air conditioning - MAC (in cars, trucks, bus, trains etc.)
- 2.F.1.f – Stationary air condition and heat pumps

In general the actual emissions from these sources occur in connection with:

- *Filling of refrigerants* (emission is 0.2 percent to 1.5 per cent of refilled amount depending on application area).

- *Continual release during the operational lifetime*. An assumed average value which accounts operational leakage including release occurring as a result of accident and damage (depending on application area, the average yearly emission differs from 3-17%).

- *End of Life*. Emission resulting from disposal of items and equipment in the applications differs from 0-20%. For most categories the emission is calculated as 0% because Danish legislation and waste treatment infrastructure ensures that management and treatment of refrigerants prevent uncontrolled emissions. For heat pumps the emission at decommissioning is estimated as 20% due to lack of control measures with decommissioning of air-air heat pumps from private household.

Medium and large size commercial refrigeration (2.F.1.a)
Commercial refrigeration, used e.g. in retail, supermarket, restaurants etc. or in industry, constitute the largest source of emissions. The most commonly used refrigerants in this product group are HFC-134a, HFC-404A, HFC-449A, HFC-452A and HFC-507A, where HFC-404A and secondly HFC-134a is the majority of the emissions in 2022.

It is not relevant to adjust for imports and exports of HFCs in large and medium size commercial refrigeration since filling of refrigerants only will take place on site when the units are installed.

Table 10 below shows the consumption, stock and actual emission for the main HFC substances used in Danish large and medium size 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 2022, 2023, 2030 and 2040 in future scenarios are also shown.

TABLE 10. Consumption, stock and actual emissions and gwp contribution from large and medium size commercial refrigeration, tonnes

Substance	Consumption 2022	Stock 2022	Actual emission 2022	GWP-contribution 2022	GWP-contribution 2023	GWP-contribution 2030	GWP-contribution 2040
HFC-134a	38,3	205,3	18,8	26.842	32.055	24.708	230
HFC-404A	18,6	127,5	12,2	47.835	50.363	36.595	307
HFC-449A	3,7	16,9	1,5	2.078	2.392	3.865	2.919
HFC-452A	2,8	17,2	2,1	2.074	1.735	1.450	1.512
HFC-507A	0,1	35,7	3,9	15.735	14.569	20	11
Other HFCs 1)	1,0	28,7	3,1	3.088	2.879	39	21
All				**97.652**	**103.993**	**66.677**	**5.000**

1) The category "other" 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 limited installations of new larger HFC refrigeration systems because of alternative refrigerants and the statutory order /30/, which do not allow construction of new installations larger than 10 kg HFC per unit after 1st of January 2007.

In the trend analysis, the total emission from this sector is estimated to have reduction of 31.7% in 2030 compared to 2022 and of 94.9% in 2040.

Stationary air condition and heat pumps (2.F.1.f)
Stationary A/C systems are used in office buildings, by retailers etc. for comfort. Heat pumps are used both in private residential houses and in the public/private sector. The most commonly used refrigerants in this product group are HFC-32, HFC-134a, HFC-407C, HFC-410A, HFC-449A, HFC-452A.

A larger amount of HFC-410A is used in air-water heat pumps. According to the innovation in heat pumps It is expected that HFC-32 and natural refrigeration (R290) will substitute HFC-410A within few years in a number of applications, particular in monoblock units /34/.

Table 11 below shows the consumption, stock and actual emission for the main HFC substances used in stationary refrigeration and heat pumps. 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 2022, 2030 and 2040 in future scenarios are also shown.

TABLE 11. Consumption, stock and actual emissions and gwp contribution from stationary refrigeration and heat pumps, tonnes

Substance	Import 2022	Stock 2022	Actual emission 2022	GWP-contribution 2022	GWP-contribution 2023	GWP-contribution 2030	GWP-contribution 2040
HFC-134a	14,9	103,3	3,6	5.175	5.341	5.816	2.261
HFC-407C	19,6	257,0	12,3	21.825	14.429	13.456	2.986
HFC-407C heat pumps	0,0	18,4	5,5	9.725	6.537	0	0
HFC-410A	32,3	269,7	9,4	19.695	18.895	21.113	6.189
HFC-410A heat pumps	38,9	432,6	15,2	31.686	34.124	40.216	20.083
HFC-449A	3,7	19,6	0,5	695	831	1.672	1.988
HFC-452A	2,8	8,1	0,2	361	530	1.583	2.401
HFC-32 heat pumps	114,6	212,7	6,7	4.545	6.894	22.916	9.554
All				**83.986**	**75.345**	**78.040**	**33.647**

In the trend analysis, the total emission from this sector is estimated to peak in 2026-2027 and decrease with approx. 7% in 2030 compared to 2022. The continuous increase of heat pump installed affects the range of uncertainties for the projection of actual emissions. The low GWP refrigerant HFC-32 is introduced to the market in smaller air-air heat pumps and the natural refrigerant R290 are being introduced to some air-water applications. It has positive effects on the emission trend, however there is a solid increase of the amount of heat pumps installed. From 2015 to 2022, it has increased from 30,000 units to 89,000 units sold pr. year. A recent study from DEPA points out potentials for large accidental emissions from air-air heat pumps installed in private households if preventive control at end of life is lacking /33/. The trend analysis calculates a 20% emission at decomissioning of heat pumps.

Stand-alone refrigerators and freezers (2.F.1.b)
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). The table below shows actual emissions from refrigerators/freezers in 2022, 2023 and 2030.

TABLE 12. Emission of refrigerants from refrigerators/freezers; tonnes

	HFC-134a			HFC-404A		
	2022	2023	2030	2022	2023	2030
Consumption	0,2	0,2	0,1	0,0	0,0	0,0
Emissions during production	0,0	0,0	0,0	0,0	0,0	0,0
Export	0,1	0,1	0,0	0,0	0,0	0,0
Stock	63,4	49,3	8,6	17,6	15,0	4,4
Emission from stock	0,6	0,4	0,1	0,2	0,1	0,0
Emissison from destruction	0,0	0,0	0,0	0,0	0,0	0,0
Actual emission	0,6	0,4	0,1	0,2	0,2	0,0
GWP contribution, 1000 tonnes CO2 equivalents	**0,8**	**0,5**	**0,1**	**0,7**	**0,6**	**0,2**

Total emissions of HFC-134a and HFC-404A refrigerants from refrigerators/freezers in 2022 were estimated to 732 tonnes of CO_2 equivalents. In the future scenario of actual emissions, it is estimated that the total emissions in 2030 will decrease to 115 tonnes CO_2 equivalents caused by a decommissioning and decreasing stock.

Mobile A/C (2.F.1.e)
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 applied 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 in 2022, 2023, 2030 and 2040 are summarized in the table below.

TABLE 13. Actual emission of hfc-134a from mac, tonnes

	2022	2023	2030	2040
Consumption to refilling	39,8	39,8	13,0	1,4
Actual emissions	39,8	39,8	13,0	1,4
GWP contribution, 1000 tonnes CO2 equivalents	**56,9**	**56,9**	**18,7**	**2,0**

Total emissions from MAC in 2022 were estimated to 56,925 tonnes of CO_2 equivalents.
In the trend analysis, the total emission from this sector is estimated to decrease with 67% in 2030 compared to 2022.

Vans and lorries with transport refrigeration system (2.F.1.d)
Actual emissions from mobile refrigeration systems in vans and lorries in 2022 are from HFC-134a, HFC-404a and HFC-452A. The emissions are stipulated in the table below.

TABLE 14. Emission from vans and lorries, tonnes

	HFC-134a			HFC-404A			HFC 452A		
	2022	2023	2030	2022	2023	2030	2022	2023	2030
Consumption	0,1	0,1	0,1	0,1	0,1	0,1	4,0	4,0	4,0
Emissions from filling	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Emissions from stock	0,0	0,0	0,0	1,6	1,2	0,4	1,6	2,0	1,9
Stock	0,2	0,2	0,2	7,9	6,0	2,1	7,9	9,8	9,2
Actual emissions	0,1	0,0	0,0	1,7	1,2	0,4	1,6	2,0	2,1
GWP contribution, 1000 tonnes CO2 equivalents	0,1	0,1	0,1	6,6	4,8	1,6	3,5	4,3	4,5

The total actual emission from mobile refrigeration systems in vans and lorries were estimated to 10,136 tonnes of CO_2 equivalents in 2022. In the future scenario of actual emissions, it is estimated that the total emissions in 2030 will decrease to approx. 6,100 tonnes CO_2 equivalents.

4.1.2 Emissions of HFCs from PUR foam products and propellants

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 zero in 2022. The calculation of actual emissions is therefore only from existing stock of household fridges and freezers.

Actual emissions of HFC-134a from insulating foam 2022 is almost zero tonnes CO_2 equivalents.

Aerosol sprays

Since 2019, the use of HFC-134a in technical aerosol applications has been phased out and substituted with HFO-1234ze.

Medical Dose Inhalers (MDI)

Medical dose inhalers use Norfluran (HFC-134a) or Apafluran (HFC-227ea) as blowing agent in spray-applications.

Until 2015, calculation of emission from MDIs has been based on yearly statistics from Danish Medicines Agency. The period 2015-2018 the Danish Medicines Agency had altered their database and the extracted data on MDI had a different format.

From 2019, the calculation has been improved and based on available public data on sale of MDI spray products pr. dose (medstat.dk) combined with calculated contents of HFCs pr. doze provided by manufactures. The content of Norfluran - HFC-134a is 25-75 mg/pr. dose, depending on product. The content of Apafluran - HFC-227ea is 69-74 mg/pr. dose depending on product. Where no producer information exists, an average of 75 mg/pr. dose is applied.

In 2020, 10 new MDI products with HFC-134a and 2 new MDI products with HFC-227ea was identified and applied for the category “medical dose inhalers” (CRF 2.F.4) for the full time series. In 2021 and 2022, new products are introduced to the market and included in the inventory.

The emission of HFC-134a and HFC-227ea from medical metered dose inhalers is estimated as 50% of the consumption in the year of application and 50% the year after.

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. A time-series of the emission of HFC-227ea from MDI has been included in the F-gas inventory from 2015, due to the new calculation method.

TABLE 15. Emissions of hfc-134a and hfc-227ea from mdi, tonnes

	HFC 134a	HFC-227ea	Total
Consumption	6,7	0,9	7,6
Actual emissions	6,7	0,9	7,6
GWP contribution, 1000 tonnes CO2 equivalents	9,1	2,5	11,6

The total actual emission from MDI were estimated to 11,619 tonnes of CO_2 equivalents in 2022.

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.

HFC-23 was not used for fibre production in 2022 (and 2015-2021). It indicates that HFC-23 has been substituted with other substances not containing F-gasses.

4.1.3 Emissions of sulphur hexafluoride

The actual emission of SF_6 in 2022 has been calculated to 0,8 tonnes, equivalent to a GWP contribution of 12,685 tonnes CO_2 equivalents.

Emissions derive from two sources - power switches and laboratories.

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:

- Service emission: release of 5 per cent on filling with new gas (average figure covering normal operation and failure/accidents)
- Stock emission: 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 appropriately 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.

TABLE 16. Emission of sf_6 from power swithces, tonnes

	2022	2023	2030
Consumption	0,7	0,7	0,7
Service emissions	0,0	0,0	0,0
Emissions from stock	0,5	0,5	0,5
Stock	101,4	101,6	103,0
Actual emissions	0,5	0,5	0,6
GWP contribution, 1000 tonnes CO2 equivalents	12,4	12,4	12,6

The total actual emissions are estimated to 12,400 tonnes of CO_2 equivalents in 2022. The trend analysis forecast is a rather 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. 0.02 tonnes SF_6 in 2022. The emission is 100% release during consumption and estimated to 296 tonnes of CO_2 equivalents. Aarhus University/DTU is the only entity in Denmark using SF_6 in particle accelerators and electronic microscopes.

Double-glazed windows
From 2022 the emission from double-glazed windows has ended. Use of SF_6 in double-glazed windows was phased out in 2002, however, there were emissions from stock until 2021. The stock was estimated from consumption data from Danish producers of double-glazed windows 1992-2002 and lifetime for double-glazed windows were determined to 20 years.

4.1.4 Emissions of perfluorinated hydrocarbons

Medium and large size commercial refrigerators
There is no longer PFC emission from medium and large size commercial refrigerators.

Optical fibre production
The PFCs are used as protection and cleaning gases 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 since 2014. No use of PFC-14 has been reported in 2022 and last recorded use of PFC-14 for any purpose was in 2017.

Low temperature stand-alone laboratory freezers
PFC-14 can be 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. No consumption of PFC-14 for laboratory freezers was reported in 2022.

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Appendix 1. GWP values for F-gases

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-449A(7)	Blend	1,409
HFC-452A(7)	Blend	1,397
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
Perfluorocyclopropane		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 HCFCs, where the GWP 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. Land Use, Land-Use Change and Forestry (LULUCF) in the most recent historical years of the inventories.

Future trend scenarios

A trend scenario is elaborated until 2020. The scenario is based 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. Consumption is determined from data directly from suppliers.

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 importers 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
The F-gas inventory is developed and made available in full in spread sheets. Input data are HFC data registered by trade names and emission is calculated from HFC tradename but also organized and checked as pure HFC substances.

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 have 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)

which 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 have been worked out to make the uncertainties for the Danish inventories complete.

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 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
	Refrigerant					
2.F.1.b	Household fridges and freezers (**Stand-alone commercial applications)**	HFC-134a	Tier 2 top-down approach: - 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. Tier 2 bottom-up approach: - Information on imports and exports of refrigerants in products based on the average quantity contained per unit and Danish statistics.	**OK according to new IPCC values** - release on filling = 2% (IPCC default – 0.5-3%) 1 % release from stock per year (IPCC default – 1-10%) Lifetime = 15 years (IPCC default 10-15 years)) Recovery: 100%. Up to and including 2000, the quantity remaining upon disposal was included as emissions (IPCC default). Legislation in Denmark ensures drawing-off of refrigerant, and consequently, the IPCC default is misleading in	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/). For the updating of stock, import/export data from 1998 are used, as well as information on annual HFC consumption by Danish producers. 1998 import/export data are = net exports of 141 tonnes HFC-134a refrigerant + net exports of 1.6 tonnes HFC-134a in foam (note: DK's largest exporter	From 2001, net exports of refrigerants in household fridges are assumed to account for 50 per cent of consumption. The consumption in the projection is not influenced by new phasing-out regulations. It is assumed that the consumption of refrigerants is equal to previous year until 2025. Then it is reduced by 20 per cent with reference to the latest imported amount.

				the Danish context. (IPCC default 0-80% of initial charge)	does not use HFC for foam moulding, therefore the export of HFC in foam is less than the export of refrigerants).	
2.F.1.a	Commercial refrigerators in retail stores, industry, etc **(medium and large commercial refrigerators)**	HFC-134a, HFC-404a, HFC-507A, HFC-449A, HFC-452A. other HFCs, PFCs (C_3F_8)	Tier 2 top-down approach: - information on refrigerant consumption was provided by importers/suppliers of refrigerants for commercial refrigerators in DK. - 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%) 10% release from operation and accidents (DK default). Recovery: 88.5% Emission at decomissioning: 11.5% Lifetime: 15 years 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. (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. 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/.	It is assumed that the consumption of old refrigerants for refilling stock will be equal to previous year until 2025. Then it is reduced by 20 per cent with reference to the latest imported amount. For HFC-449A and HFC-452a, the consumption is steady state (same as latest import data)

2.F.1.f	Stationary A/C systems and heat pumps	HFC-32 HFC-134a, HFC-407C, HFC-410A, HFC-449A, HFC-452A	Tier 2 top-down approach: - information on refrigerant consumption was provided by importers/suppliers of refrigerants for commercial refrigerators in DK. - information on distribution of refrigerant consumption at different sites is estimated using information from user enterprises, the KMO and estimates from suppliers.	1990-2009: 1.5% on refilling (DK default) (IPCC default 0,5-3%) 2010-2030: 0.5% on refilling. 1990-2009: 10% release from operation and accidents (DK default). 2010-2030: 3% release from operation and accidents Recovery: 88.5% Decomissioning: 11.5% Lifetime: 15 years 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. (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 because 1995 is the reference year and the consumption this year was 0 due to lack of data. 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/.	It is assumed that the consumption of old refrigerants for refilling stock will be equal to previous year until 2025. Then it is reduced by 20 per cent with reference to the latest imported amount. For HFC-449A and HFC-452a, the consumption is steady state (same as latest import data)
2.F.1.d	Refrigerated vans and lorries	HFC-134a, HFC-404a, HFC-452a	Tier 2 top-down approach - 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) 17% from operation annually (DK default, same as IPCC) 2% in reuse (DK default) Lifetime = 6-8 years 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	The tax effect has not been included, since refrigerated vans and lorries are exempt from taxes. Consumption is projected as steady state

					IPCC guidelines. The leakage rate for operation is still 17% in compliance with IPCC guidelines /16/.	with reference to the latest import data
2.F.1.e	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. Recovery: 88.5% until 2011 After 2011, emissions = consumption to service.		The projection is based on a steady state with reference to the latest import data. From 2026 a reduction of 20% pr. year is assumed with reference to the effects from the MAC directive.
	Foam production					
2.F.2	Foam in household fridges and freezers (closed cell)	HFC-134a	Tier 2 top-down + bottom-up approach: - information on refrigerant consumption provided by reports from the main producers of household fridges and freezers in DK.	10% release in foam production (IPCC default) 4.5% release from stock per year (IPCC default) Lifetime = 15 years (DK default) Recovery: 100% 33% remaining upon disposal which is destroyed in incineration and thereby is not released as emissions (DK default).	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 in refrigerant and foam per unit /2/. For the updating of stock, import/export data from 1998 are used, as well as information on annual HFC consumption by	

					Danish producers. 1998 import/export data are = 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).	
2.F.2	Soft foam (open cell)	HFC-134a HFC-152a Other HFCs (HFC-365)	Tier 2 - 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)		
2.F.2	Joint filler (open cell)	HFC-134a HFC-152a	Tier 2 top-down approach. - There are no longer any Danish producers of joint filler employing HFC as a foaming agent. Emissions are due to previous estimates by producers of imported joint filler products.	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. 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.	

2.F.2	Foaming of polyether (for shoe soles)	HFC-134a HFC-152a	Tier 2 top-down approach Information regarding consumption is identical to the consumption reported by producer in 1999 + an estimate of imports/exports of HFC in shoe soles, 1998. Tier 2 bottom-up approach: Imports of HFCs contained in shoes are based on the average amount per shoe and on Danish statistics.	Emission (Danish default): - Production = 15 % - Use = 4.5 % - Lifetime = 3 years - 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. Net export with the same consumption in Danish production is 0.3 tonnes HFC-134a.	
2.F.2	System foam (for panels, insulation, etc.)	HFC-134a HFC-152a 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					
2.F.4	Aerosol sprays (industrial products)	HFC-134a	Tier 2. - 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. 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.	

2.F.4	MDI (metered dose inhalers)	HFC-134a HFC-227ea	Tier 2 bottom-up approach - information on consumption is based on data from the national medical trade statistics concerning total sale of MDI in Denmark. Data from producers concerning product content of HFC-134a are used to calculate amount used pr. year. A unit factor of 72 mg HFC-134a/pr. dose is used for the calculation. The estimate for 2018 is based on 2015, 2016 and 2017. Due to change in the format of the national medical trade statistics. A reduction of 10 per cent is added to the previous year's estimated consumption, to create consistency with the decrease seen throughout previous years.	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)	HFC is used in MDI as a subsidiary for effective inhale of the medicine. It is assumed that 100 % of the subsidiary emits. The 50/50 calculation method are introduced in full time-serias from 2022. Previously it was 100% emission the year for consumption.	Steady state with reference to the latest registered import.
	Solvents					
2.F.5	Liquid cleaners	PFC (C_3F_8 Perfluorpropane)	Tier 2. - information on consumption of PFC in liquid cleaners is derived from two importers' sales reports. This is thought to represent 100% of the Danish consumption of PFCs in liquid cleaners.	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 good practice for top-down data)		Top-down data Phasing-out cf. Statutory Order 1/9 2002. It is assumed that the consumption is equally distributed over all months.
	Others					
2.G.2	Fibre Optics production	PFC-14 PFC-318 HFC-227ea	Tier 2. - information on consumption of PFC in production of fibre optics is derived from importers' sales report with specific information on the amount used	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.

			for production of fibre optics. This is thought to represent 100% of the Danish consumption of PFC-14 and PFC-318 for that purpose			
	EMISSIONS OF SF_6 FROM ELECTRICAL EQUIPMENT AND OTHER SOURCES					
2.G.2	Insulation gas in double glazing	SF_6	Tier 2 - 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): - 15% during production of double glazing. - 1% per year during the lifetime of the window - Lifetime = 20 years - Disposal - 80% of the filled content of double glazing in the production year. - Net exports = 50% of the consumption in the current year		Emissions data and lifetimes are based on information from the window producers and industry experts in Denmark /2/. The stock is determined on the basis of consumption information provided by importers back to 1990. The first Danish consumption was registered in 1991. 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.
2.G.1	Insulation gas in high-voltage power switches	SF_6	Tier 3c country-level mass-balance approach - 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. The electricity sector also provides information on the installation of new plants and thus whether the stock is increasing.	Emission (Danish default): - release on filling = 5% - loss / release in operation = 0.5% per year - release upon disposal = 0%		There is one supplier (Siemens) that imports its own gas for filling in Denmark. Suppliers (AAB, Siemens, Alstom) report on new installations. The stock in 2000 was 57.6 tonnes of SF_6, which covers power switches of all sizes in production and transmission plants. The stock has been evaluated on the basis of a questionnaire survey in 1999 which encompassed the entire Danish electricity sector /11/.
2.G.2	Shock-absorbing gas in Nike Air training footwear	SF_6	Tier 2 - top-down approach Importer has estimated imports to Denmark of SF_6 in training footwear.	Lifetime = 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.
2.G.2	Laboratories	SF_6	Tier 2. - information on consumption of SF_6 for laboratories is derived from importers' sales reports (gas or gas-containing products). The importers account for 100% of the Danish sales of SF_6.	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)	The 50/50 calculation method are introduced in full time-serias from 2022. Previously it was 100% emission the year for consumption.	

Danish consumption and emission of F-gases in 2022

Dansk resumé

De såkaldte F-gasser er potente drivhusgasser og forårsager en forøgelse af atmosfærens evne til at tilbageholde overskudsvarme udstrålet fra jorden. Som følge heraf stiger temperaturen på jordens overflade og lavere atmosfære, og det fører til klimaændringer. Den potentielle effekt af forskellige drivhusgasser varierer fra stof til stof. Dette potentiale er udtrykt ved en GWP-værdi (Global Warming Potential).

Formålet med dette projekt var at kvantificere det danske forbrug og faktiske emissioner af F-gasser (HFC'er, PFC'er og SF6) på årsbasis. Desuden er fremtidige emissioner af F-gasser ekstrapoleret frem til 2040.

Emissionsberegningerne er dels foretaget for at opfylde Danmarks internationale forpligtelser til at levere data og information om udledning af F-gas, og dels for at vurdere den danske udvikling i forbrug og udledning af HFC, PFC og SF6.

En række nye krav til beregning af F-gas-emissioner er for nylig blevet indført af FN's Mellemstatslige Panel for Klimaændringer (IPPC). Kravene omfatter nye F-gasser, nye emissionsfaktorer for visse F-gasser, nye anvendelsesområder og ændringer i produktets levetid.

Emissionsberegningerne er i overensstemmelse med de seneste reviderede IPCC metoder.

Engelsk resumé

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 SF6) on a yearly basis. Furthermore is future-emissions of F-gases extrapolated until 2040.

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 SF6.

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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