Support contract for an Evaluation and Impact assessment for amending Regulation (EU) No 517/2014 on fluorinated greenhouse gases

CLIMA.A2/ETU/2019/0016

Evaluation Final Report - ANNEXES

14th March 2022

Contents

Abbreviations

AC	Air Conditioning
BAU	Business-as-usual
BDR	Business Data Repository
BMU	German Federal Ministry of Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit)
BWP	Bundesverband Wärmepumpe
Capex	Capital expenditure
CDM	Clean Development Mechanism
CFC	Chlorofluorocarbon
CLP	Classification, Labelling and Packaging
CORAP	Community rolling action plan
CRF	Common Reporting Format
CVD	Chemical vapour deposition
DG CLIMA	Directorate-General for Climate Action
EC	European Commission
ECHA	European Chemicals Agency
EEA	European Environment Agency
EHPA	European Heat Pump Association
EPEE	European Partnership for Energy & the Environment
ETC/ACM	European Topic Centre on Air Pollution and Climate Change Mitigation
ETC/CME	European Topic Centre on Climate Change Mitigation and Energy
EU	European Union
F-gases	Fluorinated gases
FTE	Full-time equivalent
GDP	Gross domestic product
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefine
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefine
HTF	Heat transfer fluid
HV	High voltage
IA	Impact Assessment
IAEA	International Atomic Energy Agency
IMO	International Maritime Organization
ISG	Interservice Group
JI	Joint Implementation
JRC	Joint Research Centre
LT	Low temperature

MEPS	Minimum Energy Performance Standards
MP	Montreal Protocol on Substances that Deplete the Ozone Layer
MRV	Measuring, Reporting and Verifying
MT	Medium temperature
MV	Medium voltage
NAEWF	NATO Airborne Early Warning Force
NGO	Non-Governmental Organisation
NIR	National Inventory Report
OCF	One component foam
ODS	Ozone-Depleting Substance
OEM	Original Equipment Manufacturer
Opex	Operational expenditure
PBT	Persistent, Bioaccumulative and Toxic
PFAs	Poly-and perfluoroalkyl substances
PFBA	Perfluorobutanoic acid
PFC	Perfluorocarbon
PFCAs	Perfluoroalkyl carboxylic acids
PFPEs	Perfluorinated polyethers
PU Foam	Polyurethane foam
QA	Quality Assessment
R&D	Research and development
RAC	Refrigeration and Air Conditioning Sectors
RACHP	Refrigeration, Air Conditioning and Heat Pump Sectors
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals.
SME	Small and Medium-sized Enterprise
SVHC	Substances of very high concern
TEAP	Technology and Economic Assessment Panel
TFA	Trifluoroacetic acid
TFEU	Treaty on the Functioning of the European Union (TFEU)
TFF	Trifluoroacetyl fluoride
TRGS	Technical Rules for Hazardous Substances
UBA	Federal German Environment Agency (Umweltbundesamt)
ULT	Ultra low temperature
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation

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Confidentiality disclaimer

All data related to Article 19 of the F-gas Regulation assessed for this report has not been assessed related to the confidentiality criteria applied by the European Environment Agency (EEA) to determine eligibility for the EEA's public reports. However, as the present report provides data primarily in form of graphics rather than in data tables, confidentiality may possibly be considered less critical. Where this data has been used it has been sourced as follows: (data source: [EEA 2020 confidential dataset]).

Annexes

Annex 1: Methods and tools used in preparing the underpinning analyses

The evaluation of the F-gas Regulation aims to assess how it has worked, whether it has the correct scope, and the degree to which its intended impacts have been achieved. The evaluation process follows the European Commission's Better Regulation Guidelines for evaluations and fitness checks. It assesses the Regulation against five evaluation criteria of effectiveness, efficiency, relevance, coherence and EU-added value.

The evaluation covers all parts of the Regulation. It considers the period between 2014 and the date for which latest data is available. The evaluation has made use of several strands of information:

- Desk research
- Field research
    - Online public consultation (OPC)
    - Targeted stakeholder engagement – interviews
    - Targeted stakeholder engagement – stakeholder workshops.

This Annex presents the methodologies for each of these strands of evidence gathering.

Desk research – literature/evidence assessment

Desk research has comprised of literature/evidence assessment. Evidence and literature has been sourced by a number of routes:

- From references in the terms of reference for this support study.
- From current work being undertaken by project partners.
- From reports and other evidence signposted by EC.
- From a review of literature.
- From respondents to stakeholder engagement for this study.

In total over 100 literature sources have been reviewed in detail, providing evidence related to all of the evaluation criteria.

Detailed analysis and modelling of data has also been undertaken. The sources and methodologies applied are set out in further detail in the following sections of this annex.

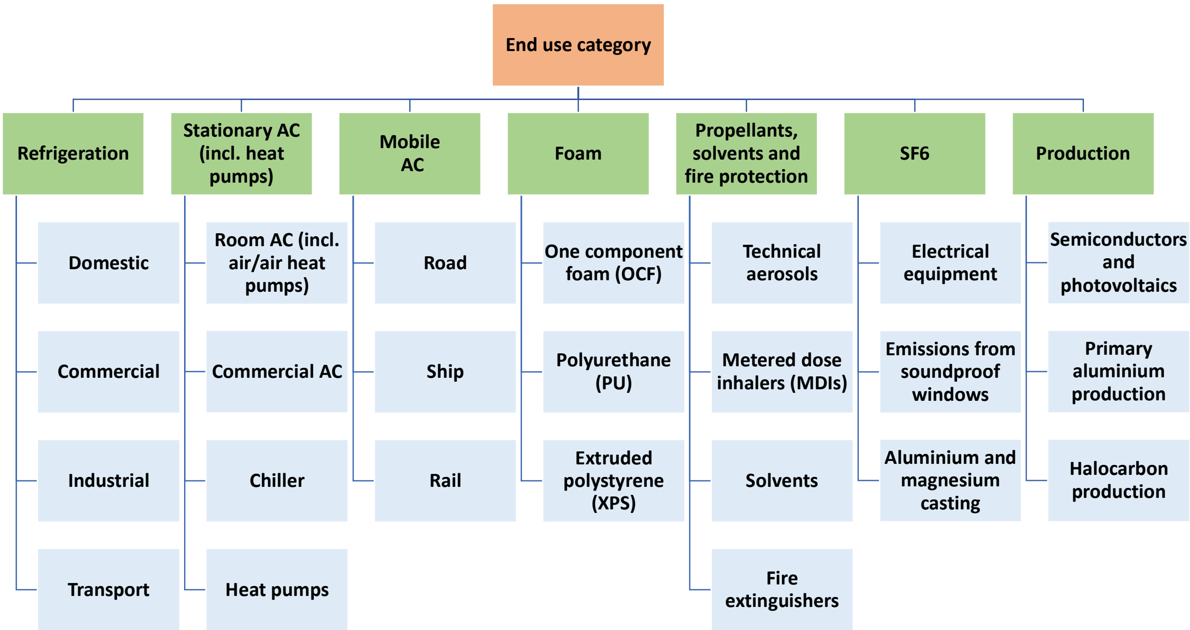
Modelling

Overview

The model AnaFgas was designed as a bottom-up stock model to derive demand and emission scenarios for F-gases in relevant sectors and sub-sectors (Figure 1) for the EU Member States[1].

[1] For the model application in the 2011 preparatory study, the UK was included in this model, while Croatia was not yet a Member State of the EU and thus not included in the original AnaFgas model. However, Croatia was added in later update of the model in the period 2017 to 2020.

Figure 1: Overview of the sectors and subsectors covered by the AnaFgas model



Source: Own illustration based on Schwarz et al. (2011)

Certain sub-sectors in Figure 1 are represented in more detail in the model (see Annex to Schwarz et al. 2011):

- **Commercial refrigeration**
  - Central systems
  - Condensing units
  - Hermetic units
- **Industrial refrigeration**
  - Food industry
    - Beer production
    - Wine production
    - Meat production
    - Dairy industry
    - Chocolate production
    - Frozen food
    - Fruit juice / Gaseous drinks
    - Milk farms
  - Other industry
    - Cold storage
    - Ice rinks
    - Other industry (50 % chemical)
- **Transport refrigeration**
  - Vans
  - Trucks and trailers
  - Fishing vessels
- **Room air conditioning**
  - Moveable (portable) units
  - Small split units including reversible air-to-air heat pumps (average charge of 1.5 kg)
- **Commercial air conditioning**
  - Large split and variable refrigerant flow (VRF) systems
  - Packaged equipment (incl. rooftop units)
- **Chiller**

    - Displacement compressor type
        - Mini-chiller
        - <100 kW chiller
        - >100 kW chiller
    - Centrifugal compressor type
- **Heat pumps**
    - Small (average charge of 2.6 kg) and medium (average charge of 26 kg) heat pumps (95% small and 5% medium units)
        - Air/water (heating only and reversible)
        - Water/water (heating only)
        - Brine/water (heating only and reversible)
        - Direct exchange
        - Exhaust air
        - Sanitary hot water
    - Large commercial heat pumps (average charge of 750 kg)
        - District heating
        - Industrial
- **Road mobile air conditioning**
    - Passenger cars
    - Commercial transport vehicles
        - Trucks N1
        - Trucks N2
        - Trucks N3
    - Buses
    - Ships
        - Cruise ships
        - Passenger ships
        - Container ships
        - Cargo ships
    - Rail
        - Trams
        - Metros
        - Trains

The underlying model logic did not deviate from the previous model in Schwarz et al. (2011) and is described for the different sectors in the Annex to the study.

For the current projections, the heat pumps sector was extended to cover medium and large equipment. All sales data for heat pumps were gathered from data provided by the European Heat Pumps Association (EHPA[2]) and the German Bundesverband Wärmepumpe (bwp[3]). For small and medium heat pumps, the sales data was identical, since data grouped by charge size was not available. A share of 95 % of sold units for small heat pumps and 5 % for medium heat pumps was assumed. For all heat pumps, an annual increase in sales of 5 % was assumed from 2020 to 2050.

For electrical equipment (including switchgear), the assumed saturation of the growth in the market in Schwarz et al. (2011) for Western and Eastern European countries in 2015 and 2020, respectively, was replaced by an assumed growth rate of 2 % per year until 2050 for all EU countries based on ZVEI (2020)[4] and expert opinion.

The latest model version features demand for and emissions of HFCs, PFCs and SF_6 as well as unsaturated HFCs and HCFCs for the period 2010 to 2050 based on market data and estimates of the quantity

[2] https://www.ehpa.org/
[3] https://www.waermepumpe.de/
[4] https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2020/April/SF_6_Reduktion/Szenario-zur-Reduktion-von-SF6-Betriebsemissionen-final-eng.pdf

of equipment or products sold each year containing these substances, and the quantity of substances required in the EU to manufacture and/or maintain equipment and products over time.

The AnaFgas model is designed to calculate demand and emissions of F-gas gases under different scenarios and will thus be used to derive a baseline, as well as a counterfactual scenario for relevant sectors in the EU. In AnaFgas, all emission and demand estimates are derived from bottom-up approaches, i.e. by estimating demand and emissions per sector through the use of underlying driving factors. These include annual changes in equipment stock, composition and charge of the equipment, leakage during equipment lifetime and during disposal. Some of these components are driven by other factors such as population development, GDP growth or technological changes. Based on these drivers, annual emissions and banks as well as use can be calculated for each year, sub-sector and EU Member State.

AnaFgas makes use of market information to build an inventory of the in-use stocks of the equipment in each of the end-uses in each country. This includes the percentage of the equipment stock that contains each F-gas. These modelled stock inventories are maintained through the annual addition of new equipment/new F-gas quantities and the retirement of equipment after an appropriate number of years. Annual leak rates, servicing emissions, and disposal emissions are estimated for each of the end-uses.

Through these emissions, which occur during the lifetime of the equipment, the lag between use of a chemical and actual emission of this chemical is reproduced. Aggregating emission and use over the different end-uses, the model produces estimates of total year-specific annual demand for, and emissions of each substance expressed in metric or GWP-weighted tonnes.

The stock model requires input regarding the market growth for each of the end-uses, as well as a history of the market penetration of F-gases. To project the use and emissions of F-gases into the future, AnaFgas incorporates the available information about probable evolutions of the end-use market, trends of F-gas substitution and trends of emission factors. It also requires assumptions on future growth trends in different areas such as population development, growth in transport (passenger and freight), change in social structure, consumer habits and lifestyle.

Projections by EU Member States and IPCC/TEAP SROC Report 8 and the recent TEAP reports are included in the growth assumptions for the model scenarios until 2050. For the projections of activity data including charges and F-gas split, and emission factors until 2050, AnaFgas generally distinguishes between three different time periods:

- Near past (5-10 years) is calculated by adjusting the stock model using data reported under Article 19 of the F-gas Regulation (reporting on supply of F-gases) and the National Inventory Reports (NIRs) submitted by the EU under the United Nations Framework Convention on Climate Change (UNFCCC, reporting on emissions and partially on first fill quantities). It must be noted, however, that the reported data is not equivalent to the modelled metrics. Under the F-gas Regulation, supply of F-gases is reported, which does not directly translate to demand. Further, the NIRs only contain data based on estimates that are not frequently changed to reflect market developments. Thus, deviations between the reported and modelled data are to be expected.

- Near future (5-10 years) is modelled on known policies and measures, technological changes, substitution patterns and expected changes in use patterns.

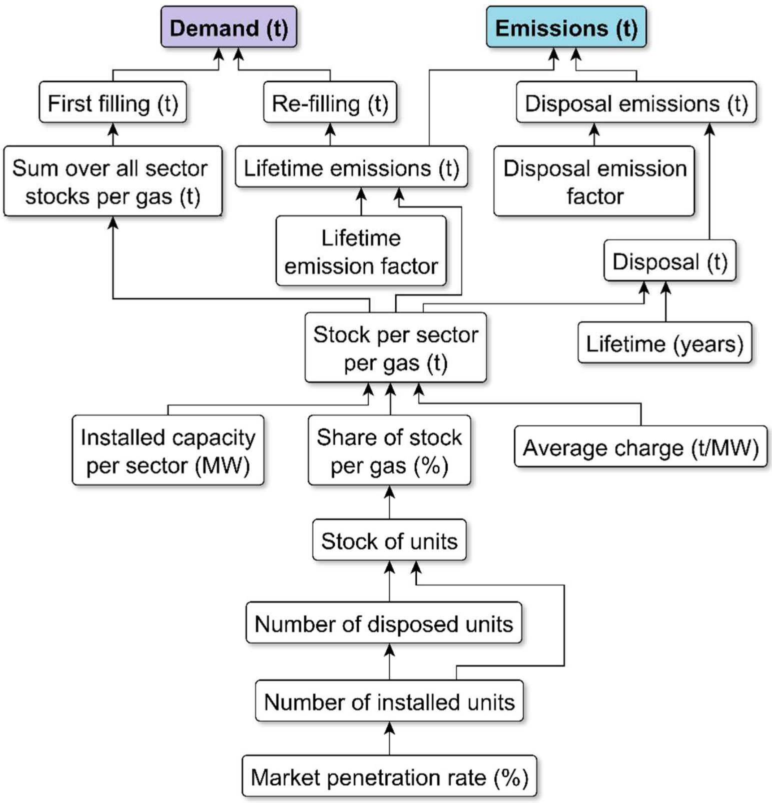
- Distant future (until 2050) is based on a continuation of trends observed, external projections of driving forces such as GDP and population and follows a business-as-usual trend as the model does not consider changes in technologies which are likely to happen within such a long timeframe.

Underlying assumptions for each sector in the model AnaFgas are outlined in detail in the model description in Annex III to the preparatory study (Schwarz et al. 2011). Specific information on each sector for the EU is summarized in the EU sector data sheets.[5] These sector sheets cover economic assessments of standard and F-gas substitution technologies and allow the calculation of abatement cost for substitution technologies and thus the generation of cost curves and cost-driven abatement scenarios, for example in response to economic interventions like the EU HFC phase-down.

Figure 2 gives a very simplified overview of the general logic behind AnaFgas. In the model, each sector has unique adaptations that add to the logic outlined below. The result, however, is always the calculation of the demand and emissions in metric tonnes for each gas in each sector/subsector for each year. Based on the GWP of the different gases, the demand and emissions can then be easily converted into CO_2 eq.

In its latest version, 33 different gases and 12 blends are covered in the model. Those include the most relevant HFCs, PFCs and SF_6 and blends of HFCs.

Figure 2: Simplified overview of the AnaFgas logic to project demand and emissions of F-gases in the EU



Source: Own illustration

Emission rates used in the AnaFgas model

Although leakage rates can be used to estimate the emissions over time, lifetime emissions go beyond leakage rates since they also include emissions that are not covered by refill, e.g. during recovery, in the last year before end of life.

The table below shows the annual emission factors applied in the AnaFgas model for the period since 2010 for lifetime, disposal and manufacturing emissions by sector and sub-sector. Lifetime emission rates decreased for many, but not all, sectors following the application of the Regulation in 2015. Disposal emission factors have also decreased since 2015 in several applications since collection and

[5] Examples for EU sector sheets are given in Annex V of the 2011 preparatory study (https://ec.europa.eu/clima/sites/clima/files/f-gas/docs/2011_study_annex_en.pdf)

recycling of both bulk and equipment containing F-gases has been improved. For many sectors, a reduction in emission rates is also expected under the counterfactual scenario, albeit not always as pronounced. This is because technological developments are also expected to occur in the absence of the Regulation.

The assumptions provided in Table -1 have been developed based on previous modelling as well as national emission reporting to the UNFCCC, literature and input from industry experts. There are no emission rates assumed for the sector “PFC and other halocarbons”. For this sector, emissions are directly taken from the UNFCCC data (National Inventory Reports, NIRs). The table shows annual emission factors for lifetime (LE), disposal (DE) and manufacturing (ME) for the baseline and the counterfactual scenario in 2015 and 2019 used in the model, while differences between scenarios are highlighted.

Table -1: Annual lifetime, disposal and manufacturing emission factors for the baseline and the counterfactual scenario in 2015 and 2019 used in the model

Sectors and subsectors	Baseline 2015/2019			Counterfactual 2015/2019		
	LE = lifetime emissions, DE = disposal emissions, ME = manufacturing emissions; one number if no change between years; differences between scenarios are highlighted					
	LE (%)	DE (%)	ME (%)	LE (%)	DE (%)	ME (%)
Refrigeration						
Domestic	0.3	29		0.3	29	
Central systems	**15/9**	**25/20**		**15/13**	**25**	
Condensing units	6	25		6	25	
Hermetic units	1	35		1	35	
Industrial (food)	5.1/4	30		5.1/4	30	
Industrial (other)	6.3/5	30		6.3/5	30	
Vans	**28/25**	30		**30**	30	
Trucks and trailers	**18**	30		**20**	30	
Fishing vessels	40/30	30		40/30	30	
Stationary air conditioning (incl. heat pumps)						
Moveable units	3	35		3	35	
Small split units incl. air/air heat pumps	5	35		5	35	
Large split and VRF units	**6/5**	**30/22**		**6**	**30/28**	
Packaged equipment (incl. rooftop units)	3	20		3	20	
Chillers	2.4	20		2.4	20	
Heat pumps (small)	3.5	35		3.5	35	
Heat pumps (medium)	4.5	35		4.5	35	
Heat pumps (large)	6	20		6	20	
Mobile air conditioning						
Passenger cars	10	40		10	40	
Buses	15	30		15	30	
Trucks (N1)	10	70		10	70	
Trucks (N2, N3)	15	70		15	70	
Rail (trams, metros and trains)	7	30		7	30	
Ships	40	30		40	30	
Foams						
One-component	100			100		
Extruded polystyrene (XPS)						
HFC-134a, HFC-1234ze(E)	0.75		30	0.75		30
HFC-125	25		100	25		100
Polyurethane (spray and non-spray)	1		10	1		10
Other HFC						
Aerosols and solvents	100			100		
Fire extinguishers						
HFC-227ea, HFC-125, HFC-23	2	9		2	9	
HFC-134a	4	9		4	9	
HFC-236fa	5	9		5	9	
SF_6						
Electrical equipment	1	5	4	1	5	4
Soundproof windows	1	100	33	1	100	33
Aluminium and magnesium casting			3			3

Note: The disposal emission rate for passenger cars was reduced from 70 % in Schwarz et al. (2011) to 40 % for all years. Lifetime (LE), disposal (DE) and manufacturing (ME)

Validation of the AnaFgas model

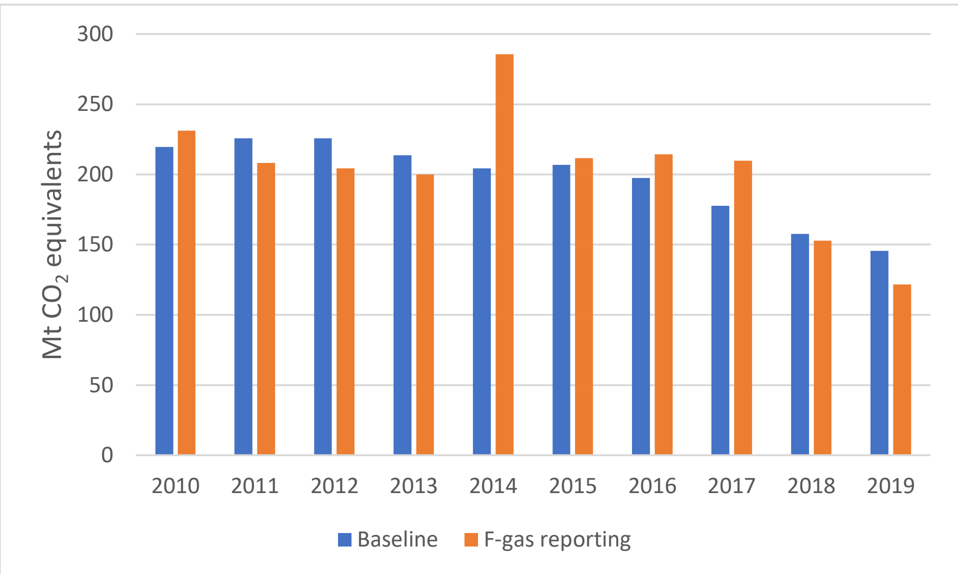
Validating the results from the AnaFgas baseline model is crucial but there only exist very limited data for comparison. In the following, demand and emissions are contrasted with supply, as calculated by the EEA based on reporting data under the Regulation, and emissions data extracted from the National Inventory Reports (NIR) for the EU under UNFCCC. However, some systematic differences between the compared data set should be noted:

- It must be noted, however, that supply as defined and calculated by the EEA [EEA 2020 public report] is not the same metric as demand used in the AnaFgas modelling. The AnaFgas demand covers the gases which are needed for the operation of equipment in the EU. In the supply metric, additionally, those gas amounts are accounted for which are charged into equipment in the EU and subsequently exported for use outside the EU. Furthermore, some interannual discrepancies may be due to stocks. The EEA supply metric is cleared of amounts stockpiled at the end of the year by producers or importers of gas. However, gases stockpiled further downstream e.g. by distributors and also gases contained in stockpiled imported equipment are contained in the supply of the year of import rather than for the year of actual use.
- UNFCCC data on emissions of F-gases are estimated values only.

When comparing demand and supply, the metrics do align closely for certain years but deviate for others (Figure 3 and Table -2). Especially in 2014, the supply is substantially higher than the modelled demand, while in 2019 the reverse is the case. The underlying causes cannot be specified precisely but in 2014, large quantities of F-gas supply were reported that most certainly were not actually used in equipment in that year. These quantities were very likely stockpiled in anticipation of shortages because of the phase-down. Stocks are not part of the derivation of demand, however, and this is the reason why 2014 shows no increase in the modelling.

For the methodological reasons stated above, it is expected that the supply is usually higher than the demand. Looking at Figure 3 this is not always the case. However, there is no direct explanation for the discrepancies between demand and supply in the years 2010 to 2013, 2016 to 2017 and 2019. Some of these differences may be explained by year-to-year carryover effects, in particular the delta changes between negative and positive.

Figure 3: Comparison between the reported F-gas supply for the EU27+UK and the results from the AnaFgas baseline modelling for F-gas demand



Sources: AnaFgas modelling and EEA 2020

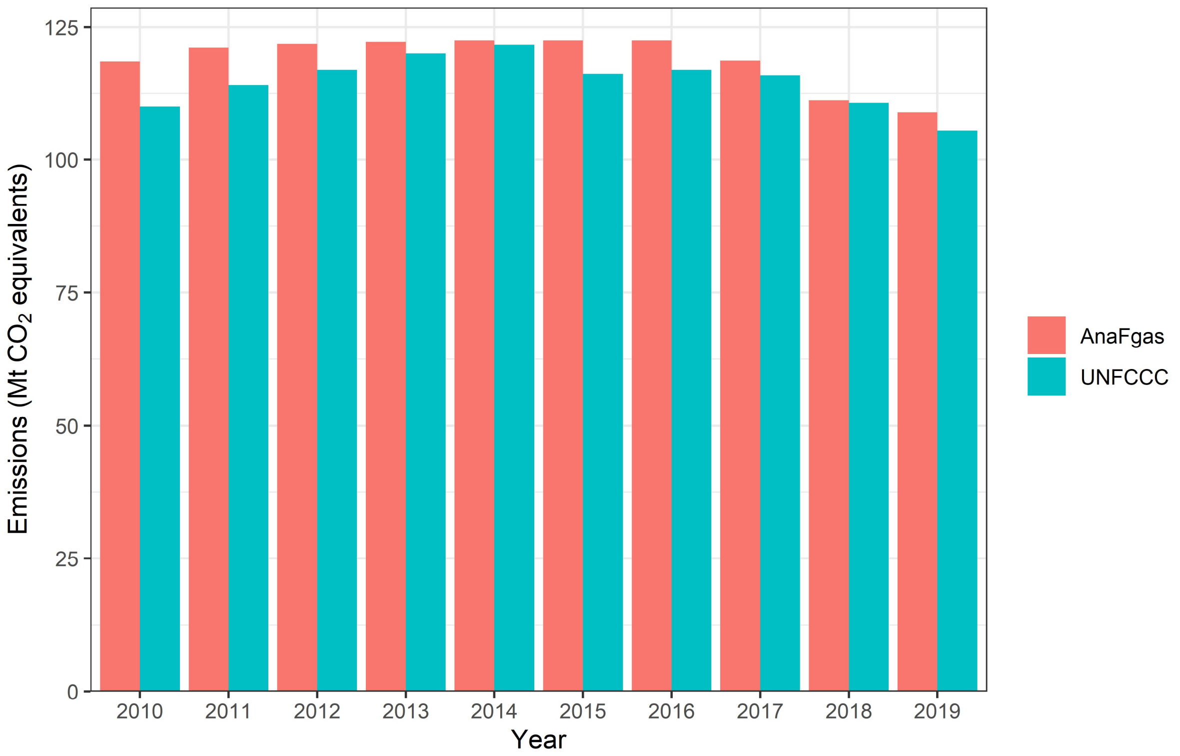
Table -2: Comparison of the modelled baseline F-gas demand and the reported F-gas supply in the EU-27+UK

Mt CO_2 eq	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
F-gas supply (F-gas reporting)	231	208	204	200	286	212	214	210	153	122
F-gas demand (AnaFgas)	221	224	227	216	206	206	198	176	157	145
Difference	5%	-7%	-10%	-7%	39%	3%	8%	19%	-2%	-16%

Source: AnaFgas modelling and EEA 2020

Regarding emissions, the AnaFgas model consistently calculates higher quantities in CO_2 eq than stated in the UNFCCC NIR (Figure 4 and Table -3) but the deviations are small (on average 3 %). Since the UNFCCC data is based on estimations, it is not possible to specify reasons for the deviations. Possible explanations could be differences in the assumed emission rates for different sectors and subsectors or charge sizes for different equipment. In any case, the deviations are small and are likely within the uncertainties of both models.

Figure 4: Comparison between the results from the AnaFgas baseline modelling and the reported emissions under UNFCCC (NIR) for the EU27+UK



Source: AnaFgas modelling and https://unfccc.int/documents/275968

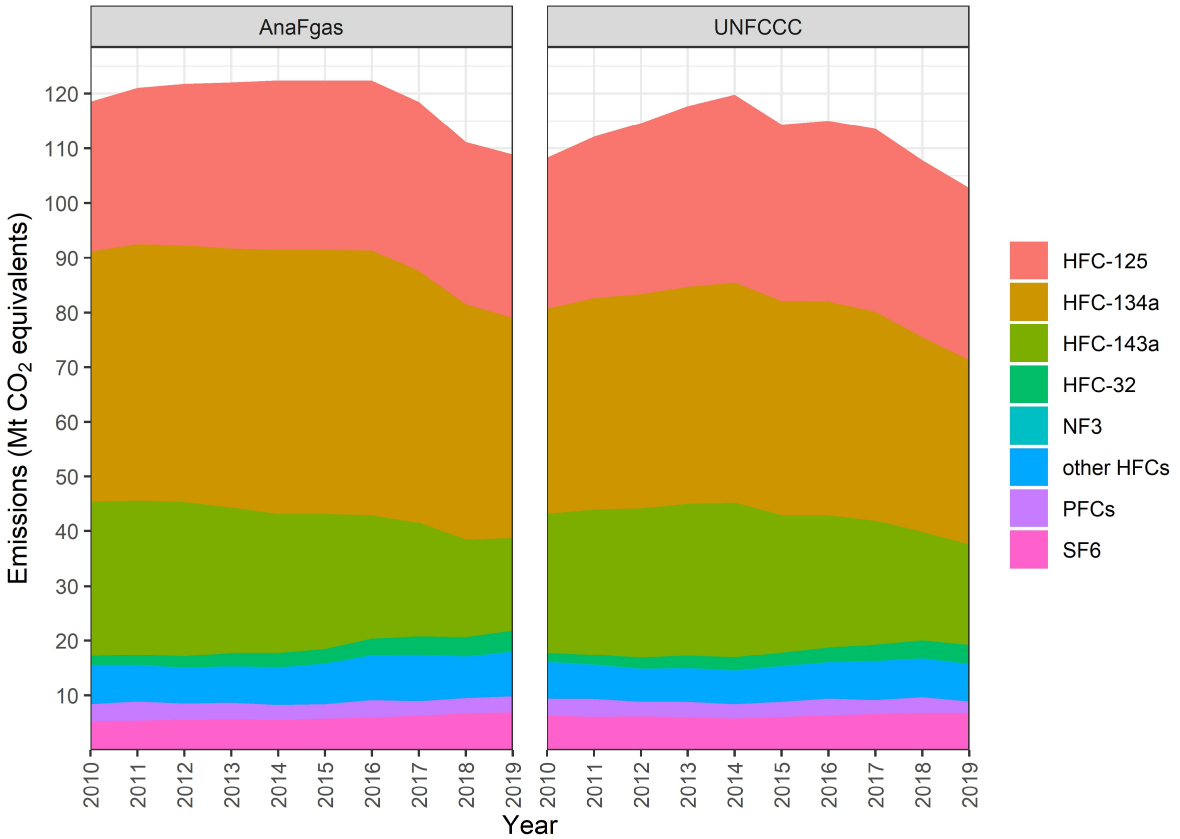
Table -3: Comparison of AnaFgas baseline modelling output with the NIR reported EU27+UK F-gas emissions

Mt CO_2 eq	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
UNFCCC	110	114	117	120	122	116	117	116	111	106
AnaFgas	119	121	122	122	122	123	122	120	112	109
Difference	8%	6%	4%	2%	0%	6%	4%	3%	1%	4%

Source: AnaFgas modelling and https://unfccc.int/documents/275968

For single gases or gas groups, the modelled emissions show similar trends to the UNFCCC data (Figure 5). Both data sources show a decline in emissions of high-GWP gases in recent years, especially for HFC-134a, HFC-125 and HFC-143a. The UNFCCC data shows an increase in emissions until the F-gas Regulation took effect in 2014, followed by a rather sharp drop with a second stronger decline from 2017 to 2019. The AnaFgas model, at first, assumes are more gradual effect of the F-gas Regulation that picks up speed from 2017 to 2018, due to the second phase-down step starting in 2018, cutting the placing on the market quantities by 30 %. From 2018 to 2019, the decline in emissions shows a more moderate reduction compared to the previous years.

Figure 5: Comparison of the AnaFgas baseline modelling output with the UNFCCC reported EU27+UK F-gas emissions by gas/gas group



Source: AnaFgas modelling and https://unfccc.int/documents/194921

Gas prices used in the AnaFgas modelling framework

Table -4: Refrigerants prices used in AnaFgas modelling, 2015-2019 averages

Gas	Counterfactual OEM purchase price	Counterfactual service company selling price	Baseline OEM purchase price	Baseline service company selling price	Baseline Reclamation selling price
	€/kg	€/kg	€/kg	€/kg	€/kg
HFC-134a	5.0	10.0	16.4	32.9	35.0
R-404A	5.0	10.0	36.4	72.7	35.0
R-407C	5.0	10.0	19.2	38.4	35.0
R-410A	5.0	10.0	21.7	43.4	35.0
HFC-32	10.0	20.0	15.4	30.8	
R-454C/R-455A	30.0	60.0	31.2	62.4	
R-466A	30.0	60.0	35.9	71.7	
R-452A	25.0	50.0	42.1	84.2	
R-452B	25.0	50.0	30.6	61.2	
R-454B	28.7	57.3	32.4	64.8	
R-513A	30.0	60.0	35.1	70.1	
R-448A/R-449A	30.0	60.0	41.1	82.3	
HFC-1234ze	30.0	60.0	30.0	60.0	
HFC-1234yf	70.0	140.0	70.0	140.0	
HCFC-1233zd	25.0	50.0	25.0	50.0	
HCs	10.0	20.0	10.0	20.0	
CO2	2.5	5.0	2.5	5.0	
NH3	2.0	4.0	2.0	4.0	
Air	2.0	4.0	2.0	4.0	

Table -5: Fire suppression agent prices used in AnaFgas modelling, 2015-2019 averages

Gas	Counterfactual OEM purchase price	Baseline OEM purchase price	Baseline Reclamation selling price
	€/kg	€/kg	€/kg
HFC-134a	14.0	25.4	
HFC-227ea	14.0	39.8	
HFC-23	14.0	132.4	
HFC-236fa	14.0	92.5	
HFC-125	14.0	42.0	35.0
FK-5-1-12	17.0	17.0	
inert gas for fire suppression: 52% N_2, 40% Ar, 8% CO2	5.0	5.0	

Table -6: Foam blowing agent prices used in AnaFgas modelling, 2015-2019 averages

Gas	Counterfactual OEM purchase price	Baseline OEM purchase price
	€/kg	€/kg
HFC-134a	5.0	16.4
HFC-152a	5.0	6.0
HFC-245fa	5.0	13.2
HFC-365mfc	6.0	12.4
HFC-43-10mee	5.0	18.1
HFC-1234ze	15.0	15.0
HCFC-1233zd	15.0	15.0
CO2	2.5	2.5

Table -7: Technical aerosol prices used in AnaFgas modelling, 2015-2019 averages

Gas	Counterfactual OEM purchase price	Baseline OEM purchase price
	€/kg	€/kg
HFC-134a	5.0	16.4
HFC-152a	5.0	6.0
HFC-1234ze	15.0	15.0

Table -8: MDI aerosol prices used in AnaFgas modelling, 2015-2019 averages

Gas	Counterfactual OEM purchase price	Baseline OEM purchase price
	€/kg	€/kg
HFC-134a	8.0	8.0
HFC-227ea	8.0	8.0

Table -9: Solvent prices used in AnaFgas modelling, 2015-2019 averages

Gas	Counterfactual OEM purchase price	Baseline OEM purchase price
	€/kg	€/kg
HFC-227ea	14.0	39.8
HFC-245fa	5.0	13.2
HFC-365mfc	6.0	12.4
HFC-43-10mee	5.0	18.1
HCFC-1233zd	25.0	25.0

Energy prices used in the AnaFgas modelling framework

Table -10: Final energy prices used in AnaFgas modelling, 2015-2019 averages

electricity/fuel type	VAT	€/ kWh final energy used in RAC equipment
electricity commercial	excl.	0.145
electricity household	incl.	0.215
electricity industry	excl.	0.095
electricity rail	excl.	0.080
fuel sea-ships	excl.	0.073
fuel road vehicles private	excl.	0.446
fuel road vehicles commercial	excl.	0.259

AnaFgas model installation parameters: sector sheets

Table -11: AnaFgas sector sheet for FGR evaluation: Domestic Refrigeration

Domestic Refrigeration			
considered gases / technologies:		**HFC 134a**	**R-600a**
GWP AR4 of refrigerant	[1]	1 430	4
refrigerating capacity	kW	0.2	0.2
electric/mechanic capacity	kW	0.13	0.12
installation lifetime	years	15	15
invest cost hardware (first fill excluded)	€	400	392
annual operating hours	h/a	7 200	7 200
final energy cost	€/kWh	0.215	0.215
discount rate (societal view / emission reduction cost)	%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	-	-
additional maintenance cost for non-HFCs	€/a	-	-
refrigerant charge	kg	0.12	0.06
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	10
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	10
installation type is refilled?		no	no
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	-	-
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	-	-
leakage rate first fill / refill	kg/kg	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	0.3%	0.3%
leakage rate operation, counterfactual scenario	1/a	0.3%	0.3%
technologically tolerable refrigerant loss	kg/kg	20%	20%
recovery rate end of life, baseline scenario	kg/kg	70%	70%
recovery rate end of life, counterfactual scenario	kg/kg	70%	70%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	-	100.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	1.0%	99.0%

Table -12: AnaFgas sector sheet for FGR evaluation: Commercial refrigeration – Hermetics

Commercial refrigeration - Hermetics				
considered gases / technologies:		**HFC 134a**	**R-600a/290-direct**	**R-454C/R-455A**
GWP AR4 of refrigerant	[1]	1 430	4	148.2
refrigerating capacity	kW	0.6	0.6	0.6
electric/mechanic capacity	kW	0.38	0.36	0.38
installation lifetime	years	10	10	10
invest cost hardware (first fill excluded)	€	1 000	980	1 020
annual operating hours	h/a	6 000	6 000	6 000
final energy cost	€/kWh	0.145	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	3	-	3
additional maintenance cost for non-HFCs	€/a	-	-	-
refrigerant charge	kg	0.4	0.2	0.4
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	10	31.2
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	10	30
installation type is refilled?		no	no	no
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	-	-	-
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	-	-	-
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	1.0%	1.0%	1.0%
leakage rate operation, counterfactual scenario	1/a	1.0%	1.0%	1.0%
technologically tolerable refrigerant loss	kg/kg	20%	20%	20%
recovery rate end of life, baseline scenario	kg/kg	61%	61%	61%
recovery rate end of life, counterfactual scenario	kg/kg	61%	61%	61%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	76.5%	23.0%	0.5%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-	-

Table-13: AnaFgas sector sheet for FGR evaluation: Commercial refrigeration - Condensing units

Commercial refrigeration - Condensing units							
considered gases / technologies:		**R-404A**	**R-134a DX**	**HC (R-290 DX)**	**R-744 (CO2)**	**R-448A/R-449A**	**R-513A**
GWP AR4 of refrigerant	[1]	3 921.6	1 430	3	1	1 392.1	631.4
refrigerating capacity	kW	4	4	4	4	4	4
electric/mechanic capacity	kW	2.5	2.5	2.43	2.38	2.45	2.45
installation lifetime	years	12	12	12	12	12	12
invest cost hardware (first fill excluded)	€	3 800	3 800	3 990	4 560	3 800	3 800
annual operating hours	h/a	5 840	5 840	5 840	5 840	5 840	5 840
final energy cost	€/kWh	0.145	0.145	0.145	0.145	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	77	77	-	-	77	77
additional maintenance cost for non-HFCs	€/a	-	-	55	90	-	-
refrigerant charge	kg	4	4	2	2.67	4	4
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	70.6	32.9	20	5	82.3	70.1
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	10	20	5	60	60
installation type is refilled?		yes	yes	yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	70.6	32.9	20	5	82.3	70.1
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	20	5	60	60
leakage rate first fill / refill	kg/kg	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
leakage rate operation, baseline scenario	1/a	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
leakage rate operation, counterfactual scenario	1/a	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%	25%	25%	25%	25%
recovery rate end of life, baseline scenario	kg/kg	71%	71%	71%	71%	71%	71%
recovery rate end of life, counterfactual scenario	kg/kg	71%	71%	71%	71%	71%	71%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	62.0%	31.0%	0.1%	0.5%	4.0%	2.4%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	75.0%	25.0%	-	-	-	-

Table -14: AnaFgas sector sheet for FGR evaluation: Commercial refrigeration - Central systems

Commercial refrigeration - Central systems								
considered gases / technologies:		**R-404A DX**	**R-134a DX**	**HC+CO2+CO2 cascade**	**R-744 transcritical**	**HC+sec. liquid+CO2**	**R-448A/R-449A**	**R-513A (also in cascade)**
GWP AR4 of refrigerant	[1]	3 921.6	1 430	4	1	4	1 392.1	631.4
refrigerating capacity	kW	100	100	100	100	100	100	100
electric/mechanic capacity	kW	40	40	37	37	40	39.2	39.6
installation lifetime	years	12	12	12	12	12	12	12
invest cost hardware (first fill excluded)	€	320 000	320 000	368 000	342 400	336 000	320 000	320 000
annual operating hours	h/a	4 380	4 380	4 380	4 380	4 380	4 380	4 380
final energy cost	€/kWh	0.145	0.145	0.145	0.145	0.145	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	655	655	-	-	-	655	655
additional maintenance cost for non-HFCs	€/a	-	-	55	255	55	-	-
refrigerant charge	kg	230	230	57.5	230	23	230	230
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	70.6	32.9	20	5	20	82.3	70.1
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	10	20	5	20	60	60
installation type is refilled?		yes	yes	yes	yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	70.6	32.9	20	5	20	82.3	70.1
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	20	5	20	60	60
leakage rate first fill / refill	kg/kg	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
leakage rate operation, baseline scenario	1/a	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
leakage rate operation, counterfactual scenario	1/a	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%	25%	25%	25%	25%	25%
recovery rate end of life, baseline scenario	kg/kg	71%	71%	71%	71%	71%	71%	71%
recovery rate end of life, counterfactual scenario	kg/kg	71%	71%	71%	71%	71%	71%	71%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	53.1%	5.4%	2.4%	12.7%	2.4%	23.0%	1.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	95.4%	4.6%	-	-	-	-	-

Table -15: AnaFgas sector sheet for FGR evaluation: Industrial refrigeration – small

Industrial refrigeration - small					
considered gases / technologies:		**R-404A**	**R-717**	**CO2 / HC**	**R-513A**
GWP AR4 of refrigerant	[1]	3 921.6	1 430	0	2.5
refrigerating capacity	kW	270	270	270	270
electric/mechanic capacity	kW	168.75	168.75	151.88	160.31
installation lifetime	years	30	30	30	30
invest cost hardware (first fill excluded)	€	425 000	425 000	531 250	552 500
annual operating hours	h/a	4 500	4 500	4 500	4 500
final energy cost	€/kWh	0.095	0.095	0.095	0.095
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	1 142	1 142	-	-
additional maintenance cost for non-HFCs	€/a	-	-	1 000	55
refrigerant charge	kg	650	650	650	650
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	70.6	32.9	4	12.5
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	10	4	12.5
installation type is refilled?		yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	70.6	32.9	4	12.5
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	4	12.5
leakage rate first fill / refill	kg/kg	1.0%	1.0%	1.0%	1.0%
leakage rate operation, baseline scenario	1/a	5.4%	5.4%	5.4%	5.4%
leakage rate operation, counterfactual scenario	1/a	5.4%	5.4%	5.4%	5.4%
technologically tolerable refrigerant loss	kg/kg	30%	30%	30%	30%
recovery rate end of life, baseline scenario	kg/kg	65%	65%	65%	65%
recovery rate end of life, counterfactual scenario	kg/kg	65%	65%	65%	65%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	56.0%	6.0%	21.0%	12.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	90.0%	5.0%	5.0%	-

Table -16: AnaFgas sector sheet for FGR evaluation: Industrial refrigeration – large

Industrial refrigeration - large					
considered gases / technologies:		**R-404A**	**R-717**	**HFC-1234ze**	**R-513A (also as cascade + CO2)**
GWP AR4 of refrigerant	[1]	3 921.6	0	7	631.4
refrigerating capacity	kW	5 000	5 000	5 000	5 000
electric/mechanic capacity	kW	2 000	1 780	1 960	1 960
installation lifetime	years	30	30	30	30
invest cost hardware (first fill excluded)	€	6 000 000	7 800 000	6 120 000	6 000 000
annual operating hours	h/a	4 500	4 500	4 500	4 500
final energy cost	€/kWh	0.095	0.095	0.095	0.095
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	1 285	-	-	1 285
additional maintenance cost for non-HFCs	€/a	-	2 000	-	-
refrigerant charge	kg	4 000	4 000	4 000	4 000
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	70.6	4	60	70.1
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	4	60	60
installation type is refilled?		yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	70.6	4	60	70.1
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	4	60	60
leakage rate first fill / refill	kg/kg	1.0%	1.0%	1.0%	1.0%
leakage rate operation, baseline scenario	1/a	4.0%	4.0%	4.0%	4.0%
leakage rate operation, counterfactual scenario	1/a	5.4%	5.4%	5.4%	5.4%
technologically tolerable refrigerant loss	kg/kg	30%	30%	30%	30%
recovery rate end of life, baseline scenario	kg/kg	65%	65%	65%	65%
recovery rate end of life, counterfactual scenario	kg/kg	65%	65%	65%	65%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	18.9%	77.5%	0.5%	3.1%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	51.9%	48.1%	-	-

Table-17: AnaFgas sector sheet for FGR evaluation: Transport refrigeration – Vans

Transport refrigeration - Vans					
considered gases / technologies:		**HFC 134a**	**R-404A**	**R-452A**	**R-513A**
GWP AR4 of refrigerant	[1]	1 430	3 921.6	2 140.5	631.4
refrigerating capacity	kW	3	3	3	3
electric/mechanic capacity	kW	1.5	1.5	1.5	1.5
installation lifetime	years	10	10	10	10
invest cost hardware (first fill excluded)	€	3 000	3 000	3 000	3 000
annual operating hours	h/a	1 500	1 500	1 500	1 500
final energy cost	€/kWh	0.259	0.259	0.259	0.259
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	77	77	77	77
additional maintenance cost for non-HFCs	€/a	-	-	-	-
refrigerant charge	kg	1.5	1.5	1.5	1.5
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	36.4	42.1	35.1
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	5	25	30
installation type is refilled?		yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	70.6	84.2	70.1
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	50	60
leakage rate first fill / refill	kg/kg	1.0%	1.0%	1.0%	1.0%
leakage rate operation, baseline scenario	1/a	28.0%	28.0%	28.0%	28.0%
leakage rate operation, counterfactual scenario	1/a	30.0%	30.0%	30.0%	30.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%	25%	25%
recovery rate end of life, baseline scenario	kg/kg	66%	66%	66%	66%
recovery rate end of life, counterfactual scenario	kg/kg	66%	66%	66%	66%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	79.0%	14.0%	6.0%	1.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	80.0%	20.0%	-	-

Table -18: AnaFgas sector sheet for FGR evaluation: Transport refrigeration - Trucks & Trailers

Transport refrigeration - Trucks & Trailers			
considered gases / technologies:		**R-404A**	**R-452A**
GWP AR4 of refrigerant	[1]	3 921.6	2 140.5
refrigerating capacity	kW	9	9
electric/mechanic capacity	kW	8	8
installation lifetime	years	10	10
invest cost hardware (first fill excluded)	€	15 000	15 000
annual operating hours	h/a	4 000	4 000
final energy cost	€/kWh	0.259	0.259
discount rate (societal view / emission reduction cost)	%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	74	74
additional maintenance cost for non-HFCs	€/a	-	-
refrigerant charge	kg	6.5	6.5
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	36.4	42.1
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	25
installation type is refilled?		yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	70.6	84.2
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	50
leakage rate first fill / refill	kg/kg	1.0%	1.0%
leakage rate operation, baseline scenario	1/a	18.0%	18.0%
leakage rate operation, counterfactual scenario	1/a	20.0%	20.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%
recovery rate end of life, baseline scenario	kg/kg	66%	66%
recovery rate end of life, counterfactual scenario	kg/kg	66%	66%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	60.0%	40.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-

Table -19: AnaFgas sector sheet for FGR evaluation: Transport refrigeration – Ships

Transport refrigeration - Ships				
considered gases / technologies:		**R-404A**	**NH3/CO2**	**R-452A**
GWP AR4 of refrigerant	[1]	3 921.6	0	2 140.5
refrigerating capacity	kW	990	990	990
electric/mechanic capacity	kW	468	439.92	439.92
installation lifetime	years	30	30	30
invest cost hardware (first fill excluded)	€	2 000 000	2 300 000	2 000 000
annual operating hours	h/a	5 000	5 000	5 000
final energy cost	€/kWh	0.073	0.073	0.073
discount rate (societal view / emission reduction cost)	%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	108	-	108
additional maintenance cost for non-HFCs	€/a	-	1 000	-
refrigerant charge	kg	1 000	750	1 000
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	70.6	4	84.2
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	4	50
installation type is refilled?		yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	70.6	4	84.2
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	4	50
leakage rate first fill / refill	kg/kg	1.0%	1.0%	1.0%
leakage rate operation, baseline scenario	1/a	40.0%	40.0%	40.0%
leakage rate operation, counterfactual scenario	1/a	40.0%	40.0%	40.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%	25%
recovery rate end of life, baseline scenario	kg/kg	54%	54%	54%
recovery rate end of life, counterfactual scenario	kg/kg	54%	54%	54%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	86.0%	12.0%	2.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-	-

Table -20: AnaFgas sector sheet for FGR evaluation: Room AC – Moveables

Room AC - Moveables			
considered gases / technologies:		**R-410A direct**	**R-290**
GWP AR4 of refrigerant	[1]	2 087.5	3
refrigerating capacity	kW	3	3
electric/mechanic capacity	kW	0.67	0.67
installation lifetime	years	10	10
invest cost hardware (first fill excluded)	€	300	294
annual operating hours	h/a	500	500
final energy cost	€/kWh	0.215	0.215
discount rate (societal view / emission reduction cost)	%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	3	-
additional maintenance cost for non-HFCs	€/a	-	-
refrigerant charge	kg	0.75	0.38
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	21.7	10
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	10
installation type is refilled?		no	no
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	-	-
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	-	-
leakage rate first fill / refill	kg/kg	0.0%	0.0%
leakage rate operation, baseline scenario	1/a	3.0%	3.0%
leakage rate operation, counterfactual scenario	1/a	3.0%	3.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%
recovery rate end of life, baseline scenario	kg/kg	53%	53%
recovery rate end of life, counterfactual scenario	kg/kg	53%	53%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	59.0%	41.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	95.0%	5.0%

Table -21: AnaFgas sector sheet for FGR evaluation: Room AC - Single split

Room AC - Single split (includes small multi-split <12 kW & reversible air-to-air heat pumps)			
considered gases / technologies:		**R-410A direct**	**HFC-32**
GWP AR4 of refrigerant	[1]	2 087.5	675
refrigerating capacity	kW	4.5	4.5
electric/mechanic capacity	kW	1	1
installation lifetime	years	10	10
invest cost hardware (first fill excluded)	€	750	750
annual operating hours	h/a	1 500	1 500
final energy cost	€/kWh	0.215	0.215
discount rate (societal view / emission reduction cost)	%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	9	9
additional maintenance cost for non-HFCs	€/a	-	-
refrigerant charge	kg	1.5	1.2
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	21.7	15.4
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	10
installation type is refilled?		yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	43.3	30.8
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	20
leakage rate first fill / refill	kg/kg	3.5%	3.5%
leakage rate operation, baseline scenario	1/a	5.0%	5.0%
leakage rate operation, counterfactual scenario	1/a	5.0%	5.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%
recovery rate end of life, baseline scenario	kg/kg	60%	60%
recovery rate end of life, counterfactual scenario	kg/kg	60%	60%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	63.0%	37.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-

Table -22: AnaFgas sector sheet for FGR evaluation: Room AC – Rooftop

Room AC - Packaged systems (rooftop units), cooling only				
considered gases / technologies:		**R-410A direct**	**HFC-32**	**R-290**
GWP AR4 of refrigerant	[1]	2 087.5	675	3
refrigerating capacity	kW	30	30	30
electric/mechanic capacity	kW	15	14.85	14.7
installation lifetime	years	10	10	10
invest cost hardware (first fill excluded)	€	10 000	10 200	10 500
annual operating hours	h/a	3 000	3 000	3 000
final energy cost	€/kWh	0.145	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	215	215	-
additional maintenance cost for non-HFCs	€/a	-	-	55
refrigerant charge	kg	10.5	8.4	5.25
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	43.3	30.8	20
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	20	20
installation type is refilled?		yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	43.3	30.8	20
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	20	20
leakage rate first fill / refill	kg/kg	0.0%	0.0%	0.0%
leakage rate operation, baseline scenario	1/a	3.0%	3.0%	3.0%
leakage rate operation, counterfactual scenario	1/a	3.0%	3.0%	3.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%	25%
recovery rate end of life, baseline scenario	kg/kg	77%	77%	77%
recovery rate end of life, counterfactual scenario	kg/kg	77%	77%	77%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	87.0%	12.5%	0.5%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-	-

Table -23: AnaFgas sector sheet for FGR evaluation: Room AC – VRF

Room AC - VRF cooling only (includes Single-split >3kg VRF Multi-Split)			
considered gases / technologies:		**R-410A direct**	**HFC-32**
GWP AR4 of refrigerant	[1]	2 087.5	675
refrigerating capacity	kW	27	27
electric/mechanic capacity	kW	8	8
installation lifetime	years	13	13
invest cost hardware (first fill excluded)	€	9 500	9 738
annual operating hours	h/a	3 000	3 000
final energy cost	€/kWh	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	226	226
additional maintenance cost for non-HFCs	€/a	-	-
refrigerant charge	kg	13.5	10.8
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	43.3	30.8
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	20
installation type is refilled?		yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	43.3	30.8
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	20
leakage rate first fill / refill	kg/kg	0.3%	0.3%
leakage rate operation, baseline scenario	1/a	5.6%	5.6%
leakage rate operation, counterfactual scenario	1/a	5.6%	5.6%
technologically tolerable refrigerant loss	kg/kg	25%	25%
recovery rate end of life, baseline scenario	kg/kg	77%	77%
recovery rate end of life, counterfactual scenario	kg/kg	68%	68%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	99.8%	0.2%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-

Table -24: AnaFgas sector sheet for FGR evaluation: Minichillers

Minichillers				
considered gases / technologies:		**R-410A**	**R-32**	**HFO-1234ze**
GWP AR4 of refrigerant	[1]	2 087.5	675	7
refrigerating capacity	kW	2	2	2
electric/mechanic capacity	kW	2	1.98	2
installation lifetime	years	12	12	12
invest cost hardware (first fill excluded)	€	450	459	450
annual operating hours	h/a	1 860	1 860	1 860
final energy cost	€/kWh	0.145	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	141	141	-
additional maintenance cost for non-HFCs	€/a	-	-	-
refrigerant charge	kg	0.65	0.43	0.72
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	21.7	15.4	30
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	10	30
installation type is refilled?		yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	43.3	30.8	60
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	20	60
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	2.4%	2.4%	2.4%
leakage rate operation, counterfactual scenario	1/a	2.4%	2.4%	2.4%
technologically tolerable refrigerant loss	kg/kg	20%	20%	20%
recovery rate end of life, baseline scenario	kg/kg	78%	78%	78%
recovery rate end of life, counterfactual scenario	kg/kg	78%	78%	78%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	88.8%	10.6%	0.6%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-	-

Table-25: AnaFgas sector sheet for FGR evaluation: Displacement chillers – small

Displacement chillers - small					
considered gases / technologies:		**R-410A**	**H2O (R-718)**	**R-32**	**HFO-1234ze**
GWP AR4 of refrigerant	[1]	2 087.5	0	675	7
refrigerating capacity	kW	80	80	80	80
electric/mechanic capacity	kW	28	26.32	27.72	27.72
installation lifetime	years	15	15	15	15
invest cost hardware (first fill excluded)	€	18 000	25 200	18 900	18 360
annual operating hours	h/a	1 860	1 860	1 860	1 860
final energy cost	€/kWh	0.145	0.145	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	143	-	143	-
additional maintenance cost for non-HFCs	€/a	-	-	-	-
refrigerant charge	kg	26	18	17.33	28.6
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	43.3	0	30.8	60
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	0	20	60
installation type is refilled?		yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	43.3	0	30.8	60
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	0	20	60
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	2.4%	2.4%	2.4%	2.4%
leakage rate operation, counterfactual scenario	1/a	2.4%	2.4%	2.4%	2.4%
technologically tolerable refrigerant loss	kg/kg	20%	20%	20%	20%
recovery rate end of life, baseline scenario	kg/kg	78%	78%	78%	78%
recovery rate end of life, counterfactual scenario	kg/kg	78%	78%	78%	78%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	82.6%	7.4%	9.5%	0.5%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-	-	-

Table -26: **AnaFgas sector sheet for FGR evaluation: Displacement chillers – large**

Displacement chillers - large							
considered gases / technologies:		**R-134a**	**R-407C**	**R-410A**	**R-717 / R-718**	**R-32**	**HFO-1234ze**
GWP AR4 of refrigerant	[1]	1 430	1 773.9	2 087.5	0	675	7
refrigerating capacity	kW	400	400	400	400	400	400
electric/mechanic capacity	kW	129	129	129	122.55	127.07	127.71
installation lifetime	years	15	15	15	15	15	15
invest cost hardware (first fill excluded)	€	70 000	70 000	70 000	87 500	73 500	73 500
annual operating hours	h/a	1 860	1 860	1 860	1 860	1 860	1 860
final energy cost	€/kWh	0.095	0.095	0.095	0.095	0.095	0.095
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	278	278	278	-	278	-
additional maintenance cost for non-HFCs	€/a	-	-	-	73	-	-
refrigerant charge	kg	150	150	150	75	120	150
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	32.9	38.1	43.3	4	30.8	60
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	10	10	4	20	60
installation type is refilled?		yes	yes	yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	38.1	43.3	4	30.8	60
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	10	4	20	60
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
leakage rate operation, counterfactual scenario	1/a	2.4%	2.4%	2.4%	2.4%	2.4%	2.4%
technologically tolerable refrigerant loss	kg/kg	20%	20%	20%	20%	20%	20%
recovery rate end of life, baseline scenario	kg/kg	78%	78%	78%	78%	78%	78%
recovery rate end of life, counterfactual scenario	kg/kg	78%	78%	78%	78%	78%	78%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	23.3%	16.9%	42.4%	7.4%	9.5%	0.5%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	28.2%	20.5%	51.3%	-	-	-

Table Fehler! Kein Text mit angegebener Formatvorlage im Dokument.**-27: AnaFgas sector sheet for FGR evaluation: Centrifugal chillers**

Centrifugal chillers					
considered gases / technologies:		**HFC 134a**	**HFO-1234ze**	**HFO-1233zd**	**CO_2 / NH_3**
GWP AR4 of refrigerant	[1]	1 430	7	4.5	0.5
refrigerating capacity	kW	1500	1500	1500	1500
electric/mechanic capacity	kW	300	297	297	270
installation lifetime	years	25	25	25	25
invest cost hardware (first fill excluded)	€	140 000	141 400	141 400	154 000
annual operating hours	h/a	3 350	3 350	3 350	3 350
final energy cost	€/kWh	0.095	0.095	0.095	0.095
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	278	-	-	-
additional maintenance cost for non-HFCs	€/a	-	-	-	-
refrigerant charge	kg	630	630	630	630
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	32.9	60	50	4.5
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	60	50	4.5
installation type is refilled?		yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	60	50	4.5
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	60	50	4.5
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	2.4%	2.4%	2.4%	2.4%
leakage rate operation, counterfactual scenario	1/a	2.4%	2.4%	2.4%	2.4%
technologically tolerable refrigerant loss	kg/kg	20%	20%	20%	20%
recovery rate end of life, baseline scenario	kg/kg	78%	78%	78%	78%
recovery rate end of life, counterfactual scenario	kg/kg	78%	78%	78%	78%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	81.5%	7.3%	7.3%	4.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-	-	-

Table -28: AnaFgas sector sheet for FGR evaluation: Heat pumps – small

Heat pumps - small (<20 kW, excluding small reversable air/air heat pumps covered in the single split subsector)								
considered gases / technologies:		**R-134a**	**R-410A**	**R-407C**	**HCs**	**R-32**	**R-513A**
GWP AR4 of refrigerant	[1]	1430	2087.5	1773.9	4	675	631.4
refrigerating capacity	kW	11	11	11	11	11	11
electric/mechanic capacity	kW	6.88	6.88	6.88	6.67	6.81	6.88
installation lifetime	years	15	15	15	15	15	15
invest cost hardware (first fill excluded)	€	8 380	8 380	8 380	8 799	8 548	8 380
annual operating hours	h/a	2000	2000	2000	2000	2000	2000
final energy cost	€/kWh	0.215	0.215	0.215	0.215	0.215	0.215
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	6	6	6	-	6	6
additional maintenance cost for non-HFCs	€/a	-	-	-	-	-	-
refrigerant charge	kg	2.6	2.6	2.6	1.3	2.08	2.6
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	21.7	19.2	10	15.4	35.1
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	5	5	10	10	30
installation type is refilled?		yes	yes	yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	43.3	38.1	20	30.8	70.1
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	10	20	20	60
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
leakage rate operation, counterfactual scenario	1/a	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
technologically tolerable refrigerant loss	kg/kg	30%	30%	30%	30%	30%	30%
recovery rate end of life, baseline scenario	kg/kg	59%	59%	59%	59%	59%	59%
recovery rate end of life, counterfactual scenario	kg/kg	59%	59%	59%	59%	59%	59%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	5.0%	81.0%	3.8%	2.8%	7.0%	0.5%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	5.0%	90.0%	5.0%	-	-	-

Table -29: AnaFgas sector sheet for FGR evaluation: Heat pumps – medium

Heat pumps - medium (20-200kW)						
considered gases / technologies:		**R-134a**	**R-410A**	**R-407C**	**HCs**	**R-32**
GWP AR4 of refrigerant	[1]	1430	2087.5	1773.9	4	675
refrigerating capacity	kW	110	110	110	110	110
electric/mechanic capacity	kW	68.75	68.75	68.75	66.69	68.06
installation lifetime	years	15	15	15	15	15
invest cost hardware (first fill excluded)	€	30 000	30 000	30 000	33 000	31 500
annual operating hours	h/a	2000	2000	2000	2000	2000
final energy cost	€/kWh	0.145	0.145	0.145	0.145	0.145
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	283	283	283	-	283
additional maintenance cost for non-HFCs	€/a	-	-	-	55	-
refrigerant charge	kg	26	26	26	13	18
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	24.7	32.5	28.6	15	23.1
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	7.5	7.5	7.5	15	15
installation type is refilled?		yes	yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	43.3	38.1	20	30.8
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	10	20	20
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	4.5%	4.5%	4.5%	4.5%	4.5%
leakage rate operation, counterfactual scenario	1/a	4.5%	4.5%	4.5%	4.5%	4.5%
technologically tolerable refrigerant loss	kg/kg	30%	30%	30%	30%	30%
recovery rate end of life, baseline scenario	kg/kg	59%	59%	59%	59%	59%
recovery rate end of life, counterfactual scenario	kg/kg	59%	59%	59%	59%	59%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	5.0%	84.5%	3.8%	1.3%	5.5%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	5.0%	90.0%	5.0%	-	-

Table -30: AnaFgas sector sheet for FGR evaluation: Heat pumps – large

Heat pumps - large (>200kW, district heating & industrial)				
considered gases / technologies:		**R-134a**	**CO2 (R-744)**	**NH3 / R-723**
GWP AR4 of refrigerant	[1]	1430	1	0
refrigerating capacity	kW	3173.08	3173.08	3173.08
electric/mechanic capacity	kW	1983.17	1913.76	1884.01
installation lifetime	years	20	20	20
invest cost hardware (first fill excluded)	€	2 800 000	3 360 000	3 220 000
annual operating hours	h/a	6000	6000	6000
final energy cost	€/kWh	0.095	0.095	0.095
discount rate (societal view / emission reduction cost)	%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	283	-	-
additional maintenance cost for non-HFCs	€/a	-	255	145
refrigerant charge	kg	750	500	500
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	32.9	5	4
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10	5	4
installation type is refilled?		yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	5	4
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	5	4
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	6.0%	6.0%	6.0%
leakage rate operation, counterfactual scenario	1/a	6.0%	6.0%	6.0%
technologically tolerable refrigerant loss	kg/kg	30%	30%	30%
recovery rate end of life, baseline scenario	kg/kg	76%	76%	76%
recovery rate end of life, counterfactual scenario	kg/kg	76%	76%	76%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	36.0%	19.0%	45.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	50.0%	5.0%	45.0%

Table -31: AnaFgas sector sheet for FGR evaluation: Mobile AC - Passenger cars

Mobile AC - Passenger cars				
considered gases / technologies:		**R-134a**	**HFO-1234yf**	**R-744**
GWP AR4 of refrigerant	[1]	1 430	4	1
refrigerating capacity	kW	4	4	4
electric/mechanic capacity	kW	4	4	3.6
installation lifetime	years	12	12	12
invest cost hardware (first fill excluded)	€	300	303	450
annual operating hours	h/a	300	300	300
final energy cost	€/kWh	0.446	0.446	0.446
discount rate (societal view / emission reduction cost)	%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	-	-	-
additional maintenance cost for non-HFCs	€/a	-	-	55
refrigerant charge	kg	0.5	0.5	0.34
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	70	2.5
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	70	2.5
installation type is refilled?		yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	140	5
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	140	5
leakage rate first fill / refill	kg/kg	0.5%	0.5%	0.5%
leakage rate operation, baseline scenario	1/a	10.0%	10.0%	10.0%
leakage rate operation, counterfactual scenario	1/a	10.0%	10.0%	10.0%
technologically tolerable refrigerant loss	kg/kg	40%	40%	40%
recovery rate end of life, baseline scenario	kg/kg	50%	50%	50%
recovery rate end of life, counterfactual scenario	kg/kg	50%	50%	50%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	30.2%	69.7%	0.1%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	30.2%	69.7%	0.1%

Table -32: AnaFgas sector sheet for FGR evaluation: Mobile AC – Buses

Mobile AC - Buses			
considered gases / technologies:		**R-134a**	**R-744**
GWP AR4 of refrigerant	[1]	1 430	1
refrigerating capacity	kW	25	25
electric/mechanic capacity	kW	16.7	15.87
installation lifetime	years	10	10
invest cost hardware (first fill excluded)	€	13 000	23 400
annual operating hours	h/a	2 000	2 000
final energy cost	€/kWh	0.259	0.259
discount rate (societal view / emission reduction cost)	%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	-	-
additional maintenance cost for non-HFCs	€/a	-	55
refrigerant charge	kg	10.4	6.97
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	2.5
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	2.5
installation type is refilled?		yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	5
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	5
leakage rate first fill / refill	kg/kg	0.0%	0.0%
leakage rate operation, baseline scenario	1/a	15.0%	15.0%
leakage rate operation, counterfactual scenario	1/a	15.0%	15.0%
technologically tolerable refrigerant loss	kg/kg	40%	40%
recovery rate end of life, baseline scenario	kg/kg	63%	63%
recovery rate end of life, counterfactual scenario	kg/kg	63%	63%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	99.2%	0.8%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-

Table -33: AnaFgas sector sheet for FGR evaluation: Mobile AC - Trucks N1

Mobile AC - Trucks N1			
considered gases / technologies:		**R-134a**	**HFO-1234yf**
GWP AR4 of refrigerant	[1]	1 430	4
refrigerating capacity	kW	8	8
electric/mechanic capacity	kW	8	8
installation lifetime	years	10	10
invest cost hardware (first fill excluded)	€	300	304
annual operating hours	h/a	300	300
final energy cost	€/kWh	0.259	0.259
discount rate (societal view / emission reduction cost)	%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	-	-
additional maintenance cost for non-HFCs	€/a	-	-
refrigerant charge	kg	1	1
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	70
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	70
installation type is refilled?		yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	140
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	140
leakage rate first fill / refill	kg/kg	0.0%	0.0%
leakage rate operation, baseline scenario	1/a	10.0%	10.0%
leakage rate operation, counterfactual scenario	1/a	10.0%	10.0%
technologically tolerable refrigerant loss	kg/kg	40%	40%
recovery rate end of life, baseline scenario	kg/kg	13%	13%
recovery rate end of life, counterfactual scenario	kg/kg	13%	13%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	92.0%	8.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%	-

Table -34: AnaFgas sector sheet for FGR evaluation: Mobile AC - Trucks N2

Mobile AC - Trucks N2		
considered gases / technologies:		**R-134a**
GWP AR4 of refrigerant	[1]	1 430
refrigerating capacity	kW	8
electric/mechanic capacity	kW	8
installation lifetime	years	10
invest cost hardware (first fill excluded)	€	300
annual operating hours	h/a	300
final energy cost	€/kWh	0.259
discount rate (societal view / emission reduction cost)	%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	-
additional maintenance cost for non-HFCs	€/a	-
refrigerant charge	kg	1
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5
installation type is refilled?		yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10
leakage rate first fill / refill	kg/kg	0.0%
leakage rate operation, baseline scenario	1/a	15.0%
leakage rate operation, counterfactual scenario	1/a	15.0%
technologically tolerable refrigerant loss	kg/kg	40%
recovery rate end of life, baseline scenario	kg/kg	13%
recovery rate end of life, counterfactual scenario	kg/kg	13%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	100.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%

Table -35: AnaFgas sector sheet for FGR evaluation: Mobile AC - Trucks N3

Mobile AC - Trucks N3		
considered gases / technologies:		**R-134a**
GWP AR4 of refrigerant	[1]	1 430
refrigerating capacity	kW	8
electric/mechanic capacity	kW	8
installation lifetime	years	10
invest cost hardware (first fill excluded)	€	300
annual operating hours	h/a	300
final energy cost	€/kWh	0.259
discount rate (societal view / emission reduction cost)	%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	-
additional maintenance cost for non-HFCs	€/a	-
refrigerant charge	kg	1
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5
installation type is refilled?		yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10
leakage rate first fill / refill	kg/kg	0.0%
leakage rate operation, baseline scenario	1/a	15.0%
leakage rate operation, counterfactual scenario	1/a	15.0%
technologically tolerable refrigerant loss	kg/kg	40%
recovery rate end of life, baseline scenario	kg/kg	13%
recovery rate end of life, counterfactual scenario	kg/kg	13%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	100.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%

Table -36: AnaFgas sector sheet for FGR evaluation: Mobile AC - Passenger ships

Mobile AC - Passenger ships		
considered gases / technologies:		**R-134a**
GWP AR4 of refrigerant	[1]	1 430
refrigerating capacity	kW	975
electric/mechanic capacity	kW	180
installation lifetime	years	30
invest cost hardware (first fill excluded)	€	123 500
annual operating hours	h/a	3 000
final energy cost	€/kWh	0.073
discount rate (societal view / emission reduction cost)	%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	2 039
additional maintenance cost for non-HFCs	€/a	-
refrigerant charge	kg	520
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10
installation type is refilled?		yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10
leakage rate first fill / refill	kg/kg	0.0%
leakage rate operation, baseline scenario	1/a	40.0%
leakage rate operation, counterfactual scenario	1/a	40.0%
technologically tolerable refrigerant loss	kg/kg	40%
recovery rate end of life, baseline scenario	kg/kg	63%
recovery rate end of life, counterfactual scenario	kg/kg	63%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	100.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%

Table -37: AnaFgas sector sheet for FGR evaluation: Mobile AC - Cargo ships

Mobile AC - Cargo ships		
considered gases / technologies:		**R-134a**
GWP AR4 of refrigerant	[1]	1 430
refrigerating capacity	kW	300
electric/mechanic capacity	kW	55.3
installation lifetime	years	30
invest cost hardware (first fill excluded)	€	38 000
annual operating hours	h/a	3 000
final energy cost	€/kWh	0.073
discount rate (societal view / emission reduction cost)	%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	778
additional maintenance cost for non-HFCs	€/a	-
refrigerant charge	kg	160
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	10
installation type is refilled?		yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10
leakage rate first fill / refill	kg/kg	1.0%
leakage rate operation, baseline scenario	1/a	40.0%
leakage rate operation, counterfactual scenario	1/a	40.0%
technologically tolerable refrigerant loss	kg/kg	40%
recovery rate end of life, baseline scenario	kg/kg	63%
recovery rate end of life, counterfactual scenario	kg/kg	63%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	100.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%

Table -38: AnaFgas sector sheet for FGR evaluation: Mobile AC – Tram

Mobile AC - Tram		
considered gases / technologies:		**R-134a**
GWP AR4 of refrigerant	[1]	1 430
refrigerating capacity	kW	35
electric/mechanic capacity	kW	15
installation lifetime	years	25
invest cost hardware (first fill excluded)	€	25 000
annual operating hours	h/a	2 000
final energy cost	€/kWh	0.08
discount rate (societal view / emission reduction cost)	%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	2
additional maintenance cost for non-HFCs	€/a	-
refrigerant charge	kg	8
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5
installation type is refilled?		yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10
leakage rate first fill / refill	kg/kg	0.2%
leakage rate operation, baseline scenario	1/a	7.0%
leakage rate operation, counterfactual scenario	1/a	7.0%
technologically tolerable refrigerant loss	kg/kg	25%
recovery rate end of life, baseline scenario	kg/kg	66%
recovery rate end of life, counterfactual scenario	kg/kg	66%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	100.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%

Table -39: AnaFgas sector sheet for FGR evaluation: Mobile AC – Metro

Mobile AC - Metro		
considered gases / technologies:		**R-134a**
GWP AR4 of refrigerant	[1]	1 430
refrigerating capacity	kW	35
electric/mechanic capacity	kW	15
installation lifetime	years	25
invest cost hardware (first fill excluded)	€	25 000
annual operating hours	h/a	2 000
final energy cost	€/kWh	0.08
discount rate (societal view / emission reduction cost)	%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	2
additional maintenance cost for non-HFCs	€/a	-
refrigerant charge	kg	8
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5
installation type is refilled?		yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10
leakage rate first fill / refill	kg/kg	0.2%
leakage rate operation, baseline scenario	1/a	7.0%
leakage rate operation, counterfactual scenario	1/a	7.0%
technologically tolerable refrigerant loss	kg/kg	25%
recovery rate end of life, baseline scenario	kg/kg	66%
recovery rate end of life, counterfactual scenario	kg/kg	66%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	100.0%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	100.0%

Table -40: AnaFgas sector sheet for FGR evaluation: Mobile AC – Train

Mobile AC - Train					
considered gases / technologies:		**R-134a**	**R-407C**	**R-744 / HCs**	**R-729**
GWP AR4 of refrigerant	[1]	1 430	1 773.9	2.5	0
refrigerating capacity	kW	35	35	35	35
electric/mechanic capacity	kW	15	15	13.5	13.5
installation lifetime	years	25	25	25	25
invest cost hardware (first fill excluded)	€	25 000	25 000	30 000	50 000
annual operating hours	h/a	2 000	2 000	2 000	2 000
final energy cost	€/kWh	0.08	0.08	0.08	0.08
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	2	2	-	-
additional maintenance cost for non-HFCs	€/a	-	-	-	-
refrigerant charge	kg	8	8	8	8
refrigerant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	19.2	6.3	2
refrigerant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5	5	6.3	2
installation type is refilled?		yes	yes	yes	yes
refrigerant cost refill, baseline scenario, average 2015-2019	€/kg	32.9	38.1	12.5	4
refrigerant cost refill, counterfactual scenario, average 2015-2019	€/kg	10	10	12.5	4
leakage rate first fill / refill	kg/kg	0.2%	0.2%	0.2%	0.2%
leakage rate operation, baseline scenario	1/a	7.0%	7.0%	7.0%	7.0%
leakage rate operation, counterfactual scenario	1/a	7.0%	7.0%	7.0%	7.0%
technologically tolerable refrigerant loss	kg/kg	25%	25%	25%	25%
recovery rate end of life, baseline scenario	kg/kg	66%	66%	66%	66%
recovery rate end of life, counterfactual scenario	kg/kg	66%	66%	66%	66%
Penetration rate in new installations, baseline scenario, 2015-2019 average	%	79.7%	20.0%	0.2%	0.1%
Penetration rate in new installations, counterfactual scenario, 2015-2019 average	%	80.0%	20.0%	-	-

Table -41: AnaFgas sector sheet for FGR evaluation: Aerosols – technical

Aerosols - technical				
considered gases / technologies:		**HFC-134a**	**HFC-152a**	**HFC-1234ze**
GWP AR4 of propellant	[1]	1 430	124	7
preparation / canning cost (propellant excluded) per kg propellant	€/kg	20	20	20
propellant charge	kg	0.15	0.15	0.15
propellant cost first fill, baseline scenario, average 2015-2019	€/kg	16.4	6.0	15.0
propellant cost first fill, counterfactual scenario, average 2015-2019	€/kg	5.0	5.0	15.0
emission rate on application	kg/kg	100%	100%	100%
Penetration rate (defined on HFC-based niche of sector), baseline scenario, 2015-2019 average	%	45.7%	15.5%	38.8%
Penetration rate (defined on HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	90.5%	9.5%	-

Table -42: AnaFgas sector sheet for FGR evaluation: Aerosols – MDIs

Aerosols - MDIs			
considered gases / technologies:		**HFC-134a**	**HFC-227ea**
GWP AR4 of propellant	[1]	1 430	3 220
preparation / canning cost (propellant excluded) per kg propellant	€/kg	706	706
propellant charge	kg	0.005	0.005
propellant cost first fill, baseline scenario, average 2015-2019	€/kg	8.0	8.0
propellant cost first fill, counterfactual scenario, average 2015-2019	€/kg	8.0	8.0
emission rate on application	kg/kg	100%	100%
Penetration rate (defined on HFC-based niche of sector), baseline scenario, 2015-2019 average	%	91.7%	8.3%
Penetration rate (defined on HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	91.7%	8.3%

Table -43: AnaFgas sector sheet for FGR evaluation: Fire extinguishers

Fire extinguishers							
considered gases / technologies:		**HFC-227ea**	**HFC-23**	**HFC-125**	**HFC-236fa**	**HFC-134a**	**low-GWP alternatives (FK-5-1-12, inert gases)**
GWP AR4 of suppression agent	[1]	3 220	14 800	3 500	9 810	1 430	0.5
room size	m^3	200	200	200	200	200	200
required gas concentration (for suppression of class C hazards (energized electrical equipment)	m^3 / m^3	5.8%	17.4%	9.0%	8.6%	15.3%	21.3%
molar mass of suppression agent	g/mol	170	70	120	152	102	175
molar volume at room temperature	l/mol	24.47	24.47	24.47	24.47	24.47	24.47
installed gas quantity	kg	80.6	99.6	88.3	106.8	127.6	303.9
Installation lifetime	years	20	20	20	20	20	20
invest cost hardware (first fill excluded)	€	14 000	11 500	14 000	14 000	14 000	14 000
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%	4%	4%
HFC operators' cost for containment & recovery (FGR Art 3-8)	€/a	117	117	117	117	117	-
additional maintenance cost for non-HFCs	€/a	-	-	-	-	-	-
suppression agent cost first fill, baseline scenario, average 2015-2019	€/kg	39.8	132.4	42	92.5	25.4	11
suppression agent cost first fill, counterfactual scenario, average 2015-2019	€/kg	14	14	14	14	14	11
installation type is refilled?		yes	yes	yes	yes	yes	yes
suppression agent cost refill, baseline scenario, average 2015-2019	€/kg	39.8	132.4	41.9	92.5	25.4	11
suppression agent cost refill, counterfactual scenario, average 2015-2019	€/kg	14	14	14	14	14	11
leakage rate first fill / refill	kg/kg	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
leakage rate operation, baseline scenario	1/a	2.0%	2.0%	2.0%	5.0%	4.0%	2.0%
leakage rate operation, counterfactual scenario	1/a	2.0%	2.0%	2.0%	5.0%	4.0%	2.0%
recovery rate end of life, baseline scenario	kg/kg	91%	91%	91%	91%	91%	91%
recovery rate end of life, counterfactual scenario	kg/kg	91%	91%	91%	91%	91%	91%
Penetration rate in new installations (in HFC-based niche of sector), baseline scenario, 2015-2019 average	%	7.8%	-	0.2%	0.8%	-	91.3%

Fire extinguishers							
considered gases / technologies:		**HFC-227ea**	**HFC-23**	**HFC-125**	**HFC-236fa**	**HFC-134a**	**low-GWP alternatives (FK-5-1-12, inert gases)**
Penetration rate in new installations (in HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	83.6%	-	5.4%	1.8%	9.1%	-

Table -44: AnaFgas sector sheet for FGR evaluation: Solvents

Solvents							
considered gases / technologies:		**HFC-43-10mee**	**HFC-365mfc**	**HFC-245fa**	**HFC-227ea**	**HFO-1233zd**
GWP AR4 of solvent	[1]	1 640	794	1 030	3 220	4.5
preparation / canning cost (solvent excluded) per kg solvent	€/kg	20	20	20	20	20
solvent charge	kg	0.15	0.15	0.15	0.15	0.15
solvent cost first fill, baseline scenario, average 2015-2019	€/kg	18.1	12.4	13.2	39.8	25.0
solvent cost first fill, counterfactual scenario, average 2015-2019	€/kg	5.0	6.0	5.0	14.0	25.0
emission rate on application	kg/kg	100%	100%	100%	100%	100%
Penetration rate (defined on HFC-based niche of sector), baseline scenario, 2015-2019 average	%	58.8%	6.9%	1.5%	16.0%	16.8%
Penetration rate (defined on HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	75.6%	6.9%	1.5%	16.0%	-

Table -45: AnaFgas sector sheet for FGR evaluation: Foam OCF

Foam OCF (one component foam)			
considered gases / technologies:		**HFC-134a**	**HFO-1234ze**
GWP AR4 of blowing agent	[1]	1 430	7
product		OCF cans, 660g, hereof 110g propellant	OCF cans, 660g, hereof 110g propellant
production facility annual output	m³/a	10 000	10 000
thermal conductivity	mW/ (m * K)	30	30
production facility insulation capacity annual output	m³/ a * ((m * K) / mW))	333	333
product density	kg/m³	42	42
blowing agent in formulation	pbw	110	110
total weight of formulation	pbw	660	660
foam product lifetime	years	50	50
invest cost for conversion of production line including development	€	-	22 500
economic lifetime of conversion investment	years	15	15
discount rate (societal view / emission reduction cost)	%	4%	4%
blowing agent cost, baseline scenario, average 2015-2019	€/kg	16.4	15.0
blowing agent cost, counterfactual scenario, average 2015-2019	€/kg	5.0	15.0
manufacturing emission factor of blowing agent	kg/kg	15%	15%
leakage rate in foam product lifetime, baseline scenario	1/a	1.0%	1.0%
leakage rate in foam product lifetime, counterfactual scenario	1/a	1.0%	1.0%
recovery rate end of life, baseline scenario	kg/kg	0%	0%
recovery rate end of life, counterfactual scenario	kg/kg	0%	0%
Penetration rate (defined on HFC-based niche of sector), baseline scenario, 2015-2019 average	%	-	100.0%
Penetration rate (defined on HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	-	100.0%

Table -46: AnaFgas sector sheet for FGR evaluation: Foam XPS

Foam XPS (extruded polystyrene)					
considered gases / technologies:		**XPS / HFC-134a**	**XPS / HFC-152a**	**XPS / HFO-1234ze**	**XPS / CO2**
GWP AR4 of blowing agent	[1]	1 430	124	7	1
product		XPS-134a Panel 1200 x 600 x 1400 mm, density 35	XPS Panel 1200 x 600 x 50 mm, density 35	XPS Panel 1200 x 600 x 1400 mm, density 40	XPS Panel 1200 x 600 x 50 mm, density 35
production facility annual output	m³/a	75 000	87 931	75 000	87 931
thermal conductivity	mW/ (m * K)	29	34	29	34
production facility insulation capacity annual output	m³/ a * ((m * K) / mW))	2 586	2 586	2 586	2 586
product density	kg/m³	35	35	40	35
blowing agent in formulation	pbw	7	10	8	10
total weight of formulation	pbw	100	90	100	90
foam product lifetime	years	50	50	50	50
invest cost for conversion of production line including development	€	-	-	1 000 000	1 500 000
economic lifetime of conversion investment	years	15	15	15	15
discount rate (societal view / emission reduction cost)	%	4%	4%	4%	4%
blowing agent cost, baseline scenario, average 2015-2019	€/kg	16.4	6.0	15.0	2.5
blowing agent cost, counterfactual scenario, average 2015-2019	€/kg	5.0	5.0	15.0	2.5
manufacturing emission factor of blowing agent	kg/kg	30%	100%	30%	30%
leakage rate in foam product lifetime, baseline scenario	1/a	0.8%	0.8%	0.8%	0.8%
leakage rate in foam product lifetime, counterfactual scenario	1/a	0.8%	0.8%	0.8%	0.8%
recovery rate end of life, baseline scenario	kg/kg	0%	0%	0%	0%
recovery rate end of life, counterfactual scenario	kg/kg	0%	0%	0%	0%
Penetration rate (defined on HFC-based niche of sector), baseline scenario, 2015-2019 average	%	18.6%	56.5%	9.5%	15.4%
Penetration rate (defined on HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	37.9%	62.1%	-	-

Table-47: AnaFgas sector sheet for FGR evaluation: Foam PU spray

Foam PU (polyurethane) spray				
considered gases / technologies:		**HFC-365mfc / HFC-245fa**	**HFO-1233zd / HFO-1336mzz**	**H2O**
GWP AR4 of blowing agent	[1]	864.8	4.5	0
product		spray foam, density 60	spray foam, density 60	spray foam, density 60
production facility annual output	m³/a	1 667	1 583	1 944
thermal conductivity	mW/ (m * K)	30	29	35
production facility insulation capacity annual output	m³/ a * ((m * K) / mW))	56	56	56
product density	kg/m³	60	60	60
blowing agent in formulation	pbw	15	15	15
total weight of formulation	pbw	245	245	245
foam product lifetime	years	50	50	50
invest cost for conversion of production line including development	€	-	22 500	22 500
economic lifetime of conversion investment	years	15	15	15
discount rate (societal view / emission reduction cost)	%	4%	4%	4%
blowing agent cost, baseline scenario, average 2015-2019	€/kg	12.6	15.0	0.0
blowing agent cost, counterfactual scenario, average 2015-2019	€/kg	5.7	15.0	0.0
manufacturing emission factor of blowing agent	kg/kg	15%	15%	15%
leakage rate in foam product lifetime, baseline scenario	1/a	1.0%	1.0%	1.0%
leakage rate in foam product lifetime, counterfactual scenario	1/a	1.0%	1.0%	1.0%
recovery rate end of life, baseline scenario	kg/kg	0%	0%	0%
recovery rate end of life, counterfactual scenario	kg/kg	0%	0%	0%
Penetration rate (defined on HFC-based niche of sector), baseline scenario, 2015-2019 average	%	80.8%	18.0%	1.2%
Penetration rate (defined on HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	100.0%	-	-

Table-48: AnaFgas sector sheet for FGR evaluation: Foam PU non-spray

Foam PU (polyurethane) non-spray			
considered gases / technologies:		**HFC-365mfc / HFC-245fa**	**HFO-1233zd / HFO-1336mzz**
GWP AR4 of blowing agent	[1]	864.8	4.5
product		Blockfoam 1 m3, density 60	Blockfoam 1 m3, density 60
production facility annual output	m³/a	10 000	9 500
thermal conductivity	mW/ (m * K)	22	21
production facility insulation capacity annual output	m³/ a * ((m * K) / mW))	455	455
product density	kg/m³	60	60
blowing agent in formulation	pbw	12	14
total weight of formulation	pbw	242	244
foam product lifetime	years	50	50
invest cost for conversion of production line including development	€	-	480 000
economic lifetime of conversion investment	years	15	15
discount rate (societal view / emission reduction cost)	%	4%	4%
blowing agent cost, baseline scenario, average 2015-2019	€/kg	12.6	15.0
blowing agent cost, counterfactual scenario, average 2015-2019	€/kg	5.7	15.0
manufacturing emission factor of blowing agent	kg/kg	15%	15%
leakage rate in foam product lifetime, baseline scenario	1/a	1.0%	1.0%
leakage rate in foam product lifetime, counterfactual scenario	1/a	1.0%	1.0%
recovery rate end of life, baseline scenario	kg/kg	0%	0%
recovery rate end of life, counterfactual scenario	kg/kg	0%	0%
Penetration rate (defined on HFC-based niche of sector), baseline scenario, 2015-2019 average	%	84.0%	16.0%
Penetration rate (defined on HFC-based niche of sector), counterfactual scenario, 2015-2019 average	%	100.0%	-

Assumptions on regional distribution of equipment in F-gas use sectors

Table -49: Regional distribution of equipment stocks EU28 south vs EU 28 north 2015-2019

AnaFgas sector	EU 28 south (35% of population)	EU 28 north (65% of population)
Domestic Refrigeration	35%	65%
Commercial refrigeration - Hermetics	55%	45%
Commercial refrigeration - Condensing units	35%	65%
Commercial refrigeration - Central systems	35%	65%
Industrial refrigeration - small	35%	65%
Industrial refrigeration - large	35%	65%
Transport refrigeration - Vans	35%	65%
Transport refrigeration - Trucks & Trailers	35%	65%
Transport refrigeration - Ships	35%	65%
Room AC - Moveables	60%	40%
Room AC - Single split (includes small multi-split <12 kW & reversible air-to-air heat pumps)	55%	45%
Room AC - Packaged systems (rooftop units), cooling only	65%	35%
Room AC - VRF cooling only (includes Single-split >3kg VRF Multi-Split)	35%	65%
Minichillers	35%	65%
Displacement chillers - small	35%	65%
Displacement chillers - large	35%	65%
Centrifugal chillers	35%	65%
Heat pumps - small (<20 kW, excluding small reversable air/air heat pumps covered in the single split subsector)	35%	65%
Heat pumps - medium (20-200kW)	25%	75%
Heat pumps - large (>200kW, district heating & industrial)	20%	80%
Mobile AC - Passenger cars	35%	65%
Mobile AC - Buses	35%	65%
Mobile AC - Trucks N1	35%	65%
Mobile AC - Trucks N2	35%	65%
Mobile AC - Trucks N3	35%	65%
Mobile AC - Passenger ships	35%	65%
Mobile AC - Cargo ships	35%	65%
Mobile AC - Tram	35%	65%
Mobile AC - Metro	35%	65%
Mobile AC - Train	35%	65%
Aerosols - technical	25%	75%
Aerosols - MDIs	30%	70%
Fire extinguishers	35%	65%
Solvents	15%	85%
Foam OCF (one component foam)	35%	65%
Foam XPS (extruded polystyrene)	35%	65%
Foam PU (polyurethane) spray	35%	65%
Foam PU (polyurethane) non-spray	35%	65%
Switchgear MV	35%	65%
Switchgear HV	35%	65%

Notes: EU 28 south: Bulgaria, Croatia, Cyprus, southern France (25% of FR population), Greece, Italy, Malta, Portugal, Romania, Spain; EU28 North: other EU 28 MS, including 75% of French population

Field research

OPC

An online open public consultation (OPC) is a requirement of the Better Regulation Guidelines. The EU Commission – supported by Ricardo, Öko-Recherche and Öko-Institut – launched an OPC on possible changes to the Regulation. The OPC focussed on the performance of the Regulation to date with respect to its relevance, effectiveness, efficiency, EU added value and internal and external coherence.

The OPC provided an opportunity for all stakeholders to provide views on the current FGR and the impacts of potential FGR amendments, irrespective of the respondents' level of familiarity with the FGR. The OPC was launched on 15 September 2020 and closed 29 December 2020 (midnight CET). The OPC questionnaire was published via the EU Survey platform on the European Commission website and was open to anyone via the online system. It was accessible in all EU languages.

The OPC aimed at gathering views from stakeholders on envisaged future policy options and their likely environmental, economic and social impacts, while also including questions capturing the context of the European Green Deal and recent technological progress, considering these as drivers for further ambition. It offered an opportunity for any interested individual from any type of stakeholder group to give their opinion on the main evaluation questions.

The questionnaire was structured with questions spread across the following four sections: 'About you – Respondent profile', 'Part 1 – Awareness of F-gases', 'Part 2 – General views on the F-gas Regulation', and 'Part 3 - Specialised views on policy options'. The OPC questionnaire included both open and closed ended questions. The OPC began with an introduction to the consultation and an initial set of background questions about the respondent. The core content of the survey posed 29 questions, including 24 multiple choice questions. For 11 of the 24 multiple choice questions, respondents were also asked to elaborate, and could provide further details through an associated open text question. In addition, there were 5 standalone open text questions. Respondents also had the opportunity to upload supporting documents

A total of 241 responses and 44 attachments were provided. Once the OPC finished, the data was downloaded from the EU Commission's consultation platform: 'Have your say'[6]. The results of the OPC are included in the Stakeholder Consultation Synopsis Report. A detailed OPC analysis has been submitted to the EU Commission.

Targeted stakeholder interviews

Targeted interviews were held with Member States authorities, business associations and NGOs.

As for the Member States authorities, the opportunity to contribute to the stakeholder consultation was announced via email in December 2020. In total, 17 Member States authorities and 4 customs authorities confirmed their interest to contribute to the targeted consultation. Participation included:

- Interviews and written response: Member States competent authorities from Austria, Belgium, Bulgaria, Denmark, Estonia, Finland, France, Germany, Italy, Netherlands, Poland, Portugal, Romania, Spain, Sweden. Customs authorities from Belgium and Poland.
- Written response: Member States competent authorities from Czech Republic, Malta. Customs authorities from Bulgaria and the Netherlands.

A questionnaire was sent out in advance of each of the agreed interviews. Some Member States sent back their initial feedback in advance of the interviews. During the interviews notes were taken. The notes were sent back to the Member States for review and potentially complementary information after the interviews.

The targeted interviews with Member State representatives took place in January-March 2021, in some cases further written feedback was received until April 2021.

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[6] https://ec.europa.eu/info/law/better-regulation/have-your-say

As for the stakeholders from business associations and NGOs, the list was established to cover all sectors concerned by the regulation and is shown in the following table.

Table -50 – Targeted stakeholder interviews

#	Entity	Description
1	Shecco (and cool coalition companies)	Manufacturers of non-F gas alternatives; IIA submission; dedicated F gas survey
2	NGOs	NGOs; IIA submission, OPC submission; paper on improvements of May 2018
3	Solvay	F gas manufacturer (some HFCs, SF6); reclaim/destruction facility
4	TEGA	F-gas distributor; reclamation
5	Westfalen Gas	F-gas distributor; reclamation
6	Verico	Verification/reporting
7	EHPA	Industry association: Heat pumps
8	ESIA	Industry association: Semiconductors
9	AREA	Industry association: Focus on training
10	EFCTC	Industry association: Gas producers
11	EUROVENT	Industry association: Ref/AC
12	APPLiA	Industry association: AC
13	EuroCommerce	Industry association: End-user (retail/wholesaler)
14	IPAC	MDIs
15	EPEE	Industry association: Ref/AC
16	EUROFEU	Industry association: Fire protection systems
17	ACEA	Industry association: Cars
18	Food Drink Europe	Industry association: End-user
19	ASERCOM	Industry association: Equipment manufacturer
20	Transfrigoroute	Transport refrigeration

Interviews took place in February and March 2021.

Workshops

A full-day online workshop was held to receive feedback from stakeholders on the findings of the evaluation, envisaged policy options and initial findings of the impact assessment. The workshop took place as a virtual event on 6 May 2021 and was attended by 355 participants. The participants were primarily industry stakeholders representing relevant business organisations and associations, with participants also including NGO's and representatives from public authorities.

The key objectives of the workshop were:

- Provide the main findings from the study to support the evaluation of the Regulation;
- Present the objectives for the revision of the Regulation and envisaged policy options;
- Present the approach to assess the impacts of envisaged policy options for amending the Regulation;
- Provide the preliminary findings of assessing the environmental, economic and social impacts of envisaged policy options;
- Present existing data gaps and ask for further input on specific aspects.

The workshop began with a keynote speech by the Deputy General Director Clara outlining the importance of the review of the F-gas Regulation in the context of the European Green Deal. Following the introductory speech an overview of the project was given, including the approach to the evaluation, the project scope, and progress to date.

Following this, the workshop then provided the project team the opportunity to present the preliminary results of the evaluation, focussing on the findings for the effectiveness, efficiency, relevance, coherence and EU added value for the Regulation. The project team then provided an overview of the policy options analysed in the study supporting the impact assessment, including how the policies were identified and their envisaged objectives. The remainder of the workshop focussed on the modelling approach taken and presentation of the different scenarios, before a presentation of the preliminary findings regarding the assessment of impacts.

The workshop concluded with an explanation of the data needs still required by the project team in order to complete both the evaluation and impact assessment. Participants were provided two and a half weeks to provide additional feedback (to 24th May) with 69 participants subsequently providing further feedback.

Limitations of the study

A summary of key limitations and gaps is in the following table, including implications for the work.

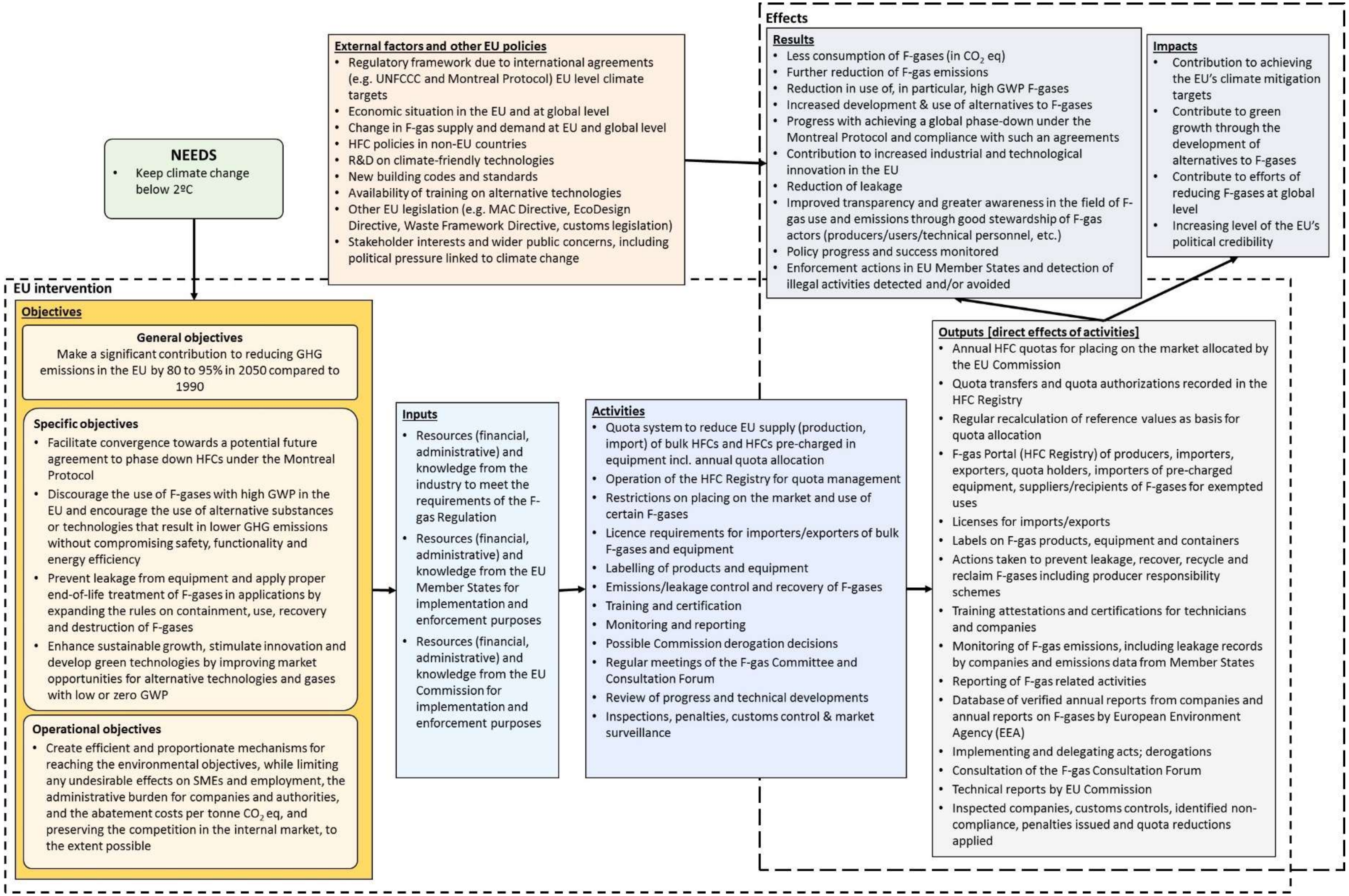
Table -51: Limitations of the current study

Limitation/ gap	What could be / has been done to address these	Implications for the evaluation
For the evaluation of the **effectiveness of prohibitions**: Reporting data for POM restrictions only covers imports and does not provide a precise sector split. Reporting data for POM restrictions only goes to 2019, so one cannot judge the impact of prohibitions which fall after this date.	Import data has been used as a proxy for compliance of whole market. Complemented by stakeholder feedback	Low
Model input data: Representation of model sectors by single model installation size & generalised expert judgement assumptions for parameters affecting cost	Breakup of model structure into several sizes where appropriate. Extensive desk research and consultation with industry experts on appropriate assumptions. Extensive plausibility checks on calculated cost results Complemented by stakeholder feedback	medium
Labelling: No comprehensive data is available on labelling compliance. Only a few indications were provided by MS authorities through stakeholder interview.	Evidence and sentiment gathered from stakeholders regarding the effectiveness of Article 12, the overall compliance and key associated issues. Key issue raised was interaction with illegal logging and mis-labelling, rather than compliance with Article 12 directly.	Low
Recycling, Reclamation: Reporting data for recycling and reclamation only exists for importers, producers and exporters, hence the data is not complete, as only undertakings which are also importers of F-gases currently need to report, but not facilities performing recycling and reclamation only.	Reporting data available for recycling cannot be assumed to give an indication on actual market activities. However, data available for reclamation appears to be more complete. Thus, data available for reclamation has been used as a signal for the whole market. Although not complete, this gives a sense of trend (and scale) upon which a judgement can be made	Low
Compliance with the leak checking requirements under Article 4 and Article 5	Data from technical literature are assessed and corroborated against stakeholder feedback. Two national databases have been accessed, analysed and included in the analysis (Germany and Poland)	Low

Limitation/ gap	What could be / has been done to address these	Implications for the evaluation
Existing national databases for mandatory reporting are often not publicly available (e.g. Poland) or even confidential (e.g. Italy, Hungary) and/or limited to sample datasets (e.g. Slovakia).	and are deemed to present a reasonable representation of the EU as a whole.	
No consistent data set tracking leakage rates pre and post implementation for the entire EU are available. Assessments of electronic databases established in some Member States are mostly not covering the years before 2014.	Data from national databases on available years were used.	Low
Illegal imports: It is not feasible to make an accurate estimate of the level of illegal imports. Illegal activities are usually not captured by official statistics	Some studies highlight case studies of illegal activities and have sought to quantify some components. EC has made a study on this issue. Furthermore, stakeholder engagement has provided further examples of illegal activity and a sense of how significant this issue is. On this basis, it is clear that illegal trade is a key issue which should be addressed as part of the IA.	Low
the analysis of economic effects is based on simplistic modelling.	Simple analysis of trade flows, production and employment in the most relevant F-gas related sectors was used a proxy for the rest of the market. This was complemented with sentiment from stakeholder engagement, in particular paying attention to any issues raised. it is unlikely that any significant impacts were missed and would not have impacted on the overall conclusions drawn around efficiency, which are predominantly driven by the key mitigation and administrative costs which are accurately determined. In addition, the time frame looked at was relatively short (2015-2019). Effects at macroeconomic level are bound to be small, as only a few sectors are concerned.	Low
Not possible to split costs by business size, MS or measure with high degree of confidence.	Questions were included in stakeholder engagement to try and illicit any evidence and/or identify any issues. Hence although no detailed data was obtained, no issues were raised regarding unequitable split of costs by business size, MS or measure. For administrative burdens, cost data collected was predominantly provided by larger firms through the stakeholder engagement. As a proxy, in order to group firms, two key sources have been used dependent upon the measure assessed. For some measures, firms have been grouped by size based upon the used to group firms in the EEA reporting database, with smaller costs applied to both medium and small companies. Other measures have grouped firms according to ratios established through a recent German industry sur-vey (2019, VDKF) of service companies, with company sized based upon the number of employees in those firms. For some measures, it is expected that the cost to companies will remain consistent irrespective of the size of the firm.	Low
There is no published data or studies analysing the administrative burden placed	Evidence from stakeholders was used where possible. A useful level of evidence was available with	Low – administrative burdens

Limitation/ gap	What could be / has been done to address these	Implications for the evaluation
on different stakeholders by the Regulation. To close this gap, data was requested from stakeholders over the course of the study. However, the database remained limited in places, in particular in the estimation of costs to industry, both due to limitations in evidence available around he costs per undertaking, and the number of undertakings affected.	respect to the costs for public authorities (Competent Authorities, DG CLIMA, EEA). For other costs, expert judgement was used to formulate quantitative estimates. These were subject to sensitivity analysis to identify the key costs and assumptions underpinning them. The cost estimates were reviewed and discussed with DG CLIMA.	are a smaller cost, relative to the compliance costs

Annex 2 – Intervention Logic



Annex 3 - Evaluation matrix

Effectiveness

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
EFFECTIVENESS				
1. To what extent have the objectives of the Regulation been met? To what extent can the observed effects be attributed to the F-gas Regulation and its individual elements?				
1a. To what extent have the 'HFC Phase down' and 'Pacing on market and control of use' requirements discouraged the use of F-gases and encouraged use of alternatives?				
(i). What has been the combined effect?	• Reduction in use of F-gases relative to the baseline • Increase in use of alternatives to F-gases relative to the baseline	• Quantity of F-gases that are supplied (EEA definition), placed on the market, and reclaimed • Quantity of F-gases calculated by sector, to assess the contributions or shortfalls of the sectors to the HFC phase-down • Levels of avoided F-gas use over evaluation period • Quantity of F-gas alternatives used, split by sector	• Analysis of F-gas use in the different sectors (especially RAC&HP) • Results of quantitative analysis of the reported quota use, split by sector • Comparison of use of F-gases and alternatives to baseline • Analysis of quotas system, price developments and illicit activities	• AnaFgas model • Datasets from F-gas portal (availability needs to be clarified) • EU NIR data on F-gas emissions reported under UNFCCC • Modelling results obtained from Task 1 • Literature review (e.g. indications of illegal HFC trade, EEA data on emissions and supply of F-gases in Europe) • Stakeholder consultation (interviews, survey(s), workshop)
(ii). To what extent have the 'Placing on market and control of use' requirements (Articles 11-13) discouraged the use	• All affected stakeholders (i.e. public authorities, producers/importers/exporters/suppliers of F-gases, importers/manufacturers of equipment, service technicians, equipment operators) were able to meet the requirements of Art. 11-13	• Quantity of substances listed in Annex I and II that are: supplied (EEA definition), placed on the market • Continued sale of products and equipment listed in Annex III	• Analysis of F-gas use in the relevant sectors • Comparison of use of F-gases and alternatives to baseline • Exploit previous analysis on technology development (OR, 2018)	• AnaFgas model • Datasets from Business Data Repository (BDR) • EU NIR data on F-gas emissions reported under UNFCCC

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
of F-gases and encouraged use of alternatives?	• Companies have complied with restrictions regarding placing on market and labelling • Reduction in use of F-gases relative to the baseline in relevant (sub-)sectors • Increase in use of alternatives relative to the baseline in relevant (sub-)sectors • No reports of non-compliance with labelling requirements or prohibitions	• Quantity calculated by sector of use, to assess whether certain sectors are falling behind and vice versa • Levels of avoided use over evaluation period • Quantity of alternatives used, split by sector • Market developments • Usefulness of Labelling requirements	• Analysis of stakeholder views and reporting of issues around labelling	• Modelling results obtained from Task 1 • Literature review (e.g. EEA data on emissions and supply of F-gases in Europe, national studies performed in certain EU Member States) • Stakeholder consultation (interviews, survey(s), workshop) • Technology development study (OR, 2018)
(iii). To what extent have the 'HFC phase down' requirements (Articles 14-18) discouraged the use of F-gases and encouraged use of alternatives?	• All affected stakeholders (i.e. public authorities, producers/importers/exporters/suppliers of F-gases, importers/manufacturers of equipment) were able to meet the requirements of Art. 14-18 • Quota system was respected e.g. Companies had sufficient quota for POM (e.g. balance between placing on the market of HFCs and related quotas at EU level) • Reduction in use of HFCs relative to the baseline • Increase in use of alternatives to HFCs relative to the baseline	• Quantity of HFCs that are supplied (EEA definition), placed on the market, and reclaimed • Quantity of HFCs calculated by sector, to assess the contributions or shortfalls of the sectors to the HFC phase-down • Levels of avoided HFC use over evaluation period • Quantity of HFC alternatives used, split by sector • Market developments (HFC availability and alternatives) • Number of participating companies • Illegal activities	• Mapping of market actors and quotas allocated • Analysis of HFC use in the different sectors (especially RAC&HP) • Results of quantitative analysis of the reported quota use, split by sector • Comparison of use of HFCs and alternatives to baseline • Analysis of quotas system, price developments and illicit activities	• AnaFgas model • Datasets from F-gas portal (availability needs to be clarified) • EU NIR data on F-gas emissions reported under UNFCCC • Modelling results obtained from Task 1 • Literature review (e.g. indications of illegal HFC trade, EEA data on emissions and supply of F-gases in Europe) • Stakeholder consultation (interviews, survey(s), workshop) • HFC price monitoring survey

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
				• Technology development study • Quota system evaluation study • Illegal trade study
1b. How effective has the F-gas Regulation been in preventing leakages of F-gases (Articles 3-8 and 10)?	• All affected stakeholders (i.e. equipment operators, service technicians) were able to meet the requirements of Art. 3-8 and 10 • Reduction in the levels of leakages of F-gas emissions in the different sectors • Reduction in the levels of leakages of F-gas emissions relative to the baseline • Company recording is compliant with the provisions, including frequency of leak checking is sufficient • Availability of certification programmes and trainings that cover containment measures • Sufficient number of natural and legal persons holding certificates/attestations (by EU Member States and sectors) that allow them to carry out activities requiring certification	• Levels of F-gas leakage and emission, development of leakage rates since the F-gas Regulation entered into force, expectations/experts estimate for future periods • Leak checking requirements being complied with • Relevance of emissions from production/transport/storage and by-production & compliance with rules • Company recording of leak checks (logbooks) available according to Article 4 (3) and Article 5 (3) and (4) of the F-gas Regulation, where possible • Number of natural and legal persons trained and certified since the F-gas Regulation entered into force Relevance of emissions at end-of-life and afterlife and compliance with rules	• Analysis of F-gas leakage levels, and relative to the baseline from Task 1 • Qualitative and/quantitative evidence from stakeholders on records of leak checks and maintenance activities, including e.g. refill of the equipment • Quantitative analysis of EU Member State actions related to training on the prevention of F-gas leakages • Qualitative information on leakages from P/T/S and by production • Qualitative/ quantitative analysis of EU Member States related to end-of-life and afterlife	• AnaF-gas model • Datasets from F-gas portal (availability needs to be clarified) • EU NIR data on F-gas emissions reported under UNFCCC • Modelling results obtained from Task 1 • Literature review (e.g. national reports and/or databases on leakage and leak reductions) • Stakeholder consultation (interviews, survey(s), workshop) • EU Member State training and certification records • EU Member State end-of-life and afterlife records
1c. How effective have the reporting and verification obligations (Articles 19-20) and the F-gas	• All relevant companies are registered and report within the required deadlines	• Reporting levels and frequency for companies under Article 19 • Smoothness of reporting/verification processes	• Evidence around reporting on production, import and export • Review of EU Member State activities related to Article 20	• Datasets from F-gas portal/BDR • NL study on verification

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
Consultation Forum (Article 23) been in supporting the achievement of the objectives of the F-gas Regulation?	• No/limited problems identified with the reporting and electronic verification procedures • No/limited gaps in the level of information • Reporting requirements provide sufficient information to inform policy making • Reporting requirements provide sufficient information to help assess quota compliance • Reporting requirements provide sufficient information for international compliance • No/limited problems identified with the national-level reporting procedures Consultation Forum on F-gases is an effective means of providing advice and expertise to the EU COM	• Usefulness of verification • Usefulness for policy making, reporting to MP, quota compliance • Implementation of Article 20 covering EU Member State national reporting systems for emissions • Experience of the F-gas Consultation Forum –considering the types of information relayed, regularity of meetings, breadth of stakeholder representatives, information dissemination from the forum to other stakeholders • Feedback from EU COM and participants related to the Forum	• Qualitative analysis of the functioning of the F-gas Consultation Forum	• Review of minutes from the F-gas Consultation Forum • Stakeholder consultation (interviews, survey(s), workshop), especially EEA
1d. To what extent have Member State actions contributed to the achievement of the objectives? (covering Articles 9 and 25)	• Producer responsibility schemes have been introduced and are effectively contributing to the objective of enhancing recovery, recycling, reclamation, and destruction of F-gases • National measures, where introduced, complement the EU F-gas Regulation (e.g. F-gas tax, prohibitions, green public procurement, additional reporting obligations, funding to support the market uptake of alternatives, etc.) • Enforcement action is consequently taken for non-compliance • National penalties applicable to infringements of the F-gas Regulation are effective, proportionate, and dissuasive	• EU Member State actions taken to develop/enhance producer responsibility schemes • Number of EU Member States that have introduced additional or more stringent measures • Number and type of enforcement actions taken by EU Member States (inspections, penalties, customs control, and market surveillance) • Actions by EU Member States to disseminate information on the F-gas Regulation to raise industry awareness	• Quantitative analysis of Member State actions –certification, producer responsibility schemes • Analysis of the performance of enforcement procedures, reviewing processes in place • Qualitative analysis of industry / EU Member State initiatives for awareness raising, e.g. looking at geographical coverage, sectors addressed, accessibility in different languages	• Datasets from competent authorities of EU Member States • Review of literature, national studies • Stakeholder consultation (interviews, survey(s), workshop)

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
1e. How effective has the F-gas Regulation been to enhance sustainable growth, stimulate innovation and develop green technologies by improving market opportunities for alternative technologies and gases with low or zero GWP?	• R&D investment has increased • Energy efficiency of products and equipment has increased • Frequency of new alternatives / numbers of patents logged coming to market has increased • Take up of new alternatives is higher than under the baseline • No evidence that the F-gas Regulation has prevented innovation activity which could have led to further improvements against the objectives	• Energy intensity per unit of economic output for F-gas sectors • R&D investment in alternatives • Number of new alternatives • Number of patents filed for new alternatives or in F-gas sectors • Penetration rates of new technology	• Quantitative analysis of energy efficiency relative to economic output • Quantitative assessment of uptake of alternatives linked to Task 1 • Quantitative (where possible) analysis of R&D spent and patents lodged • Otherwise, analysis will be complemented by views of stakeholders	• Eurostat – R&D investment • European Patent Office data - patents • Stakeholder consultation (industry, civil society NGOs, academics/experts, Member State competent authorities, EU Commission) Technology assessment, market survey, technical publications, national reports on F-gas alternatives and their market uptake in the EU in recent years and forecast • AnaFgas model
1f. How far has the F-gas Regulation facilitated convergence towards a potential future international agreement?	• Evidence of convergence / progress, and political achievements at international level since the F-gas Regulation was put in place • F-gas Regulation and EU action is internationally recognized as having an important role in pushing forward international agreement	• Convergence and progress towards the agreement on the Kigali Amendment in 2016 • EU's role in the negotiations in the framework of the Montreal Protocol	• Review and analysis of negotiation developments prior to the Kigali Amendment •	• Literature review (reports, bulletins) related to Kigali Amendment • Stakeholder survey/interviews (especially EU Member State authorities, NGOs, international organisations)
4. What factors have contributed to or hindered the achievement of the objectives of the F-gas Regulation? What have been the unintended/unexpected effects?				
4a. What internal factors have contributed to the success or not of the F-gas Regulation?	• No significant issues / challenges identified that have had a tangible impact on the success of the F-gas Regulation • Where issues have been identified, action at EU or EU Member State level has been	• Issues and challenges associated with the F-gas Regulation (e.g. illegal trade, misuse of quota system, lack of enforcement) are a result of lack of (clarity of) legal text	• Qualitative analysis of reports on the implementation of the F-gas Regulation • Review of implementing acts • Analysis of stakeholder opinion	• Literature review • Legislation on F-gases • Stakeholder consultation (industry, civil society,

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
	taken (e.g. legislative acts issued to provide more detailed rules on measures in the F-gas Regulation)	• Significance (including scale and consequences) of issues and affected stakeholders • Response of EU Commission where issues identified • Effective measures under the F-gas Regulation to address the issues identified		NGOs, academics/experts, EU Member State competent authorities, EU Commission, other authorities (e.g. customs))
4b. What external factors have contributed to the success or not of the F-gas Regulation?	• No significant issues / challenges identified that have had a tangible negative impact on the success of the F-gas Regulation • Where issues have been identified, action at EU level has been taken where possible	• Issues and challenges presented that are not directly associated with the F-gas Regulation (e.g. impact of international agreements, macroeconomic context, EU political context, changes in building codes and safety standards, lack of awareness, lack of alternatives, lack of training etc.)	• Qualitative analysis of reports on the implementation of the F-gas Regulation • Review of implementing acts • Analysis of stakeholder opinion	• Literature review • Legislation on F-gases • Stakeholder consultation (industry, civil society, NGOs, academics/experts, EU Member State competent authorities, EU Commission, other authorities (e.g. customs))
4c. Have there been any unintended/unexpected effects of the intervention, including on trade of F-gases?	• No significant unexpected effects have occurred that have had a tangible negative impact on the success of the F-gas Regulation • Where issues have been identified, action at EU or EU Member State level has been taken where possible	• Effects not anticipated in the 2012 Impact Assessment for the review of Regulation (EC) No 842/2006 on certain F-gases. These effects could include impacts on: – EU competitiveness – Trade flows/illegal trade activities (e.g. trade of non-refillable F-gas containers, import of F-gases (bulk and in equipment and changes in trends between the two) not covered by quota/authorisations) – Emissions of F-gas alternatives – Shift from HFCs to PFCs	• Modelling of emissions of alternatives from Task 1 • Analysis of trade flows of F-gases • Analysis of FGR reporting data • Review of reports looking at effects of F-gas alternatives • Review of implementing acts • Qualitative analysis of reports on the implementation of the F-Gas Regulation • Collation of stakeholder views, in particular around competitiveness of industry and impacts of alternatives • Analysis of price trends to see how prices of HFCs have developed and incentivized	• Literature review • Trade statistics • Stakeholder consultation (industry, civil society, NGOs, academics/experts, EU Member State competent authorities, EU Commission, other authorities (e.g. customs)) • Previous analysis • HFC price monitoring survey

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
		– Toxicity associated with alternatives – Numbers of companies (strong increase in market players) – Number of illegitimate market players – Price trends	the switch to alternatives, while also looking at underlying market factors	

Efficiency

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/data collection methods
EFFICIENCY / COSTS AND BENEFITS				
3. What have been the benefits of the F-gas Regulation?				
3a. What environmental benefits has the F-gas Regulation delivered?	• Reduction of emissions from F-gases • Future GHG emission savings (and energy savings) associated with actions/activities • Increased energy savings (energy efficiency) or energy use associated with the F-gas Regulation	• Direct GHG emissions (emissions of F-gases, weighted with GWPs of the IPCC's AR4 and AR5 reports) • Energy efficiency of standard equipment (of the counterfactual scenario) and of installed substitution equipment • Energy consumption	• For GHG emissions: apply Task 1 modelling framework • Comparison of direct GHG emissions in the counterfactual and baseline scenarios • Energy efficiency: compare energy efficiency of example installations	• AnaFgas model • GHG emissions: use Task 1 modelling results; UNFCCC GHG reporting data • Energy efficiency: use results of subtask 1.2 • Market surveys on energy efficient products and installations (Topten statistics ranking of energy efficient consumer products and on how the energy efficiency changed over time, Chilling facts report assessing supermarket chains on their RAC installations etc)
3b. What economic benefits has the F-gas Regulation delivered?	• Increased levels of investment in R&D of alternative technologies • Increased number and market penetration of new alternatives/products relative to baseline • increased investment costs in new equipment is higher value added for the manufacturer.	• Levels of investment in R&D • Range of new alternatives / products • Market share of companies with alternative products	• Use the modelling framework developed in Task 1 (technology-specific cost data and stock models) to identify uptake of alternatives • link to questions on effectiveness around levels of innovation and price data	• AnaFgas model • Literature review and stakeholder consultation
3c. What social benefits (health and safety) has the F-gas Regulation delivered?	• Minimum requirements for training and certification implemented • Availability of training programmes • Sufficient number of technicians trained	• National systems for training and certification, availability of training programmes • Employment	• Qualitative analysis of stakeholder input and case studies	• Literature review and stakeholder consultation

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/data collection methods
	• F-gas Regulation has supported sustainable employment			
4. What have been the costs of the F-gas Regulation?				
4a. What has been the change in operative and other costs to businesses of undertakings? How are these costs split by sector and EU Member State?	• Costs are reasonable and proportionate to the benefits	• Average (over equipment lifetime) annual operating cost including the respective annualised share of the investment. • Split of costs by sector (i.e. technical application sectors as used in the AnaFGas) • Split of costs by business size (SMEs and other) • Split of costs by MS	• Use the modelling framework developed in Task 1 (technology-specific cost data and stock models) to derive demand reduction cost curves in combination with the BAU and policy option scenarios • Split by business size is challenging. Define and apply assumptions on SME among operators in different sectors (e.g. using outputs of OPC) • Split by MS also challenging. Define qualitative/semi-quantitative approach considering regional distribution as in 2011 Impact Assessment	• AnaFgas model • For cost per installation: use results of subtask 1.2 • For total cost: use Task 1 modelling results • Stakeholder consultation

4b. Which administrative costs have been incurred by companies?	• Administrative costs are reasonable and proportionate to the benefits	• Administrative cost for different types of businesses (operators, importers)
		  ○ By type of undertaking
		  ○ Split of costs by business size (SMEs and other)
		  ○ Split of costs by MS
		• Admin costs to MS
		• Admin costs to EC and agencies
			• Use of standard cost model	• Informed by literature review and stakeholder engagement

4c. What have the environmental costs of the F-gas Regulation been?	• Adverse environmental effects are negligible	• Substance classifications shall be checked on the basis of the ECHA Table of harmonized entries in Annex VI to Regulation (EC) No 1272/2008 (CLP) and on the basis	• Adverse environmental effects (e.g. toxicity and persistence) of alternatives in sectors where F-gases were banned/replaced substitutes shall be screened to determine if they have properties that	• ECHA Table of harmonized entries in Annex VI to Regulation (EC) No 1272/2008 (CLP): https://echa.europa.eu/information-on-chemicals/annex-vi-to-clp

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/data collection methods
		of the ECHA data base for substance information. • Negative effects on energy use, if any	could lead to negative impacts in case of emissions. • Classifications with potential to lead to adverse impacts on the environment (highest risk categories for aqua-toxicity, persistence, bioaccumulation, endocrine disruptive, etc.) shall lead to the classification of a substitute as having a potential to impact environmental toxicity. • On a qualitative basis it shall be considered whether the application in the specific sector could potentially lead to emissions or if risks are controlled. • If risks are not controlled indication shall be given whether the potential for risks is considered high/moderate/low based on the potential for emissions and the expected market volumes of the substitute in question.	• ECHA database for substance information: https://echa.europa.eu/information-on-chemicals/cl-inventory-database • ECHA substance information system: http://echa.europa.eu/information; • Literature on adverse environmental impacts of alternatives (e.g. UNEP TEAP reports, national studies etc.)
4d. Have there been any other (indirect) economic costs?	• Does the operational cost of equipment using F-gases or substitutes have a significant impact on prices of consumer products? • Higher costs to end users • Higher costs in income for green companies • Reduction in domestic production and value in one sector is offset by increases in another • No deterioration in trade balance with non-EU countries	• Proportion of operational cost of equipment using F-gases or substitutes in the value chain for consumer products (like refrigerated goods) • Magnitude of difference in domestic production and value added including structural shifts between sectors • Ratio of EU production vs imports and exports • Ability of legitimate companies to sell what they should	• Assess whether the F-gas Regulation resulted in a change in F-gas use in supply chains for consumer products which could have a significant price effect. • If so, estimate the potential quantity of these products, and the business costs that undertakings are likely to pass on to consumers, and the elasticity of demand for these products as a result of price increases • In case of significant deviation between scenarios in terms of sectoral investment and operating costs, apply EmIO-	• Use Task 1 modelling results • For HFC prices; use data from quarterly price surveys carried out by Öko-Recherche • EEA F-gases reports and UN Comtrade database • JRC model

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/data collection methods
	• Legitimate companies are able to sell what they should and are not prevented from doing so by multiple registrations of illegitimate companies		F Europe model operated by Öko-Institut • Macroeconomic modelling with JRC • Use of statistical data	
4e. What have the social costs of the F-gas Regulation been?	• Reduction in employment is minimized	• Changes in employment associated with structural shifts	• For investment and operating costs: apply Task 1 modelling framework • Magnitude of difference between scenarios in investments and operating cost including structural shifts between sectors, multiplied by sectoral employment coefficient • Derive employment coefficients from Eurostat employment and input-output statistics • In case of significant deviation between scenarios, apply *EmIO-F Europe* model operated by Öko-Institut	• For investment and operating costs: use Task 1 modelling results • Employment data from Eurostat National Accounts • For *EmIO-F Europe* model application: Update model to use latest available Eurostat Input-Output Tables
1. To what extent have the costs been proportionate to the benefits?	• Achievement of commitments is cost effective – i.e. costs are minimised (including qualitative impacts) • Additional benefits are delivered • Abatement costs are below €50	• Cost effectiveness of achievement of international commitments • Qualitative impacts • Abatement costs	• Combine outputs of questions 5 and 6 • Abatement costs in different sectors	• Questions 5 and 6 • AnaFgas model
2. Are there any unnecessarily complicated or burdensome aspects and areas of excessive costs? What are the reasons and magnitude of any identified inefficiencies?	• Cost of individual measures are considered proportionate to the benefits achieved	• Presence of measures with high administrative burden (e.g. multiple registration of illegitimate companies, verification for SMEs for PCE)	• Identification of measures with high administrative burden • Estimate of cost savings associated with potential alternative options • Stakeholder views on cost-effectiveness of different measures and areas for refinement	• Stakeholder consultation • Question 6

Relevance

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/data collection methods
RELEVANCE				
7. To what extent do the objectives of the F-gas Regulation continue to reflect and respond to the needs of the EU?				
7a. Does the problem persist?	• F-gases are GHGs with high GWP • F-gases continue to be emitted in the EU	• GWP of F-gases • Climate change impacts and level of risk associated with identified F-gases • F-gas emissions in the EU	• Analysis of these indicators will demonstrate the extent to which F-gases are still widely emitted despite the entry into force of the F-gas Regulation	• Analysis of data from F-gas emission reporting to UNFCCC • AnaFgas model
7b. Does the F-gas Regulation cover all relevant F-gases, sectors and sub-sectors that use F-gases, as well as all actors in the F-gas supply and use chain?	• F-gases covered by the Regulation and sectors and sub-sectors using them are still relevant today • The scope of the F-gas Regulation covers all relevant actors in the F-gas supply and use chain • Data on F-gas EU supply is known and where these quantities are used • The scope of reduction measures (placing on the market and use bans, phase-down) covers all relevant F-gases • The requirements for production, containment, certification, recovery, and labelling are applicable to all relevant actors in sectors and sub-sectors that produce, sell, or use F-gases as well as all relevant actors in the F-gas supply and use chain	• Sectors and sub-sectors that produce, sell, and use F-gases • Actors who are involved in F-gas supply and use chain (producers, importers, exporters, distributors, users, etc.) • Current market statistics for EU F-gas quantities and F-gas containing equipment, split by sector and sub-sector • Number and type of reporting companies • Sectors using F-gases covered by the different measures (HFC phase-down and quota system, placing on the market and restrictions, containment, certification, etc.) and relevant actors	• Analysis of these indicators will demonstrate which sectors and sub-sectors are important and if relevant sub-sectors or applications are missing • Analysis of these indicators will demonstrate which actors in the F-gas supply and use chain are important and if relevant actors are missing • Analysis will show how different measures apply to different sectors and sub-sectors • Analysis will show the initial and ongoing issues to address the specific sectoral and sub-sectoral needs	• Literature review e.g. annual EEA F-gas reports, sector-specific publications • Literature analysis on F-gas Regulation's rationale for intervention and the formulation of EU policy needs • Triangulation of formulation of objectives with formulation of needs and rationale • Stakeholder survey/interviews • AnaFgas model

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/data collection methods
7c. Does the F-gas Regulation continue to sufficiently contribute to EU climate change goals (also with view to the ambition raising as part of the EU Green Deal)?	• The supply, use and emission quantities of F-gases in the EU are known • The requirements for HFC phase-down, containment, use and placing on the market restrictions, certification, recovery, and labelling, etc. are strict enough to reduce F-gas emissions in line with EU climate change goals to 2050	• EU climate change goals (and interpretation of what this means for F-gases), considering 2012 climate objectives and new objectives set in the EU Green Deal (2050 trajectory developed in line with the Climate Law) • Current market statistics for F-gas use and emissions • F-gas emissions annually reported to UNFCCC and forecast to 2050	• Qualitative analysis using input from literature and stakeholders (public authorities, industry, NGOs, research institutions, public/citizens) • Quantitative analysis by using (inventory) reports and statistics • Modelling of F-gas production, demand, and emissions in the AnaFgas model	• Literature review (e.g. annual EEA F-gas reports, EU GHG inventory report to UNFCCC) • Stakeholder survey/interviews (EU Member State authorities, industry, civil society, NGOs, academics/experts) • AnaFgas model
7d. Does the F-gas Regulation sufficiently safeguard compliance with international commitments related to the Montreal Protocol (Kigali Amendment)?	• The production, import, export, and use quantities of HFCs in the EU are known from licensing and reporting systems in place • Company reporting under the FGR provides the means to collect data needed for MP reporting. • Registration obligation under the FGR meets requirements of licensing system needed under the MP • Measures to reduce HFCs are restrictive enough to keep the EU HFC consumption and production in line with the EU's requirements under the Montreal Protocol	• F-gas production (reported data, expert estimates) and consumption (market statistics) • Reporting • HFC license system • HFCs reduction schedule applying to the EU as Non-A5 country/region under the Kigali Amendment to the Montreal Protocol	• Qualitative analysis by using input from literature and stakeholders (public authorities, industry, NGOs, research institutions, public/citizens) • Quantitative analysis by using (inventory) reports and statistics, modelling of future EU HFC market	• Literature review (e.g. annual EEA F-gas reports) • Stakeholder survey/interviews (EU Member State authorities, industry, civil society, NGOs, academics/experts) • AnaFgas model
8. Has the F-gas Regulation been flexible enough to respond to new or emerging is-	• Technically and economically feasible alternatives with a lower GWP that have entered the EU market since the F-gas Regulation entered into force	• Market penetration of alternatives since the adoption of the F-gas Regulation in 2015 in the different sectors and sub-sectors	• Review literature evidence and interview experts which highlight the availability of alternatives	• Literature review • Review of relevant reports, e.g. EU COM report on barriers posed by

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/data collection methods
sues, such as technological or scientific advances or other changes?	• F-gas Regulation contains sufficient provisions to allow the EU to quickly adjust to issues and adopt changes • Applications for derogations/exemptions from existing provisions, if any	• Type and number of new alternatives in the different sectors and sub-sectors and their current market penetration (as of 2020) • Emergence of new issues (e.g. safety standards, gas shortages, illegal trade) • Ability for new advancements to contribute to meeting the needs • Coverage and provisions of the Regulation	• Review literature and gather stakeholder opinion on issues that have arisen, and response • Review of provisions, and gather stakeholder views (in particular EU COM and EU Member States ability to respond quickly to emerging issues) • This will link strongly to the analysis of the 'effectiveness' of the F-gas Regulation, in particular around the objective to stimulate innovation	codes, standards and legislation concerning the use of climate-friendly technologies in RAC&HP and foam sectors; expert reports • Stakeholder survey/interviews (EU Member State authorities, industry, civil society, NGOs, academics/experts) • Webinars, product presentations, trade fairs to the extent possible • Analysis of effectiveness questions

Coherence

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
COHERENCE				
9. To what extent is the F-gas Regulation externally consistent and coherent, i.e. with other interventions which have similar objectives?	• Stakeholders view the F-gas Regulation as coherent and consistent with other EU/international policies • Synergies are harnessed • Possible inconsistencies have been avoided / mitigated	• Whether the F-gas Regulation is coherent with international F-gas and climate policies (Montreal Protocol/Kigali Amendment, Paris Climate Agreement, bilateral trade agreements), e.g. need to clarify 'R23 by-production in line with MP reporting requirements' • Whether the F-gas Regulation is coherent with other EU policies (including EU Climate law, ODS Regulation, MAC Directive, Ecodesign Directive, WEEE Directive, IED, customs legislation, REACH) • Consistency of definitions and requirements (e.g. thresholds, exemptions) • Overlaps, Contradictions, Gaps, and needs for clarification	• Qualitative assessment comparing the F-gas Regulation and other EU environmental and wider EU policies/international conventions	• Desk research • Relevant legislative acts • Stakeholder consultation (interviews, survey(s), workshop), especially with EU COM and EU Member State authorities
10. To what extent is the F-gas Regulation internally consistent and coherent, in particular across its implementing acts? How well do the different provisions of the F-gas Regulation operate together to achieve its objectives?	• Stakeholders view the F-gas Regulation and related implementing acts as internally coherent • Provisions and their detailing have contributed to achieving the objectives of the F-gas Regulation • No provisions/requirements unnecessary, unclear, or contradictory	• Clarity of provisions / ambiguity • Contradictions, Gaps, Overlaps • Unintended consequences	• Qualitative discussion on whether the provisions are all working together, and the F-gas Regulation is delivered in a coherent and simple manner • Qualitative assessment whether the F-gas Regulation has diverged from the original intention • Review of legal proceedings and guidance that would hint to lack of clarity or coherence and critical review of the F-gas Regulation and its implementing acts	• Stakeholder consultation (interviews, survey(s), workshop), especially the with EU and EU Member State authorities • Literature review of objectives and requirements of the recast 2014 Regulation and the 2006 F-gas Regulation

EU added value

Sub-questions	Success criteria	Indicators	Data analysis approach	Data sources/Data collection methods
EU ADDED VALUE				
11. To what degree has the F-gas Regulation enabled successful and cost-effective EU action regarding the reduction of F-gases beyond what would have been possible at national level?	• EU action has: ○ Created a level playing field for industry across the EU ○ Created/captured synergies ○ Facilitated compliance with international requirements ○ Facilitated coherence with other EU/international policies ○ Avoided overlaps ○ Led to cost savings compared to MS approach ○ Allowed for higher environmental ambition	• Degree of uptake of leak checks and reporting • Reductions in F-gas supply • Reduction in leakage rates • Rate of adoption of alternatives • Compliance with international requirements • Facilitation of innovation • Ease and costs of implementation (overall and for individual EU Member States)	• Assessing the likely degree of achievements without the EU-wide policy (e.g. F-gas reductions, reporting, availability of alternatives, …) • Triangulation with analysis on effectiveness of specific actions from the F-gas Regulation that could unlikely have been achieved by individual EU Member State action • Qualitative discussion on synergies and overlaps • Qualitative assessment of implementation in EU Member States and consideration of available resources • Semi-quantitative approach to assessing the costs of MS-level actions	• Outputs from question 3 and 5 on reduction in F-gas emissions to the baseline • Relevance / effectiveness / efficiency questions will answer these questions • Stakeholder consultation, particularly with officials of the EU Commission and EU Member State competent authorities across thematic areas • Literature review, e.g. cumulative costs assessments, impact assessments and evaluations of other community legislation

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Annex 5 - Consultation synopsis

Provided as a separate document.

Annex 6 – Summary slide-deck

Developed for the workshop and provided as separate document.

Annex 7 – Detailed tables on scope of F-gas Regulation

Table -52 Overview of placing on market and control of use requirements introduced by the revision of the F-gas Regulation, 2014 (Article 11 to 13 of the F-gas Regulation)

<table>
<tr><th colspan="2">Placing on the market restrictions for products and equipment (Article 11 in conjunction with Annex III)</th><th>Date of prohibition</th></tr>
<tr><td colspan="2">3. Fire protection equipment that contain HFC-23</td><td>01/01/2016</td></tr>
<tr><td colspan="2">10. Domestic refrigerators and freezers that contain HFCs with GWP of 150 or more</td><td>01/01/2015</td></tr>
<tr><td rowspan="2">11. Refrigerators and freezers for commercial use (hermetically sealed systems)</td><td>Containing HFCs with GWP of 2500 or more</td><td>01/01/2020</td></tr>
<tr><td>Containing HFCs with GWP of 150 or more</td><td>01/01/2022</td></tr>
<tr><td colspan="2">12. Stationary refrigeration equipment, that contains, or whose functioning relies upon, HFCs with GWP of 2 500 or more except equipment intended for application designed to cool products to temperatures below – 50 °C</td><td>01/01/2020</td></tr>
<tr><td colspan="2">13. Multipack centralised refrigeration systems for commercial use with a rated capacity of 40 kW or more that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 150 or more, except in the primary refrigerant circuit of cascade systems where fluorinated greenhouse gases with a GWP of less than 1 500 may be used</td><td>01/01/2022</td></tr>
<tr><td colspan="2">14. Movable room air-conditioning equipment (hermetically sealed equipment which is movable between rooms by the end user) that contain HFCs with GWP of 150 or more</td><td>01/01/2020</td></tr>
<tr><td colspan="2">15. Single split air-conditioning systems containing less than 3 kg of fluorinated greenhouse gases, that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 750 or more</td><td>01/01/2025</td></tr>
<tr><td rowspan="2">16. Foams that contain HFCs with GWP of 150 or more except when required to meet national safety standards</td><td>Extruded polystyrene (XPS)</td><td>01/01/2020</td></tr>
<tr><td>Other foams</td><td>01/01/2023</td></tr>
<tr><td colspan="2">17. Technical aerosols that contain HFCs with GWP of 150 or more, except when required to meet national safety standards or when used for medical applications</td><td>01/01/2018</td></tr>
<tr><th colspan="3">Use prohibitions (Article 13)</th></tr>
<tr><td colspan="2">Use of SF_6 in magnesium die-casting and the recycling of magnesium die-casting alloys in quantities of less than 850 kg per year</td><td>01/01/2018</td></tr>
<tr><td colspan="2">Use of F-gases with a GWP of 2500 or more to service or maintain refrigeration equipment with a charge size of 40 tonnes of CO_2 equivalent or more, with the exception of
Military equipment or equipment intended for applications to cool products below - 50 °C
Reclaimed F-gases with a GWP of 2500 or more used for maintenance or servicing of existing refrigeration equipment with labelling according to Article 12 (until 01/01/2030)
Recycled F-gases with GWP of 2500 or more used for maintenance or servicing of existing refrigeration equipment if recovered from such equipment and used by the recovery undertaking or the undertaking where recovery was carried out for maintenance or servicing (until 01/01/2030)</td><td>01/01/2020</td></tr>
</table>

Table -53 Overview of categories for reporting F-gases contained in imported products or equipment

Stationary equipment for comfort cooling or heating	
Direct design	Standalone/monobloc units of moveable type
	Standalone/monobloc units of rooftop type
	Standalone/monobloc units of other type
	Single split units charged with 3 kg or more of refrigerant
	Single split units charged with less than 3 kg of refrigerant
	Multi split units
Indirect design	Standalone/monobloc units for domestic use
	Standalone/monobloc units for commercial or industrial use
	Standalone/monobloc units for other use
	Split units for domestic use
	Split units for commercial or industrial use
	Split units for other use
Direct and indirect	Standalone/monobloc units
	Split units
	Other
Stationary equipment for refrigeration	
Direct	Standalone/monobloc units for domestic use
	Standalone/monobloc units for commercial or industrial use
	Standalone/monobloc units for other use
	Split units for commercial or industrial use
	Split units for other use
	Stationary equipment for process cooling or heating
	Stationary HACR equipment for any other purposes
Indirect	Standalone/monobloc units for commercial or industrial use
	Standalone/monobloc units for other use
	Split units for commercial or industrial use
	Split units for other use
	Standalone/monobloc units
	Split units
	Stationary equipment for process cooling or heating
	Stationary HACR equipment for any other purposes
Direct and indirect	Stationary equipment for process cooling or heating
	Stationary HACR equipment for any other purposes
	Heat pump tumble dryers
	Other
Mobile refrigeration equipment	
	Light duty vehicles (e.g. vans)
	Heavy duty vehicles (including trucks and trailers)
	Ships
	Other
Mobile air conditioning equipment	
	Passenger cars
	Buses
	Vans (light duty vehicles)
	Trucks and trailers (heavy duty vehicles)
	Agricultural, forestry and construction vehicles and machinery
	Rail vehicles
	Ships
	Aircrafts and helicopters
	Other
Foam products	
	Extruded polystyrene (XPS) insulation boards
	Polyurethane (PU) insulation boards
	One component foam (OCF)
	Other
Other	
Fire protection equipment (including systems incorporated in vehicles)	

Medical or pharmaceutical aerosols
Non-medical aerosols
Medical equipment (without aerosols)
Switchgear for transmission and distribution of electricity
Other electrical transmission and distribution equipment
Particle accelerators
Other products and equipment containing gases listed in Annex I or II of the F-gas Regulation

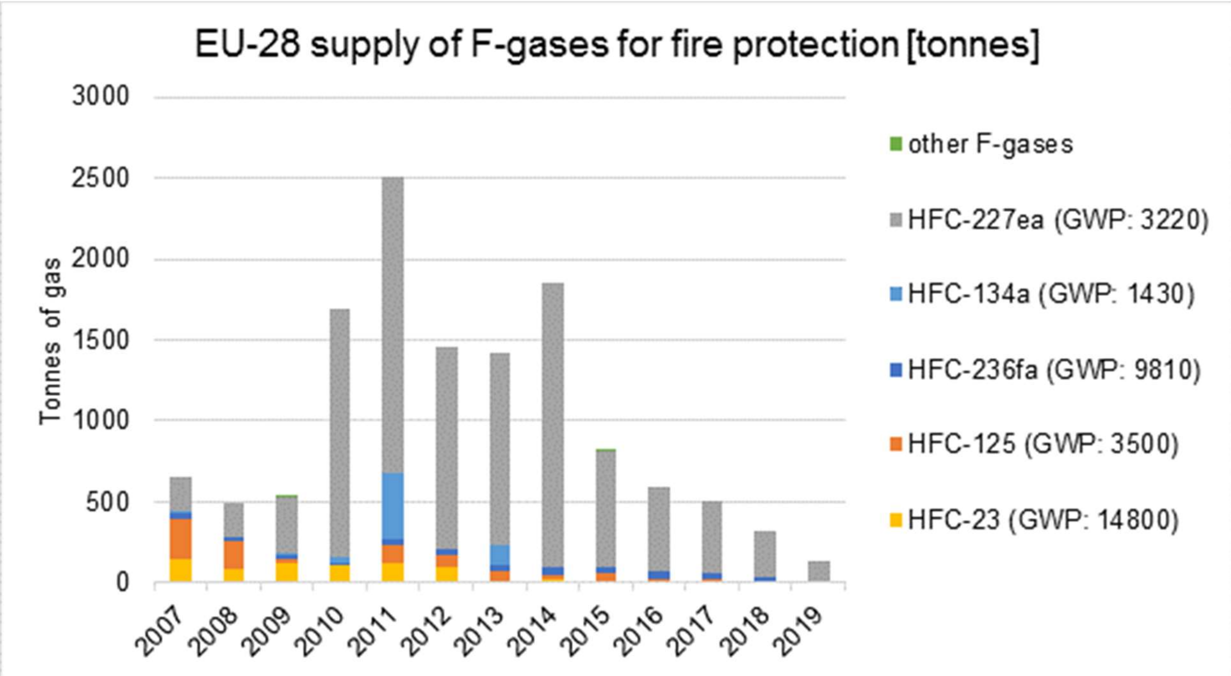
Annex 8 – Annex to the effectiveness section

Article 11 provisions by sectors

Fire protection

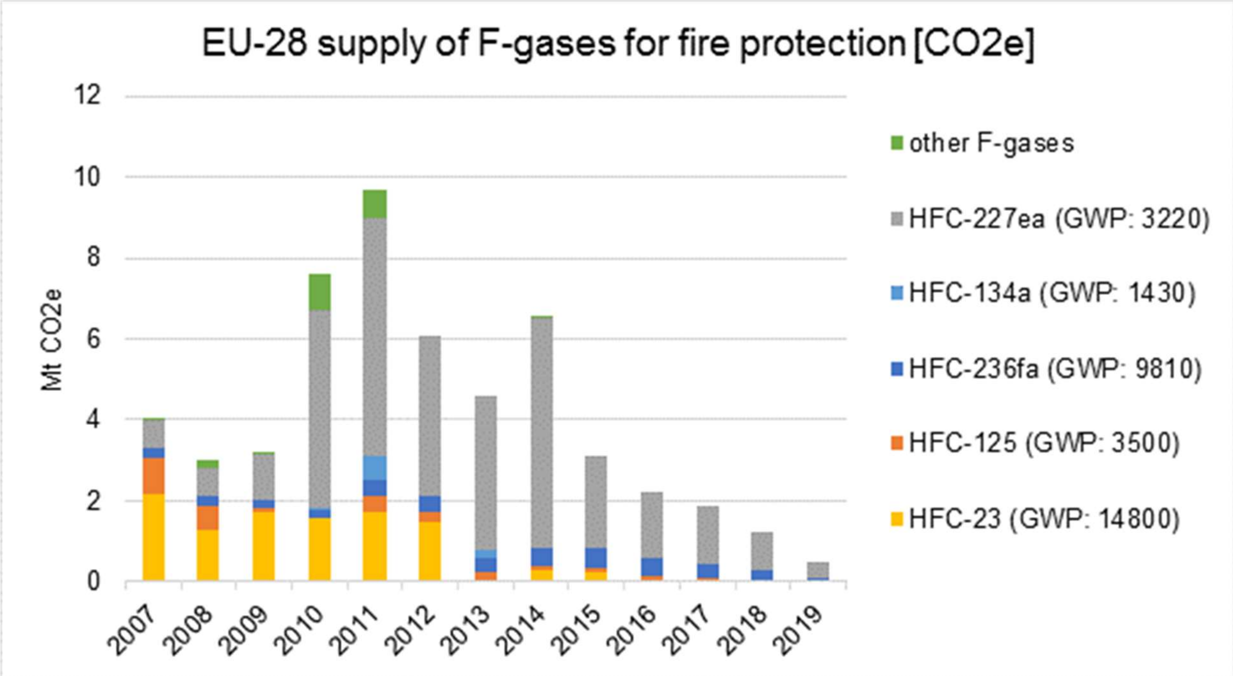
According to Article 11, in conjunction with Annex III No 3b of the Regulation, placing on the market of fire protection equipment containing HFC-23 has been prohibited since 1 January 2016. The effectiveness of this measure can be checked against the data reported by importers and producers under Article 19 of the Regulation where the intended applications of gases or the type of imported equipment needs to be specified. The EU supply of F-gases for fire protection is depicted in Figure 6 and Figure 7 in units of tonnes of gas and million tonnes of CO_2 equivalents (Mt CO_2e) respectively.

Figure 6: EU-28 supply of F-gases for fire protection (in tonnes)



Source: [EEA 2020 confidential dataset], own calculations

Figure 7: EU-28 supply of F-gases for fire protection (in Mt CO_2e)



Source: [EEA 2020 confidential dataset], own calculations

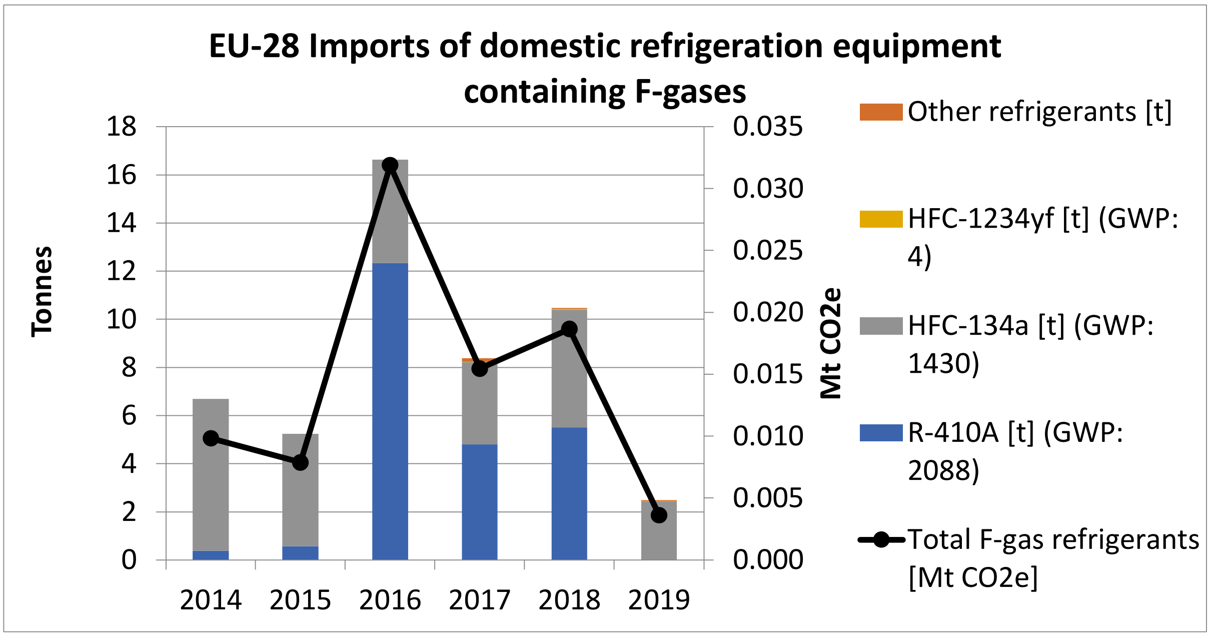
Both the total amounts of F-gases and the amounts of HFC-23 supplied into the fire protection sector have been declining since 2011 in part due to use of other F-gases or non-F-gas alternatives such as water mist and CO_2 which are less costly. The supply of HFC-23 into the fire protection sector after 2015 has only been reported in marginal quantities which may have been used for refill that is not covered by the prohibition under Article 11. It can therefore be summarised that the POM prohibition for fire protection equipment using HFC-23 was effective.

As visible in Figure 6 and Figure 7 the overall amounts of F-gases supplied into the fire protection sector have significantly declined. Alternatives to HFC-23 used by affected EU industries thus appear to be low-GWP alternatives outside the scope of F-gases covered by the Regulation. These effects on the other gases (besides HFC-23) can be attributed to the phase-down measure, as there is no prohibition in place.

Domestic refrigerators and freezers

According to Article 11 in conjunction with Annex III No 10 of the Regulation, placing on the market of domestic refrigerators and freezers containing HFCs with a GWP above 150 has been prohibited since 1 January 2015. Refrigerants used in imported “stationary refrigeration equipment for domestic use” relying on F-gases are depicted in Figure 8 based on data reported under Article 19.

Figure 8: EU-28 imports of domestic refrigeration equipment relying on F-gas refrigerants in tonnes (bars) and Mt CO_2 eq (dots and line))



Note: Data relate to reporting category 11B1: Stationary equipment for refrigeration, direct design: standalone/monobloc units for domestic use. It should be noted that equipment relying on R-410A is likely to be mis-reported for section 11B1 as R-410A is in use only for air-conditioning applications.
Source: [EEA 2020 confidential dataset], own calculations

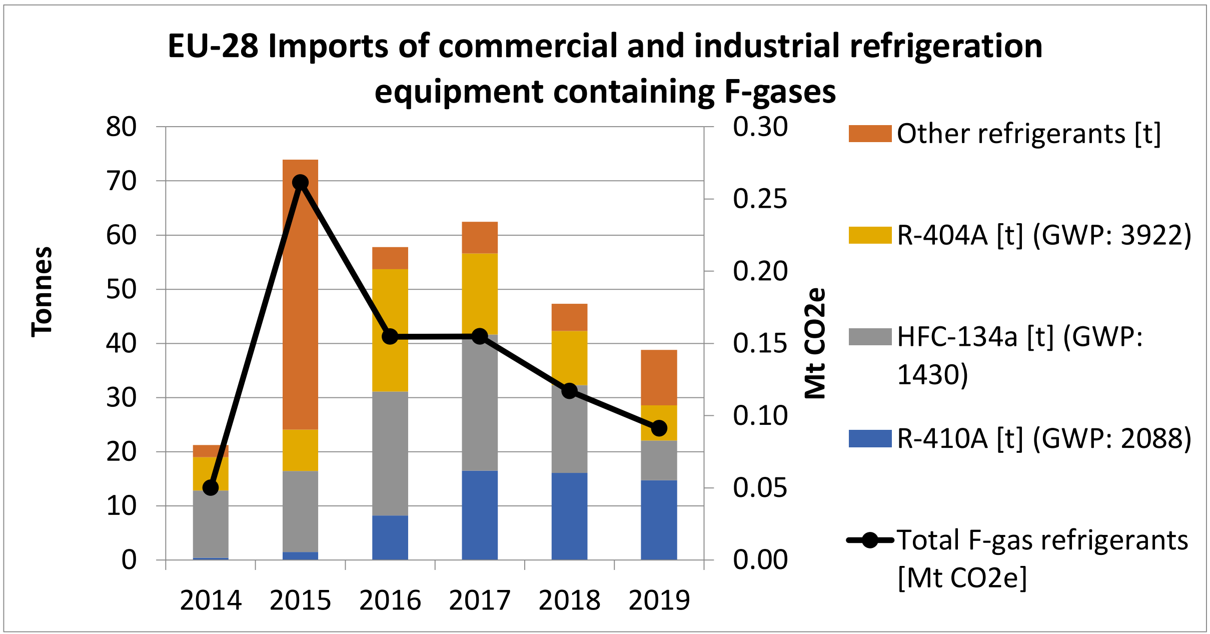
Imports of F-gas refrigerants above the GWP threshold of 150 in domestic refrigeration equipment were reported in low quantities of less than 20 tonnes per year and have shown a strong decline since 2016. At the same time, imports of F-gas refrigerants in such equipment below that GWP threshold was reported only in marginal amounts, less than 0.05 t per year of HFC-1234yf. Imports of equipment relying on hydrocarbons (with a GWP < 150) are outside the scope of the reporting data shown in Figure 8. For such gases, the AnaFgas model data can be assessed (see below).

It should be noted that the BDR reporting category 11B1 assessed in Figure 8 ("imported domestic refrigeration equipment") covers a wider definition of equipment than the prohibition of Annex III, No.10 ("domestic refrigerators and freezers") and includes, for example, equipment used to heat and refrigerate tap water. Thus, a conclusion that the prohibition of Annex III, No.10, may possibly not have been fully complied with since 2015 is not possible based on the data from EEA reporting.

Hermetically sealed commercial refrigerators and freezers

According to Article 11 in conjunction with Annex III No 11 of the Regulation, placing on the market of hermetically sealed commercial refrigerators and freezers containing HFCs with a GWP above 2500 has been prohibited since 1 January 2020. A GWP threshold of 150 will be in place starting 1 January 2022. Refrigerants used in imported "stationary refrigeration equipment for commercial or industrial use" relying on F-gases are depicted in Figure 9, again taken from data reported under Article 19. It should be noted that those reporting data jointly refer to commercial and industrial refrigeration equipment, so there is a scope issue. For imported and prefilled equipment, as subject to the reporting obligation, a high share of hermetically sealed commercial equipment can be assumed.

Figure 9: EU-28 imports of commercial and industrial refrigeration equipment relying on F-gas refrigerants (in tonnes (bars) and Mt CO_2e (line))



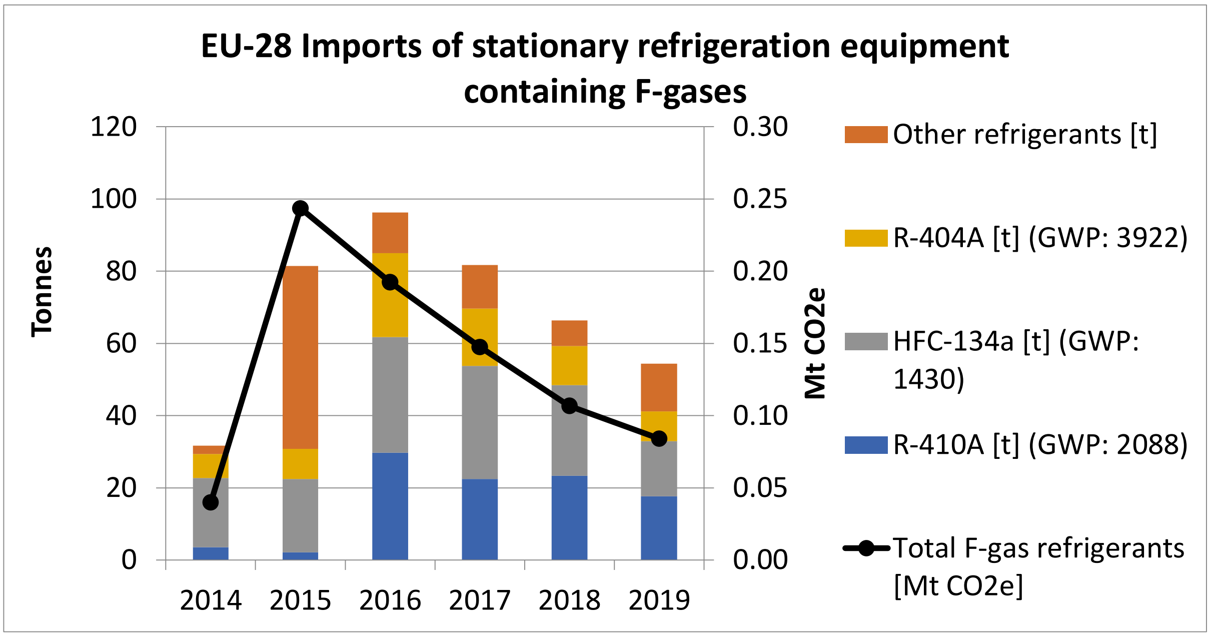
Note: Data relate to reporting categories 11B2: Stationary equipment for refrigeration, direct design: standalone/monobloc units for commercial or industrial use; 11B4: Stationary equipment for refrigeration, direct design: split units for commercial or industrial use; 11B6: Stationary equipment for refrigeration, indirect design: standalone/monobloc units for commercial or industrial use; 11B8: Stationary equipment for refrigeration, indirect design: split units for commercial or industrial use; Low amounts reported for 2014 may be due to incomplete reporting for that first years of the reporting obligation for equipment importers. Also the 2015-2017 rise in R-410A amounts is likely to be due to more complete reporting rather than actual increase in imported equipment. **Source**: [EEA 2020 confidential dataset], own calculations

It should be noted that the equipment types covered in Figure 9 go beyond the definition of Annex III No 11, as reported data are not restricted to hermetically sealed equipment and include also applications for industrial use. Furthermore, the evidence concerns only imported equipment, the data does not allow to conclude on equipment manufactured or charged within the EU. Nevertheless, it is evident that HFCs with a GWP of 2,500 and more (in this case most relevant: R404A) have declined and are on track to meet the prohibition date of 1 January 2020. However, refrigerants with a GWP below 150, as required from 1 January 2022, have not yet been reported. The unsaturated HFC-containing blends R454C and R455A (GWP ~146) have been announced as potential replacements for R404A. This would relate most likely either to hydrocarbons and partly CO_2 (used in some vending machines), which are outside the scope of reporting, but which are commonly and increasingly used in this sector. A conclusion related to the achievement of the prohibition date in 2022 is not yet possible.

Stationary refrigeration equipment containing or relying on HFCs with GWP 2500 or more

According to Article 11 in conjunction with Annex III No 12 of the Regulation, placing on the market of stationary refrigeration equipment containing or relying upon HFCs with GWP of 2,500 or more has been prohibited since 1 January 2020, with the exception of equipment intended to cool products to temperatures below -50°C. Indicative information related to stationary refrigeration equipment can be gained from the data reported by importers of refrigeration equipment under Article 19 of the Regulation. Refrigerants used in imported "stationary refrigeration equipment" relying on F-gases are depicted in Figure 10.

Figure 10: EU-28 imports of stationary refrigeration equipment relying on F-gas refrigerants (in tonnes (bars) and Mt CO_2e (line))



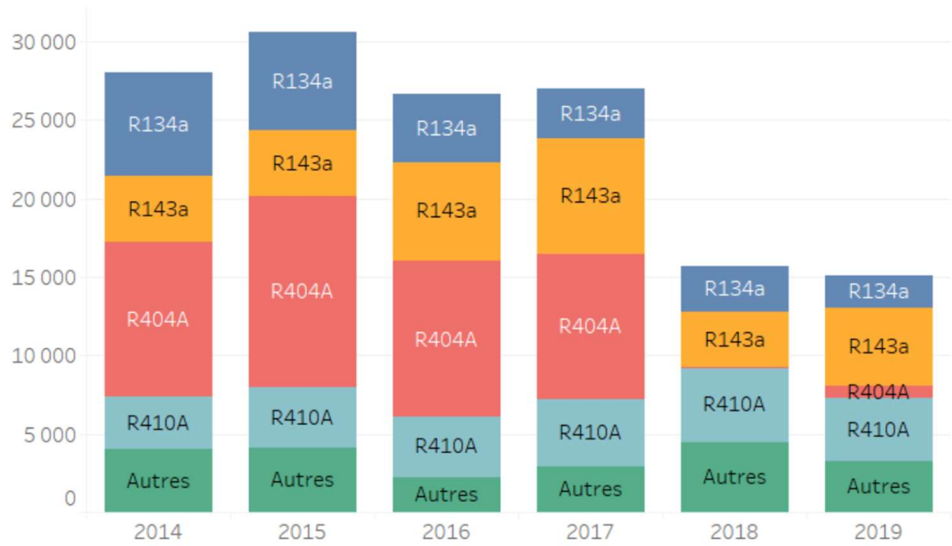
Note: Data relate to reporting category 11B: Stationary equipment for refrigeration, comprising sub-categories 11B1 – 11B14, as partially also shown in Figure 8 and Figure 9. Low amounts reported for 2014 and 2015 may be due to incomplete reporting for those first years of the reporting obligation for equipment importers. **Source**: [EEA 2020 confidential dataset], own calculations

HFCs with GWP of 2,500 and more (in this case most relevant: R404A) have decreased and are on track to meet the prohibition date 1 January 2020. It should be noted, however, that the equipment types covered in Figure 10 may include equipment for low temperatures below -50°C which are exempted from the prohibition.

National datasets confirm the decrease of use of R404A. The data on France from ADEME show that R404A virtually disappeared from the French market in 2018 and 2019[7].

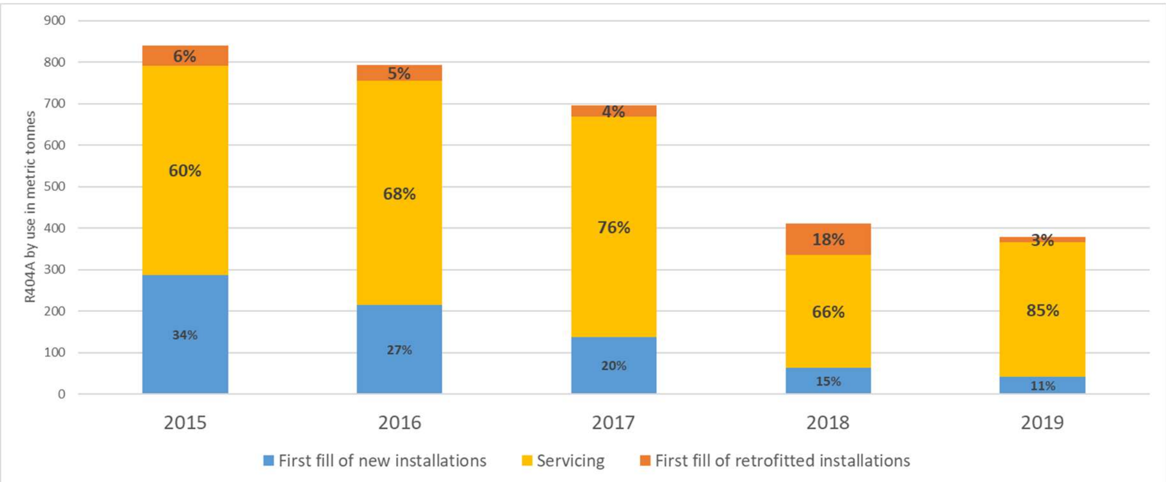
[7]In Extenso Innovation Croissance, Alice Deprouw, Beatriz Berthoux. ADEME, Olivier Benoit. Octobre 2020, Rapport annuel de l'Observatoire des fluides frigorigènes et gaz fluorés. Donnés 2019, Rapport, 78 pages.

Figure 11: Placing on the market of F-gases in France in 2014 – 2019 (metric tonnes). Source: ADEME.



This is supported by statistical data from Germany (Destatis) which show a strong decrease of the quantities going into first fill (38% in 2015, 15% in 2019)[8].

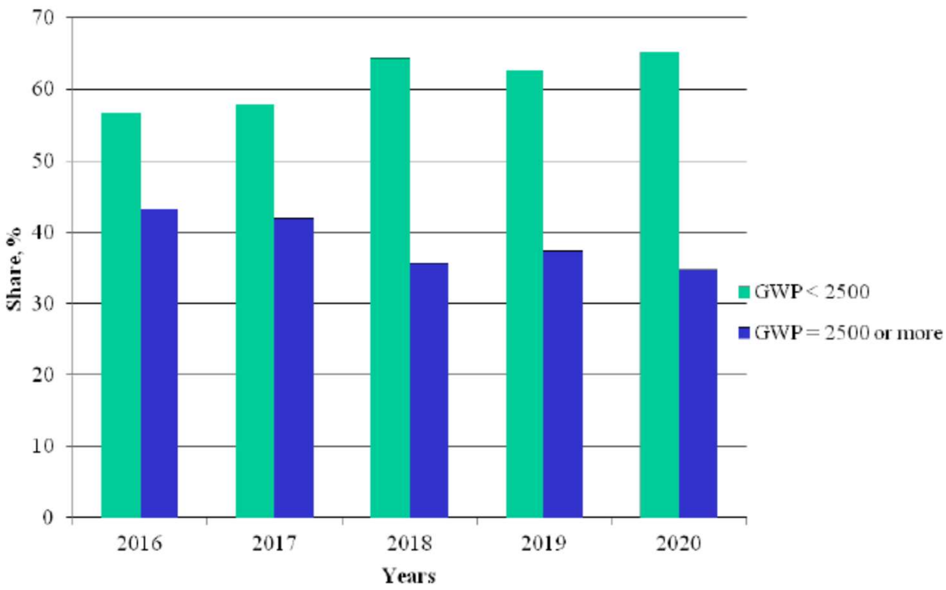
Figure 12: Use of R404A as refrigerant in Germany (2015-2019; metric tonnes). Source: Destatis.



Furthermore, data from the Polish electronic equipment register on RACHP equipment (containing charges of 5 t CO_2 eq or more) support that the share of high-GWP (2,500 or more; i.e. R404A, R507A etc.) has been decreasing in the period 2016-2020 while the share of gases with GWP <2500 was rising[9].

[8] Own analysis of data from Destatis: Erhebung klimawirksamer Stoffe 2015-2019.
[9] Janusz Kozakiewicz: Electronic databases and equipment logbooks in Poland. Presentation given at the ECA online meeting, 10th February 2021.

Figure 13: Shares of high-GWP and low-GWP gases in the period 2016-2020 in Poland. Source: Polish Electronic database.



Multipack centralised refrigeration systems for commercial use with a rated capacity of 40 kW or more containing or relying on F-gases with GWP of 150 or more

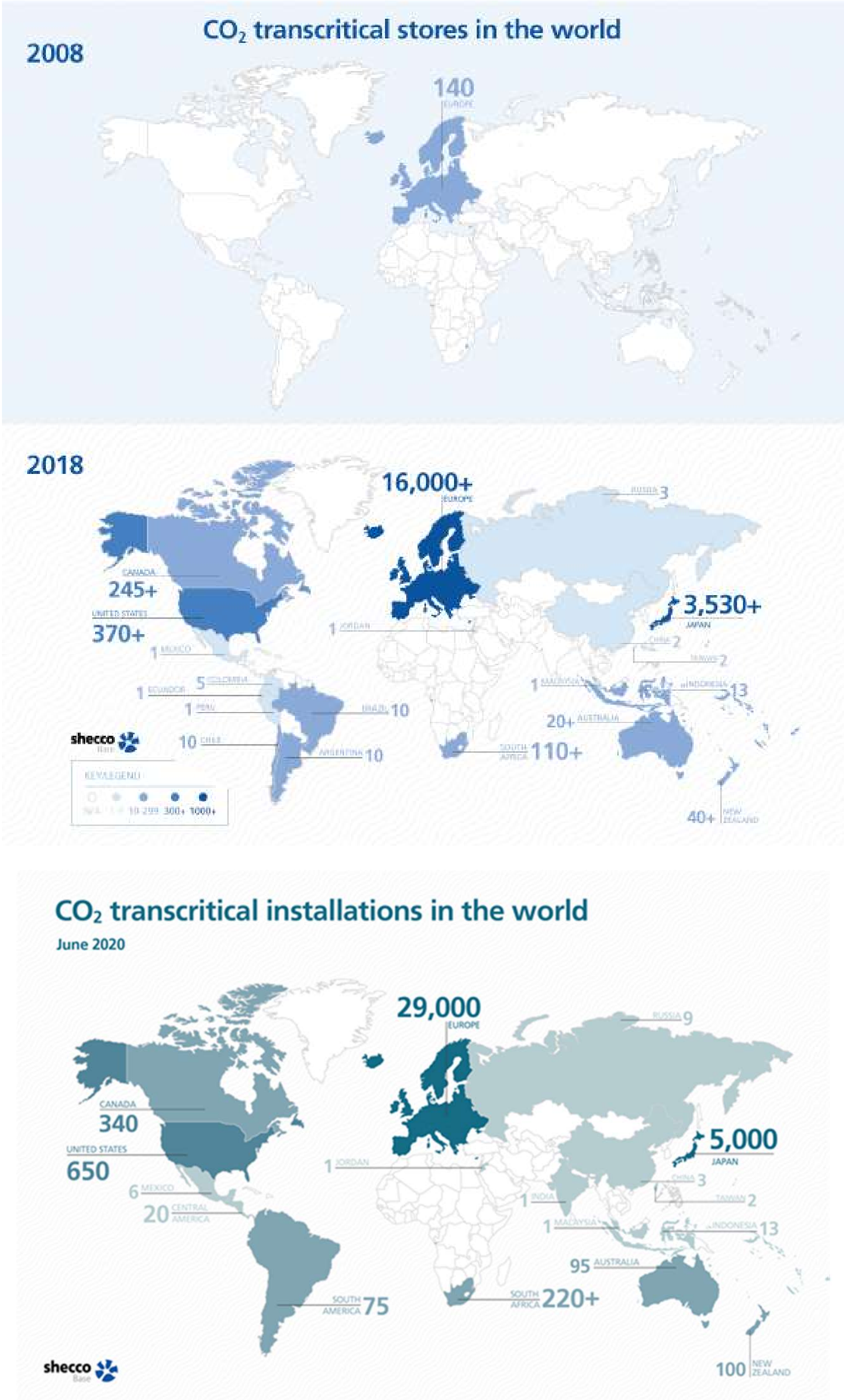
According to Article 11 in conjunction with Annex III No 13 of the Regulation, placing on the market of multipack centralised refrigeration systems for commercial use with a rated capacity of 40 kW or more containing F-gases with GWP of 150 or more are prohibited starting 1 January 2022, except in the primary refrigerant circuit of cascade systems where F-gases with a GWP of less than 1500 may be used. For that type of equipment, it is not possible to derive indicative information based on data reported by importers of refrigeration equipment under Article 19 of the Regulation as none of the reporting categories allows identifying such equipment types.

The EU Commission's 2017 assessment of availability of cost-effective, technically feasible, energy-efficient, and reliable alternatives to multipack centralised refrigeration systems[10] found that there are several cost and energy efficient alternatives available on the market. As a result of the assessment, it was concluded by the EU Commission that it is not necessary to amend the provision pursuant to Annex III of the Regulation (EU) No 517/2014.

Surveys by an industry organisation show the massive market uptake of transcritical CO_2 systems in retail in the EU and worldwide since 2008 (Figure 14).

[10] https://ec.europa.eu/clima/sites/clima/files/f-gas/legislation/docs/c_2017_5230_en.pdf

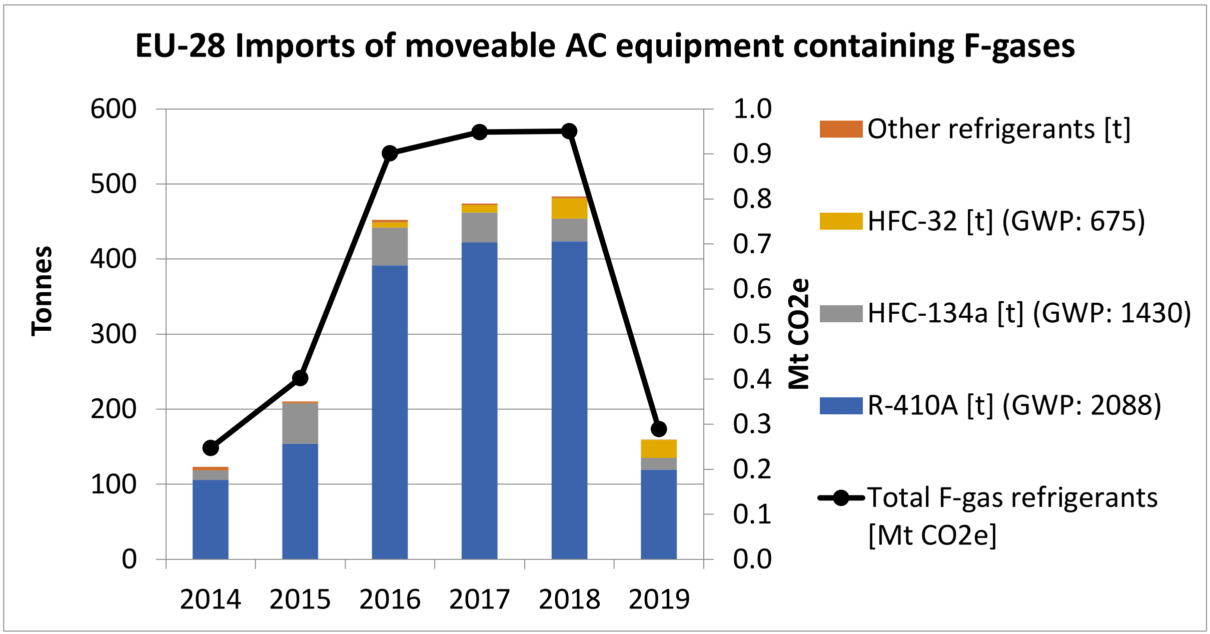
Figure 14: Number of transcritical CO2 systems in retail in the EU and worldwide in 2008, 2018 and 2020. Source: Shecco.



Moveable air conditioning (AC) equipment containing HFCs with GWP of 150 or more

According to Article 11 in conjunction with Annex III No 14 of the Regulation, placing on the market of moveable AC equipment containing HFCs with a GWP of 150 or more has been prohibited since 1 January 2020. Indicative information related to moveable AC equipment can be gained from the data reported by importers of AC equipment under Article 19 of the Regulation. Refrigerants used in imported moveable AC equipment relying on F-gases are depicted in **Fehler! Verweisquelle konnte nicht gefunden werden.**Figure 15.

Figure 15: EU-28 imports of moveable AC equipment relying on F-gas refrigerants (in tonnes (bars) and Mt CO_2e (line))



Note: Data relate to reporting category 11A1: Stationary equipment for comfort cooling/heating, direct design: standalone/monobloc units of moveable type
Source: [EEA 2020 confidential dataset], own calculations

No F-gas refrigerants with a GWP below 150 were imported between 2014 and 2019 for moveable AC equipment. However, the amounts of moveable AC equipment relying on F-gases strongly declined in 2019. Imports of equipment relying on natural refrigerants (with a GWP < 150)[11] are outside the scope of the reporting data shown in Figure 15. Given the strong decline observed for 2019 in imports of equipment with gases above the GWP threshold of 150, however, the prohibition appears to be effective.

For information on the penetration of low-GWP solutions for moveable AC equipment, the AnaFgas model data can be assessed. Based on the modelling results, R410A that consist in equal parts of HFC-125 and HFC-32 had the largest share of the demand of F-gases and their replacements in moveable AC equipment in the period 2010 to 2018 under both scenarios. Under the counterfactual, this remains to be the case until 2019 and R290 (propane) remains at a relatively low level. For the baseline, on the other hand, the share of R410A decreases continuously, especially starting in 2015 where propane shows an exponential growth and surpasses the share of R410A in 2019.

The small quantities of HFC-134a are explained by older R407C units that are still in stock until 2013.

Although evidence from the reported data for the prohibition date of 1 January 2020 is currently still missing, it can be shown on the basis of the modelling results that the prohibition has already led to an effective reduction of HFCs and a significant increase in low-GWP alternatives (propane).

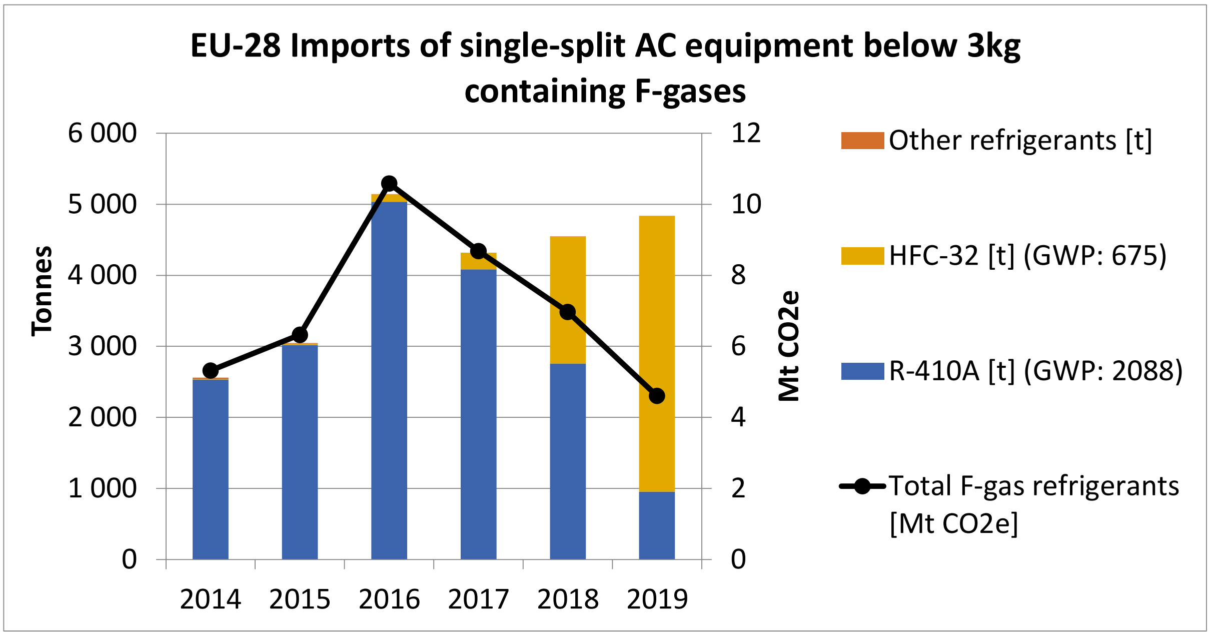
Single-split AC with a charge of less than 3 kg containing or relying on F-gases with GWP of 750 or more

According to Article 11 in conjunction with Annex III No 15 of the Regulation, placing on the market of single-split AC with a charge of less than 3 kg containing or relying on F-gases with a GWP of 750 or more will be prohibited starting 1 January 2025. Indicative information related to single-split AC equipment below 3 kg can be gained from the data reported by importers of AC equipment under Article 19

[11] For moveable AC equipment, in particular propane (R-290) with a GWP of 3 is the key replacement for HFCs.

of the Regulation. Refrigerants used in imported single-split AC equipment below 3 kg containing or relying on F-gases are depicted in **Fehler! Verweisquelle konnte nicht gefunden werden.**

Figure 16: EU-28 imports of single-split AC equipment below 3 kg containing or relying on F-gases (in tonnes (bar) and Mt CO_2e (line))



Note: Data relate to reporting category 11A5: Stationary equipment for comfort cooling/heating, direct design: single split units charged with less than 3 kg of refrigerant
Source: [EEA 2020 confidential dataset], own calculations

For this AC equipment category, HFC-32 with a GWP of 675 has been introduced to the market from 2014 and has started replacing R410A (GWP 2,088) in large amounts since 2018 reaching a share of about 80 % of F-gas refrigerants in imported AC equipment of that category. Furthermore, 2019 imports of R-410A in that equipment category were about 80 % below 2016. While it is too early to determine the effectiveness of the prohibition of this category of AC equipment, it can be concluded that the EU-28 is clearly on track for meeting this condition, five years ahead of the prohibition date.

For small single split AC systems, the EU Commission's report published in 2020 noted alternatives such as R-290 already exist and thus may be suitable alternatives for < 7 kW air conditioning units, where safety standards and/or other limitations do not restrict their use[12]. However, in the case of systems with a cooling capacity > 7 kW there is currently no alternative to F-gases. compared to R410A, R32 has a significantly lower climate impact and is estimated to be more energy and cost efficient. This development is likely due to the phase-down pushing for lower GWP gases, rather than the prohibition in this sector which is foreseen only for 2025.

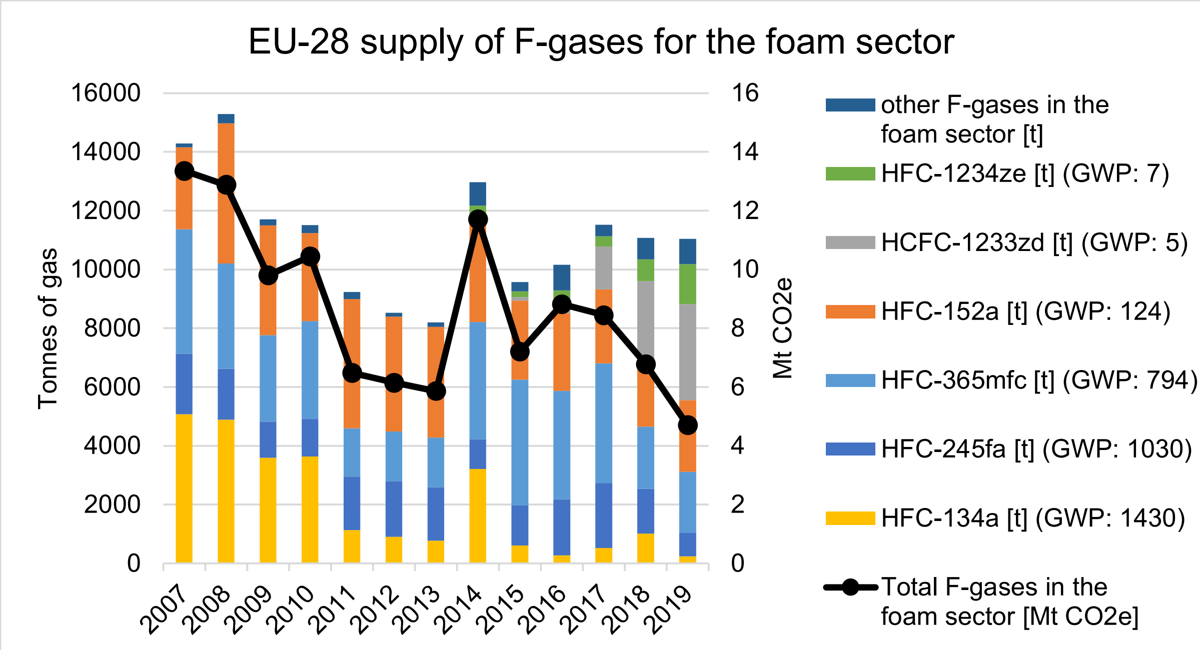
Foams containing HFCs with GWP of 150 or more

According to Article 11 in conjunction with Annex III No 16 of the Regulation, placing on the market of foams containing HFCs with a GWP of 150 or more will be prohibited starting 1 January 2023 (for extruded polystyrene (XPS) foams starting 1 January 2020) unless required to meet national safety standards. The effectiveness of this prohibition can be checked against the data reported by importers and producers under Article 19 of the Regulation where the intended applications of gases or the type

[12] https://ec.europa.eu/clima/sites/clima/files/news/docs/c_2020_6637_en.pdf

of imported equipment needs to be specified.[13] The EU supply of F-gases for the foam sector is depicted in Figure 17.

Figure 17: EU-28 supply of F-gases for the foam sector (in tonnes (bars) and Mt CO_2e (line))



Source: [EEA 2020 confidential dataset], own calculations

Before the revision of the Regulation, HFCs most commonly used in the EU foam sector were HFC-134a, HFC-152a, HFC-245fa and HFC-365mfc. Of these, only HFC-152a has a GWP below 150. As shown in Figure 17, the amounts of the three main HFCs with a GWP above 150 supplied into the EU foam sector have been declining in particular after 2017. In 2019, supplies into the foam sector of HFC-134a, HFC-245fa and HFC-365mfc are at less than 50 % of the 2017 amounts (measured in tonnes of gas). Commonly there are two low-GWP F-gases being used as replacements by EU industries: unsaturated HCFC-1233zd and unsaturated HFC-1234ze, both covered in Annex II of the Regulation. These gases were not used before 2014 at all and have since gained significant market shares (equating to almost 50 % in 2019). While evidence for the prohibition date 1 January 2023 (1 January 2020 for XPS) is still a few years away, it can be concluded that the EU-28 is on track to meet the prohibition requirement. A comparison of the gases used in 2019 compared to those in 2013 (before stockpiling in 2014), shows that the gases used has greatly changed, which is attributable to the measures of the Regulation.

During the stakeholder consultation, the industry association PU Europe confirmed that HFCs are being replaced. The best guess estimate of a known industry expert is that more than 75% of production has already been converted from HFCs to HFO/HCFOs in advance of the 2023 ban[14].

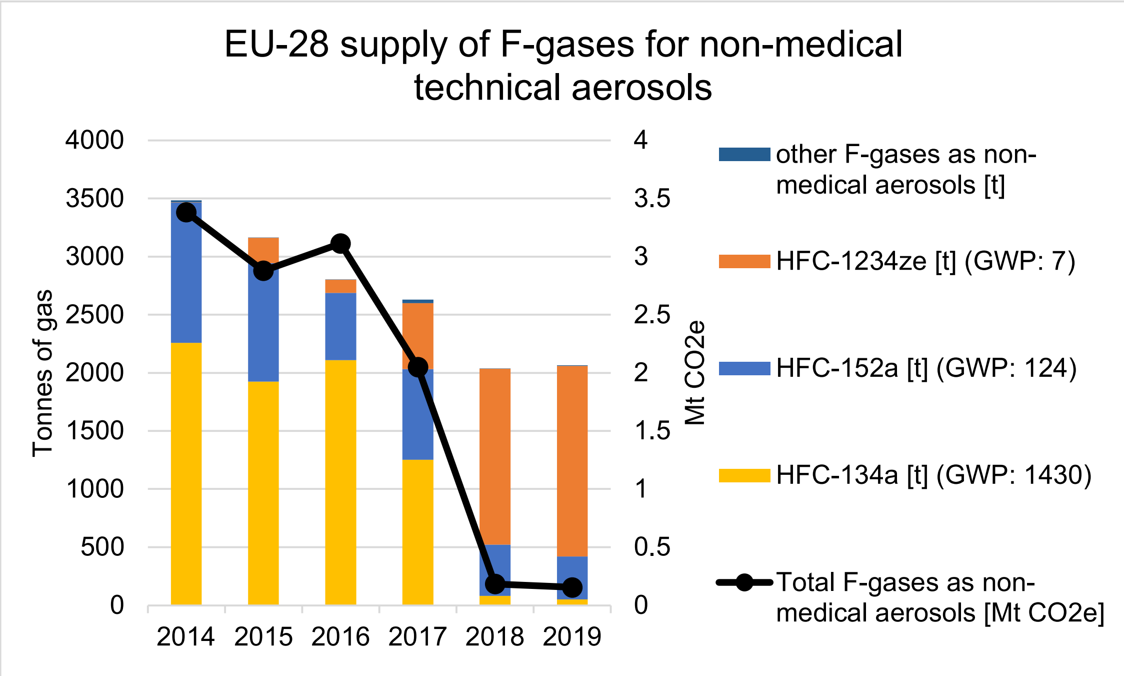
Technical aerosols containing HFCs with GWP of 150 or more

According to Article 11 in conjunction with Annex III No 17 of the Regulation, placing on the market of technical aerosols containing HFCs with a GWP of 150 or more have been prohibited since 1 January 2018 unless required to meet national safety standards or when used for medical applications. The effectiveness of this prohibition can be checked against the data reported by importers and producers under Article 19 of the Regulation where the intended applications of gases or the type of imported

[13] Specific information related to XPS foams is to be reported under Art 19 of the FGR only in case of imports of XPS foam containing F-gases. However, so far, no such import has been reported by companies. (EEA 2020 [confidential dataset of FGR Art. 19 reporting])
14 Personal communication

equipment needs to be specified. The EU supply of F-gases for non-medical aerosols since 2014[15] is depicted in Figure 18.

Figure 18: EU-28 supply of F-gases for non-medical aerosols (in tonnes)



Source: [EEA 2020 confidential dataset], own calculations

Before entry into force of the prohibition, HFCs most commonly used in the EU as non-medical technical aerosols were HFC-134a and HFC-152a. Of these, only HFC-152a has a GWP below 150. As shown in Figure 18, the amounts of HFC-134a (GWP: 1430) supplied into the EU for use as non-medical technical aerosol has declined from 2016 to 2018 by more than 95%. Supplies of HFC-134a as non-medical aerosol after entry into force of the 1 January 2018 prohibition have been at levels below 100 tonnes per year (or below 0.15 Mt CO_2e per year).[16] As a replacement for HFC-134a, and possibly also as a replacement for the declining amounts of HFC-152a, in particular low-GWP unsaturated HFC-1234ze has been phased in by EU industries from 2015. However, certain formulations still rely on small quantities of HFC-134a in mixtures with an overall GWP below 150 and/or for safety reasons. Thus, it can be concluded that the POM prohibition for non-medical aerosols involving HFCs above a GWP of 150 appears to have been generally complied with. Also, the measure has been very effective in reducing the use of high GWP gases in this sector.

The overall 35 % reduction in the use of F-gases supplied in the EU for non-medical technical aerosols in period 2015 to 2019 suggests that alternatives to F-gases appear to have been employed, but this cannot be identified from the reporting under Article 19 of the Regulation as no data on alternatives are to be reported.

The European Aerosol Federation confirmed that the use of HFCs in technical aerosols practically stopped before 2018[17].

Cross-media-effects, toxicity

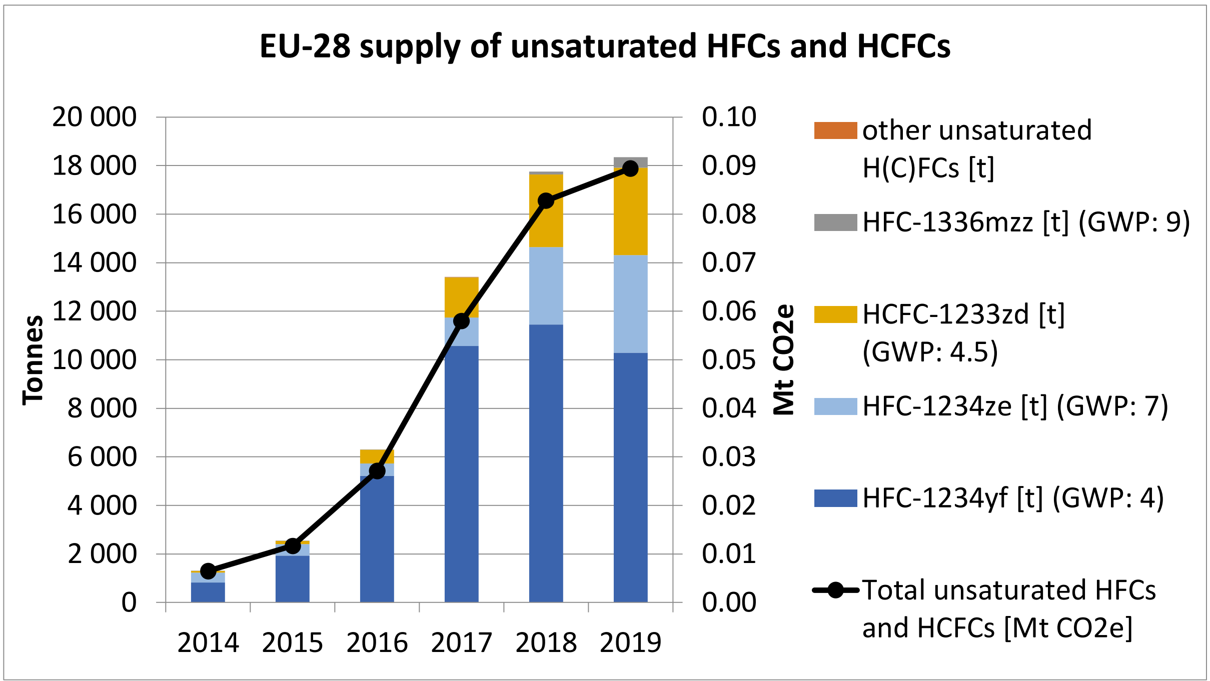
[15] In the reporting data for years before 2014 medical and non-medical aerosols were not differentiated.
[16] The reporting data does not allow to judge whether or not the supplied amounts fall under the exemption related to national safety standards.
17 Personal communication with FEA by email, 11th December 2020.

To review whether the Regulation has introduced other environmental impacts (i.e. cross-media effects) through the elimination of certain F-gases and the consequential introduction of their alternatives, potential substitutes have been reviewed as to their hazardous properties. Linking the causality of such impacts to the Regulation, furthermore, required the review of market data to determine whether the reduction in use of certain F-gases correlates to changes in the trend of use of possible substitutes. In this sense, the following section first looks at market data to understand the use of which substitutes has probably increased due to the phase-out of HFCs and PFCs. This is followed by a review of hazardous properties of potential substitutes and conclusions particularly related to those substitutes for which an increase in use can be tied to the Regulation.

Substitutes for HFCs and PFCs

Figure 19 provides an overview of the development of the EU supply of unsaturated H(C)FCs which have replaced HFCs. The EU supply of unsaturated H(C)FCs grew more than ten-fold from 2014 to 2019 and reached a level of about 18 000 tonnes per year. For a visualisation of declining HFC supply, please refer to EQ1a(iii) in the effectiveness chapter.

Figure 19: EU-28 supply of unsaturated HFCs and HCFCs listed in Annex II of the FGR

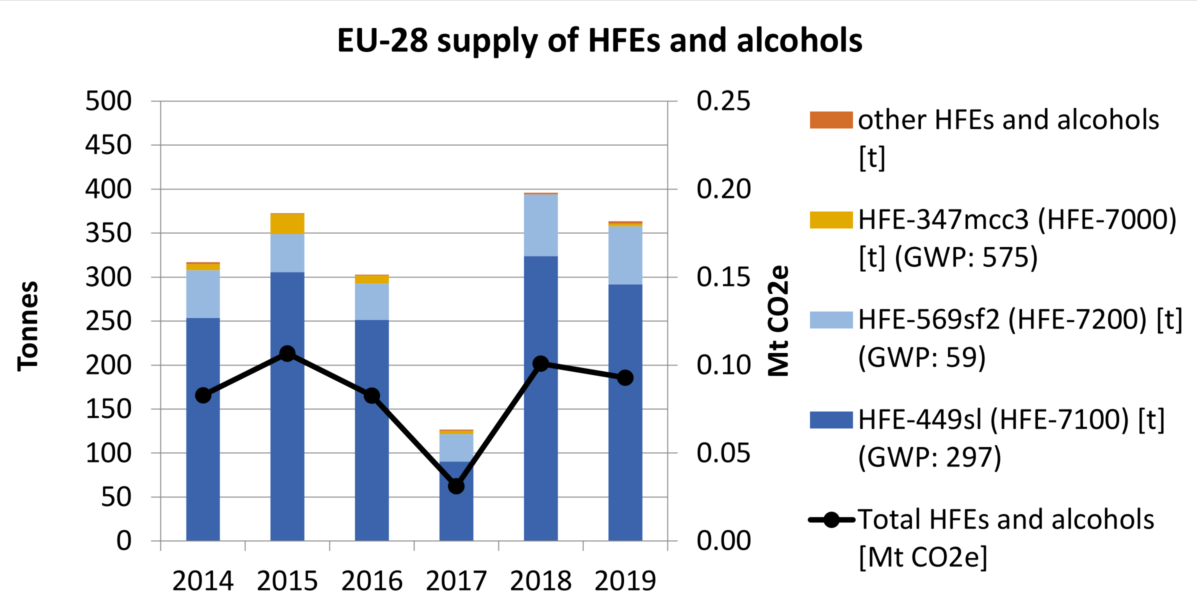


Source: [EEA 2020 confidential dataset], own calculations

The key unsaturated fluorinated substances phased in as HFC substitutes since the 2014 FGR revision are HFC-1234yf, HFC-1234ze and HCFC-1233zd.

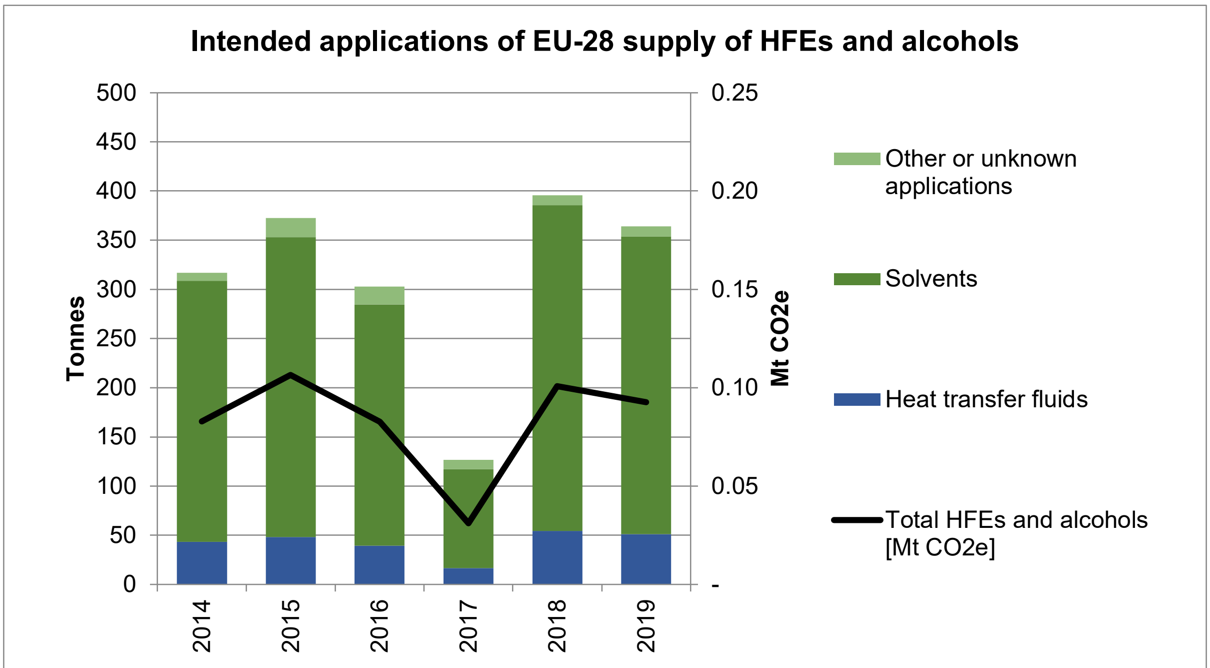
Figure 20 shows the EU supply for hydrofluoroethers (HFEs), as listed in Annex II of the FGR, which are suited to partly replace high-GWP PFCs and HFCs. As shown in Figure 21, HFEs are mostly used as solvents and heat transfer fluids.

Figure 20: EU-28 supply of HFE and alcohols listed in Annex II of the FGR



Source: [EEA 2020 confidential dataset], own calculations

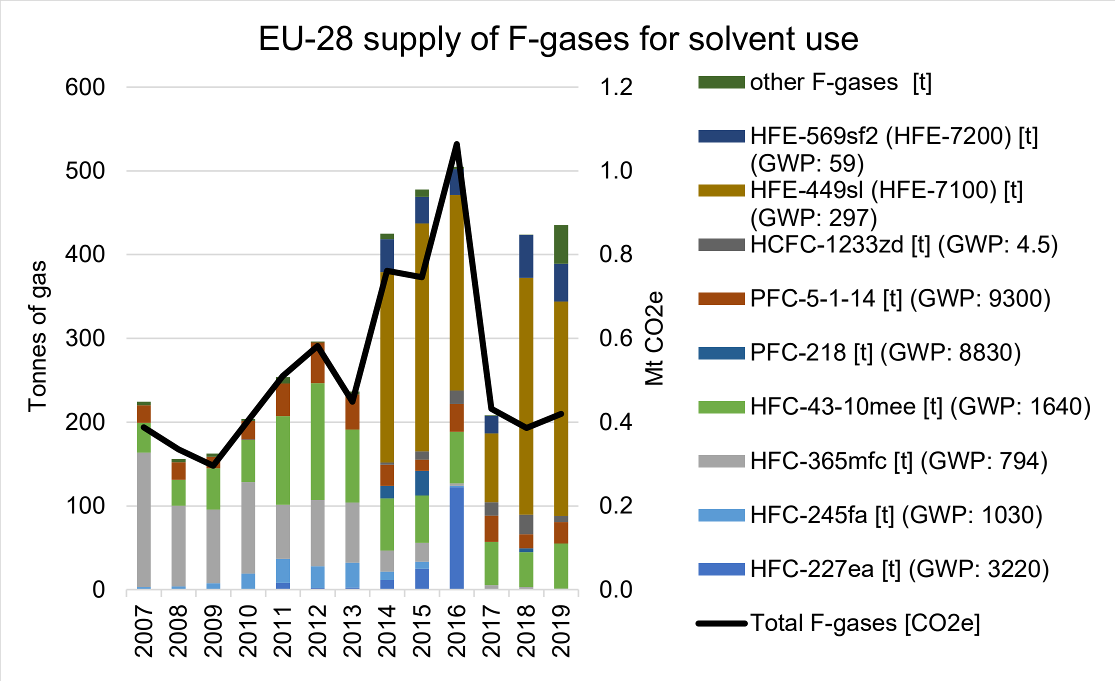
Figure 21: Intended applications of EU-28 supply of HFE and alcohols listed in Annex II of the FGR



Source: [EEA 2020 confidential dataset], own calculations

For HFEs the case is different from that of unsaturated H(C)FCs, in so far that although there have been changes in the amounts of supply, these do not seem to correlate with reductions in supply of HFCs and PFC. Though a slight increase is observed when comparing between the amounts supplied in 2014 and 2018, these are difficult to tie directly to the Regulation as HFEs enjoyed use in similar volumes in 2014. This conclusion is confirmed by an assessment of all F-gases supplied for use as solvents and heat transfer fluids, where the use of HFEs is more prevalent, as shown Figure 22 and Figure 23, respectively.

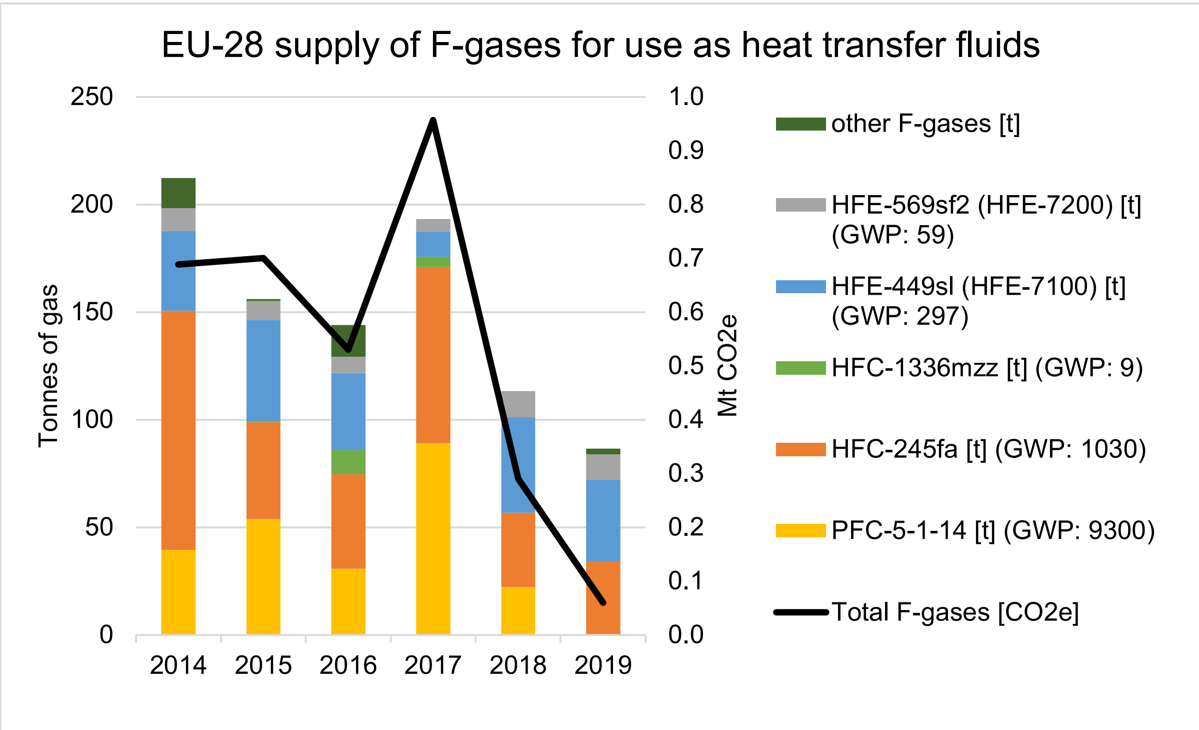
Figure 22: EU-28 supply of F-gases for solvent use



Note: HFEs and H(C)FCs were not subject to reporting for the years before 2014.

Source: [EEA 2020 confidential dataset], own calculations

Figure 23: EU-28 supply of F-gases for the use as heat transfer fluids



Source: [EEA 2020 confidential dataset], own calculations

Despite a strong declining trend for HFCs used as solvents, there is no clear growth trend observed for HFE as solvents. Similarly, for heat transfer fluids no clear growth trend is visible for HFEs despite a clear decline in the use of PFCs. Thus, there is no strong evidence that HFEs actually replaced HFCs or PFCs in response to the 2014 FGR Revision. It should also be noted that the 2019 market volume for HFEs (Figure 20) was at about 2 % of unsaturated H(C)FCs (Figure 19).

Toxicity

The study team compiled a list of potential substitutes for HFC and PFC to have declined in use following the 2014 FGR Revision. This list has been based to some degree on the substances listed in Annex II of the FGR, but also on general familiarity of the consultants with the relevant use sectors. To this end, substances investigated in relation to their hazardous properties included various unsaturated HFC, HCFC and HFE, as well as alternatives such as the hydrocarbons butane and propane.

A first screening of hazardous properties and toxicity of these potential alternatives to HFCs and PFCs was performed based on data available from the European Chemicals Agency website (substance classification, information on substances) and from suppliers of such substances (general information and safety data sheets where available). Available data has been compiled in the table below and provides an initial overview of associated hazards and classifications as well as derivatives of substances and similar aspects. The list included in the table is of potential substitutes and not only those for which an increase in volumes of use has been reported which may or may not be linked to the FGR Revision (i.e., substitutes to have phased-in as replacements for PFCs and HFCs). In this sense, substitutes for which evidence supports that their increase in use is linked to the FGR Revision appear at the beginning of the table and they are highlighted in green.

Hazard classifications are assigned to a substance in the first order by its suppliers: The Classification, Labelling and Packaging Regulation (EC) No. 1272/2008 (CLP) requires suppliers of substances and mixtures to decide on the classification of a substance or mixture to be placed on the market. This information needs to be taken into consideration for example in the labelling of the substance, in its safety data sheets, etc. This is called a self-classification and may differ for a substance between suppliers and thus has a lower certainty, though providing indication as to possible hazardous properties of a substance. Harmonised classifications are listed for some substances in the CLP Regulation and have a higher level of certainty as they have been subjected to scrutiny. Such properties appear in *italics* in the tables below.

The Hazard Statement weighting factors (WF) of the Technical Rules for Hazardous Substances (TRGS) of the German BAuA[18] have been used to clarify the severity of the various hazard statements that specific substances are classified with. Hazard properties (and categories) that fulfil the REACH criteria for substances of very high concern (SVHC) appear in bold in the tables below. This usually includes properties with a WF of 1000 and above, though in certain cases properties with a WF of 500 are also on the REACH Candidate List (i.e. SVHC) such as Toxic for reproduction Cat. 1 and 2 and Respiratory sensitisation Cat. 1.

This method has been used to derive a first indication of the possible toxicity and hazardousness of substances and their level of severity, however actual impacts to incur are a result not only of the amounts of a substance used and its properties but also of the likelihood of actual exposure to occur for a certain route of use and to result in adverse impacts. In this respect, the results below are to be perceived with caution and should not be interpreted as severe impacts without further investigation of the actual range of impacts to have incurred.

It is noted that many of the potential substitutes have classifications regarding their flammability in light of the pressured gas consistency of the substance – a physical hazard as opposed to those related to toxicity. This potential risk is well known and addressed in practice through relevant legislation, the use of harmonised standards and/or appropriate risk assessment and not least the design of equipment to

[18] See Technical Rule for Hazardous Substances (TRGS) 600 Substitution, established by the Committee on Hazardous Substances (AGS) and announced by the German Federal Ministry of Labour and Social Affairs, Edition: August 2008 (unofficial version; mandatory is the current German version), Annex 2 Comparative assessment of the health and safety hazards (column and effect factor model), 2: The effect factor model, pg. 21: https://www.baua.de/EN/Service/Legislative-texts-and-technical-rules/Rules/TRGS/pdf/TRGS-600.pdf?__blob=publicationFile&v=2

reduce related incidents. In this sense, it is assumed that this potential risk does not translate into an actual impact for the most part and does not suggest a reduced effectiveness of the Regulation in that sense. In other words, the trade-off between GWP and the need to redesign equipment to prevent impacts in the case of flammable alternatives is considered to be acceptable and not a sign of a shortcoming of the FGR.

Regarding alternatives for HFCs, most substitutes have classifications with relatively low hazard categories. The main concern is in relation to HFC-1234yf (2,3,3,3-tetrafluoroprop-1-ene), which has been included in the community rolling action plan (CORAP) for possible identification as a substance of very high concern (SVHC). The European Chemicals Agency[19] explains that substances that may have serious effects on human health and the environment can be identified as SVHCs[20]. This is a result of the substance having certain hazardous properties of a relatively high severity (i.e. properties with a weighing factor (WF) of 1000 and above). In relation to HFC-1234yf, the listing required the substance to be investigated for mutagenicity and carcinogenicity properties. Should this investigation conclude in an identification as SVHC, this could affect the ability to further apply this substitute. More importantly, the data in Figure 19 indicates that the increase in use in this substance corelates to the decrease in use of HFCs. This is of particular concern, seeing as the increase in use of HFC-1234yf corelates to the decrease in use of HFCs (the highest use is in passenger cars). In the case of SVHC identification, it is difficult to argue that the Regulation has led to the increased introduction of a substance that may have serious effects on human health and the environment as it was not known at the time. This does, however, support the strengthening of the link between the FGR and REACH in the future to ensure that such hazardous impacts can be taken into consideration where relevant. Behringer et al.[21] have further found HFC-1234yf to have a significant contribution to the formation of trifluoroacetyl fluoride (TFF) which in turn reacts with water and forms trifluoroacetate (TFA) in the atmosphere. TFA is considered as being highly persistent and highly mobile, meaning that once it is in the environment in high volumes, it is difficult to reverse the situation. This also suggests that the Regulation (and, in particular, the MAC Directive) may have contributed to an increase in the amounts of TFA in the environment and subsequent impacts thereof.

Potential alternatives for PFCs include hydrofluoroethers (HFEs). Of these there is concern related to HFE 7000 and HFE 7100 which are under assessment together with two other HFEs (7500 and 7800) due to their structural similarity for identification as Persistent, Bioaccumulative and Toxic (PBT) substances. PBT properties are of relevance for identification as substances of very high concern and can be regulated through the REACH Regulation (restriction or authorisation). PBTs can also be restricted under the Stockholm convention (transposed into the EU POPS Regulation). Both cases could affect use in the future should the process conclude with an identification. Furthermore, according to Wang et al. (2014)[22] among HFEs, HFE-7100 and 7200/8200 can react with OH radicals and form $C_4F_9OC(O)H$ as well as $C_4F_9OC(O)CH_3$ and $C_4F_9OC(O)H$, respectively. These intermediates can undergo further reaction with OH radicals and form perfluorobutanoic acid (PFBA) which has been connected to the formation of long-chain perfluoroalkyl carboxylic acids (PFCAs, $CnF_2n+1COOH,n\geq7$), known for their

[19] See further detail, ECHA Website, Substances of very high concern (SVHC), https://echa.europa.eu/-/chemicals-in-our-life-chemicals-of-concern-svhc, last viewed 26.11.2020

[20] Once a substance is identified as an SVHC it is added to the Candidate list, meaning that companies manufacturing or importing articles containing the substance in a concentration above 0.1% have obligations to inform recipients of the presence of the substance and how to use it safely as well as providing this information to consumers that request it. A further consequence, depending on how well risks from the substance can be controlled, is that such substances can be subject to restrictions on use or require companies to obtain an authorisation to allow further use. The general aim, particularly when an authorisation for use is required is to phase-out the substance completely.

[21] Behringer, D., Heydel, F., Gschrey, B., Osterheld, S., Schwarz, W., Warncke, K., Freeling, F., Nödler, K., Henne, S., Reimann, S., Blepp, M., Jörß, W., Ludig, S., Liu, R., Rüdenauer, I., Gartiser, S., (2021), Persistent degradation products of halogenated blowing agents and refrigerants in the environment: type, environmental concentrations and fate with particular regard to new halogenated substitutes with low global warming potential, prepared by Öko-Recherche Büro für Umweltforschung und -beratung GmbH and Oeko-Institut e.V. for the German Umweltbundesamt, FKZ 3717 41 305 0, available under: https://www.umweltbundesamt.de/publikationen/persistent-degradation-products-of-halogenated

[22] Zhanyun Wang, Ian T. Cousins, Martin Scheringer, Robert C. Buck, Konrad Hungerbühler (2014) Global emission inventories for C4–C14perfluoroalkyl carboxylic acid(PFCA) homologues from 1951 to 2030, part II: The remaining pieces of the puzzle, Environment International 69 (2014) 166–176, https://www.sciencedirect.com/science/article/pii/S0160412014001172, last viewed 8.10.2020

persistence. As both HFEs are classified as causing long-lasting harmful effects to aquatic life, the link to persistence is of concern, as increased amounts to emit to the environment could increase the risk to aquatic organisms over time.

With regard to the possible increased accumulation of persistent chemicals in the environment as a result of the Regulation, 64% of 156 respondents to the OPC have indicated that they do not believe this will be the case. That said, there is a difference of opinion amongst stakeholders. The majority (but not all) of Member States, industry and citizens adhere to this overall consensus, whereas the majority of NGOs/environmental organisations noted they were concerned that this could be a detrimental environmental result of the Regulation. It should be noted that there was a relatively high number of respondents who said they cannot say (34%) which may reflect the technical understanding required to answer such a question, suggesting that a large (but not a majority) of stakeholders are unaware or do not feel sufficiently informed about such issues to be able to comment..

Finally, various considerations on a ban of PFAS substances must also be noted. In October 2020, the European Commission published a staff working document on poly-and perfluoroalkyl substances (PFAS)[23], forming part of the Chemical Strategy for Sustainability. In the screening of potential substitutes, the potential PFC alternative HFE-449sl was found to be listed on a list of substances identified by the OECD as "PFOS, PFAS, PFOA, PFCA, Related Compounds and Chemicals that may Degrade to PFCA"[24]. The Member States Germany, the Netherlands, Norway, Sweden and Denmark have also agreed to prepare a joint REACH restriction proposal to limit the risks to the environment and human health from the manufacture and use of a wide range of PFAS. In this respect, a call for evidence was issued in May 2020[25] in this respect, asking for information on *"substances that contain at least one aliphatic -CF2- or -CF3 element* [… as they] *are considered to contribute to the concentrations of persistent PFASs in the environment* ". Various substances considered as potential substitutes, as well as R-1234yf are of relevance to this assessment. The investigation of PFAS is however an ongoing and complex assessment involving current research.

[23] European Commission (2020), Commission Staff Working Document: Poly-and perfluoroalkyl substances (PFAS) - Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment, Brussels, 14.10.2020 SWD(2020) 249 final, available under: https://ec.europa.eu/environment/pdf/chemicals/2020/10/SWD_PFAS.pdf

[24] For more details see: OECD (2018) Toward a new comprehensive global database of per-and polyfluoroalkyl substances (PFASs): Summary report on updating the OECD 2007 list of per-andpolyfluoroalkyl substances (PFASs), Series on Risk Management No. 39, ENV/JM/MONO(2018)7, available under: https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV-JM-MONO(2018)7&doclanguage=en

[25] See ECHA Notification of 11.5.2020, "Five European states call for evidence on broad PFAS restriction" available under: https://echa.europa.eu/de/-/five-european-states-call-for-evidence-on-broad-pfas-restriction

Table -54: Classified hazards for potential alternatives to PFCs and HFCs

Gas identification in FGR	Substance identifiers	Classified hazards	Derivatives and transformation products	Comments
HFC-1234yf	**2,3,3,3-tetra-fluoroprop-1-ene** CAS: 754-12-1 Synonyms: HFC-1234yf, HFO-1234yf, 1-Propene, 2,3,3,3-tetrafluoro Mol. formula: C3H2F4	H220 Extremely flammable gas. H280 Contains gas under pressure; may explode if heated. May displace oxygen and cause rapid suffocation[26]. H221: Flammable gas[27]		Substance included in CORAP; mutagenicity invitro study and carcinogenicity study required. Contributes significantly to the formation of trifluoroacetyl fluoride (TFF) which in turn reacts with water and forms trifluoroacetate (TFA) in the atmosphere, which is considered as being highly persistent and highly mobile[28].
HFC-1234ze	**trans-1,3,3,3-tetrafluoropropene** CAS: 29118-24-9 Synonyms: HFC-1234ze Mol. formula: C6H5F9O	Press. Gas (Liq.), H280: Contains gas under pressure; may explode if heated;[29],[30]		
HFO-1234ze	**Trans-1,3,3,3-tetrafluoroprop-1-ene** CAS: Synonyms: HFO-1234ze	Press. Gas (Liq.), H280: Contains gas under pressure; may explode if heated;[31]		Seems identical to HFC-1234ze but identified with different CAS number.
HCFC-1233zd	**(1E)-1-chloro-3,3,3-trifluoro-prop-1-ene** CAS: 102687-65-0 Synonyms: HCFC-1233zd, trans-1-Chloro-3,3,3-trifluoropropene Mol. formula: C3H2ClF3	Press. Gas (Liq./ Comp.), H280: Contains gas under pressure; may explode if heated; Aquatic Chronic 3, H412: Harmful to aquatic life with long-lasting effects;[32], [33]		

[26] https://www.airgas.com/msds/001193.pdf; https://www.3eonline.com/ImageServer/ImageViewer.aspx?id=3Q%2FfAR8ne%2FvPh6syVnSymkS%2BBDo8OjmbVocxRCMEgeHholbaONwmM4XP1e1dOdcIddB5zxzJXIW7nbmF5mKrdg%3D%3D, last viewed 2.10.2020
[27] ECHA Website, Substance Infocard: https://echa.europa.eu/de/substance-information/-/substanceinfo/100.104.879, last viewed 8.10.2020
[28] Behringer et al. (on-going)
[29] https://amp.generalair.com/MsdsDocs/AG1209S.pdf, last viewed 2.10.2020
[30] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/247458, last viewed 8.10.2020
[31] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/9943, last viewed 30.11.2020
[32] https://produkte.linde-gas.at/sdb_konform/R1233zd_10030715EN.pdf, last viewed 2.10.2020
[33] ECHA Website, substance infocard, https://echa.europa.eu/de/substance-information/-/substanceinfo/100.149.148, last viewed 8.10.2020

Gas identification in FGR	Substance identifiers	Classified hazards	Derivatives and transformation products	Comments
HFE-347 mcc3 (HFE-7000)	CAS: 484-450-7 Synonyms: HFE-7000 Trade name: 3M(TM) NOVEC(TM) ENGINEERED FLUID	Not classified[34]		Substance included in CORAP; study of persistence, bioaccumulation and toxicity required Under assessment as Persistent, Bioaccumulative and Toxic together with HFE 7100, HFE 7500 and HFE 7800.[35]
HFE-449sl (HFE-7100)	**Methyl nonafluorobutyl ether (40%) and Methyl nonafluoroisobutyl ether (60%)** (mixture) CAS: 163702-07-6 Synonyms: HFE-7100 Mol. formula: C5H3F9O	Skin Irrit. 2, H315: causes skin irritation; Eye Irrit. 2, H319: causes serious eye irritation; STOT SE 3, H335: may cause respiratory irritation Aquatic Chronic 4, H413: may cause long lasting harmful effects to aquatic life[36]	PFBA, connected to the formation of persistent PFCAs (Wang et al. (2014).	Under assessment as Persistent, Bioaccumulative and Toxic together with HFE 7100, HFE 7500 and HFE 7800.[37] Found on a global list of substances identified as PFAS: per- and polyfluoroalkyl-substances[38]
HFE-569sf2 (HFE-7200)	**Butane, 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro*** CAS: 163702-05-4/ EC: 425-340-0 Synonyms: HFE-569sf6 - HFE-7200; Ethoxy-nonafluorobutane Tradenames: 3M Novec 7200 Mol. formula: C6H5F9O	H413: Aquatic Chronic 4 - may cause long lasting harmful effects to aquatic life[39], [40]	PFBA, connected to the formation of persistent PFCAs (Wang et al. (2014).	From data sheet[41]: “The material is minimally irritating to the eyes, non-irritating to the skin and is not a mutagen” “Novec 7200 fluid (C4F9OC2H5) consists of two inseparable isomers with essentially identical properties. These are (CF3)2CFCF2OC2H5 (CAS No. 163702-06-5) and CF3CF2CF2CF2OC2H5 (CAS No. 163702-05-4)”

[34] ECHA Website, summary of Classification and Labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/88844, last viewed 30.11.2020
[35] Spanish Ministry for the Ecological Transition (2019), Justification Document for the Selection of a CoRAP Substance - Group Name: Hydrofluoroethers, https://echa.europa.eu/documents/10162/e9c6cf99-9744-460d-dd64-092b99b631eb, last viewed 30.11.2020
[36] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/60626, last viewed 8.10.2020
[37] Spanish Ministry for the Ecological Transition (2019), Justification Document for the Selection of a CoRAP Substance - Group Name: Hydrofluoroethers, https://echa.europa.eu/documents/10162/e9c6cf99-9744-460d-dd64-092b99b631eb, last viewed 30.11.2020
[38] See footnote 24.
[39] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/63941 and https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/62693 , and https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/59607 last viewed 8.10.2020
[40] Data sheet for 3M™ Novec™ 7200 Engineered Fluid: https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8lzU9lYtUmxtePv7zg17zHvu9lxUb7SSSSSS--, last viewed 30.11.2020
[41] Product Information for 3M™ Novec™ 7200 Engineered Fluid: https://multimedia.3m.com/mws/media/199819O/3m-novec-7200-engineered-fluid-en.pdf, last viewed 8.10.2020

Gas identification in FGR	Substance identifiers	Classified hazards	Derivatives and transformation products	Comments
HFC-1336mzz	**(2Z)-1,1,1,4,4,4-Hexafluorobut-2-ene** CAS: 692-49-9 Synonyms: HFC-1336mzz Mol. formula: C4H2F6	Press. Gas (Liq./ Comp), H280: Contains gas under pressure; may explode if heated; Skin Irrit. 2, H315: causes skin irritation; Eye Irrit. 2, H319: causes serious eye irritation; STOT SE 3, H336: May cause drowsiness or dizziness; STOT SE 3, H335: may cause respiratory irritation; H380-May displace oxygen and cause rapid suffocation;[42]		According to ECHA data the substance is not classified.[43]
Propane	CAS: 74-98-6	Press. Gas (Liq./ Comp), H280: Contains gas under pressure; may explode if heated; *Flam. Gas 1. H220 Extremely flammable gas*[44]		
Butane	CAS: 106-97-8	*Butane: Flam. Gas 1. H220 Extremely flammable gas* *Butane (containing ≥ 0,1 % butadiene (203-450-8)): Flam. Gas 1. H220 Extremely flammable gas* ***Muta. 1B, H340: May cause genetic defects*** ***Carc. 1A, H350: May cause cancer***[45]		
	Perfluoro(2-methyl-3-pentanone) CAS: 756-13-8 Synonyms: 1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone, fluorinated ketone Trade names: NOVEC 1230 $C_6F_{12}O$	Aquatic chronic 3, H412: Harmful to aquatic life with long lasting effects[46], [47]		

[42] https://www.chemicalbook.com/ChemicalProductProperty_US_CB31515706.aspx, last viewed 2.10.2020
[43] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/223282, last viewed 8.10.2020
[44] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/124413, last viewed, 30.11.2020
[45] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/91685, last viewed, 30.11.2020
[46] https://pubchem.ncbi.nlm.nih.gov/compound/Perfluoro_2-methyl-3-pentanone#section=Safety-and-Hazards and https://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSuUn_zu8lZNe482xNx29Mv7zg17zHvu9lxUb7SSSSSS--, last viewed 30.11.2020
[47] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/110279, last viewed 30.11.2020

Gas identification in FGR	Substance identifiers	Classified hazards	Derivatives and transformation products	Comments
HFC-1224yd	**(1Z)-1-chloro-2,3,3,3-tetrafluoroprop-1-ene** CAS: 111512-60-8 Synonyms: HFC-1224yd Mol. formula: C3HClF4	Press. Gas (Liq.), Skin Irrit. 2, H315: causes skin irritation; Eye Irrit. 2, H319: causes serious eye irritation; H280: Contains gas under pressure; may explode if heated; STOT SE 3, H335: may cause respiratory irritation (lungs, inhalation); STOT SE 3, H336: May cause drowsiness or dizziness (inhalation);[48]		
HCFE-235da2 (Isofluorane)	**Isoflurane** CAS: 26675-46-7 Synonyms: HCFE-235da2 Mol. formula: C3H2ClF5O	Skin Irrit. 2, H315: causes skin irritation; Eye Irrit. 2, H319: causes serious eye irritation; STOT SE 3, H335: may cause respiratory irritation; H336: May cause drowsiness or dizziness (respiratory tract, central, nervous system/inhalation); **Rep. 1A, H360: May damage fertility or the unborn child (inhalation);** Repr. 2, H361: Suspected of damaging fertility or the unborn child; STOT SE H371: May cause damage to organs; STOT RE 2, H373: May cause damage to organs through prolonged or repeated exposure (inhalation, liver)[49]		
	Propane,1,1,1,3,3,3-hexafluoro-2-(fluoromethoxy) CAS: 28523-86-6 Synonyms: HFE-347mmz1 Trade name: Sevoflurane Mol. formula: C4H3F7O	Skin Irrit. 2, H315: causes skin irritation; Eye Irrit. 2, H319: causes serious eye irritation; STOT SE 3, H336: May cause drowsiness or dizziness (respiratory tract/organs/central nervous system/inhalation); **Resp. Sens. 1, H334: May cause allergy or asthma symptoms or breathing difficulties if inhaled;** Repr. 2, H361: Suspected of damaging fertility or the unborn child; **Rep. 1A, H360: May damage fertility or the unborn child (inhalation);** STOT RE 2, H373: May cause damage to organs through prolonged or repeated exposure (nervous system)[50]		

[48] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/253963, last viewed 8.10.2020
[49] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/substance-information/-/substanceinfo/100.043.528, last viewed 8.10.2020
[50] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/176065, last viewed 8.10.2020

Gas identification in FGR	Substance identifiers	Classified hazards	Derivatives and transformation products	Comments
HFE-236ea2 (desfluorane)	**1H,3H-Perfluoro(2-oxabutane)** CAS: 57041-67-5 Synonyms: HFE-236ea2 Trade name: Desflurane Mol. formula: C3H2F6O	Skin Irrit. 2, H315: causes skin irritation; Eye Irrit. 2, H319: causes serious eye irritation; STOT SE 3, H336: May cause drowsiness or dizziness; **Rep. 1A, H360: May damage fertility or the unborn child;** Repr. 2, H361: Suspected of damaging fertility or the unborn child; STOT RE 2, H373: May cause damage to organs through prolonged or repeated exposure (liver, inhalation) [51]		A majority of data submitters agree this substance is Toxic to Reproduction.[52]

Note: Properties of substances supported with a harmonised classification in the CLP Regulation appear in italics. Properties that would fulfil the REACH criteria for substances of very high concern appear in **bold**. Properties listed in ECHA "Summary of Classification and Labelling" represent the majority of notifications. **Notes:** *Information for HFE-7200 (Butane, 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro) is based on three separate web-pages of ECHA for the substance, two refer to the substance and its CAS number with differing EC numbers and a third to the substance and its EC number without CAS number.

[51] ECHA Website, summary of classification and labelling: https://echa.europa.eu/de/information-on-chemicals/cl-inventory-database/-/discli/details/219543, last viewed 8.10.2020

[52] ECHA Website, Substance Infocard, https://echa.europa.eu/de/substance-information/-/substanceinfo/100.214.382, last viewed 8.10.2020

Annex 9 – Annex to the efficiency section

Annex to EQ4a

Approach taken for cost assessment

Businesses directly affected by the 2014 revision of the Regulation and addressed in this cost assessment were:

- On one hand the EU ***F-gas using industries***, i.e. the ***operators of equipment*** usually relying on F-gases (or low-GWP alternatives), and
- On the other hand, businesses involved in the ***supply chain of the gases***, i.e.
  - Producers and importers of gases
  - Gas distributors
  - Service companies.

Capital expenditure (capex) and operational expenditure (opex) incurred ***by F-gas using industries*** in the evaluation period 2015 -2019 have been calculated in the AnaFGas modelling framework, both for the baseline and counterfactual scenarios. Capex and opex can be added to result in total expenditure (totex) and compared between both scenarios for all sectors of F-gases use. The spread between totex calculated for the baseline scenario and the counterfactual scenario are the 'operative compliance costs'. These can be averaged over the evaluation period and divided by the average totex of the counterfactual scenario to provide a relative increase or decrease in totex for F-gas using sectors.

Capex includes the equipment operators' investment in new hardware. In all F-gas application sectors where the gases are not directly emitted on application, the cost of the first fill of F-gases is also considered as capex, e.g. the first fill of refrigerants into a refrigeration equipment. Opex includes the cost of refill of gases into equipment (to balance losses from leakage), the cost for electricity or fuel needed to operate the equipment and maintenance cost affected by the Regulation (i.e. additional cost for leak checks and repairs as imposed for HFC installations by the Regulation, and for installations using CO_2, NH_3 or hydrocarbons as refrigerants instead of HFCs).

For a meaningful assessment of ***F-gas using industries'*** compliance cost it is crucial to differentiate compliance cost between:

a) the cost of technological change and
b) the ***cost related to HFC price increases*** induced by the HFC phase-down instrument chosen in the Regulation.

The cost of technological change is borne by those equipment operators which invest in alternatives to the established HFC-based technologies and thus possibly experience a difference in capex and/or opex.

Cost experienced by equipment operators for the first fill or refill of gases/refrigerants are split into a:

- (Counterfactual) reference price [€/kg] which does not take into account HFC price increases induced by the HFC phase-down, and
- HFC surcharge [€/t CO_2 eq] induced by the HFC phase-down and as observed on the EU HFC markets. Based on the EU HFC price monitoring conducted by Öko-Recherche, an average HFC surcharge of 8 €/t CO_2 eq at gas distributor selling price level, or 16 €/t CO_2 eq at service company selling level, is estimated as an average for the 2015-2019 evaluation period. Note that HFC taxes as charged in some EU Member States have not been considered for the analysis as such taxes are not directly related to the 2014 revision.

The counterfactual reference prices of used gases are considered for the calculation of the cost of technological change. The cost for the HFC surcharge, however, is allocated to the cost for the HFC price increase.

The cost of the HFC price increase is borne by:

- operators of existing (HFC-based) equipment which needs to refilled subject to increased HFC prices,
- operators of new installations still based on established high-GWP HFC-based technologies or on substitution technologies relying on alternative medium-GWP HFC substitution technologies.

The cost for operators of such medium HFC substitution technologies (e.g. AC equipment relying on HFC-32 (GWP 625) instead of the previously established R410A (GWP 2088)) is thus partly allocated to cost of technological change and partly to cost of increased HFC prices.

It should be noted that the HFC price increase borne by the equipment operators and F-gas users is being 'offset' (in cost-benefit analysis terms) by equivalent additional profits in the ***businesses in the supply chain of HFCs***:

- On one hand, it's the producers and importers[53] of HFCs that can sell the gases to the gas distributors at considerably higher prices than they could have done without the Regulation. Given the free allocation of quota under the Regulation, these additional revenues come without[54] associated cost.
- On the other hand, service companies usually charge their customers (i.e. operators of equipment in need of refill) a levy in proportion to bulk prices (e.g. a fixed mark-up on bulk prices) and thus fully hand down and additionally add to any upstream price increase. The same principle holds for gas distributors, situated between producers/ importers in the HFC supply chain. On average, prices per kg of gas sold at service level are approximately twice the price of gases sold by distributors at bulk level[55].

Thus, when considering both the ***equipment operators*** and the ***gas supply chain*** as the affected industries in the cost assessment, equipment operators' cost for the HFC price increases is fully offset by respective profits in the HFC supply chain, and the overall **net** compliance costs are limited to the equipment operators' cost of technological change.

[53] Importers of bulk HFCs receive quota for free. However, importers of pre-charged RAC equipment do have to acquire quota authorisation from quota holders. Thus, equipment importers are basically in the same situation like EU original equipment manufacturers (OEMs): Both have to pay GWP-based a surcharge on the HFCs charged / to be charged into equipment. Findings of the Öko-Recherche HFC prices management support that authorisation cost have been approximately at the same level as HFC prices increases experienced by EU OEMs.

[54] Except for small admin cost related to quota management.

[55] Source: EU HFC price monitoring conducted by Öko-Recherche

Detailed results tables

Table -55: Average annual FGR Revision operative compliance cost to industry 2015-2019, subsector-level

	Total equipment operators' compliance cost	thereof: cost of HFC price increase (= cost for equipment operators, =revenue in HFC supply chain)	thereof: Cost of technological change (= net EU industry compliance cost)	Total equipment operators' compliance cost
	Mio € / a	Mio € / a	Mio € / a	% of equipment operators' totex in counterfactual scenario
Domestic Refrigeration	-3.7	-	-3.7	-0.0%
Commercial refrigeration – Hermetics	-6.1	2.3	-8.4	-0.2%
Commercial refrigeration - Condensing units	92.2	88.8	3.4	1.0%
Commercial refrigeration - Central systems	491.7	405.2	86.6	5.8%
Industrial refrigeration - small	103.6	76.4	27.2	4.4%
Industrial refrigeration - large	316.6	75.8	240.8	4.5%
Transport refrigeration - Vans	7.2	7.1	0.2	1.5%
Transport refrigeration - Trucks & Trailers	51.5	46.9	4.6	0.9%
Transport refrigeration - Ships	22.1	21.0	1.2	10.5%
Room AC - Moveables	2.1	3.1	-1.0	0.5%
Room AC - Single split	201.2	190.7	10.6	0.9%
Room AC - Rooftop	90.1	85.6	4.5	0.5%
Room AC - VRF	99.3	99.2	0.1	1.5%
Minichillers	1.1	1.2	-0.1	0.1%
Displacement chillers - small	15.9	10.2	5.7	1.3%
Displacement chillers - large	94.5	73.3	21.2	1.5%
Centrifugal chillers	9.3	7.6	1.7	1.0%
Heat pumps - small	42.3	30.2	12.1	0.2%
Heat pumps - medium	27.9	24.8	3.1	0.4%
Heat pumps - large	-3.1	4.5	-7.5	-0.1%
Mobile AC - Passenger cars	271.0	271.0	-	0.2%
Mobile AC - Buses	23.2	23.2	-0.0	0.4%
Mobile AC - Trucks N1	29.3	25.1	4.2	0.4%
Mobile AC - Trucks N2	4.9	4.9	-	0.6%
Mobile AC - Trucks N3	16.0	16.0	-	0.6%
Mobile AC - Passenger ships	16.7	16.7	-	10.7%
Mobile AC - Cargo ships	11.3	11.3	-	10.7%
Mobile AC - Tram	0.4	0.4	-	0.5%
Mobile AC - Metro	0.1	0.1	-	0.5%
Mobile AC - Train	1.2	1.2	0.0	0.5%

	Total equipment operators' compliance cost	thereof: cost of HFC price increase (= cost for equipment operators, =revenue in HFC supply chain)	thereof: Cost of technological change (= net EU industry compliance cost)	Total equipment operators' compliance cost
	Mio € / a	Mio € / a	Mio € / a	% of equipment operators' totex in counterfactual scenario
Aerosols - technical	22.4	12.5	9.9	7.2%
Aerosols - MDIs	-	-	-	-
Fire extinguishers	44.8	25.8	18.9	22.0%
Solvents	1.8	1.5	0.3	11.8%
Foam OCF	-	-	-	-
Foam XPS	29.1	12.4	16.7	26.1%
Foam PU spray	26.1	21.1	5.0	15.4%
Foam PU non-spray	14.1	10.4	3.7	15.0%
Total	**2 169**	**1 707**	**461**	

Source: AnaFgas cost modelling

Annex to EQ5

Approach taken for the comparison of cost and emission reductions

As discussed in EQ4a it makes sense to separate total compliance cost of EU equipment operators / F-gases end-users into

- cost due to the HFC price increase induced by the HFC phase-down (this cost to equipment operators is counterbalanced by additional profits further upstream in the HFC supply chain), and
- cost of technological change (which are the net EU industry cost comprising both the equipment operators and the gas supply chain).

Only cost of technological change, i.e. the net cost, are directly linked emission reductions. Therefore, it makes sense to restrict the calculation of emission reduction cost for the evaluation to the cost of technological change.

However, for a meaningful comparison of the change in operative cost to equipment operators (see EQ4a) against reductions in the demand and/or emissions of F-gases (see EQ1 in the effectiveness section) the involved data sets have to be recalculated to comparable annual amounts:

In most of the F-gas sectors, a switch from an established (HFC-based) technology to a low-GWP substitution technology for a new installation implies that the demand of F-gases (measured in t CO_2 eq) is strongly reduced in the first year of operation due to the avoided or reduced first fill. In subsequent operation years of such a new installation the annual demand reduction is much lower as only the refill to compensate for leakage losses is reduced. For actual emissions avoided from such a new installation the distribution over the operation lifetime is different: Emission (and thus emission reductions) occur first in usually low quantities during the first fill of the equipment, and then as leakage emissions during the whole lifetime. The largest single emission event over the equipment lifetime, however, occurs with the disposal of the equipment as usually not the complete remaining charge of F-gases is recovered at that point in time. For a thorough assessment of emission reduction cost, the emission reductions of a single model installation (compared to a counterfactual reference installation) thus need to be averaged over the complete equipment lifetime.

The observed emission reductions in the 2015-2019 evaluation period (see EQ1 in the effectiveness section) cover the reductions observed in the first few operational years of new equipment installed in 2015-2019. The observed emission reductions thus logically cannot cover the emission reductions to be expected in the future for the remaining years of use and at the time of disposal. Therefore, the ***average annual emission reductions observed for 2015-2019 are significantly below the 'implied' annual emission reductions*** from those new installations if averaged over the complete lifetime of the installations. Typical lifetimes in the RAC sector are 10-15 years, for other equipment such as foams this may be up to 50 years.

For demand reduction it is the other way around: Due to the avoided/reduced first fill, the average annual demand reductions observed for 2015-2019 are disproportionally high compared to 'implied' annual demand reductions from those same new installation if averaged over the complete lifetime of the installations.

Recalculations from observed 2015-2019 emission reductions to implied lifetime-averaged lifetime-integrated annual emission reductions from equipment installed in 2015-2019 were made in the AnaFgas modelling framework. Recalculation factors are sector-specific and are influenced mostly by assumptions for equipment lifetime, lifetime emission factors and emission factors at disposal.

Next to emissions, costs also need to be recalculated to annual amounts in order to merge Capex and Opex (see cost assessment in EQ4a) in a meaningful way for a calculation of emission or demand reduction cost: For that purpose, Capex are annualised over equipment lifetime using a discount factor of 4%[56]. Annualised Capex and average Opex are then added to derive average annualised compliance cost for the installations operated in the 2015-2019 evaluation period.

Based on this approach, operators' ***emission reduction cost for technological change*** are calculated by dividing the annualised cost for technological change of new equipment installed in the 2015-2019 evaluation period by the implied average annual emission reductions of that new equipment installed in the 2015-2019 evaluation period. In order to allow for aggregation across sectors, lifetime-integrals of emission reductions and cost are used rather than annual averages. The emission reduction cost for technological change are methodologically comparable to GHG abatement cost usually calculated for GHG emission reduction measures in other sectors.

Detailed results tables

Table -56: Average emission reduction cost 2015-2019 (sub-sector level)

	Implied lifetime-integrated emission reductions of new equipment installed in 2015-2019 average	**Cost of technological change of lifetime-integrated emission reductions of new equipment installed in 2015-2019 average**	**Calculated emission reduction cost for technological change**
	Mt CO_2e	Mio €	€ / t CO_2e
Domestic Refrigeration	0.013	-13.3	-1 052
Commercial refrigeration - Hermetics	0.035	-26.7	-758
Commercial refrigeration - Condensing units	0.143	-2.7	-19
Commercial refrigeration - Central systems	6.938	95.9	14
Industrial refrigeration - small	1.365	20.3	15
Industrial refrigeration - large	3.684	37.1	10
Transport refrigeration - Vans	0.027	0.7	27
Transport refrigeration - Trucks & Trailers	0.543	13.2	24
Transport refrigeration - Ships	0.228	0.8	3
Room AC - Moveables	0.176	-5.8	-33
Room AC - Single split	4.146	18.1	4
Room AC - Rooftop	0.245	-11.8	-48
Room AC - VRF	0.007	0.2	24
Minichillers	0.005	-1.2	-250
Displacement chillers - small	0.052	0.5	10
Displacement chillers - large	0.342	3.8	11
Centrifugal chillers	0.055	-1.9	-34
Heat pumps - small	0.247	-24.4	-99
Heat pumps - medium	0.106	-4.5	-43
Heat pumps - large	0.137	1.8	13
Mobile AC - Passenger cars	-	-	NA
Mobile AC - Buses	0.008	2.5	334
Mobile AC - Trucks N1	0.121	9.5	78
Mobile AC - Trucks N2	-	-	NA

[56] A value of 4% is suggested in the EU Better Regulation Guidelines.

	Implied lifetime-integrated emission reductions of new equipment installed in 2015-2019 average	Cost of technological change of lifetime-integrated emission reductions of new equipment installed in 2015-2019 average	Calculated emission reduction cost for technological change
	Mt CO_2e	Mio €	€ / t CO_2e
Mobile AC - Trucks N3	-	-	NA
Mobile AC - Passenger ships	-	-	NA
Mobile AC - Cargo ships	-	-	NA
Mobile AC - Tram	-	-	NA
Mobile AC - Metro	-	-	NA
Mobile AC - Train	0.000	0.0	513
Aerosols - technical	1.359	10.3	8
Aerosols - MDIs	-	-	NA
Fire extinguishers	1.164	13.9	12
Solvents	0.026	0.3	11
Foam OCF	-	-	NA
Foam XPS	0.008	0.1	10
Foam PU spray	0.006	0.0	5
Foam PU non-spray	0.002	0.0	7
Total	**21.2**	**137**	**6.4**

Source: AnaFgas cost modelling

Annex to EQ4b - Analysis of administrative costs

There are a number of measures in the Regulation that result in some ***administrative burden*** for a range of actors. The administrative costs have been outlined for industry and public authorities, with costs linked to the specific requirements as described within the Regulation.

Costs to industry

OPC

The OPC offered some insights into administrative costs. Business associations and companies thought the costs of different measures (noting this question did not specifically refer to administrative costs only) were not excessively high, but also not marginal. By way of exception: labelling was seen as having only marginal costs, while 'restrictions on use and equipment' and the 'quota system' were seen as comparatively more expensive measures than the others (corroborating the interview responses). However, the higher costs associated with these requirements are considered to be more significantly associated with the costs of compliance, rather than exclusively administrative costs.

Overall, a majority of business associations and companies agreed that the costs of the individual measures were justified to achieve the objectives, i.e. that the benefits of action had outweighed the costs (a result which matched overall responses across all stakeholder groups).

The table below has provided a detailed breakdown of responses of business associations/organisations to the OPC question assessing the cost of each measure. The 'additional feedback provided' column provides a sample of open text responses provided by businesses/organisations through the OPC. Each statement is attributed to one business association/organisation unless otherwise stated.

Table -57: Summary of responses from business associations/organisations assessing cost implications (OPC responses)[57]

Measure	Costs identified by business associations/organisations as a significant cost: Ranked scale 1 (marginal costs) to 5 (very high costs).	Costs vs benefits identified by business associations/organisations: Ranked 1 (benefits significantly outweigh the costs) to 5 (costs significantly outweigh the benefits)	Additional feedback provided from business associations/organisations on significant costs
Containment	The responses were mixed regarding the costs of this measure: 32% of respondents considered the costs to be either marginal or low. 22% of respondents ranked the costs neither high nor low. 24% of respondents considered this to be a high or very high cost. The average score across the responses provided was 2.89.	40% of respondents felt that the benefits outweighed the costs compared to 15% who felt the costs were more significant. 20% felt that the costs and benefits of the measure were equally weighted.	*- The following feedback represents a response from a large French company specialising in providing energy and automation digital solutions for efficiency and sustainability:* *There is significant investment in equipment for control and prevention of leakage.' This is estimated to be upwards of €100,000 at plant level with respect to manufacturing energy technologies for buildings and infrastructure...* *- 'Leakage tests can result in costs of approximately €150,000 per year.' (Feedback based on a chemical company serving markets including construction, automobiles and textiles). The feedback was provided by a large chemical company and it is assumed that the costs are specific their own expenses. However, the costs are*

[57] To note, that stakeholders would not have differentiated between costs due to measures of the old 2006 Regulation and what was newly introduced by the 2014 Regulation.

Measure	Costs identified by business associations/organisations as a significant cost: Ranked scale 1 (marginal costs) to 5 (very high costs).	Costs vs benefits identified by business associations/organisations: Ranked 1 (benefits significantly outweigh the costs) to 5 (costs significantly outweigh the benefits)	Additional feedback provided from business associations/organisations on significant costs
			expected to include, but are not exclusive to admin burden.
Training & certification	Respondents provided mixed responses, with 31% believing the costs to be neither high nor low. Similar responses were provided for low/marginal costs (29%) and high/very high costs (26%). The average score across the responses provided was 3.	The vast majority of respondents (59%) felt that the benefits outweighed the costs compared to 10% who felt the costs were more significant. 18% felt that the costs and benefits of the measure were equally weighted.	*'It is clear that operators had to quickly invest in certification and training. They underwent additional administrative costs to achieve success today.' (Feedback from an organisation supporting manufacturers and professionals on the operational implementation of f-Gas regulations.)*
Recovery & producer responsibility schemes	Respondents provided mixed responses, with 27% believing the costs to be neither high nor low. Similar responses were provided for low/marginal costs (24%) and high/very high costs (23%). The average score across the responses provided was 3.	40% of respondents felt that the benefits outweighed the costs compared to 18% who felt the costs were more significant. 21% felt that the costs and benefits of the measure were equally weighted.	*'Costs and the operation of equipment to recovery, recycling and reclaim are significant.' This was a coordinated response between large business associations (inc, manufacturers of fluoroproducts and speciality materials) – signifying its impact.* *'Producer responsibility schemes create the risk of free-riders.' This view is with respect to producers involved in sectors including refrigerants, solvents and propellants.*
Labelling	A high proportion of respondents considered the costs to be marginal/low (57%), followed by neither high nor low (24%). Only 5% of respondents considered this to be a high or very high cost. The average score across the responses provided was 2.16.	48% of respondents felt that the benefits outweighed the costs compared to 11% who felt the costs were more significant. 25% felt that the costs and benefits of the measure were equally weighted.	
Restrictions on use & equipment	34% of respondents considered this to be a high or very high cost, compared to 18% which considered it to be a marginal/low cost. 23% considered the costs to be neither high nor low. The average score across the responses provided was 3.25. It is important to consider that although respondents have considered the costs to be high, the question also required respondents to consider compliance costs in their judgement.	27% of respondents felt that the benefits outweighed the costs compared to 14% who felt the costs were more significant. The largest number of respondents (32%) felt that the costs and benefits of the measure were equally weighted.	*The additional comments for this measure were focussed on compliance costs.*
HFC quota system	35% of respondents considered this to be a high or very high cost. The greatest number of respondents (16%) considered this to be	29% of respondents felt that the benefits outweighed the costs compared to 20% who felt the costs were more sig-	*'An additional resource needed for quota management and F-gas registrations / certifications (2 respondents).' This requirement for additional resource*

Measure	Costs identified by business associations/organisations as a significant cost: Ranked scale 1 (marginal costs) to 5 (very high costs).	Costs vs benefits identified by business associations/organisations: Ranked 1 (benefits significantly outweigh the costs) to 5 (costs significantly outweigh the benefits)	Additional feedback provided from business associations/organisations on significant costs
	a very high cost. 23% considered the costs to be neither high nor low and only 10% considered the costs to be marginal/low. The average score across the responses provided was 3.54. It is important to consider that although respondents have considered the costs to be high, the question also required respondents to consider compliance costs in their judgement.	nificant. 16% of respondents felt that the costs and benefits of the measure were equally weighted.	*has applied to the refrigerant and aerosol sectors.* *'HFC-quota cost is approximately €7500 per year including the report (6 coordinated responses relating to the industrial gas sector and markets including electronics and healthcare). One respondent has stated this cost to be €5000 per year.'* *'The quotas systems are effective, but costly as there are substantial costs associated with continuous monitoring of quota usage during the year.' This applies to sectors including sectors including refrigerants, solvents and propellants.* *'Monitoring of the quota system on HFCs in terms of reporting and verification represent significant administrative costs for reporting industrial (for some members, this means a person half-time during the year).' The view from the stakeholder reflects a wide range of businesses organisations across a number of sectors.* *An additional comment regarding the costs of compliance was also provided:* *HFC refrigerant price increases resulting from the HFC phase-down has led to up to 10% equipment price increase.' This increase in equipment price is with respect to manufacture of air conditioning and heating systems.*
Reporting & verification	A large proportion of respondents (37%) did not consider this to be a high or low cost. Indeed the average score across the responses provided was 2.87 indicating that respondents considered this measure a moderate cost, relative to the other measures.	33% of respondents felt that the benefits outweighed the costs compared to 21% who felt the costs were more significant. The largest number of respondents (27%) felt that the costs and benefits of the measure were equally weighted.	*'Reporting and verification systems are effective, but costly.'* *'Reporting and verification of our installations using F-gases costs: one time equivalent or 200,000 Euro/year + software servicing, data input: 200,000 €/year.' The installations refer to those implemented across a large chain of retail establishments.*
Additional feedback	*'The establishment of processes to manage the return of cylinders of HFCs. Destruction of returned mixed or not re-useable HFCs are significant (5 respondents).'* *'Transport across EU national boundaries require major documentation for each shipment (5 respondents).'* *Both above comments were coordinated responses from organisations across sectors including manufacturers of fluoroproducts and speciality materials* *'Several million Euros for replacement of high GWP provision plant units (R404a-R507)'*		

Note: Response breakdown includes all business associations/organisations which have participated in the survey. It should be noted that typically a number of participants chose the option that they were "unable to provide an answer" or did not respond to the question.

Targeted interviews

In addition to the responses to the OPC, businesses associations/organisations and Member state competent authorities were asked to provide information on the impact of the Regulation on administrative costs through a series of targeted interviews.

Only limited quantitative data was provided by business associations and organisations. However, stakeholders were able to provide some additional qualitative responses. A sample of some of the key points raised has been included in the table below.

Table-58: Sample of responses from business associations/organisations assessing the impacts on administrative costs (targeted interview responses)

Measure	Business association/organisation response to the impact upon administrative costs
Labelling and product and equipment information	**Increased costs** *'Definitely resources are required but difficult to estimate how much as it is covered by normal workload.'* **No change** *'Containers are typically re-used for the same F-gas and have historically had a number of labelling requirements the additional labelling required by the 517/2014 regulation have only added minor costs'*
Documenting compliance for pre-charged equipment with HFCs	**Increased costs** *'Definitely resources are required but difficult to estimate how much as it is covered by normal workload'*
Complying with the HFC phase-down and quota system, registration in the HFC Registry and its use for quota and authorisation management and transfer	**No change** *'The registration process is relatively quick provided you have all of the required information to hand'* **Increased costs** *'Needed to change IT systems to ensure we stay within our quota limits and to monitor compliance'* *'Resources assigned to ensure proper and timely completion with these measures. Total equivalent resource approximately = 1 FTE'* *'Managing HFC quota/ quota authorisations is quite a large drain on time as we have monthly review meeting involving several disciplines to manage our Quota, including submitting authorisations. Note we did employ a person specifically for 1-2 years to set up and manage the initial quota system'* *'Due to the undue structure and implementation of the quota process especially SMEs faced severe burdens which were not necessary to implement the actual goals of the Regulation'* *'Administrative costs increased due to the quota handling which were not necessary before. Approximately 25% of 1 employee for central organisational work'*
Reporting and verification	**No changes** '*If the internal reporting system is set up to automatically extract data from other business management systems, the preparation of the annual report is limited to routine confirming the applicability of the set up and ensuring that any changes to the reporting requirements are incorporated into the internals systems/methodology.'* '*We use a multi discipline team attending each of the verification days. We have 2-4 verification days per year plus some time spent extracting data required by the verification process.'* *Both of the above responses have been based upon a feedback from a large company.* **Dependent** *'Dependent upon how BDR works and if there are IT issues'*
Training & certification	*'Stakeholders down-the-value chain stakeholders do have a more direct cost impact, and this is expected to increase especially if/when the proper usage of all refrigerants (including non-fluorinated gases) is included in training & certification requirements, which is our recommendation. All refrigerants should be addressed to ensure safety, environmental, climate, and performance are optimized.'*

Feedback to the workshop

Following the completion of the targeted interviews, a workshop was held to present the preliminary findings of the evaluation to date. The workshop presented an opportunity to request further information from stakeholders regarding the administrative burden of the Regulation. A sample of the key views offered following the workshop have been outlined below.

Table-59 Sample of responses from business associations/organisations assessing the impacts on administrative costs (Following stakeholder workshop)

Measure	**Extent to which the actions represent a cost** Do not know / no costs / minor costs / medium costs / high costs / very high costs	Additional comments provided on the administrative burden of the measure
Prevention of F-gas emissions (Article 3 and Article 7)	High: 5 responses Medium: 3 Responses Minor: 2 responses Negative costs: 1 response	*'We employ competent staff to develop SF6 Strategies, Procedures and Processes to proactively control and minimize SF6 leakage.'* *'Most of costs are linked to voluntary actions to avoid the emissions during manufacturing of switchgears and handling of SF6.'*
Record keeping (Article 6)	High: 2 responses Medium: 2 responses Minor: 1 response	*'We use and configure IBM Maximo for purpose of record keeping and tracking. This involves cost of software expenditure, system development and configuration, ongoing maintenance and administration.'* *'No costs as record keeping is part of daily business'*
Training and certification (Article 10)	Medium: 7 responses Minor: 3 responses	*'We provide regular training to staff such as SF6 equipment top up when leaking, relevant processes and systems.'* *'Training and certification has always been a part of emission reduction program (see also existing voluntary self-commitment)'*
Labelling and product and equipment information (Article 12)	High: 3 responses Medium: 1 response Minor: 6 responses Do not know: 1 response	*'Administrative costs have risen without clear returns.'*
Documenting compliance for pre-charged equipment with HFCs (Article 14)	Medium: 2 responses Minor: 1 Response	
Complying with the HFC phase-down and quota system (Article 15 + Article 16 + Annex V + Annex VI) and registration in the HFC Registry (Article 17) and its use for quota and authorisation management and transfer	Very High: 2 responses High: 1 Response Medium: 1 response Minor: 3 responses	
Reporting and verification (Article 19)	Medium: 4 Responses Minor: 4 responses	*'The administrative activities to comply with the reporting obligation are very burdensome, due to the complexity of reporting data (too many steps in the reporting procedure in the website).'* *'As the end user of SF6 equipment, we report emissions to UK Regulatory bodies as part of our annual submissions.* *'Although costs are not applicable, voluntary reporting to the Spanish Ministry of Environment is annually made under the Voluntary Agreement.'*

Further feedback collected from industry stakeholders (which did not concern a specific measure within the table above) included: *'Local building regulations, insurances, technical experts etc. considerably increase administrative effort, necessary lead time and thus costs.'*

Additional feedback was also provided from both the OPC and the interviews with respect to the costs of complying with the Regulation measures.

- *'HFC alternatives are either more expensive, flammable, or under high pressure. Many markets outside Europe are not mature to accept new refrigerants, therefore manufacturers with significant sales outside the EU will have to design and manufacture distinct products for the EU and non-EU markets. This is adding complexity, costs and administrative burdens on EU manufacturers with the risk of lack of competitiveness for export'*
- *Approximately €100m associated with research and development for the adaption of the products and adaptation of production facilities' referring to the manufacture of central heating products such as heat pumps.*

Analysis

The table below shows the steps taken to estimate administrative cost associated with the Regulation.

The estimated costs have been calculated only for the measures which have not been included within the separate assessment of compliance costs undertaken through the AnaFGas modelling, so as to avoid any potential double-counting.

Stakeholders have provided further information explaining whether the costs would also have been incurred as a result of the 2014 Regulation and hence are additional to those already incurred as a consequence of the 2006 Regulation. Where the costs were determined to be the same under both Regulations they have been excluded.

The table sets out the assumed average expected working days for each measure, based upon the data collected through stakeholder feedback (following the workshop) and obtained during targeted interviews conducted with industry stakeholders. These estimates are then extrapolated to estimate the overall impact upon industry, based on the following logic:

- The stakeholder consultation focussed primarily upon interviews and feedback from large business organisations, and it was therefore considered that the average costs would be more representative of the costs borne by large companies.
- For some measures, the costs for large companies were expected to be equivalent to the costs borne by small and medium companies. In these instances, the costs collected through stakeholder engagement have been applied to the estimated number of companies irrespective of sizes.
- For a number of other measures, the costs are expected to vary dependent upon the level of activity of the firm, and the costs have therefore been adjusted accordingly.
    - For the majority of these measures, firms have been grouped by size based upon the ratio of different sized companies in the EEA reporting database.
    - For two additional compliance measures, firms have been grouped according to ratios established through a recent German industry survey (2019, VDKF) of service companies, with company sizes based upon the number of employees in those firms.
    - The approach selected to determine the number of companies impacted by each measure was selected based on expert understanding of the sector, data collected through the BDR reporting database, and online desk based research.

Average days per measure has been used in preference to monetary costs per measure provided by stakeholders. This choice was made given it was considered there was a risk that the monetary estimates may include costs which are 'technical' – e.g. for costs associated with the phase down, data provided by stakeholders may also have included costs of purchasing quota itself, which is captured in the modelling of technical costs.

In some cases, the average days per company per measure have been adjusted based upon expert understanding of the sector and the requirements of the measure. This is necessary as there is uncertainty around the extent to which stakeholders split out administrative burden from other compliance costs in their responses. Additionally, as noted, expert understanding has helped to differentiate costs borne as a result of the 2014 Regulation and those which also incurred through the 2006 Regulation.

The administrative burden was then estimated assuming a cost of EUR 230 per day (based on an assumed average annual salary of around EUR 50,000, and annual days worked around 220).

In the process of estimating administrative costs, the coverage of the AnaFGas model with respect to compliance costs was explored. This identified two categories of compliance costs which were not currently covered in the AnaFGas model, in part as they are similar in nature to administrative burdens (i.e. are incurred in terms of people time, rather than direct expenditure). As such, these two costs were also estimated following similar steps to the administrative burden, and are presented in Table 61 below. These are additional, and can be added to, the compliance costs estimated as part of the AnaFGas model.

Table -60 Calculation of Administrative Costs to Industry

Measure	Action	Overlap with Costs Included in Mitigation Model	Impact on costs relative to the 2006 Regulation as determined by stakeholder feedback	Estimated number of Companies Impacted	Average Working Days Reported per annum	Estimated Total Sector Working Days	Total Cost (EUR, M)
Record Keeping (Article 6)	Record keeping for each piece of leak-checked equipment New requirement for refrigerated trucks and trailers and ORCs included in the 2014 FGR	No	Increase in Costs: 4 Responses No Change/significant impact: 1 Response It has been noted within stakeholder feedback that the costs attributed to this measure have not necessarily diverged from the costs incurred as a result of the 2006 Regulation.	The extension of scope of the 2006 Regulation will require truck and trailer operators to oblige with the requirement on record keeping. The total number of companies impacted has been derived from the number of refrigerated trucks and trailers operated within the EU. The number has been derived based upon the total number of registrations of refrigeration trailers in Germany, France, Spain and Poland in 2016, as referred to in the ICCT[58]. Based upon the proportion of semi-trailers which are known to be refrigerated (based upon ICCT figures), a total number of refrigerated trailers has been estimated. Using population sizes, this figure has been extrapolated to provide an estimate for the total number of refrigerated trailers in the EU. Total: 25,752	Range reported by stakeholders (Excluding outliers): 5-12 days pa Average (Excluding outliers): 8 days per large company pa The costs per trailer operator have been revised downward and are estimated to be approximately 0.5 day per year based on expert judgement. The costs have been applied equally across all sized firms.	12,900 days pa	3
Training and Certification (Article 10)	Attending training programmes Completion of theoretical and practical tests (examination) Receiving personal certificates or company certificates	No	Increase in Costs: 1 Responses No Change/significant impact: 3 Responses	The total number of companies impacted has been based upon the number of companies which are required to ensure their employees (technicians for specialised refrigerated trucks and trailers) attend the appropriate training course.. Although the exact number is uncertain, based upon expert judgment this is expected to be approximately 5% of the number of service	Range reported by stakeholders (Excluding outliers): 5-10 days pa Average (Excluding outliers): 8 days per large company pa However, as the stakeholder costs include the costs of at-	9,400	2.2

[58] https://theicct.org/sites/default/files/publications/EU_Trailer_Market_20180921.pdf

Measure	Action	Overlap with Costs Included in Mitigation Model	Impact on costs relative to the 2006 Regulation as determined by stakeholder feedback	Estimated number of Companies Impacted	Average Working Days Reported per annum	Estimated Total Sector Working Days	Total Cost (EUR, M)
				companies in the RACHP sector (derived from a survey by AREA). Total: 9,400	tending training, which is considered a compliance cost, the costs have been revised down based on expert judgement of the administrative burden. The costs are expected to be approximately 1 day per undertaking. It should be noted the costs are expected to be a one-off cost only. The costs have been applied equally across all sized firms.		

Labelling and product and equipment information (Article 12)	Labelling of F-gas containers Labelling of products or equipment containing or relying on F-gases	No	Increase in Costs: 6 Responses No Change/significant impact: 2 Responses	The extended labelling requirements (relative to the 2006 Regulation) concern few adjustments and more details. The extension is expected to impact producers labelling F-gas containers and equipment manufacturers. The number of companies has been derived from the number of bulk producers, importers and equipment importers as provided in the 2020 EEA report. Additionally, an estimate of the number of companies manufacturing equipment within the EU has been included. Given costs will vary with levels of activity, this has then been split by size according to the split of companies in the EEA reporting database. Total: 4,699 Large: 36 Medium: 191 Small: 4,455	The administrative cost has been determined through analysis of stakeholder feedback. Due to the high average cost reported through feedback, and the known costs already incurred as a result of the 2006 Regulation, expert judgement has been used to support the final cost estimation. It should also be noted that the costs are closely related to those incurred as a result of CLP or REACH Regulations. Range reported by stakeholders (Excluding outliers): 2-50 days pa Average cost (large company): 1 days per annum Values for small and medium companies (scaled down by reporting thresholds): Small: 0.25 day pa Medium: 0.5 day pa	1,245 days pa	0.3
Admin costs linked to documenting compliance for pre-charged equipment with HFCs	Documentation of compliance and drawing up a declaration of conformity	No (if costs relate to registering & managing transactions in the registry.	Increase in Costs: 3 Responses No Change/significant impact: 1 Response	The number of companies impacted has been based upon the number of equipment importers as registered through the HFC registry. In addition, the number of EU equipment manufacturers (estimated	Range reported by stakeholders (Excluding outliers): 1-40 days pa	20,749 days pa	4.77

. HFC equipment importers (EEA) - EU equipment manufacturers.	Verification of documentation and declaration of conformity by an independent auditor Obtaining quota authorisations for equipment imports Registering in the electronic HFC registry	Cost for authorisations purchases etc are captured in technical cost modelling)		based upon expert judgement) will also be impacted. Total: 2,900 Given costs will vary with levels of activity, this has then been split by size according to the split of companies in the EEA reporting database. Large:22 Medium:118 Small: 2,749	Average (Excluding outliers): 27 days per large company pa The costs for medium sized companies is expected to be approximately half of the costs of large companies. The costs incurred by smaller companies is expected to be a quarter of those incurred by large companies.		
Admin costs linked to Complying with the HFC phase-down and quota system (Article 15 + Article 16 + Annex V + Annex VI) and registration in the HFC Registry (Article 17) and its use for quota management and transfer.*	Applying for HFC quota/declaring quota need Transfer of HFC quota (excl. purchase price) Registering in the electronic HFC registry	No (if costs relate to registering & managing transactions in the registry. Cost for quota purchases etc are captured in technical cost modelling)	Increase in Costs: 8 Responses	Quotas are required for the import and production of bulk HFC's. The number of bulk importers (1694) and F-gas producers as reported for the year 2019 in the EEA report on fluorinated greenhouse gases 2020. Total: 1701 Given costs will vary with levels of activity, this has then been split by size according to the split of companies in the EEA reporting database. Large: 13 Medium: 69 Small: 1,613	Range reported by stakeholders (Excluding outliers): 1-21 days pa Average (Excluding outliers): 15 days per large company pa The costs for medium sized companies is expected to be approximately half of the costs of large companies. The costs incurred by smaller companies is expected to be a quarter of those incurred by large companies.	6,709 days pa	1.5

Reporting and verification*	Preparation of the annual F-gas report Verification of the F-gas report by an independent auditor Submission of the F-gas report and the verification report through the Business Data Repository (BDR)	No	Increase in Costs: 7 Responses No Change/significant impact: 1 Response	The number of companies impacted has been aggregated based upon four criteria: - Number of equipment importers operating above the threshold of > 100 t CO2e (1024) - Number of bulk importers required to report (1694) - Number of bulk importers operating above > 10000 t CO2e requiring verification (179) - Number of bulk exporters require to report (112) Total: 3,009 Given costs will vary with levels of activity, this has then been split by size according to the split of companies in the EEA reporting database. Large: 23 Medium: 122 Small: 2,853	Range reported by stakeholders (Excluding outliers): 5-30 days pa Average (Excluding outliers): 13 days per large company pa The costs for medium sized companies is expected to be approximately half of the costs of large companies. The costs incurred by smaller companies is expected to be a quarter of those incurred by large companies.	10,499 days pa	2.4
Total						**61,400**	**14.1 pa**

In addition to the administrative costs outlined in the table above, stakeholders were also asked to provide feedback on the costs associated with the measures listed in Table 61. The costs for the measures below have not been captured in the AnaFGas detailed within the report.

Table -61 Additional compliance costs to Industry (not covered by the AnaFGas modelling)

Measure	Action	Impact on costs relative to the 2006 Regulation as determined by stakeholder feedback	Range of estimated Cost Per Company (Based on Stakeholder Feedback)	Number of companies impacted	Total Cost
Prevention of F-gas emission (Article 7)	Preventing emissions from production	Increase in Costs: 7 Responses No Change/significant impact: 1 Response To note responses also considered costs incurred as a result of Article 3	Cost per company has been estimated at approximately 3.5 days per year based on stakeholder feedback of combined costs for Article 3 and Article 7 and understanding of the sector.	The compliance costs associated with Article 7 are expected to impact approximately 1700 companies. This has been based upon the known number of importers of bulk gases, as determined by the 2020 EEA report[59]	0.4M
Recovery of F-gases (Article 8)	Carrying out recovery of F-gases from equipment by a certified person so that those gases are recycled, reclaimed or destroyed The requirement existed in the 2006 FGR for most sectors. Additional provision was introduced in the 2014 Regulation for refrigerated trucks and trailers	Increase in Costs: 7 Responses No Change/significant impact: 1 Response	5 – 10 days/year (excluding outliers and based upon three stakeholders) Average cost based on stakeholder feedback (Large company): 7 days/year However, for refrigerated trailer operators specifically the costs have been revised downward and are estimated to be approximately 1 days per year.	The number of companies has been set to the equivalent as the number of companies impacted by Article 6 'Record keeping'. The costs have been adjusted down to take into consideration that the measure is only an extension. The cost will only impact the refrigerated trucks and trailers sector.	5.9M

[59] https://www.eea.europa.eu/publications/fluorinated-greenhouse-gases-2020

Costs to public bodies

European Commission

An overview of the administrative costs incurred by the EU Commission have been provided in Table below. The costs have been collected through the use of a questionnaire designed to capture the administrative costs linked to the administration, implementation and enforcement of the Regulation. The costs have been provided by DG CLIMA. When providing the costs, EU Commission services noted that this was the current situation and that initially costs had been around 3.5 FTEs, increasing to 5 FTEs. It is evident from the below table that the most significant number of working days have been associated with IT related aspects of the HFC Registry, as well as providing information on the implementation of the Regulation (including compliance) to stakeholders. The costs focus on those borne by DG CLIMA and do not cover those of other services, e.g. DG TAXUD and others on illegal trade issues and building CERTEX (Single Window).

Table -62: Administrative costs incurred by the EU Commission

Measure	Working days per year
Derogation decisions (Article 11)	/
Calculation of reference values / allocation of quota (Article 16)	30 days + 20 external
IT-related aspects of the HFC Registry (Article 17) (including development & set-up, maintenance, hosting)	330 (1.5 person years) Plus hosting costs (€12.500)
Ensuring smooth functioning of the HFC Registry and the quota system: • Assessing registrations and declarations • Exclusion of illegitimate market actors • Helpdesk ("how do I?" support on using the system)	100 120 + 20 external 60
Enforcement of compliance with bulk quota	80
Enforcement of compliance of equipment importers (authorisations)	20
Publication of reports (Article 21)	20 + 15 external
F-gas Consultation Forum (Article 23)	10 + 5 external
Assuring compliance by EU Member States (e.g. infringement proceedings, EU pilots)	60
Notifications to EU Member State competent authorities (e.g. cases of non-compliance)	20
Providing information on the implementation of the Regulation (including compliance) to stakeholders	230 + 10 external
Illegal Trade incl. Single Window	60
Legal Issues incl. Court cases	160
Reporting	10 + 5 external
Monitoring the phase-down	10 + 20 external
Access to files	20
Committee meetings, implementing acts,	60
Meeting with stakeholders	30
Total	**1100 + 95 external** **EC: 5+ people: 1100 days + 330 days (IT)**

European Environment Agency (EEA)

Data was provided by the EEA regarding their costs over the implementation period.

The data provided from the EEA are based on actual EEA time recording and invoice information from EEA's contractors. The costs provided have been detailed from 2012 onward as the EEA have stated that this was the year they managed the F-gas reporting for the first time and compiled data on company-level transactions.

In preparation for the 2012 reporting round, the Business Data Repository (BDR) was developed as a shelf system to store the companies' confidential data submissions. With regard to the BDR helpdesk work, the vast majority of work is related to F-gases (approximately 80 %).

From the data it is evident that there has been a gradual increase in administrative costs since 2012 for all factors listed within the table. The greatest number of workdays have been linked to external IT consultancy support for F-gases webform.

The costs provided also highlight a spike in costs for External IT consultancy support in the year 2018. The EEA have noted that after the 2017 reporting round the old MS Access F-gas database suffered from the increased volume of data from many new companies. It was hence re-developed into MS SQL during 2018, which required a significant number of extra IT-development days.

Table -63: Administrative costs incurred by the EEA

	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020
EEA in-house F-gas thematic project management	**FTE**	0.25	0.30	0.40	0.50	0.50	0.50	0.50	0.50	0.50
EEA in-house BDR Helpdesk support (both ODS and F-gases)	**FTE**	0.10	0.10	0.10	0.20	0.20	0.25	0.30	0.30	0.25
EEA in-house IT project management	**FTE**	0.20	0.20	0.20	0.20	0.20	0.20	0.25	0.25	0.25
European Topic Centre (F-gases thematic consultancy support)	**days**	85	95	89	135	140	116	100	100	103
External IT consultancy support (F-gases webform)	**days**	n.a.	n.a	n.a.	86	133	58	710	121	158
External IT consultancy support for BDR development and maintenance	**days**	n.a.	n.a	n.a.	87	179	191	120	51	148

Member State competent and customs authorities

Targeted survey

As part of the targeted interviews, all 27 Member States were asked to fill out a questionnaire related to the administrative costs associated with the implementation and enforcement of the Regulation (see Annex 5 Consultation Synopsis). The questionnaire provided the option of reporting either time or financial outlay (average number of annual working days or average annual cost in €) and invited information around certainty of estimates.

For Member State CAs, a good base of data was collected on which an estimate of administrative costs could be made. In total 13 Member States provided information on administrative burdens, with six noting upfront costs. 13 Member States provided data on time effort required, and 9 Member States have provided data on annual financial costs.

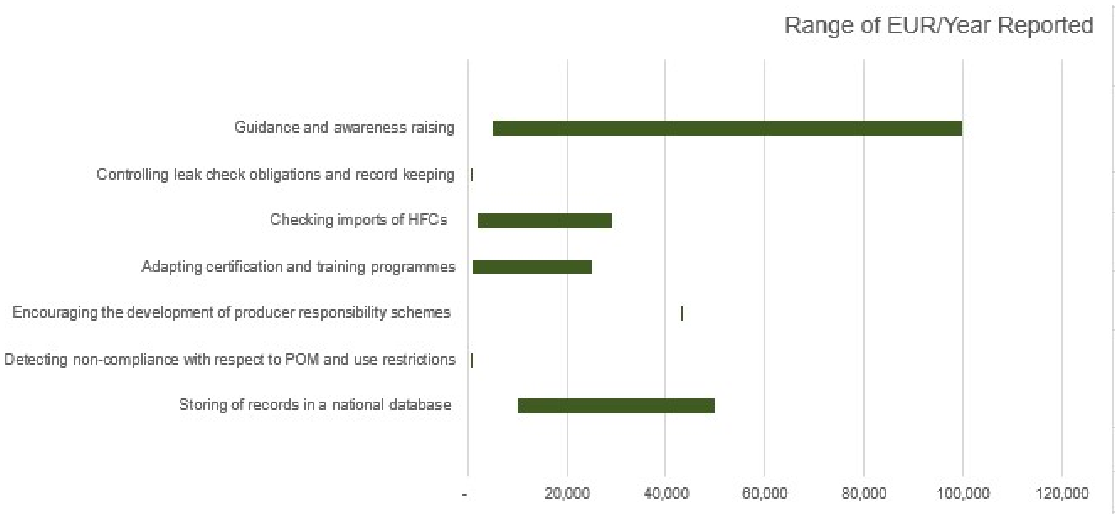
That said, the data collected carries a number of limitations:

- Not all respondents were able to provide an answer to all the questions and the figures obtained include a combination of time effort and monetary expenditure estimates.
- The level of certainty ranges from ‘definitive’ to ‘rough estimates.’
- Costs provided are unlikely to be sole estimates of the administrative burden, but also included implementation & enforcement costs. As such the data provided may represent an over-estimation of the true administrative burden as it is challenging to distinguish these costs from compliance and enforcement costs also.
- MS noted there are challenged in determining the specific costs per measure as a result of the F-gas Regulation solely have been acknowledged. For example, one Member State noted that the national inspection costs are not always solely due to inspections linked to F-gases.
- Some respondents reported overlaps in administrative efforts with the implementation of the Regulation EC 1005/2009 on ozone depleting substances while others mentioned that e.g. F-gas related inspections are usually part of general environmental inspection activities.

Figure 24**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the range of financial estimates (€) and Figure 25 presents the range of working day estimates reported by MS through the targeted interviews associated with ***ongoing annual costs***, split by measure. The tables below each Figure show numerically the upper and lower range illustrated.

For the measures where only one Member State has provided a value this has been listed as both the upper and lower range.

Figure 24: Financial estimates of recurrent administrative costs per MS per annum, linked to the implementation and enforcement of the Regulation



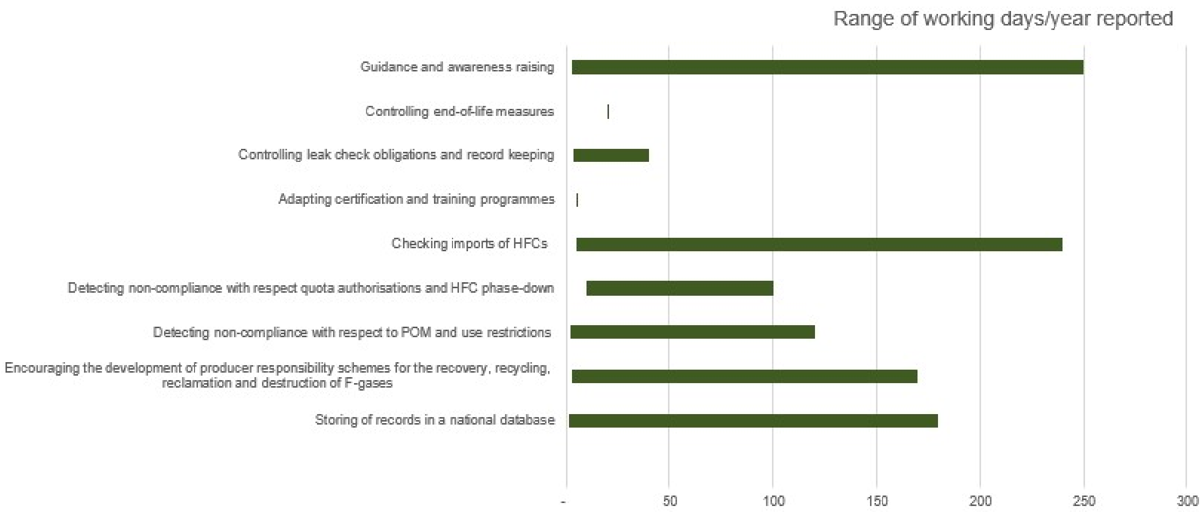
Note: In addition to the chart, costs have also been provided for the measure Conducting national inspections or checks e.g. linked to emission prevention and leakage check (Article 3 to 6) or labelling (Article 12) requirements with a reported range of EUR 15,000 – 350,000 reported.

The costs in Table 64 have been determined based upon the stakeholder feedback collected of the financial estimates of recurrent administrative costs. The lower and upper range represent the spectrum of costs provided by the Member State authorities, with the median cost determined based upon all costs provided by the stakeholders.

Table -64 Financial estimates of recurrent administrative costs per MS per annum, linked to the implementation and enforcement of the Regulation

Measure	No. Responses	Lower Range (€)	Median (€)	Upper Range (€)
Storing of records in a national database	3	10,000	25,000	50,000
Detecting non-compliance with respect to POM and use restrictions	1	600	600	600
Encouraging the development of producer responsibility schemes	1	43,000	43,000	43,000
Adapting certification and training programmes	3	1,000	5,000	25,000
Checking imports of HFCs	2	2,000	15,400	29,200
Controlling leak check obligations and record keeping	1	425	425	425
Guidance and awareness raising	4	5,000	23,500	100,000
Conducting national inspections or checks e.g. linked to emission prevention and leakage check or labelling requirements	4	15,000	40,350	350,000

Figure 25**: Time estimates of recurrent administrative costs per MS per annum, linked to the implementation and enforcement of the Regulation**



Note: In addition costs have also been provided for the measure Conducting national inspections or checks e.g. linked to emission prevention and leakage check (Article 3 to 6) or labelling (Article 12) requirements with a reported range of 3 – 2,975 days reported.

The costs in Table 65 have been calculated based upon the same approach detailed for Table 64 above.

Table-65 Time estimates of recurrent administrative costs per MS per annum, linked to the implementation and enforcement of the Regulation

Measure	No. Responses	Lower Range (days/pa)	Median (days/pa)	Upper Range (days/pa)
Storing of records in a national database	4	1	23	180
Encouraging the development of producer responsibility schemes for the recovery, recycling, reclamation and destruction of F-gases	3	3	25	170
Detecting non-compliance with respect to POM and use restrictions	4	2	30	120
Detecting non-compliance with respect quota authorisations and HFC phase-down	2	10	10	100
Checking imports of HFCs	3	5	5	240
Adapting certification and training programmes	1	5	5	5
Controlling leak check obligations and record keeping	2	4	50	40
Controlling end-of-life measures	1	20	50	20
Guidance and awareness raising	6	3	40	250
Conducting national inspections or checks e.g. linked to emission prevention and leakage check or labelling requirements	10	3	144	2,975

In addition to the annual costs outlined above, respondents provided estimates for a range of ***one-off costs***, including: for setting up a database for storing records (Article 6 of the Regulation), and establishing a reporting system for emissions data or a joined database. It should be noted, however, that the cost of establishing the reporting system is not unique to the F-gas Regulation, nor is it fully prescribed, but will also be incurred as a result of EU Monitoring Mechanism regulation.

The table below shows the range of one-off costs or ranges reported by the respondents. Given that Member States had the opportunity to report either financial estimates or working days, the ranges for a measure can vary dependent upon the costs provided by different Member States. To note:

- Italy reported significant costs (€560,000) for the storing of records in a national database and establishing reporting systems for emissions data. The costs have not been included in the table below as it was noted that the costs also included the ongoing management of the databases.
- There is a relatively high number of working days provided by stakeholders associated with reporting requirements. One explanation is that this could be as a result of stakeholders also considering the effort of establishing the measures themselves, rather than solely the reporting requirements.

Member States reported a total of approximately €1m upfront costs, with seven Member States providing a financial cost estimate for those measures considered to incur a one-off cost. This figure excludes the costs provided by Italy for the reasons noted below.

Table -66: Examples of one-off administrative costs reported by national competent authorities

Measure	Cost (Range Reported)
Reporting to the EU Commission (e.g. Articles 9, 10, 25)	320 – 1,000 (EUR) 1 – 50 (days)
Storing of records in a national database	50,000 (EUR) 1 – 180 (days)
Establishing training and certification programmes for service technicians carrying out F-gas related activities	15,000 - 170,000 (EUR) 2.5 – 300 (days)
Establishing reporting systems for emissions data (Article 20) and national database	20,000 - 226,000 (EUR) 2.5 – 180 (days)

Analysis

Given that cost data was only provided by a sample of MS, it was necessary to extrapolate the cost data to produce an illustration of the total administrative burden over the study period.

Two means of extrapolation were considered. We first considered extrapolating from the 'median' costs per measure provided by MS. However, this method was considered a less robust approach.

Instead, it was decided to first aggregate the costs from those MS that provided cost data, and extrapolate from this partial total to an overall total using the number of reporting companies in each Member State[60]. The aggregation of the costs was based upon the stakeholder feedback collected as detailed in Tables 64 and 65, with the costs used all falling within the ranges outlined in each table. The costs for the Member States which had not reported were then determined based upon the relative to the proportion of reporting companies based in the Member State to the EU-total. This approach considering the total number of reporting companies has been applied to the majority of measures as this was considered to provide the most accurate basis for extrapolating the costs. However, where appropriate, in some cases the extrapolation has been based upon the number of reporting importers within Member

[60] EEA report - Fluorinated greenhouse gases: Data reported by companies on the production, import, export and destruction of fluorinated greenhouse gases in the European Union, 2007-2019, 2020, 2020, EEA

States. This approach is an approximation and may be more valid for some measures than others. Indeed, the distribution of undertakings across MS affected by each specific measure may vary between measures. By applying the MS distribution of undertakings in the Registry, we implicitly assume that for all other measures, the distribution of undertakings affected across MS is the same. However, no other complete dataset detailing the distribution of the number of undertakings affected by a particular measure is available: many (21) Member States did provide numbers of persons trained and certified for example, but without a full dataset covering all 27+UK Member States, this data cannot be used to fill the gaps in the administrative cost database.

MS provided cost estimates both in monetary terms, and expressed as days per measure. The coverage of the samples provided for each varied across MS and measures. For comparison, we have calculated the administrative burden using each separate data set applying the extrapolation approach described above.

This results in the following estimates of ***annual ongoing administrative burden***:

- Using monetary cost data provided, the total yearly costs across all Member State competent authorities and across all **measures is estimated to be 8.8 million €**
- Using days worked data provided, the total yearly costs across all Member State competent authorities and across all measures is **estimated to be 58,300 working days** to ensure compliance with the Regulation (including small costs associated with guidance and awareness raising).

From the data collected the aggregation of working days has led to a slightly greater cost than the aggregation of the financial costs provided: as an illustration, combining 58,300 days with an illustrative cost per day of €230 per day gives a total cost estimate of €13.4m. It is unclear as to the exact reasoning behind this, although a larger dataset was gathered for the working days associated with each measure.

One of the most significant costs reported is linked to conducting environmental inspections. The bulk of the cost is associated with the need for local authorities to check smaller companies on leakage-related aspects while undertaking other environmental checks. Sweden, for example, reported the involvement of 280 local and 20 regional authorities with a total estimate for inspection work of around 1,450 working days per year, with Poland also estimating a high cost for this measure. In Sweden, these costs comprised of implementation and enforcement activities associated with controlling leak checks obligations, record keeping and controlling end-of-life measures. Considering this, and given that some Member States only included national costs linked to inspections while others covered local and regional authorities, the enforcement cost category is excluded from the overview in Figure 24 and 25. For additional context, **total costs calculated excluding inspection costs, have been estimated to be €7.6m, or 49,600 working days**.

It is important to note, prior to the 2014 Regulation requirements existed around some of the measures, such as the controlling leak check obligations, record keeping and controlling end-of-life measure. As such, where Member States report such costs, it may be that not all of these are 'additional' relative to the activities they had to undertake under the prior 2006 Regulation. A final point to note is that there are some synergies with Waste regulation with respect to encouraging producer responsibility schemes. As such, not all costs reported by Member States in order to encourage the development of producer responsibility schemes for the recovery, recycling, reclamation and destruction of F-gases (Article 9) may strictly be attributable to the F-gas Regulation specifically.

In terms of upfront costs, Member States provided both financial and time cost estimates. In addition, on review of the evidence provided and the nature of the measures, expert judgement was applied to denominate some of the costs reported as ongoing instead as upfront. As a result, the analysis concludes for upfront administrative burden that:

- Member States reported a total of approximately **€1m upfront costs**, with seven Member States providing a financial cost estimate for those measures considered to incur a one-off cost. This figure excludes the costs provided by Italy for the reasons noted below and has not been extrapolated to all MS.
- Alternatively, Member States expended an **estimated 20,100 working days initially** as a result of the measures. This figure reallocates some of the costs reported as ongoing, and has been extrapolated following the methodology applied to ongoing costs.

Annex 10 – Technical background

Technical background information on the use of F-gases and alternatives to F-gases in the different application sectors is summarized here.

Refrigeration

New refrigerants

The measures set out in the EU F-gas Regulation led to the development and introduction of a number of new refrigerant blends with lower GWPs than the conventional refrigerants, mainly consisting of HFCs, HFOs and possibly also other components such as natural refrigerants.

The following table provides an overview of common refrigerant blends introduced in recent years but does not constitute a full list.

Table -67: Overview of a selection of HFO-HFC blends

Blend name	GWP	Safety group	Composition	Replacement for
R448A	1387	A1	HFC-32: 26 % HFC-125: 26 % HFC-134a: 21 % HFO-1234yf: 20 % HFO-1234ze: 7 %	R404A, R507, R407A
R449A	1397	A1	HFC-32: 24,3 % HFC-125: 24,7 % HFC-134a: 25,7 % HFO-1234yf: 25,3 %	R404A, R507, R407A
R450A	605	A1	HFC-134a: 42 % HFO-1234ze: 58 %	R134a
R452A	2140	A1	HFC-32: 11 % HFC-125: 59 % HFO-1234yf: 30 %	R404A, R507
R452B	698	A2L	HFC-32: 67 % HFC-125: 7 % HFO-1234yf: 26 %	R410A
R454A	239	A2L	HFC-32: 35 % HFO-1234yf: 65 %	R404A
R454B	466	A2L	HFC-32: 68.9 % HFO-1234yf: 31.1 %	R410A
R454C	148	A2L	HFC-32: 21,5 % HFO-1234yf: 78,5 %	R404A, R507
R455A	148	A2L	HFC-32: 21,5 % HFO-1234yf: 75,5 % R744 (CO_2): 3 %	R404A, R507
R469A	1357	A1	R744: 35% HFC-32: 32.5% HFC-125: 32.5%	R23
R470A	980	A1	HFC-32: 17% HFC-125: 19%	R410A

Blend name	GWP	Safety group	Composition	Replacement for
			HFC-134a: 7% HFC-227ea: 3% HFO-1234ze(E): 44% R744 (CO_2): 10 %	
R470B	743	A1	HFC-32: 11.5% HFC-125: 11.5% HFC-134a: 3% HFC-227ea: 7% HFO-1234ze(E): 57% R744 (CO_2): 10%	R404A, R507
R472A	353	A1	HFC-32: 12% HFC-134a: 19% R744 (CO_2): 69%	R23
R473A	1831	A1	HFC-23: 10% HFC-125: 10% HFO-1132a: 20% R744 (CO2): 60%	R23
R513A	631	A1	HFC-32: 44 % HFO-1234yf: 56 %	R134a
R514A	13	B1	HC-1130E: 25.3 % HFO-1336mzz(Z): 74.7 %	R132, R245fa
R515B	293	A1	HFC-227ea: 8.9 % HFO-1234ze(E): 91.1 %	R134a

Domestic refrigeration

Domestic refrigerators and freezers, including combined products of refrigerators with small integrated freezers, are hermetically sealed units operating with a standard vapour-compression technology. Not-in kind alternatives, e.g. absorption refrigeration, where the energy for cooling is derived from a heat source, exist but they are much more costly and uncommon.

Back in the 1980s, the common refrigerant in domestic refrigeration used to be the ozone-depleting substance R12, which was then regulated under the Montreal Protocol. While R134a was introduced as replacement in certain countries, R600a (isobutane) quickly became the alternative of choice in Germany and other European countries. At international level, major manufacturers converted their production to R600a since 1993 and today hydrocarbon technology accounts for around two thirds of the global annual production of domestic refrigerators and freezers. Also, research on the potential of R1234yf as replacement for R134a was performed.

Hydrocarbons have proven to be an energy efficient alternative to R134a.

In the EU, the placing on the market of domestic refrigeration equipment containing HFCs with GWP of 150 or more was banned according to the F-gas Regulation from 2015 but had been uncommon in most EU Member States already many years before. Hence the HFC bank contained in domestic refrigeration equipment in the EU is considered to be rather low.

Commission Regulation (EU) 2019/2019 (since March 2021 replacing Regulation 643/2009) establishes ecodesign requirements for the sale or putting into service of refrigerating appliances with a capacity of between 10 and 1,500 litres. These rules are obligatory for all manufacturers and importers wishing to sell their products in the EU. For the first time, the ecodesign measures include requirements for reparability and recyclability, which will contribute to circular economy objectives by improving the life span, maintenance, re-use, upgrade, recyclability and waste handling of appliances.

Delegated Regulation (EU) 2019/2016 lays down rules on the labelling of, and supply of additional product information on domestic refrigeration appliances. Energy efficiency classes and related labels are established.

Commercial refrigeration

Stand-alone units (hermetically sealed)

This category refers to hermetically sealed stand-alone equipment in general and thus includes appliances for commercial and domestic use.

Chilled and refrigerated appliances are commonly used in convenience stores, supermarkets of varying size, cafes, restaurants, canteens and other places. They are hermetically sealed units equipped with a complete refrigeration circuit that only necessitates a power supply. Examples of hermetic units for commercial use are refrigerated display cabinets, beverage coolers, small ice cream freezers and vending machines.

In the past R404A and R134a were mainly used as refrigerant in these units and in the case of vending machines, only R134a. However, In the last 10 years, there has been a conversion from R404A and R134a to R290 (propane) and R600a (isobutane), mainly in units with smaller charge sizes (<0.15 kg), but lately also in larger units with charges of up to 0.5 kg. The units are found to be particularly energy efficient and can also be linked to a water-loop in some cases. According to Annex III to the F-gas Regulation, the placing on the market of hermetic units for commercial containing refrigerants with a GWP over 2500 is banned since January 2020. From January 2022 onwards, refrigerants with a GWP over 150 are also prohibited.

The market share of R290 units is growing fast and is assumed to reach 85% in Germany by 2025 (UBA 2020, p.29), which is likely also in other Member States. The number of R290-based stand-alone units in the EU in 2020 ranges > 10,000[61]. Manufacturers are expecting a push towards hydrocarbons in this application once the EU standards will be harmonised with international standards allowing for charges of up to 0.5 kg, which is assumed to take place in the first half of 2021. R744 (CO_2) is also an option for vending machines and solutions have been developed for bottle coolers but are not very widespread.

Furthermore, as an alternative to R404A the HFC-HFO blends R448A and R449A are being used by some manufacturers. In addition, the HFC-HFO blends R454C and R455A (GWP 148) have been announced as potential replacements for R404A. Both blends contain a large percentage (>75%) of HFC-1234yf and are classified as flammable according to the ASHRAE Standard 34 (class A2L, “lower flammability”)[62]. However, few suppliers seem to be using these refrigerants in their appliances to date.

For commercial refrigeration equipment with direct sales function, energy efficiency requirements are established in Regulation 2019/2024[63] and energy labelling requirements (Commission Delegated Regulation 2019/2018[64]) apply for small commercial units for direct sale from 1 March 2021 onwards.

Further to stand-alone equipment for commercial use, this category also refers to a variety of small hermetic appliances containing HFCs that could be used in both, domestic and small commercial environment. For most of these small appliances, models running on HFCs are still being produced and

[61] Chillventa eSpecial 2020: Presentation by Emerson, 13.10.2020.

[62] ANSI/ASHRAE Standard 34-2019, Designation and Safety Classification of Refrigerants

63 Commission Regulation (EU) 2019/2024 of 1 October 2019 laying down ecodesign requirements for refrigerating appliances with a direct sales function pursuant to Directive 2009/125/EC of the European Parliament and of the Council (Text with EEA relevance.)

[64] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R2018&rid=8

marketed but hydrocarbons, notably R290, were mentioned as technical trends by the industry association Applia. The types of appliances include for example:

- Ice cream makers (gelato makers): HFC refrigerants are R134a and R404A, however R600a has been introduced in 2015 by some manufacturers. The refrigerant charge ranges below 0.1 kg for HFCs and at 0.02 kg for R600a.R290 is also said to be introduced.
- Water coolers and carbonate stream soda makers: The main HFC refrigerant is R134a. Models running on R290 were already introduced on the EU market by the Italian manufacturer Blupura in 2010. They are particularly energy efficient (up to 75% saving in electricity[65]).
- Milk coolers at larger coffee machines
- Heat pump appliances: Heat pumps were introduced to appliances to reduce electricity consumption.
    - Tumble driers: Heat pump tumble driers have been on the market since about 2000 and dominate the market today[66]. The main refrigerants used to be R134a and R407C (charges 0.2-0.5 kg). Since ca. 2015 also units containing R290 (charges 0.15 kg) are being offered. Some manufacturers also started using R450A in recent years (e.g. Whirlpool[67]).
    - Dishwashers: Heat pump dishwashers were introduced on the market in 2014 by the Swiss manufacturer V-Zug and subsequently other manufacturers. This type of equipment is commonly found in canteens, restaurants, cafeterias etc. These units are using R134a (charge ca. 2.5 kg), one manufacturer (Hobart) announced a shift to R513A in 2020.
    - Washing machines: Heat pump washing machines have been on the market since 2016 and also use R134a (Swiss manufacturer V-Zug[68]).

While lifetime emissions of these appliances are low, refrigerant recovery at end of life could become problematic in many cases as small refrigerant quantities can hardly be recovered at reasonable cost, if technically feasible at all, and are thus be fully emitted. In most Member States, WEEE schemes are not set-up to perform refrigerant recovery from a variety of electric products other than refrigerators, freezers and possibly air conditioners. Furthermore, the labelling requirements of the F-gas Regulation are not applied to all of these equipment categories.

Condensing units

Condensing units exhibit refrigerating capacities ranging typically from 1 kW to 20 kW and are typically composed of one (or two) compressor(s), one condenser, and one receiver. The units are normally located external to the sales area and the cooling equipment consists of one or more display case(s) in the sales area and/or a small cold room. Condensing units are common for bakeries, butchers and small convenience stores. In the past, R404A and R134a were commonly used for this application.

However, according to Annex III, point 12 of the F-gas Regulation, stationary refrigeration equipment that contains HFCs with a GWP of 2500 or more is banned from placing on the market in the EU since January 2020 (equipment for cooling below -50 °C is exempted from this prohibition).

As a replacement for R404A, the industry introduced HFC-HFO blends such as R448A and R449A, both blends with GWPs slightly below 1400. Also, R513A was introduced as a replacement for R404A and R134a and R450A as a replacement for R134a. While both R513A and R450A have much lower GWPs than R448A or R449A, further replacements with lower GWPs of 148 were introduced in the

[65] http://www.hydrocarbons21.com/articles/blupura_presents_new_range_of_r290_water_coolers
[66] In Switzerland, tumble driers must be equipped with heat pump technology since 2012.
[67] https://www.honeywell-refrigerants.com/europe/?press_release=honeywell-solstice-n13-refrigerant-deployed-by-whirlpool-in-heat-pump-tumble-dryer-range
[68] https://www.vzug.com/medias/sys_master/root/h4f/hd8/8845152190494/Press-release-WA-AdoraSLQ-WP-2014-e.pdf

form of R454C and R455A. Both blends contain over 75% of the unsaturated HFC-1234yf but pure unsaturated HFCs, mainly R1234yf and R1234ze(E), are also marketed.

R744 and hydrocarbons, such as R290 (propane) and R1270 (propene), are natural refrigerant solutions for condensing units: New R-744 condensing units have become commercially available in Europe in recent years from several manufacturers (e.g. Green&Cool, Danfoss, TEKO, Area Cooling Solutions, Daikin Europe...) and are getting increasingly popular for units with larger capacities. For condensing units with small cooling capacities, hydrocarbons are the preferred choice. In both cases, trained personnel are necessary for installation and servicing, which could be a limiting factor for the present and near future.

Ecodesign requirements for condensing units (MT <50 kW, Lt <20 kW) are set out in Commission Regulation 2015/1095[69] which increased the previously existing Minimum Energy Performance Standards (MEPS) from July 2018.

Distributed systems where multiple condensing units in the vending area individually service more than one display cabinet are becoming more common in Europe nowadays. These multifunctional systems employ compact condensing units often with an air conditioning functionality typically occur in convenience stores and some small supermarkets with cooling capacities of less than 40 kW. - **In water-loop self-contained systems**, each cabinet is equipped with its own evaporator, compressor, expansion valve, water-cooled condenser, and often an inverter. Water circulated in a loop and cooled in a central chiller is connected to each cabinet condenser and used for heat rejection from the cabinet. Two water loops are provided: a MT and a LT loop. In most systems, a dry cooler is used to provide free cooling (e.g., cooling from 25 °C to 20 °C) to the water loop. Should the external temperature be too high to cool down the water loop, the dry cooler fans are turned off and the water is cooled by a water-to-air chiller located downstream of the dry cooler. Furthermore, the system can be implemented with a water-water heat pump so that if some heating is required, the dry cooler fans are turned off and the water is employed as the heat pump cold source. Thus, the water loop is cooled down as required, operating at the same time as heat recovery.

The main advantages of water-loop systems have been identified as a lower required compression ratio, independent for each cabinet, lower pressure drops in the lines, and heat recovery via a heat pump. At the same time, the above advantages are partly offset by pumping energy and the existence of a double refrigeration cycle. The initial cost of investment is estimated to be about 30% higher than for the conventional multiplex, due to the need for a LT chiller and a heat pump, and the higher specific cost of compressors (several compressors are required, one for each cabinet, even if at lower capacity). This higher cost of investment is partly counterbalanced by a lower installation cost. In fact, as the compressors and the refrigeration piping are contained in the cabinet, the cabinet manufacturer can carry out several of the installation operations and thereby standardizing the process. In water-loop systems, hydrocarbons are commonly used.

For small store formats, a heat-pump based solution has been developed and introduced in recent years, which combines heating and cooling. A charge of below 5 kg of R290 is used in several cooling (ESyCool Green by Viessmann).

Centralized systems

For large cooling requirements in supermarkets and hypermarkets, display cases and storage rooms are connected to a central refrigeration system, usually in a dedicated machine room. Centralized systems can be directly connected to display cases and condensers or consist of two refrigeration circuits, one for low temperature (LT) cooling for frozen foods (-20 °C) and one for medium temperatures (MT) for chilled foods (4 °C). Such systems are usually split in two cascading circuits with different refrigerants in the primary and secondary circuit.

[69] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R1095&from=de

According to the F-gas Regulation, Annex III, point 12, does no longer allow for the use of HFCs with GWP of 2500 or more in stationary refrigeration equipment (except equipment intended for ultra-low temperature cooling at temperatures below -50°C).

Furthermore, Annex III, point 13, from January 2022, for systems with a capacity over 40 kW, the refrigerant may not exceed a GWP of 150, with the exception of cascading systems, where the refrigerant in the primary circuit can have a maximum GWP of 1500.

R404A (R507A) and R134a were the most relevant refrigerants in centralized systems in the past but are now being replaced by unsaturated HFC-blends, namely R448A, R449A, R450A and R513A, but also by R744 which might be used either for the entire system or the low temperature stages of cascade systems. Transcritical CO_2 systems can be used in colder climates and R134a/CO_2 cascade systems in warmer areas. The market share of CO_2 centralized supermarket systems in the EU is estimated by industry experts at ca. 15% in 2020.

R717 (ammonia) is another natural alternative but this option is rarely found on the European market. There also seems to be current development on the use of systems with R454C and R455A but no widespread use.

For retrofit of existing systems, R448A and R449A have been used widely in the last 2-3 years, but also R513A to some extent. A new refrigerant option, R470B (GWP 717) might become also relevant in the next years but seems to be hardly used so far.

In some cases, smaller supermarkets also switched to stand-alone units running on hydrocarbons or water-loop systems, just as it has been common for discounters for many years.

Ultra-low temperature refrigeration

Ultra-low temperature (ULT) refrigeration systems can be defined as equipment delivering temperatures below -50°C and down to around -100 °C. Overall, ULT refrigeration represents a niche as the number of units for this application is relatively low compared to refrigeration above -50°C. Typical application areas include freeze-drying, cooling in pharmaceutical, chemical and petrochemical industry as well as material research. ULT systems are excluded from the scope of certain measures addressing other refrigeration systems set out by the EU F-gas Regulation such as the placing on the market prohibitions of Annex III. They commonly used refrigerants R23 (GWP 14800) and R508 (GWP 13,396) are hardly available on the EU market any more due to the high quota needs. Research has been performed lately to identify and commercialize alternatives also for this application.

In 2020, the testing chamber manufacturer WeissTechnik developed the refrigerant blend R469A (GWP 1357) as an alternative to R23 for the temperature range to -70°C. The blend is classified as A1 refrigerant and is composed of 35% R744, 32.5% R32 and 32.5% R125. It is used in testing chambers for climate simulations which require wide temperature ranges. Such systems are small with comparably low charges.

In the literature R1132a[70] (GWP <1), R1270 (ethane, GWP 5.5) and R1150 (ethylene, GWP 4) are considered suitable alternatives to R23 for certain applications (Mota-Babiloni et al 2020). For ULT transport refrigeration, R744+R41 and R744+R1132a blends provide capacities close to R23 while also having GWPs less than 150. Temperature glides are less than 2 K however these alternatives are both flammable. As regards R469A, the capacity was found to be significantly lower than R23 which might not turn it into an ideal alternative. A new, proprietary so-called “BlendA” refrigerant was found to offer a reasonable match to R23 capacity with only small impacts on efficiency (modest temperature glide of 3 K). Still, its GWP of 1830 is relatively low and A1 (non-flammable) prospective classification make it

[70] R1132a is relatively new to the refrigerant sector but is currently produced in large quantities as a major component in the manufacture of PVDF fluoropolymers.

an attractive option. Heat exchanger designs and choice of upper stage refrigerant would need to be optimized. (Kujak & Schultz 2020)

Concerning natural refrigerants, literature finds that flammable alternatives based on methane, ethane and ethylene are available but are not viable for all applications due to their flammability. Carbon dioxide cannot be used for applications below -50 °C due to CO_2's triple point at -56 °C. Nitrous oxide with a triple point at -92 °C seems to be an alternative. However, possible exothermal decomposition of N_2O calls for additional measures to be able to operate such systems safely. In latest research work, two low-temperature systems have been developed, built and successfully operated at evaporation temperatures down to - 80 °C with mixtures of N_2O and CO_2 (GWP < 300 but ODP 0,017) and different lubricants. The units achieved similar energy efficiency as the standard HFC-equipment used for freeze drying. Possible decomposition of N_2O could successfully be supressed by various measures. (Kauffeld et al. 2020)

Furthermore, air (R729) has been identified and successfully tested as feasible technical option for certain applications within the temperature range of -40°C to -160°C. This type of technology has been trialled for various special applications and R729 systems are commercially available for freeze-drying, medical applications and storage of medical products (Mirai Intex, Coolinn, Hof Sonderanlagen), which also represent rather small units/quantities.

In 2021, two new blends were announced so far:

R472A (GWP 353; 69% CO2/ 19% R134a/ 12% R32) by Angelantoni, an Italian manufacturer of environmental test chambers, is said to be an easy retrofit solution for existing R23 units for temperatures down to -70°C without any modifications to the system and with no adverse effect on performance. R472A is also said to be proven to be compatible with the components used in R23 cascade refrigeration plants.

R473A (GWP 1830; 10% R23/60% CO2/20% R1132a/10% R125) by the manufacturer Koura is classified as A1 refrigerant and designed to achieve high performance in high value cold chains, biomedical storage, climate test chambers, deep sea shipping and other medical uses. It is said to be effective to at least -75°C and said to offer better capacity and energy efficiency than R23. R473A has been designed for new systems but is currently tested for conversion of existing R23 systems.

Further research on alternatives for ULT applications of various temperature ranges is ongoing.

Industrial refrigeration

In industrial refrigeration in in the EU ammonia (R717) is the main refrigerant, especially for large installations. The 2014 UNEP RTOC assessment report (p.102) estimated the share of R717 use in large industrial installations to range at 90% in Europe and Russia. For small industrial refrigeration installations, the proportion of R717 is estimated at 25% in Europe but variations within Europe are mentioned, e.g. "for example, the use of R717 in small industrial systems is quite common in Germany, but not in France" (p.103). HFCs (R404A, R507A, R134a) thus account for larger market shares in the small refrigeration installations compared to large systems. The market for large systems in the EU is about 4 times the market of small systems (based on market value).

In the last five years, a shift from high-GWP refrigerants such as R404A and R507 towards F-gas alternatives with lower GWP has been observed. New refrigerant options in small industrial applications in DX systems have been investigated by Cohr Pachai et al. 2018 and include

- R134a alternatives such as R513A, R450A, R513B, R456A, R1234yf, R1234ze
- R404A alternatives such as R448A, R449A, R454A, R454C, R457A, R444B, R1234ze
- R410A alternatives such as R32, R447B, R452B, R454B, R459A.

In 2020, R450A, R513A and R1234ze are already common technical solutions and are considered in the model.

Furthermore, options include R744 or glycol in secondary systems and R290 is starting to be used in small systems. Recent research found also that the increasing availability of components for higher capacities with CO2 allows shifting the technical boundaries between CO2 and NH3 to higher capacities. Moreover, the investment costs for CO2 boosters equipped with ejectors are already below those of conventional ammonia systems so that R744 represents a cost-effective alternative in certain applications, e.g. food industry.

As R12334ze compressors can be used to -20°C and this refrigerant is considered for cold stores and other applications with storage temperatures below 0°C +/- 3°C or lower. It is also suitable for the high stage of a CO2 system. Since R717 is used in similar applications, it was found relevant to compare R1234ze and R717 and they were found to be rather comparable in terms of COP (Cohr Pachai et al. 2018). Further options relate to solutions in combination with CO2 such as R7171/R744, R290/R744, R1234ze/R744 or R513A/R744 along with CO2 only systems (in case ambient temperatures allow).

Road transport refrigeration (mobile refrigeration)

Transport refrigeration relates to refrigeration systems in vans, trucks and trailers as well as reefer containers. Leak rates tend to be higher in transport refrigeration as compared to stationary applications due to the increased level of vibration in motion.

As for refrigerated vans, R134a and R404A used to be the main refrigerants of choice. R452A (GWP 2141; from ca. 2015 onwards) and R513A were introduced in recent years in this application by major manufacturers.

For trucks and trailers, R404A, R134a and to limited extent also R410A (e.g. Frigoblock company since 1997) used to be main refrigerants in the past. The F-gas Regulation addresses this application in provisions for leakage control. Alternatives include R452A as well as R513A.

For existing equipment, the 2018 RTOC report underlines "With the progress of F-gas regulation it is reasonable to expect that availability of R452A will be reduced, and new alternatives may be required. New refrigerants R448A and R449A stand out as lower GWP (approx. 1,400) options, requiring system changes with various degree of complexity (typically addition of liquid injection to limit discharge temperatures)" (p.126).

Research and development of further solutions based on natural refrigerants have been carried out in parallel since and resulted in certain options such as **R744** and **R290** although concerns related to flammability, availability and efficiency continue to exist.

For new equipment, solutions relying on R744 are available although the efficiency of R744 continues to prove higher than incumbent refrigerants at low to moderate ambient, but inferior, when compared to R404A at medium to high ambient temperatures. For this reason, the first truck and trailer commercial applications of R744 are located in moderate ambient regions in small numbers.

Refrigeration powered by evaporation of cryogenic liquids is also commercially available – around 2,000 units operate in Europe, from manufacturers including Frostcruise (Linde, UK), blueeze (Air Liquide, France), Frappa Trailers (France), and Cryotherm (Germany).

Ship refrigeration (fisheries) (mobile refrigeration)

Most fishing vessels in the EU are used for coastal fishing and are not equipped with refrigeration systems. In contrast, larger vessels feature refrigeration and often also freezing systems. The typical refrigerants for this application used to be R404A (new systems built after ca. 2000).

In recent years cascade systems became introduced (CO_2 for LT, HFC for MT) in new systems and are gaining market shares. In Norway, transcritical CO_2 systems are being promoted. Furthermore, ammonia systems are commercially available and used to some extent. In addition, small, compact chillers running on R1234ze and R513A are being offered as options for marine applications.

For existing systems, retrofit options include R407F.

Reefer containers

In the past, refrigerated containers were relying on R134a and R404A. Due to challenges related to the worldwide travel and servicing needs that must be possible at all destinations, research focussed on non-flammable lower GWP alternatives in recent years. R513A, R513B, and R456A are potential candidates for replacement, and R513A seems to attract most interest.

Also, R744 has been researched thoroughly since 2011 and is available from at least one major manufacturer. However, an efficiency gap at high ambient temperatures and a still limited component supply seem to limit the market uptake.

While no solutions with flammable or mildly flammable refrigerants are available on the market today, significant research and development on the use of R290 were carried out in the last five years. König et al. (2014) have shown that frequency of hazard and probabilities of fatalities for the global reefer container fleet would be below 10-6 if adequate design changes were in place and best practice guidelines were established. A second paper studies energy efficiency of the different replacement options in container or truck/trailer and identifies different design approaches to mitigate the flammability risks (König et al., 2016).

Several manufacturers of container units have announced an interest to use R290 and R32 in the long term especially focusing on energy efficiency. The relevant safety standard ISO 20854 for refrigerating systems using flammable refrigerants in marine containers was revised and includes a risk-based assessment for design and operation in its latest version which was published in October 2019.

Stationary air-conditioning

Room air-conditioning

Moveables

Movables have a notable market share in Europe with sales figures of around 400,000 units in total. Their capacity ranges at 2-7 kW and the refrigerant charge is 0.2-2 kg.

While in the past R410A and R407C were common refrigerants for this type of units, R290 has picked up large market shares in recent years and is the refrigerant of choice nowadays.

Refrigerants with a GWP of over 150 are no longer allowed in moveable systems from January 2020 onwards (Annex III of the F-gas Regulation).

The estimated number of units running on hydrocarbons ranges at 200 000 as of 2020 and within the next 2 years all new products are expected to use R290 (Shecco).

Single-split systems

Single-split systems contain of one indoor and one outdoor unit. Both are connected by a pipe carrying the refrigerant. There are generally two types of single-split systems:

1. Small single-split systems with a charge size below 3 kg and a cooling capacity below 12 kW and
2. larger single-split systems with a charge size above 3 kg and a cooling capacity above 12 kW.

According to Annex III of the F-gas Regulation, refrigerants with a GWP of over 750 are no longer allowed in small systems starting in January 2025.

As summarized in a recent Commission report, the blend R410A (GWP 2088; class A1) has been the most important refrigerant for split A/C systems in the past, but in recent years it has been largely replaced by R32 (GWP 675; class A2L) in new systems. Safety legislation regarding flammability of refrigerants, such as building codes and installation requirements, are the reason why market shares of R32 differ within the EU market. While Italy and Spain have relaxed their legislation in the past two to three years, allowing for an increase of R32 in single-split systems, France still prohibits A2L and A3 refrigerants in high rise buildings. Most European countries, however, have reached a share of R32 for single-split systems of more than 80% in 2019 and this share is expected to grow. From a technical perspective, R32 has the potential to be used in all single-split systems on the European market but this potential is severely dampened by its relatively high GWP. As a consequence of the EU HFC phase-down, prices for R32 are expected to increase in the future, making alternative solutions more feasible.

Apart from R32, only R290 (propane) is currently a market-ready alternative for single-split systems with one Chinese system having been awarded the German ecolabel “Blue Angel” in 2018[71]. However, Chinese and Indian manufacturers primarily sell to domestic markets so far.

From summer 2021, one large Chinese manufacturer (Midea) formally announced that single-split systems with R290 by the Chinese manufacturer Midea were announced to be commercially available on the EU market[72].

Several other refrigerant blends are being researched for future use in split systems but are not marketed yet (Sethi & Motta 2016; Mota-Babiloni et al. 2017; Schultz 2019).

Multi split (VRF) systems

In multi-split systems, a single outdoor unit feeds two or more indoor units. This type of system is mainly used in commercial buildings, especially office buildings. VRF (Variable Refrigerant Flow) systems are a sub-category of multi-split air conditioning systems and are distinguished from regular multi-split systems by their ability to modulate the refrigerant flow in response to the system demand. The outdoor unit can adjust the refrigerant flow in response to the demand from each indoor unit. In some configurations, these systems can have independent cooling or heating functionality for each indoor unit thus simultaneously heat and cool separate indoor spaces.

Multi split systems, in particular VRF systems, which came in relevant quantities onto the EU market in 2003, show significantly higher refrigerant charges than single split and moveable units and their capacity is typically >12 kW (can range up to 300 kW).

The typical refrigerant has been R410A for many years and the range of charge size is between 5 and 50 kg (specific HFC refrigerant charges tend from around 0.3 kg/kW cooling capacity upwards). Due to these higher refrigerant charges, the selection of alternatives to R410A is progressing slowly but recently updated safety standards are addressing flammability issues for this type of systems.

The following alternatives are available today:

R32 has been introduced in multi split systems since ca. 2015 in the EU and is today used in the capacity range of up to ca. 20 kW (small and medium capacities). A mini-VRF system running on R32 was presented by LG in early 2020. For larger capacities of multi-split systems, R410A is still the refrigerant of choice. A European manufacturer started their own refrigerant recycling and reclamation programme to be able to ensure availability of this refrigerant for servicing needs throughout the next years.

[71] https://www.blauer-engel.de/en/products/electric-devices/stationary-air-conditioners/midea-split-type-room-air-conditioner-all-easy-ser (last accessed: 29.07.2020)

[72] https://www.linkedin.com/posts/unido_energy-efficient-and-climate-friendly-split-activity-6834093115918360578-v_jJ

In addition, so called hybrid VRF systems were introduced from ca. 2015 onwards: They represent indirect systems where the refrigerant is circulating between the outdoor unit and a “hydro unit” while water is circulating inside the building. In this way, the refrigerant charge is significantly reduced. Hybrid-VRF systems are offered with R410A and R32.

The potential of R466A is being discussed, however, major manufacturers (e.g. Panasonic) indicated that issues such as corrosion inhibit the use in their products. Furthermore, R454A or R455A might be suitable alternatives but are currently not used in any product on the market.

Chillers

Chillers are commonly used to cool large buildings and often use water as a secondary refrigerant.

Smaller chillers (<100 kW) typically relied on R410A or R407C in the past and used to contain charges between 5 and 50 kg. Several alternatives are being trialled in this segment or have recently entered the market and might reach a certain market penetration in the future. A strong role of R290 is expected.

Since 2018, chillers running on R32 are available on the EU market from several manufacturers and for various capacity ranges.

Already at the 2018 Chillventa a propane mini-chiller was presented (5-30 kW; 2-4 kg charge, with a secondary glycol/water loop) and represents a solution for various applications.

Low-charge ammonia chillers (20 kW at AC conditions; total system charge < 800 g) are also being researched and provide particularly high energy efficiency.

Large chillers (>100 – 1500 kW) often run on R134a, R410A or R407C and have typical refrigerant charges between 50 kg and 500 kg. In the last 2-3 years, also R32 and several HFC-HFO blends became introduced such as R513A, R452B, R454B.

As regards alternatives to conventional HFCs in this segment, R717 (ammonia) plays a significant role already. Propane (R290), CO_2 (R744) as well as water (R718) are also entering the market in this application. Furthermore, unsaturated HFCs (R1234zd and R1234ze) might gain market shares.

As for turbochillers (>1500 kW), a long lifetime of 25 years is estimated. R134a was the most common refrigerant in this application in the past. However, due to the long lifetime of this type of chillers, unsaturated HFCs have been introduced to quite some extent already and are estimated to be the main refrigerant solution from ca. 2025 onwards at the latest.

Heat pumps

Domestic & small commercial heat pumps

Heat pumps are major sources of renewable energy. In Europe the term is used for heating only units with the heat sources outside air or exhaust air from the ventilation system, ground and ground water, combined with hydronic heat distribution systems (Halozan 2017). In this strict sense, the model includes in this category only residential heat pumps, i.e. units for space heating only, which use ambient air or the heat in the ground for inside hot water circulation. Tap water heat pumps and reversible air-to-air heat pumps are not included here. Air-to-air heat pumps are identical with reversible air conditioning systems and are already considered there. Heat pumps of the heating only type are common in central and northern Europe while in southern parts of Europe often reversible air conditioners are used temporarily for heating.

While in the past ground-source heat pumps (ground, ground water, surface water) dominated the market, air-source heat pumps are most common nowadays.

R134a, R407C and especially R410A have been widely used in water and space heating heat pump systems for many years and are well commercialized globally. The typical charge size is below 3 and at maximum up to 5 kg. There are to date no significant barriers or regulatory measures to the use of these refrigerants, but their high GWP has put them under pressure in the last years, requiring a change towards lower GWP fluids.

As for alternatives to conventional HFCs, the following developments are to be mentioned:

The use of R32 in heat pumps is already commercialised on a larger scale and products are available from several manufacturers.

HFC-HFO blends are entering the market as well, several manufacturers presented new models running on R454C (Stiebel-Eltron, MHI) and R513A (Ochsner) (all exhibited at ISH 2018).

Other options suggested by industry include R455A (especially for heat recovery systems) as well as R452A, R452B and R454B.

R744 has been introduced in Europe for medium sized water heating heat pumps. Air source and ground source water heating heat pumps are available up to around 50 kW. However, the market share is overall low due to the design modifications that are required to achieve equivalent performance compared to HFCs when applying R744 for space heating alone.

Hydrocarbons represent another alternative and include three main refrigerants used in water and space heating heat pumps such as R290 (propane), R1270 (propene) and R600a (isobutane). In the EU, R290 heat pumps have been commercialized at larger scale in recent years. However, charge size limitations in safety standards represent a barrier. Development work is being done on charge minimization to increase the capacity of the system for a given charge.

Industrial heat pumps

Commercially available heat pumps can supply heat only up to 100°C. As industrial waste heat, available at low-temperatures, represents about 25% of the total energy used by the manufacturing industry, research focused on high-temperature heat pumps able to recover heat at relatively low temperatures, generally between 5°C and 35°C for hot water supply, hot air supply, heating of circulating hot water and steam generation at temperatures up and higher than 100°C. Application areas include district heating/cooling, waste heat recovery from industrial processes or wind power. Reuse of process energy for space heating and hot water often provides an opportunity for energy savings.

As for industrial heat pumps, R717 as well as R134a and R245fa were used in the past. Research identified R290, R1234ze(E) and R1234yf as ideal candidates to replace R134a, whereas R1233zd(E) and R1224yd(Z) were the most promising low-GWP refrigerants to replace R245fa. In the context of the 2020 Chillventa, Flaktgroup presented larger heat pumps running on R454B. Lately, several manufacturers presented solutions relying on natural refrigerants such as R717 and R744.

Mobile air-conditioning

Passenger cars

The model is based on the stock of registered cars in the EU and represented the largest sector of HFC use for many years. Based on empirical data from several Member States used for their emission estimates, the share of passenger cars equipped with an air-conditioning system is estimated at 96% from 2015 onwards. An average refrigerant charge of 0.63 kg per vehicle is assumed.

As a consequence of the MAC Directive, R134a is being replaced by R1234yf and to small extent by R744 in new car models since 2014. As R134a is not replaced in the stock of existing vehicles, it will remain the dominant refrigerant in the market until the mid-2020s.

In the last years, electric vehicles have been gaining increasing relevance on the market. So far, no single technical solution for battery cooling, air conditioning and heating of the vehicles is established on the market but several approaches are taken by manufacturers and in research. As in conventional vehicles, R1234yf plays a prominent role but also R744 is already used in heat pumps systems (e.g. in

Audi e-tron[73] and Volkswagen ID.3[74] models) and might become increasingly relevant in upcoming years. Furthermore, research on charge-size minimization of R290 systems is showing promising results.

In 2021, Daikin announced a new refrigerant for this application[75], called D1V140, which blends R1234yf with 23% of HFO1132(E). The overall GWP is said to range <10.

Buses

For buses the share of vehicles equipped with an air conditioning system is lower than for passenger cars and is differentiated by regions (Northern/Central Europe 80%, Eastern Europe/UK 57%, Southern Europe 96% from 2015). The assumed average charge for new vehicles and stock is 10.5 kg throughout the time series. The MAC Directive does not require the introduction of alternatives to R134a for buses so that the use of alternatives with low GWP is only getting started slowly.

Long-term experience is already available for R744: Since 2003, a large German manufacturer (Konvekta) has on-going fleet tests of R744 systems in buses. Since 2012, a Polish bus manufacturer (Solaris) is selling battery-driven electric buses with reversible R744 heat pump systems for heating and cooling. Industry sees potential for R744 heat pump systems especially in electric buses. However, until today only about 500 vehicles on the EU market are equipped with R744 systems (including 100 diesel busses and 400 hybrid/electric busses). Further use in diesel buses is inhibited by the fact that compressors for this application have not reached serial production.

R1234yf and R513A are not registered for use in air conditioning systems on public transport vehicles under REACH and thus cannot be used so far. R290 has been researched but not used in bus air conditioning systems.

Trucks (N1, N2 and N3) and trailers

For trucks and trailers, the MAC Directive does not foresee the introduction of low GWP alternatives to R134a. Therefore, R134a is the main refrigerant at present although R1234yf is allowed for some smaller vehicles (class N1). A major manufacturer confirmed that they are trialling R1234yf in larger truck models but introduction will only happen in 2022/2023 at the earliest. Also, for the installation of an AC system in trucks originally built without AC system, units with R134a and to minor extent with R1234yf are available on the market.

R744 has not been introduced on the market by any manufacturer beyond prototypes yet. For heavy-duty vehicles, some industry experts see a certain potential for R513A, however, this refrigerant is not currently used in new or existing systems. In the next few years, a wider introduction of R1234yf in trucks and trailers is expected by industry experts. For electric vehicles, also R744 is considered as an option but is no e-trucks equipped with R744 air conditioning systems/ heat pumps are available on the market at this stage.

Rail

For many years, the standard refrigerants in rail AC used to be R134a and R407C (mainly in Southern Europe; in trams and underground railcars). Due to the long lifetime of rail vehicles (25-30 years) the choice of refrigerants is becoming increasingly relevant. R513A has been introduced as a retrofit option for R134a systems but is already today seen as an interim solution only.

Research on alternatives to HFCs in new systems started already back in about 2005 and led to the introduction of R729 (air) in air conditioning of some high-speed trains in Germany (ICE 3).

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[73] https://www.audi-mediacenter.com/en/electric-suvs-in-the-premium-compact-segment-the-audi-q4-e-tron-and-the-q4-sport-back-e-tron-13887/battery-thermal-management-and-charging-13902
[74] https://www.volkswagen.de/de/elektrofahrzeuge/id-technologie/waermepumpe.html
[75] https://www.coolingpost.com/world-news/daikin-develops-more-efficient-refrigerant-for-electric-vehicles/

In the last few years, R744 has been trialed and is being implemented in some trains in Germany and in Scandinavia. In 2019, Deutsche Bahn signed an agreement for 100 additional trains equipped with R744 AC (in addition to existing 23) by 2023. R744 and R729 are available and established technologies for railway AC today but are considered not optimal due to costs, weight, energy efficiency constraints of the onboard electrical system and since these systems provide a single source for cooling.

Thus, current research is also looking into the potential of R290 for rail AC (Faiveley) and evidence has been provided that the same level of safety can be reached compared to common R134a systems. R290 AC systems are not in use yet but might be commercially available in the next 3-5 years. A field trial is currently taking place in Germany.

R1234yf is used for battery cooling in trains with hydrogen propulsion in France, whereas the comfort air conditioning system of such trains still rely on R134a. Other use of R1234yf in rail vehicles is not known to date.

Overall, several alternatives are currently being researched and might be available on the market to larger extent in the next years.

Ship

Passenger and cargo ships pass through every climate zone as they sail around the world. Providing the optimal temperature for passengers and cargo on board thus represents a technical challenge. All vessels above 100 GT (of which according to International Maritime Organization (IMO) there are in excess of 180,000 globally) have a cooling requirement for their provision rooms, air conditioning for cabin space, bridge and for the electrical equipment in the engine control room. More specialised ships have greater cooling requirements, including e.g. cruise ships, ferries etc.

As of 2018, during all voyages from and to EU ports as well as stays at EU ports, monitoring, reporting and verification for ship emissions are required. An emission report is likewise required for each ship annually. IMO already has minimum requirements regarding highest allowed GWP in new equipment. CO_2 equivalent emissions are now monitored.
The typical refrigerant for air conditioning systems on ships used to be R134a since 2001. Especially cruise liners have extremely large AC systems and use large centrifugal systems with R134a (up to 10,000 t) and circulating chilled water. Systems using R717 or flammable refrigerants are difficult to envisage without radical redesign. Nevertheless, R290 chillers are being offered for merchant ships. Indirect systems (where refrigerant is confined to a machine room and secondary coolant is distributed) are mostly used today and they could be redesigned for flammable refrigerants. However, little information on retrofits is available so far.

The use of HCFC-22 on cruise liners has been virtually eliminated. Some ships still operate with screw compressors and R410A. Cruise liners operating with centrifugal chillers on R134a have been successfully retrofitted to R513A with a 1% reduction in energy efficiency. Leak rate for these systems is less than 0.5% per year. The storage rooms present a bigger challenge, (sometimes 50 or 60 in number on a liner). Indirect systems (where refrigerant is confined to a machine room and secondary coolant is distributed) can be retrofitted by either changing the refrigerant or changing the cooling system to R744. Ships with direct systems are the most problematic, they have large charges and are leaky due to pipe work length. The typical refrigerant charge differs by type of merchant ship

Cruise ships: 6,400 kg charge.

Passenger ships: 520 kg charge.

Container ships: 160 kg.

Other cargo ships: 160 kg.

Foams

Literature finds that significant improvements in the development and availability of additives, co-blowing agents, equipment and formulations enabling the successful commercialisation of foams and foam systems containing low GWP blowing agents have been made in recent years.

The provisions of the F-gas Regulation relating to foams are summarized follows:

- In 2015, all HFCs with GWP greater than 150 were banned for foam use in domestic appliances.
- From 2020 onwards, XPS foams containing HFCs with GWP greater than 150 are no longer allowed to be placed on the market (except when required to meet national safety standards).
- By 2023 all HFCs with GWP greater than 150 will cease being used in all foam manufacturing and foams containing HFCs with GWP greater than 150 are no longer allowed to be placed on the market (except when required to meet national safety standards).
- Foams and polyol-blends containing HFCs must be labelled, and the presence of HFC has to be mentioned in the technical documentation and marketing brochures.

On the supply-side, the HFC phase down limits supply of HFCs so that availability of HFC blowing agents is being constrained well before the phase-out dates.

Extruded polystyrol (XPS)

Insulation boards made of XPS used to be produced with HFC-134a (GWP 1430) or HFC-152a (GWP 124) from 2001 when the use of HCFC-142b and HCFC-22 (both ODS) were banned. Emissions of HFCs as blowing agents for XPS foam arise both on manufacturing of the insulation boards (in countries with own production) and in the use-phase from installed foam (in all countries that use self-produced or imported XPS products). The lifetime of XPS boards is estimated 50 years.

As regards alternatives to the conventional HFCs used in XPS, HFO-1234ze plays a major role as alternative for HFC-134a where the thickness of the foam boards is relevant. This is the case for certain special applications but also in certain Member States more requirements apply (e.g. France). In other applications, where the thickness of the materials is not relevant, CO_2 has been applied for many years. CO_2 also represents the alternative for HFC-152a, which however is not subject to the Annex III prohibition due to its low GWP. The use of HFC-152a is expected to continue for some more years.

Polyurethane (PU)

PU rigid foam exists in a great diversity of product types, including continuous and discontinuous panels or blocks, laminate, appliances, pipe-in-pipe foam, or spray foam. There are three HFCs in use: HFC-134a replaced ODS in a variety of products in the 1990s. The most widespread ODS blowing was HCFC-141b, which was replaced by new-developed HFCs like HFC-245fa and HFC-365mfc[76], from 2003 onwards but also pentane. In addition to PU rigid foam, PU integral foam is blown with HFCs.

Lifetime of the typical HFC blown PU rigid foam products in the EU is estimated 50 years. Therefore, disposal emissions are not calculated in the model. Blowing agents for PU integral skin emit completely on manufacturing.

According to Annex III of the F-gas Regulation, HFCs with a GWP of over 150 are no longer allowed in foams starting in January 2023. As stated by the industry association PU Europe, the PU foam industry is well underway to comply to the ban by end 2022 and >75% of the HFC applications have been converted already from HFCs to HFO/HCFOs. This conversion posed challenges because HFOs and HCFOs are not drop in solutions and require reformulation and re-certification of the products in some cases. Especially for discontinuous and spray foam, pentane poses flammability or explosion risks, in particular when handled by smaller companies or on construction sites.

[76] The latter is blended with 5-10% HFC-227ea to reduce the flammability of the pure fluid.

One-component foam (OCF)

The propellant gas in canned one-component PU foam (including so-called two-component PU foam) can contain HFCs which have replaced HCFC-22 from 2002. The gas expels the foam from the aerosol cans; on application, it is completely released to the atmosphere. In the past, about 10% of the OCF foams sold in the EU contained HFCs (especially HFC-134a) in the formulation, mainly special foam types such as fire safe foam, winter foam, however the share of HFC containing products showed annual variations.

According to Annex III of the F-gas Regulation, HFCs with a GWP of over 150 are no longer allowed in foams starting in January 2023. Hydrocarbons already represent the main propellant type in OCF foams (>99%).

Aerosols

Technical aerosols

In the past the use of HFC-134a as an aerosol propellant was common for certain specialized applications. Examples include sprays for testing and some industry applications but also household and leisure products to limited extent (e.g. signal horns, confetti sprays). The F-gas Regulation contains several provisions on aerosols in its Annex III:

- Novelty aerosols: A placing on the market ban for aerosol generators marketed and intended for sale to the general public for entertainment and decorative purposes and signal horns, that contain HFCs with GWP of 150 or more is established since 4 July 2009. – This prohibition had been assessed previously and was found to be fully implemented.
- Technical aerosols; The placing on the market of technical aerosols that contain HFCs with a GWP of 150 or more, except when required to meet national safety standards or when used for medical applications, is banned from 2018 onwards.

The bans led to reformulations of certain aerosol products: Some applications still contain smaller shares of HFC-134a but the overall GWP is below 150. Moreover, the introduction of low-GWP alternatives, notably HFC-1234ze and HFC-152a (as a pure substance or mixed with other common aerosol propellants) took place. Significant remaining uses of aerosols containing high-GWP HFCs are not known.

Metered dose inhalers (MDIs)

HFC are used as propellants in aerosol sprays for drug application. Two types of F-gases such as HFC-134a (GWP 1430) and HFC-227ea (GWP 3220) are used for MDIs: Globally, the share of HFC-227ea is about 8% compared to 92% of HFC-134a (2018 MCTOC Report). The content of propellant per inhaler ranges at 9ml for HFC-134a and 10 ml for HFC-227ea.

Regarding alternatives to these HFCs, the 2018 MCTOC report (p.25) mentions three potential propellants including isobutane, HFC-152a and HFO-1234ze(E) but also not-in-kind alternatives such as dry-powder inhalers (DPI) which have been available on the EU market for many years.

HFC-152a is currently being researched intensively and two MDI manufacturers announced that they will put products for asthma and COPD treatment employing this propellant on the EU market starting from 2024/2025. The performance of HFC-152a is considered to be at least as good as HFC-134a and HFC-227ea or better.

Solvents

While the use of HFCs in solvents has become rather uncommon, a small residual market remains for HFC-based solvents, with HFC-4310mee being the main HFC-based product. HFC-4310mee is an efficient solvent for non-destructive applications in the sense that it performs well as a cleaning solvent and it evaporates fast, leaving no trace a few moments after the cleaning. HFC-365mfc and small amounts of HFC-134a are also used as solvents in the EU.

Alternatives to HFC-43-10mee include HFOs and HFEs:

- Both HFC-1233zd and HFC-1336mzz(Z) can be used as solvents. However, because of the presence of chlorine in HFC-1233zd, its effectiveness is higher.
- HFEs such as e.g. HFE-7200 are widely used for solvent applications.
- PFPEs might also be suitable for certain uses, however their high GWPs (between 5000 and 10000) and their less desirable solvency properties are disadvantageous despite the relatively cheap price.

Fire protection

Fixed systems use HFC-227ea, HFC-125 and HFC-23 (until 2015), while HFC-236fa is used in portable fire extinguishers. HFC-227ea represents the most used gas in the EU, followed by HFC-125 (introduced as halon replacement). The market for portable devices containing HFC-236fa is said to represent a niche in the military or naval applications.

Typical applications could include chemical storage areas, clean rooms, communications facilities, laboratories, museums, robotics and emergency power facilities.

Halotron 2 (HFC blend B: Tetrafluoroethane (86%) CH_2 FCF_3; Pentafluoroethane (9%) HF_2CF_3; Carbon dioxide (5%) CO_2; GWP 1598) is also on the market and used in normally unoccupied spaces. Sectors such as the military, aviation and oil and gas sectors still require the use of HCFCs, HFCs and halons, because they require substances with superior extinguishing capacities, which cannot be satisfied by the alternatives currently on the market.

Alternatives include the chemical extinguishing agent FK-5-1-12 (Novec 1230) and inert gases. FK-5-1-12 is a fluoroketone (chemical formula: $CF_3CF_2C(=O)CF(CF_3)_2$) supplied by 3M. It has established itself as the main replacement for HFC-227ea and is used in many applications. FK-5-1-12 systems are already becoming less expensive than HFC-227ea[77]. Its fire extinguishing mechanism is similar to HFCs or PFCs and comprises primarily the removal of heat, i.e., reduction of the flame temperature to a temperature below that required for the maintenance of combustion.

FK-5-1-12 has good fire suppression performance and is now being used in many new building applications (in museums, libraries, server rooms etc.) to replace of HFCs or PFCs. Its potential drawback is that it has a relatively low vapor pressure. Systems using this chemical may need to be pressurized with alternative substances such as nitrogen.

Further alternatives to HFCs for certain applications include 2BTP, CH3I and inert gases.

- 2-BTP is a brominated fluoroolefine (bromofluoroolefine; CH_2=$CBrCF_3$) supplied by American Pacific under a trade name Halotron BrX™. Its fire extinguishing mechanism comprises releasing Br* free radical which reacts with any hydrogen-bearing fuel and forms HBr that further reacts with HO* free radicals which are formed in combustion process to produce water and Br* that is able to react again with hydrogen-bearing fuel. This mechanism enables a lower weight equivalence to halon 1211, FK-5-1-12 or HFCs and therefore smaller and less heavy fire extinguishers may be used with 2-BTP. As FK-5-1-12, 2-BTP is electrically non-conductive,

[77] http://www.sea-fire.com/2018/09/sea-fire-europe-to-cease-distribution-of-hfc-based-products/

leaves no potentially harmful residues after being used and has relatively high boiling point what enables the fire extinguisher operator to stay at a distance from the fire. Considering that it has already been approved for use on board of passenger aircraft 2-BTP could become a major replacement for HFCs and PFCs in non-residential applications like aviation, marine, commercial, industrial or military sectors.

- CF_3I (FIC-1311) is supplied by Pacific Scientific and other (mostly Chinese) producers. It is a very effective extinguishing agent even at low concentrations (3-7%) and is not electrically conductive but is toxic to human beings and therefore is recommended to be used only in non-occupied spaces. Its proven application is protection of floating roof tanks by Saval company and it is also considered as alternative to halon 1301 in engine nacelles, dry bays and fuel tanks in military aircraft, specifically F-16.
- Inert gases and mixtures of inert gases have been widely used as replacements for halons and HFCs/PFCs. The most common are:
  - Inergen ™ (IG-541) supplied by Ansul - N_2 (52%), Ar (40%), CO_2 (8%)
  - Argonite ™ (IG-55) supplied by Ginge-Kerr - N_2 (50%), Ar (50%)
  - Argotec ™ (IG-01) supplied by Minimax – Ar
  - NN100 ™ (IG-100) supplied by Koatsu – N_2

The inert gases listed above extinguish fire via oxygen dilution, slowing down the combustion reaction to the point where it can no longer sustain itself and therefore relatively high concentrations (40-60%) are needed to protect the same space. Because of that the systems using inert gases are much heavier and need much more space than those using fluorinated fire extinguishing agents. Hence inert gases are not applied in aviation sector but are common in the naval sector or in buildings. Inert gases are non-toxic for human beings, not electrically conductive and do not leave any residues, so they are ideal replacements for halons or HFCs/PFCs in protection of frequently occupied spaces like libraries, museums, computer rooms or military command centers. These gases do not produce fog when discharged, so evacuation routes are visible.

SF_6

Electrical equipment

SF_6 (GWP 22800) was developed as insulating gas in electric switchgear equipment c.a. 50 years ago and is used globally in electrical switchgear equipment. Its decomposition products are considered as hazardous waste and must be properly handled. Leakage rates from modern equipment usually does not exceed 0.1% per year.

For medium voltage (MV) switchgear applications, alternatives to SF6 have been on the EU market for many years and are offered by several EU manufacturers. The following table provides an overview of the alternatives to SF6 established in MV applications.

Table -68: Overview of SF_6 alternatives for MV applications (based on T&D Europe: Technical report on alternative to SF6 gas in medium voltage & high voltage electrical equipment, Brussels, 2020)

Medium voltage switchgear		SF_6 alternatives
Switch	Insulating medium	Air; Dry air in sealed tank + solid (hybrid), liquid; Solid
	Breaking medium	Vacuum; Air
Circuit breaker	Insulating medium	Air; Dry air in sealed tank + solid (hybrid), liquid. Solid
	Breaking medium	Vacuum:

For MV applications, experts estimate that alternative solutions will not be deployed on an industry wide scale without policy intervention. End users are highly satisfied with the techno-economic performance and the perceived no-risk associated with SF_6-GIS. This means, in the current regulative environment, there is no market-pull for alternative solutions.

As for high voltage (HV) switchgear, alternatives to SF6 are technically feasible and have been researched and demonstrated by several manufacturers. However, they are not yet widely introduced to the EU market. Up to 145 kV GIS and Life Tank Breakers (LTB) have been demonstrated with various SF_6-free gas blends. Solutions for up to 245 kV will be piloted and commercial solutions will be introduced in the next years. Development of alternatives for higher voltages will take 5 years at least. Progress monitoring is a precondition for defining transitions.

In space restricted environments, GIS designs based on fluoronitriles may be the only alternative to SF_6 because other solutions require more space. For most applications, however, this is not limiting.

Magnesium casting

SF_6 has historically been used as a cover gas in the magnesium industry to prevent the hot molten metal from burning. All gas applied is considered to be released to the atmosphere (manufacturing emission factor = 100%). In the past, three technologies were applied in Europe: Die casting (large scale production), sand casting (prototypes and small-scale production), and recycling of die casting alloys. The 2006 F-gas Regulation already established a ban for the use of SF_6 in large scale magnesium die casting from 2008 onwards (quantities higher than 850 kg per year) and for small scale production from 2018 onwards (quantities below 850 kg per year; Article 13).

Melt-protection alternatives consisting of HFC-134a, fluorinated ketones and dilute SO_2 (1.5%) mixed with a carrier gas, generally N_2, CO_2 or dry air are commercially available. Current information suggests that all manufacturers converted their production processes to alternatives such as SO_2 and HFC-134a and a special gas formulation SGE N2 (0.3% HFC-134a, nitrogen type 50).

The use of a fluoroketone alternative supplied by 3M (Novec 612: dodecafluoro-2-methyl-3-pentanone or $(CF_3CF_2C(O)CF(CF_3)_2)$[78], is said to be more reactive at melt temperatures and thus more efficiently

[78] https://multimedia.3m.com/mws/media/713947O/3m-novec-612-magnesium-protection-fluid.pdf

utilized than SF_6 so that it can be used at very low concentrations. The greater reactivity of this fluid also means that it is best to upgrade components of the cover gas delivery system as needed rather than to use it as a simple drop-in replacement agent. Specifically, it will be beneficial to optimize cover gas formulation, agent concentration and flow rates, cover gas distribution over the molten metal and allow for flow rate adjustments during process operations. However, this alternative does not (yet) seem to be established on the EU market.

Furthermore, several alternative melt protection technologies that are not currently commercialized or readily available have been developed.

As regards the use of HFC-134a as cover gas, companies reported that higher quantities are needed as compared to SF_6 and that slag formation has increased.

Particle accelerators

SF_6 is used as an insulating gas in particle accelerators of various sizes used in research at universities and in industry as well as for medical applications (cancer therapy). Typically, high voltage equipment is contained and operated within a vessel filled with SF_6 at a pressure exceeding atmospheric pressure. When the equipment is serviced, SF_6 is transferred into storage tanks. SF_6 emissions occur during gas recovery and transfer, when pressure relief valves are actuated and through leakage. The 2019 IPCC Refinement report estimates the annual emission rate at 5-7% depending on the vessel opening frequency and the efficiency of recovery and transfer equipment.

Based on expert input from the IAEA, several types of applications can be distinguished:

1. Ion electrostatic accelerators for research: SF_6 contained is from about 90 kg (for 1 MV machines) up to about 22 tonnes for the biggest systems (for 14 MV machines; a few machines in Europe contain these large amounts of SF_6) with most machines ranging at around 3 MV (500-600 kg of SF_6 contained). An overview by the International Atomic Energy Agency (IAEA) lists 84 accelerators in the EU, however the list might not complete and some of the older machines might be running on different gas compositions of N_2O and CO_2 at higher pressure. It is estimated that up to 200 tonnes of SF_6 is banked in ion electrostatic machines in research in Europe.
2. Electron beams used in welding, semiconductor manufacture, additive manufacturing
3. Medical applications: Electron microscopes, medical radiation therapy
4. Industrial applications, e.g. in automotive industry[79,80]

Military use

HFCs, PFCs and SF_6 are used in military applications. HFCs are employed as refrigerants and fire extinguishing agents and are exempted from the HFC phase down when used in military equipment (Article 15(2)d). “Military equipment” is defined as “arms, munitions and war material intended specifically for military purposes which are necessary for the protection of the essential interests of the security of Member States”. This would relate for example to cooling as well as fire protection systems in tanks and other military vehicles, onboard of marine applications and aircrafts.

PFCs and SF_6 in military use serve more specific purposes:

SF_6 is used as an insulation medium in the radar systems of military reconnaissance planes of the Boeing E-3A type of the NAEWF (NATO Airborne Early Warning Force), which is commonly known as AWACS. The purpose of SF6 is to prevent electric flashovers in the hollow conductors of the antenna in which voltage levels >135 kV can occur. Other inland radar systems for aircrafts are employing lower voltage levels (up to 30 kV) so that no SF6 is needed but silicon oil. Emissions of AWACS are very high during operation as SF6 is automatically released from the system to maintain the appropriate pressure

[79] http://www.accelerators-for-society.org/case-studies/case-study-car.php
[80] https://www.mhi.com/products/industry/accelerating_device.html

difference between the system and the outside air when the plane ascends. When the plane descends SF6 is charged into the system from an SF6 container on board. Further to these intended emissions also unintended emissions through leakage might happen. Annual emissions per plane have been estimated to be 740 kg while the charge of each system is 13 kg. Sixteen E-3A aircrafts are assigned to the NATO base in the EU (NATO Air Base in Germany, forward operating bases in Greece and Italy).

Other military applications are also using SF6 and PFCs, particularly as heat transfer fluids due to their stability and dielectric properties. The specific PFCs used in military applications are believed to be similar to those identified as heat transfer fluids in electronics manufacture. The PFCs are contained in a closed system and replacement or refill are mostly not required.

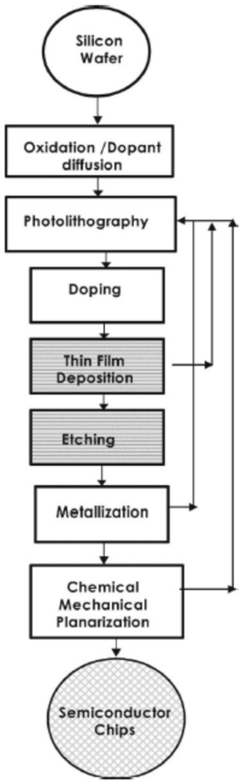
PFCs, other halocarbons and NF_3

Semiconductor and electronics industry

To produce semiconductor devices, gaseous fluorinated compounds, silanes, doping and other inorganic gases are required. Wafers consist of high-purity silicon and are the basic building blocks for all semiconductor components. The PFCs used in semiconductor manufacturing process include hexafluoroethane (C_2F_6), octofluoropropane (C_3F_8), tetrafluoromethane (CF_4), octofluorocyclobutane (c-C_4F_8), nitrogen trifluoride (NF_3), sulfur hexafluoride (SF_6), and hydrofluorocarbons, such as trifluoromethane (CHF_3).

Essentially, these high-purity gases are used as starting compounds in a number of different process steps. The semiconductor wafer production process is shown in the following diagram indicating the steps where the fluorinated compounds are used (see the patterned rectangles).

Figure 26: Semiconductor process flow diagram (wafers undergo multiple iterations of the steps as indicated by the return arrow). F-gases are used in the processes in patterned rectangles. (From Illuzzi & Thewissen 2010).



PFCs are applied as etching gases for plasma etching of the submicron patterns on metal and dielectric layers of advanced integrated circuits. Etching gases such as SF6 that is decomposed by the plasma allows the etching chambers to be cleaned. PFCs and SF6 are also used as cleaning agents for the chemical vapour deposition (CVD) tool chambers. When the silicon and silicon-based dielectric layers are being applied, a similar layer is deposited on the CVD chamber walls. During the wafer testing stage, SF6 is used as insulation gas for power device testing as it is relevant for automotive applications to check the semiconductor device reliability. SF_6 is often kept in a closed cycle and reused to the extent possible.
In the context of a voluntary industry agreement significant reductions of emission have been reached through process optimisation and more efficient alternative processes, use of alternative chemistries and the installation of abatement equipment in Europe-based facilities.

One relevant process optimization that was introduced in recent years relates to the NF_3 remote plasma process. In terms of alternatives to the conventional gases used, perfluorinated polyethers (PFPEs), hydrofluoroethers (HFEs) and other gases are to be mentioned.

PFPEs (PFPMIE)

Perfluorinated polyethers (PFPEs) remain liquids even at molecular weighs and feature a high GWP of ca. 10,300. Manufacturers of PFPEs include Solvay Solexis in Italy, which markets these substances under the brand name GALDEN, as well as Chemours (brand name Krytex), Daikin, Nye Lubricants, Dow Korning, Kluber Lubrication.[81] PFPEs with molecular weights between 750-1200 in the boiling range 160 °C - 260 °C are used for vapour-phase-reflow-soldering (VPRS) of printed circuit boards as

[81] Other applications include aerospace industry and automotive industry. Furthermore, PFPEs with a boiling range of approx. 55 °C (GALDEN HT-55) are used in ORC-systems as a 35 % component in the ORC working fluid "Solkatherm SES 36“, blended with 65 % HFC365mfc.

well as for thermal shock tests (TST) of semiconductor chips. Low-molecular, low-boiling PFPEs (molecular weight range 340-610; boiling range 55 °C - 135 °C) are used as solvents and as heat transfer fluids (HTF) during semiconductor manufacture (wafer production).

Low boiling PFPEs are used as solvents for the viscosity adjustment (diluting) of PFPE based high molecular lubricants (relevant products include e.g. Fomblin grease and oil by Solvay). On application in lubricants, the solvents are released into the atmosphere completely.

HFEs

Several HFE products (pure substances and mixtures with other components) were introduced to the market and are increasingly being used as heat transfer fluids (HTF) and precision cleaning agents.

The first application of HTF in semiconductor manufacturing are special cooling units which are meant to establish clearly defined and constant operating temperatures in the various wafer processing chambers. Secondly, HTF are used in temperature-controlled devices for automatic tests of finished semiconductor chips. In both cases, the temperatures are established via HTF in secondary circulating systems which are cooled down by a primary refrigeration circuit.

Few HFEs which serve as substitutes for PFCs and PFPEs were commercially relevant in the last years: HFE-7100 (HFE-449sl; GWP 297), HFE-7500 (GWP 100) (brands of 3M) and H-GALDEN (brand of Solvay Solexis; HFE-43-10pccc124; H-Galden 1040x, HG-11; GWP 1870). Decreasing demand however caused Solvay Solexis to cease the production of H-GALDEN in 2011.

As precision cleaning agents, HFEs have been on the EU market since the late 1990s. Since about 2005, industrial cleaning equipment containing HFE-7100 for surface cleaning has been established in significant numbers.

Furthermore, HFEs are also used as “surface modifiers” in electronics industry. “Surface modifiers” are certain polymers which are applied to printed circuit boards, electronic components or hard disc components, in order to provide a protective film against humid air or certain solvents. HFE-7100 and HFE-7200 are used as diluting agents.

In addition, large quantities of HFE-7100, HFE-7200 (HFE-569sf2; GWP 59) and HFE-7300 (GWP 210) serve as carriers for lubricants in the electronics industry.

Other gases

The use of molecular fluorine (F_2) has been established as replacement for high GWP fluorinated cleaning and etching gases such as NF_3 and SF_6 which are used in semiconductor and flat panel display manufacture.

Photovoltaics industry

In the production of photovoltaic cells, F-gases are used within the silicon-based thin film technology which represented in 2010 approximately 5% of the globally installed manufacturing capacity for photovoltaic cells. In Europe, this technology had only been applied in Germany to some extent in the past. Recently solar cell production with the silicon-thin-film technology started also in Spain and in Italy.

Similar to the manufacture of semiconductors or liquid crystal displays (LCD), in the manufacture of silicon-based thin film cells SF_6 or – increasingly – NF_3 is used for cleaning silicon off the chemical vapour deposition chambers, which has not been properly deposited on the substrate but onto the walls, electrodes, and product carriers inside the reactor chamber instead.

Aluminium production

Primary aluminium production primarily leads to PFC (mainly CF_4, C_2F_6) emissions. SF_6 emissions occur during production of secondary aluminium. A global agreement of the aluminium industry to reduce

PFC production emissions by 50% per tonne of production by 2020 (baseline 2006) led to significant emission reductions through process optimization.

As stated by the association European Aluminium, the environmental performance of the industry improved greatly in the last years: Perfluorocarbon (PFC) emissions have dropped significantly: CF_4 has dropped by 50% and C_2F_6 by 52% compared to 2010. Total PFC emissions are said to have fallen by 97% compared to 1990. Atmospheric measurements confirm the strong reduction of CF_4 emissions from aluminium production.

The sector is covered by the EU-ETS. While PFC emission reductions have been achieved in the past, it is currently unclear if it will be possible to further decrease emission levels substantially during the processes applied.

Emissions from halocarbon production

F-gas emissions can be generated as by-product emissions or might be released as fugitive emissions during halocarbon manufacture. All types of F-gases (HFCs, PFCs, SF_6, other F-gases) are produced in the EU. HFC-23 by-product emissions arise from the production of HCFC-22 and other halocarbons.

Generally, manufacturing emissions of both types may occur at any production site of halocarbons and are thus linked to the Chemical Industry. Article 7 of the F-gas Regulation addresses these emissions and sets the following requirements:

- Article 7(1) Producers of fluorinated compounds shall take all necessary precautions to limit emissions of fluorinated greenhouse gases to the greatest extent possible during: (a) production; (b) transport; and (c) storage. This Article also applies where fluorinated greenhouse gases are produced as by-products.
- Article 7(2) Without prejudice to Article 11(1), the placing on the market of fluorinated greenhouse gases and gases listed in Annex II shall be prohibited unless, where relevant, producers or importers provide evidence, at the time of such placing, that trifluoromethane, produced as a by-product during the manufacturing process, including during the manufacturing of feedstocks for their production, has been destroyed or recovered for subsequent use, in line with best available techniques.

Apart from the F-gas Regulation, Regulation (EC) No 166/2006 specifies a European Pollutant Release and Transfer Register (EPRTR) for operators in different sectors (see Annex I to the EPRTR Regulation) to report releases of pollutants in the environment above specific thresholds. Pollutants include F-gases, namely HFCs, PFCs and SF_6. These groups are further specified to cover certain representatives of the respective groups (Table -69). However, gases do not have to be reported individually, but as the total mass of the sum over each group. Thus, calculation in CO_2 eq is only possible for SF_6. Reported data can be publicly accessed for non-confidential data[82]. As can be seen in Figure 27, pollution to air with PFCs was reported in the largest quantities since 2016, comparing the three groups. Quantities reported for HFCs and SF_6 decreased since 2007 but accidental releases increased.

Looking closer at the data, PFCs are very likely reported erroneously. Starting in 2016, one operator in Iceland started to report PFC pollutant releases in the range of 30 000 to 50 000 tonnes per year. This seems highly unlikely, given that no other operator ever reported such high quantities. Correcting for this reporter (using the average reported data from 2008 to 2015 from this operator[83] and replacing the reported value in 2016 through 2019 with this average), the PFC releases to air are substantially lower than before the correction (around 450 times lower in 2019) and lower than the releases of HFCs (Figure 28).

[82] https://industry.eea.europa.eu/

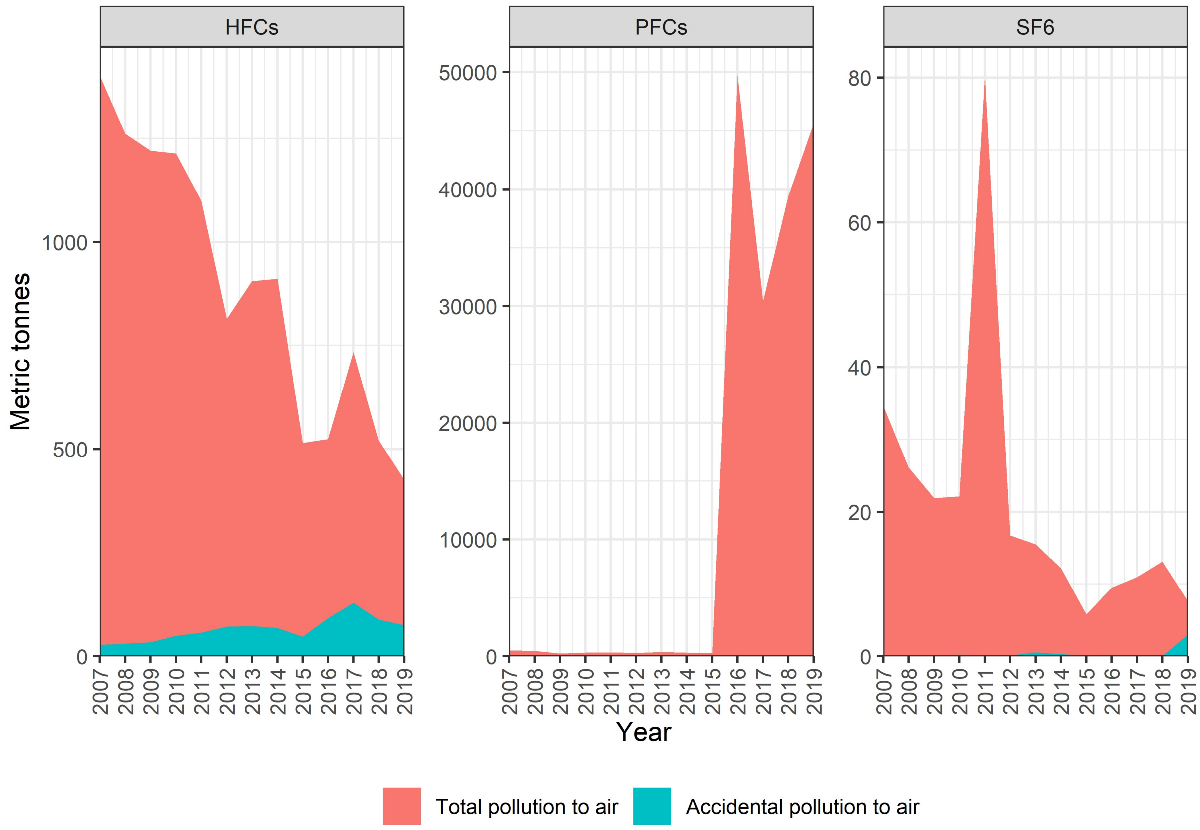
[83] This company did not report PFC release for 2007

Table -69: F-gases to be reported under Regulation (EC) No 166/2006 (EPRTR)

Gas group	Gas	Threshold for re-lease	Total release in 2017 in t (accidental)	Total release in 2018 in t (accidental)	Total release in 2019 in t (accidental)
HFCs	HFC-23	100 kg/year to air	734 (129)	520 (89)	426 (76)
	HFC-32				
	HFC-41				
	HFC-43-10mee				
	HFC-125				
	HFC-134				
	HFC-134a				
	HFC-152a				
	HFC-143				
	HFC-143a				
	HFC-227ea				
	HFC-236fa				
	HFC-245ca				
	HFC-365mfc				
PFCs	CF_4	100 kg/year to air	30 420 (-) Corrected: 324	39 411 (-) Corrected: 315	45 627 (-) Corrected: 101
	C_2F_6				
	C_3F_8				
	C_4F_{10}				
	$c\text{-}C_4F_8$				
	C_5F_{12}				
	C_6F_{14}				
SF_6	SF_6	50 kg/year to air	11 (0.1)	13 (0.9)	8 (3)

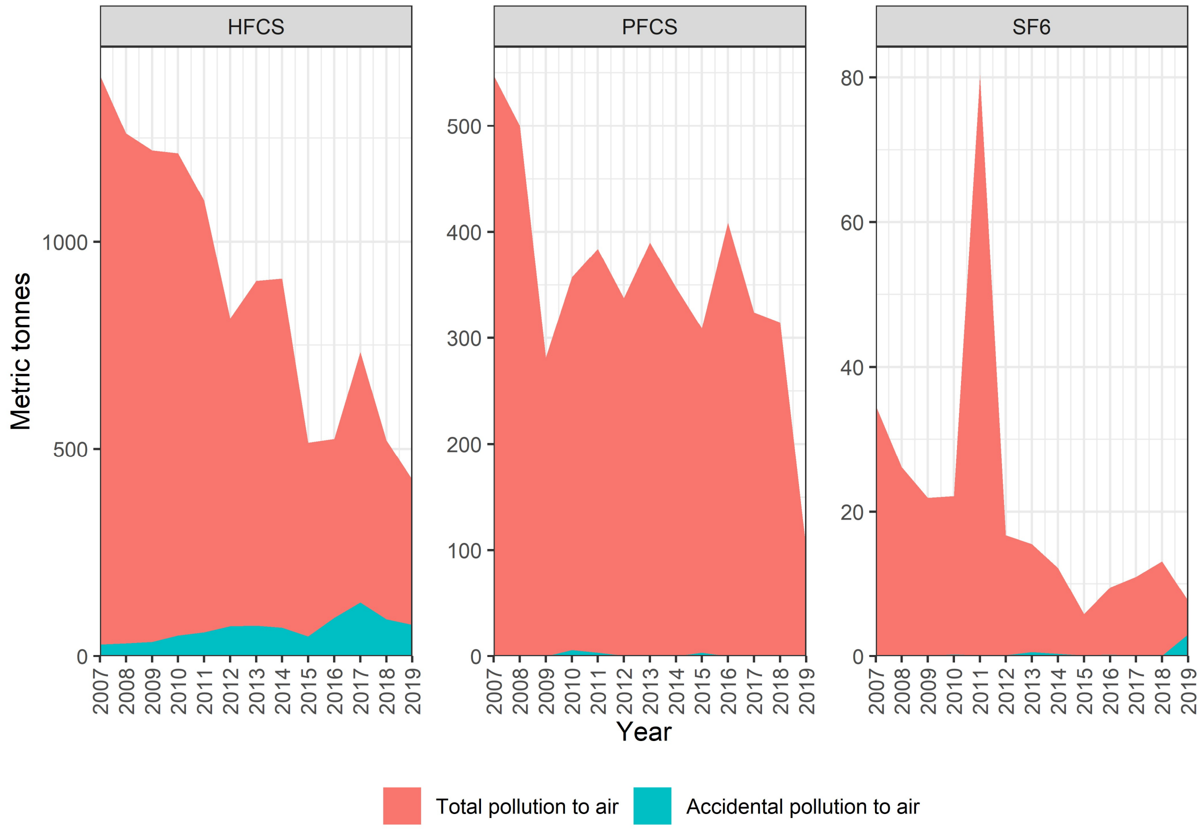
Source: https://www.eea.europa.eu/data-and-maps/data/industrial-reporting-under-the-industrial-3/user-friendly-tables-in-excel-1/industrial-reporting-db-excel-extracts-1/at_download/file, For the corrected data ,PFC release for 2016 to 2019 from one Icelandic operator was replaced with the average PFC release reported by this company from 2008 to 2015

Figure 27: Reported pollution to air from operators for HFCs, PFCs and SF_6 in the EPRTR



Source: https://www.eea.europa.eu/data-and-maps/data/industrial-reporting-under-the-industrial-3/user-friendly-tables-in-excel-1/industrial-reporting-db-excel-extracts-1/at_download/file, Figure by Öko-Recherche

Figure 28: Corrected reported pollution to air from operators for HFCs, PFCs and SF_6 in the EPRTR



Source: https://www.eea.europa.eu/data-and-maps/data/industrial-reporting-under-the-industrial-3/user-friendly-tables-in-excel-1/industrial-reporting-db-excel-extracts-1/at_download/file, data modified by replacing the PFC release for 2016 to 2019 from one Icelandic operator with the average PFC release reported by this company from 2008 to 2015, Figure by Öko-Recherche

Despite the decreasing production in the EU, relevant emission levels were identified in atmospheric measurements.

Other application areas

Cosmetic/ personal products

HFCs, HFOs and perfluorodecalin ($C_{10}F_{18}$) have entered this market in recent years.

As in technical aerosols (see related chapter), HFCs (HFC-152a) and HFOs (HFC-1234ze) are typically applied as propellants where the product is dispensed as a spray, e.g., hair spray, cologne, deodorant, etc. HFC-152a also produces foams or mousses and is used in aerosol foam products, e.g., hair styling and skin conditioning mousses. These products are mainly imported and the imports might be below reporting thresholds to the EEA.

Perfluorodecalin ($C_{10}F_{18}$; PFC-9-1-18; GWP > 7 500) serves as a carrier for oxygen and is thus used in various cosmetic (nail care and skin care, especially anti-wrinkle creams). F2 Chemicals is the only EU manufacturer of this halocarbon, which is currently not covered under the F-gas Regulation. The amount supplied annually to the cosmetics industry in the EU has been rather static over the last 5 years and ranges at about 2 tonnes annually which is emitted upon use of the product.

Medical applications

PFCs with relatively large molecular weights are known to play a role in medical applications due to their capacity to carry oxygen to living tissue. Most prominently, perfluorodecalin ($C_{10}F_{18}$; PFC-9-1-18), which is liquid at room temperature, is thus also applied in in **eye surgery**. The quantities used for this application amount to about 3 tonnes annually and have been fairly stable in recent years.

In the last years, fluorinated ethers gained importance in medical applications, mainly as **inhalation anaesthetics**, where they represent the standard gases today.

The three HFE anaesthetic gases are: Sevoflurane (HFE-347mmz1; GWP 216), desflurane (HFE-236ea2; GWP 989) and isoflurane (HCFE-235da2; GWP 350; ODP 0.03). Currently only desflurane is subject to reporting under the F-gas Regulation (Annex II), but little information is available.

Estimated shares for the use of these anaesthetic gases are available for Germany and range at 55/35/10%.

At room temperature these HFEs are liquid with boiling points between 22.8 °C and 58.5 °C. During application, the liquids are vaporized using a certain type of equipment that dilutes them in a carrier gas (HFE/HCFE concentrations of between 1 % and 6 %). Inhalation anaesthetic gas is exhaled unaltered, so that consumption and emissions are considered to be equal (100 % emission factor). Next to the use in medical applications, large quantities are also used in veterinary medicine.

Total emissions are estimated to exceed emissions from all HFE industrial applications. Quantitative data is hardly available at present though.

Other

SO_2F_2: Sulfuryl fluoride (SO_2F_2) is used primarily as a fumigant in cereal grain mills and food processing facilities, but also for fumigation of timber, building and construction materials for quarantine pre-shipment purposes and particularly as a replacement to ozone-depleting methyl bromide, which is subject to phase out measures under the Montreal Protocol. In Europe, sulfuryl fluoride is sold under the trademarks of Vikane and Profume. The quantities supplied to the EU market range at > 200 metric tonnes.

SO_2F_2 may also have applications in the semi-conductor industry and as a cover gas for magnesium melt protection (alternative to SF_6).

SF_5CF_3: Trifluoromethyl sulphur pentafluoride is used as a tracer gas in oceanography. So called tracer-release experiments are performed from at least one EU research institute in other parts of the world.

SF_5CF_3 is subject to Article 19 reporting under the F-gas Regulation.

$C_9F_{21}N$ and $C_5F_{11}NO$: Both substances, $C_9F_{21}N$ (Fluorinert FC-3283, perfluoro-tri-N-butylamine; GWP 8 690) and $C_5F_{11}NO$ (Fluorinert FC-3284, perfluoro-N-methylmorpholine; GWP 9 500) are used as heat transfer fluids and for testing purposes in electronics industry. Both are clear, colorless, thermally stable, fully fluorinated liquids (liquid ranges at-50°C to 128°C and -73°C to 50°C respectively).

$C_{12}F_{27}N$: Similar as the two gases mentioned above, $C_{12}F_{27}N$ (perfluorotributylamine; PFTBA; Fluorinert FC-43; GWP 7 100) contains nitrogen and is fully fluorinated. The substance is produced by 3M. Potential applications include electronics industry, use for calibration in mass spectroscopy, aircrafts and eye surgery.

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