Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases

Final Report

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0. Executive Summary

Background

Fluorinated greenhouse gases (F-gases) are used in numerous applications and include three types of gases: HFCs, PFCs and SF_6. F-gas emissions are mainly released from refrigeration and air conditioning equipment, foams, aerosols, solvents, fire protection equipment, from halocarbon production, from certain industrial processes in semiconductor and non-ferrous metal industry and from equipment for transmission of electricity during manufacture, use and at disposal.

Due to their relatively high global warming potentials, F-gases are addressed by international conventions such as the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, as well as by policies at European and at national level in EU Member States and other countries, for example Switzerland, Japan, Australia and the USA.

The EU committed to reduce overall greenhouse gas emissions by 8% compared to the base year 1990 during the first commitment period 2008-2012. In order to comply with these commitments, the European Commission identified and developed an EU strategy through the European Climate Change Programme (ECCP) which, inter alia, led to the adoption of Directive 2006/40/EC, the so-called MAC Directive, and Regulation (EC) No 842/2006, the so-called F-gas Regulation.

The F-gas Regulation applies since 4 July 2007 with the exception of Article 9 and annex II, which apply since 4 July 2006. The Regulation has been complemented by 10 Commission Regulations adopted between December 2007 and April 2008, which establish certain technical elements of the provisions[1]. Whilst provisions have been directly applicable in the Member States, a few elements rely upon implementation through national legislation.

The MAC Directive, transposed at national level, applies since 5 January 2008. Its measures are expected to reduce F-gas emissions from mobile air conditioning systems in passenger cars from 2011 onwards.

Objective and scope of this project

The overall objective of this project is to assist the Commission in reviewing Regulation (EC) No 842/2006 by providing technical data, analyses and general support. This service contract carried out by Öko-Recherche and partners since December 2009 includes the following tasks[2]:

- A review of relevant F-gas markets and policies internationally as well as in the EU-27, including investigation of possible interactions, complementarities or overlaps amongst the EU F-gas policy framework (F-gas Regulation and MAC Directive) and other EU or international policies.

[1] Commission Regulations (EC) No 1493/2007, 1494/2007, 1497/2007, 1516/2007, 303/2008, 304/2008, 305/2008, 306/2008, 307/2008, 308/2008.

[2] European Commission: Specifications to tender ENV.C.4/SER/2009/0033 Service contract to provide technical support for conducting a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases.

- An assessment of the effectiveness of current EU F-gas policy, through the development of appropriate models and datasets for emission scenarios in EU-27 and an ex-post assessment of the key elements in the current EU F-gas policy.
- An assessment of the feasibility of emerging options for an international emission reduction arrangement for HFCs and, if appropriate, other F-gases by assessing the feasibility and cost-effectiveness of the replacement of F-gases, developing and comparing scenarios for the control of supply and/or production of HFCs while considering any other elements that could be appropriate to complement a possible international reduction arrangement for HFCs.
- The development of options and recommendations for the review of the F-gas Regulation and an analysis of their impacts.

The project was guided by a Steering Group from the European Commission. In addition, an Expert Group consisting of experts on fluorinated gases from authorities in EU-27, industry and non-governmental organisations has commented and provided further input to the work. This process has enabled the authors of this report to substantially improve the model assumptions and background data.

F-gas markets and policies

The main influencing factors for F-gas **markets** include the CFC and HCFC phase out under the Montreal Protocol, which have led to the development of HFCs as substitutes for ODS. For many applications pure HFC species (e.g. HFC-134a) could not reach the refrigeration performance of HCFC-22, therefore blends containing several HFC types were developed and placed on international markets as replacements for HCFCs. HFC production in developed countries is only slightly growing today, while a strong increase in developing countries is projected due to growing demand for HFCs.

F-gas **policies** were identified on international, European and Member State level as well as at national level in countries outside of EU-27. The underlying approaches include regulatory action, market-based mechanisms and voluntary initiatives.

Furthermore, a number of international, European and national standards apply to all sectors relying on F-gases. Although they are, in principle, voluntary to use and do not impose any regulation, many governments, as well as industry groups and trade associations require products or services to adhere to a standard before they can be placed on the market.

Interactions between the EU F-gas policy and other policies have been analysed. In some cases, F-gas policies and pieces of climate and energy legislation as well as waste legislation complement each other (e.g. WEEE Directive, EPB Directive). The Renewable Energy Directive promotes the installation of heat pumps, which has lead to strong growth of this subsector that is expected to continue. In some cases interlinkages between the F-gas Regulation and other policies need to be respected when deciding on particular review options influencing e.g. GWP thresholds set out by other legislation and definitions.

Application of the current EU F-gas policy framework

Whilst provisions of Regulation (EC) No 842/2006 are directly applicable in all Member States a few elements relied upon implementation by Member States. These include provisions on certification/ attestation systems according to Article 5(2) and on penalties according to Article 13. For both aspects, national legislation had to be established and the

Commission had to be informed about. This “implementation” refers to the legal establishment of provisions at Member State level. The relevant notifications of the Member States to the EU Commission serve as indicators. Furthermore, the “application” of the current F-gas Regulation has been analyzed which refers to the realization and possible enforcement of the provisions of the F-gas Regulation in the Member States.

As of 4th July 2011, **notification** for Member States certification/attestation bodies was still lacking from some Member States in all sectors. The status of notification in the largest sector, the stationary refrigeration, air conditioning and heat pump sector according to Regulation (EC) No 303/2008 is illustrated in figure ES-1. Notification for rules on penalties were lacking from 4 Member States.

Figure ES-1: Status of notification of certification bodies in the stationary refrigeration, air conditioning and heat pump sector according to Regulation (EC) No 303/2008 in July 2011.

Green: 20 Member States in compliance with notification obligations.
Red: 7 Member States not yet in full compliance.

A review of the progress in the application of the F-gas Regulation in the Member States considers separately its key provisions: Training and certification (Article 5), containment provisions (Article 3), requirements for proper recovery of F-gases (Article 4), reporting obligations (Article 6), labelling requirements (Article 7) and bans (Article 8 and 9).

With regard to training and certification (Article 5), it should be noted that further to the establishment or adaptation of the legal framework the actual availability of training centres is a prerequisite for the application of the requirements in the Member States. The establishment of training infrastructure for application of the certification requirements of the F-gas Regulation in the main sectors (stationary refrigeration, air conditioning and heat pumps; mobile air conditioning) has improved in almost all Member States during the analyzed time period from early 2010 to July 2011.

The **certification** status in the different sectors varies considerably between Member States. For EU-27, average shares for final personnel and company certification/attestation were determined on the basis of empirical data (table ES-1). About 600,000 persons are subject to certification and attestation requirements according to Regulations (EC) No 303-307/2008, thereof ca. 60% in the mobile air conditioning sector, 38% in the stationary refrigeration, air conditioning and heat pump sector and about 2% in the other sectors.

Table ES-1: Status of final personnel and company certification per sectors, EU-27 (July 2011)

Sector	Personnel holding final certifications	Companies holding final certifications
Stationary refrigeration, AC, heat pumps	48%	43%
Fire protection	34%	9%
High voltage switchgear	72%	-
F-gas based solvents	54%	-
Recovery of F-gases from AC systems contained in passenger cars	43%	-

While in some sectors and Member States the share of certified personnel and/or companies out of the personnel and/ or companies subject to certification provisions is high, certification of personnel and companies are delayed in other sectors and Member States.

This is partly due to delays in the establishment of national legislation implementing the requirements of the F-gas Regulation. In addition, coordination between institutions, industry associations and other stakeholders as well as discussions on recognition of existing qualifications and the integration of the minimum requirements of the F-gas Regulation in the training programs needed time and effort. Furthermore, training facilities and providers had to be put in place in some Member States, in particular for the small, very specialized sectors.

With regard to **containment** (Article 3) and **recovery** (Article 4) provisions, application also differs widely within EU-27. For the effectiveness of containment and recovery measures set out by the F-gas Regulation only little evidence has been found so far. Reliable data on a broad basis to assess the quantitative effects of these measures is not yet available. Systematic enforcement and control activities by authorities with regard to recovery and containment provisions seem to be lacking widely.

Concerning **reporting** obligations (Article 6), it can be stated that reporting is well-established and benefits from experiences made under the earlier ODS reporting, which involved the majority of companies also covered by F-gas reporting. Considering that all large producers/importers/exporters fulfil their reporting obligation, the reported sales and production quantities of F-gases are well within acceptable statistical error range. Control and enforcement mechanisms with regard to reporting seem to be not fully active at this point in time.

Labelling provisions (Article 7) affect in the sector of stationary air conditioning and refrigeration incl. heat pumps around 50.000 companies (OEM and contractors assembling in site components), about 100 F-gas suppliers including suppliers of cylinders for fire protection sector and about 25 manufacturers of high voltage switchgear equipment. Industry efforts focus on harmonization of labels, in particular in sectors where products and equipment are marketed across Europe, and integration of the additional labelling requirements into other labels. Voluntary industry action in terms of labelling of household appliances should be noted. Compliance with labelling provisions is high among large manufacturers active in several Member States. However, not all importers of products and equipment subject to labelling requirements are compliant, which might partly be due to a lack of awareness and/or information.

Bans (Articles 8 and 9) have been the most effective type of measure so far and resulted in significant and measurable reductions of the use of F-gases and hence F-gas emissions. SF_6

has been substituted in large magnesium die casting facilities (>850 kg/year) and is no longer used for filling of vehicle tyres. Full compliance with Articles 8 and 9 can be stated for the novelty aerosols and PU canned foam sub sectors as HFCs are today only used as components of preparations with GWP <150. However, further investigation of the application and potentially enforcement of the bans in soundproof windows seems necessary. Articles 8 and 9 have been applied to a large extent with minor administrative costs since conversion of production in these sectors largely took place so far, without significant needs for enforcement and control by authorities.

Costs associated with the F-gas Regulation result mostly from its application and enforcement in the Member States. One-off costs, which are related to implementation and application of the F-gas regulation, are estimated in the range of €617 million. Almost 90% thereof result from costs for certification of the personnel and companies. 66% of the certification costs relate to the SRAC sector. Recurring annual costs of provisions set out by the F-gas Regulation are estimated at €702 million for EU-27 in 2010, at €1,061 million in 2015 and at €1,551 million in 2030. Containment measures account for high shares of these costs (leakage checks, records) and occur mostly in the stationary refrigeration, air conditioning and heat pump sector. The share of recovery costs increases significantly over time.

Impact and cost-effectiveness of the current EU F-gas policy framework

The impact of the F-gas Regulation is illustrated by a comparison of two scenarios calculated by the model AnaFgas (Analysis of Fluorinated greenhouse gases in EU-27[3]): A counter-factual scenario "Without Measures" (WOM) and a scenario "With Measures" (WM), which includes the MAC Directive and the F-gas Regulation.

Empirically verified data on emission factors of different emission sources are lacking largely.

In particular, quantitative data on large scale on the effects of the containment provisions of Article 3 on emissions of refrigerants and fire protection extinguishing agents (i.e. sectors affected by Article 3) are not yet available. Similarly, for the application of recovery provisions (Article 4) little quantitative information is available on F-gas quantities recovered and recycled on site as well as on waste streams of recovered F-gases for reclamation and destruction. For certain sub sectors such as supermarket and industrial refrigeration, data sets on the use of F-gases during several years have been made available by few companies. However, these limited data do not yet allow extrapolation of emission factors to large scale.

It was generally found that none of the reporting schemes currently established for fluorinated greenhouse gases allows calculation of emission factors in the different sectors reflecting the impact of particular measures for emission reductions.

By taking into account the current state of application of the relevant provisions and assuming that by 2015 all provisions should be fully implemented and applied, it can be expected that emission factors will be reduced significantly during the 2010-2015 period as a result of the containment measures (Article 3) and recovery measures (Article 4) complemented by the training and certification measures (Article 5). The quantified changes

[3] The model AnaFgas is a bottom-up stock model to derive consumption and emission scenarios for F-gases in relevant sectors and sub-sectors for the EU-27 Member States. Data series for consumption and emissions of HFCs, PFCs, SF_6 and HCFC-22 can be modelled for the period 1995 to 2050.

of emission factors are based upon expert estimates and are considered “best case” assumptions.

On this basis, emission reduction potentials of the key types of measures in the current F-Gas policy framework have been calculated (table ES-2). At this point in time only the bans for use and placing on the market are already contributing to measurable emission reductions. In the medium-term a significantly larger emission reduction potential is expected to emerge from containment and recovery measures (Articles 3 and 4), in the sectors covered by these types of measures. Overall, most of the long-term reduction potential is a result of the provisions of the MAC Directive.

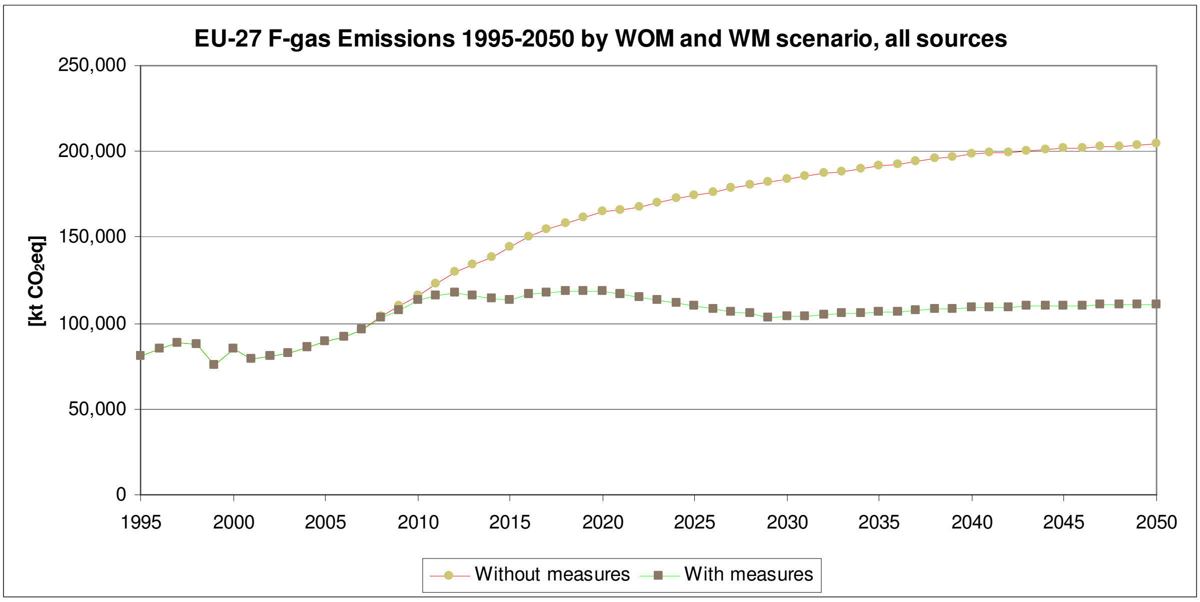

Figure ES-2: F-gas emissions in 1995-2050 in a scenario without measures (WOM) and a scenario with measures (WM) of EU F-gas legislation. The shape of the emission curves indicates the emission reduction potential for F-gas emissions. From 2008 onwards the two curves distinctly split up. In the WM scenario, emissions will remain at a stable level from 2010 until 2050, while in the WOM scenario emissions would continue to increase up to almost the double. It should be noted that even in the WM scenario absolute emissions in 2050 will be higher than in the WOM scenario in 2008 (by 6,800 kt CO_2 eq).

The current EU F-gas policy framework including the F-gas Regulation and the MAC Directive opens up the opportunity to significantly slow down the increase of future emissions (figure ES-2). The emission reduction relative to the WOM scenario totals 2,900 kt CO_2 eq at present (-2.6%), increasing to 30,800 kt CO_2 eq in 2015 (-22%) and 93,300 kt CO_2 eq in 2050 (-46%).

Table ES-2: Emission reduction potentials (kt CO_2 eq) of measures set out by EU legislation on F-gases (including F-gas Regulation and the MAC Directive) in 2008-2050 (WOM-WM)

		2008	2009	2010	2015	2020	2030	2050
MAC Directive		0	0	0	3,419	13,150	40,965	49,916
F-gas Regulation	Art 3 and Art 4	0	0	0	24,357	29,478	35,609	38,815
	Art 8 and Art 9	909	2,687	2,861	3,012	3,223	3,750	4,616
Total		**909**	**2,687**	**2,861**	**30,787**	**45,850**	**80,325**	**93,347**

With regard to cost-effectiveness of the F-gas Regulation, abatement costs of 40.8 €/t CO_2 eq in 2015 and 41.0 €/t CO_2 eq in 2030 have been calculated on the basis of the WM scenario.

Furthermore, significant shares of projected F-gas emissions remain unabated although their sources might be subject to containment and recovery provisions already. The following sectors will contribute large proportions of future F-gas emissions: Room air conditioning, commercial refrigeration, industrial refrigeration.

Currently certain F-gas emissions are not effectively addressed by the EU F-gas policy framework. These include HFC emissions from mobile air conditioning systems contained in ships and rail vehicles, from transport refrigeration and refrigerated ships, from foams, from halocarbon production, HFC-23 by-product emissions, PFC emissions from industry, SF_6 emissions from certain applications. F-gas emissions from Organic Rankine Cycles and emissions from other fluorinated gases are currently not covered (NF_3, SO_2F_2, unsaturated HFCs, other HFCs and PFCs).

In the light of international and EU unilateral commitments to reduce greenhouse gas emissions, further reductions of F-gas emission seem to be appropriate. These will need to be based on additional policy measures.

State and potential of technology in the different sectors

The projected F-gas demand in 2050 and emissions of the WOM and WM scenario are based on sub sector specific assumptions of growth rates. These assumptions do not include in most cases technological changes or growing shares of alternative technologies but are based on continued use of conventional technology ("frozen technology").

In order to identify the maximum reduction potential of F-gas emissions, the potential for the replacement of F-gases by low-GWP solutions in all sectors currently relying on F-gases is assessed. For each sector, technically feasible and cost-effective alternative technologies to sector-typical conventional F-gas technology were identified and are hereafter referred to as "alternative options". The selection of replacement technology was guided by three criteria including the reduction potential of CO_2-weighted use of F-gas and emissions, cost effectiveness (expressed in abatement cost of €/t CO_2 eq) and energy consumption. For each alternative option, the penetration rate, which is defined as maximum potential of each technical choice to replace new products or equipment relying upon F-gas, was estimated. Penetration rates are given for each alternative option based on technical feasibility to replace existing F-gas technology by a specific alternative technology, at least cost.

On the basis of a sector penetration mix, which is the set of alternative options in a sector with the highest aggregated technical reduction potential, sector specific (average) abatement costs and related reduction potentials for demand and emissions of F-gases through the use of alternative technologies in 2030 are calculated.

At the international level, this results in the findings that HFC consumption in 2030 can be reduced by ca. 760 Mt CO_2 eq in developed countries (figure ES-3) and by almost 2,000 Mt CO_2 eq in developing countries (figure ES-4) at costs < 20 €/t CO_2 eq. In both, developed and developing countries, abatement costs > 20 €/t CO_2 eq occur for abatement options in buses, multi split systems, ducted air conditioners, and heat pumps.

At EU level, technically feasible and cost effective abatement options are analysed in terms of HFC demand reductions (=potential emissions) and actual HFC emission reductions. In relation to the WM scenario, HFC demand of 136 Mt CO_2 eq can be reduced at costs < 20 €/t CO_2 eq in EU-27 in 2030 (figure ES-5) and HFC emissions of 66 Mt CO_2 eq can be abated at costs < 25 €/t CO_2 eq in EU-27 in 2030 (figure ES-6).

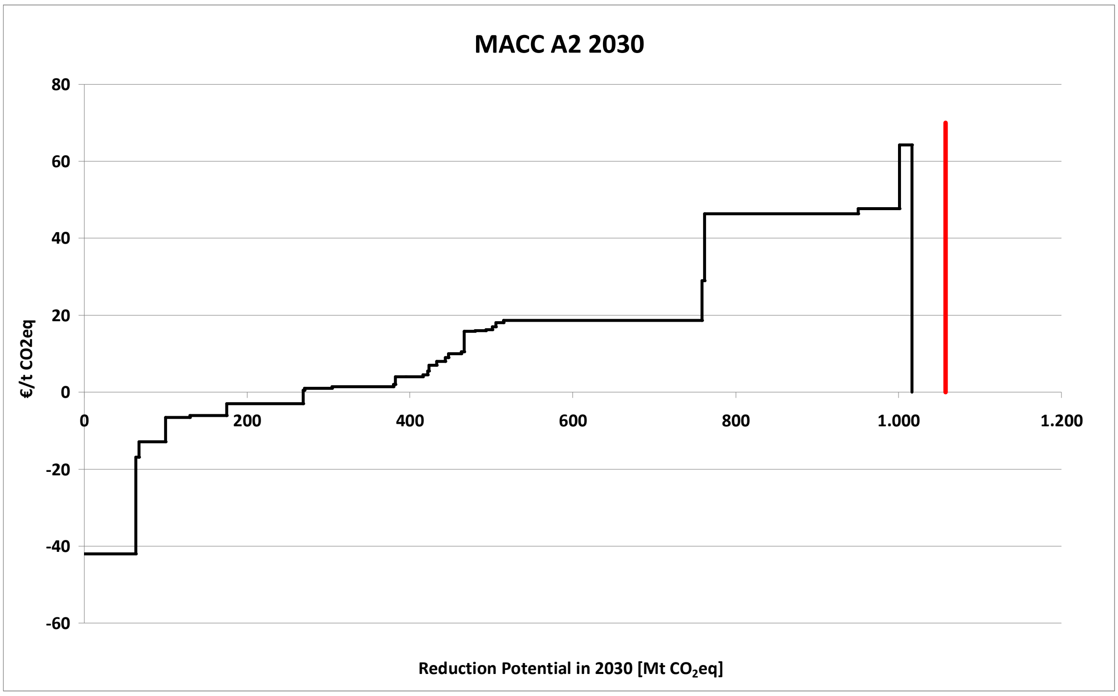

Figure ES-3: Marginal Abatement Cost Curve for consumption reductions in developed countries in 2030. The red line on the right indicates total HFC consumption in developed countries in 2030.

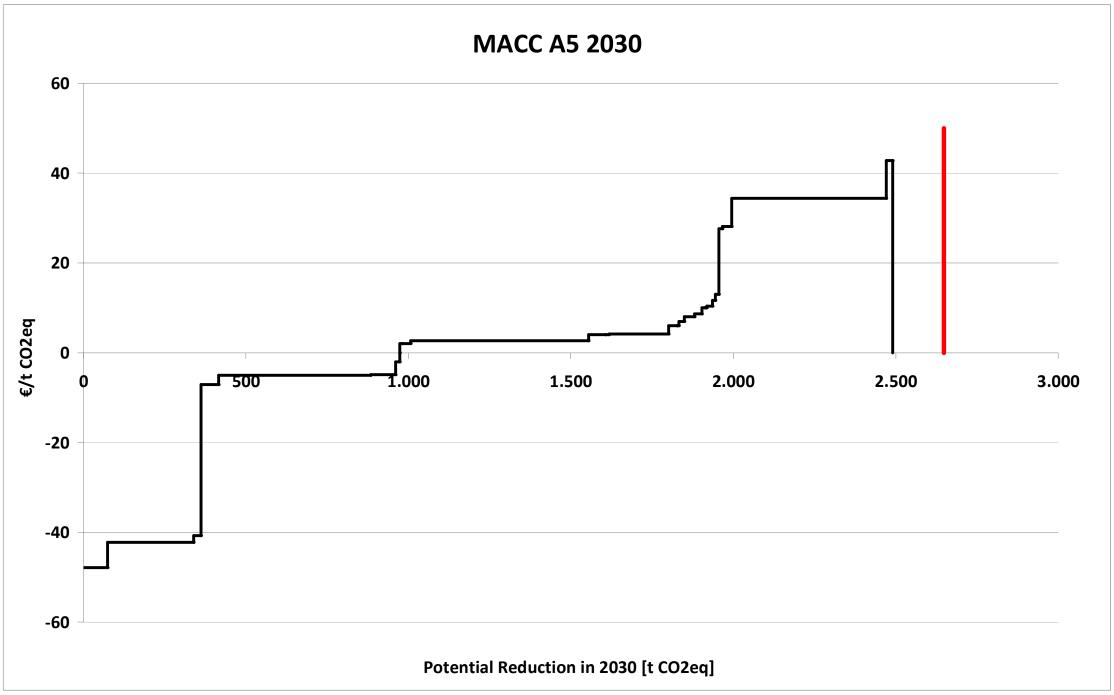

Figure ES-4: Marginal Abatement Cost Curve for consumption reductions in developing countries in 2030. The red line on the right indicates total HFC consumption in developing countries in 2030.

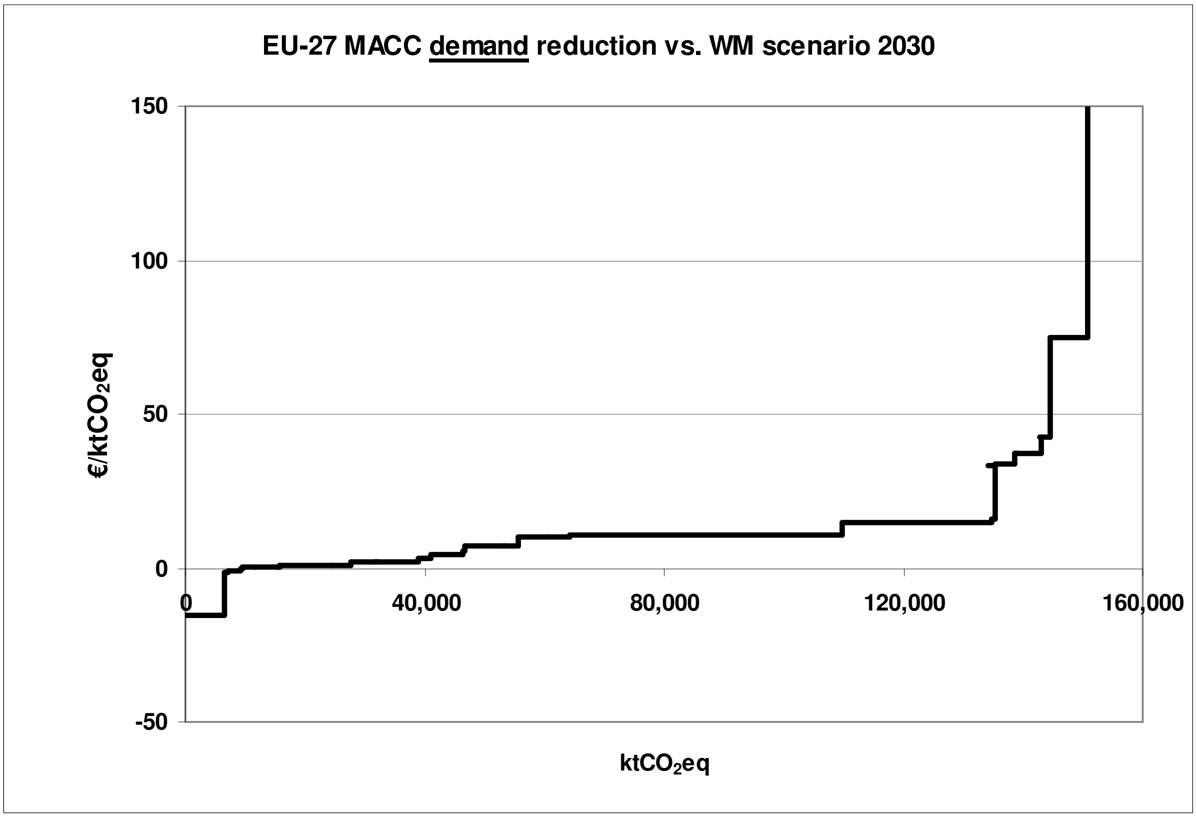

Figure ES-5: Marginal Abatement Cost Curve for F-gas demand reduction in EU-27 in 2030. Demand includes quantities contained in pre-filled imported equipment imported in the EU.

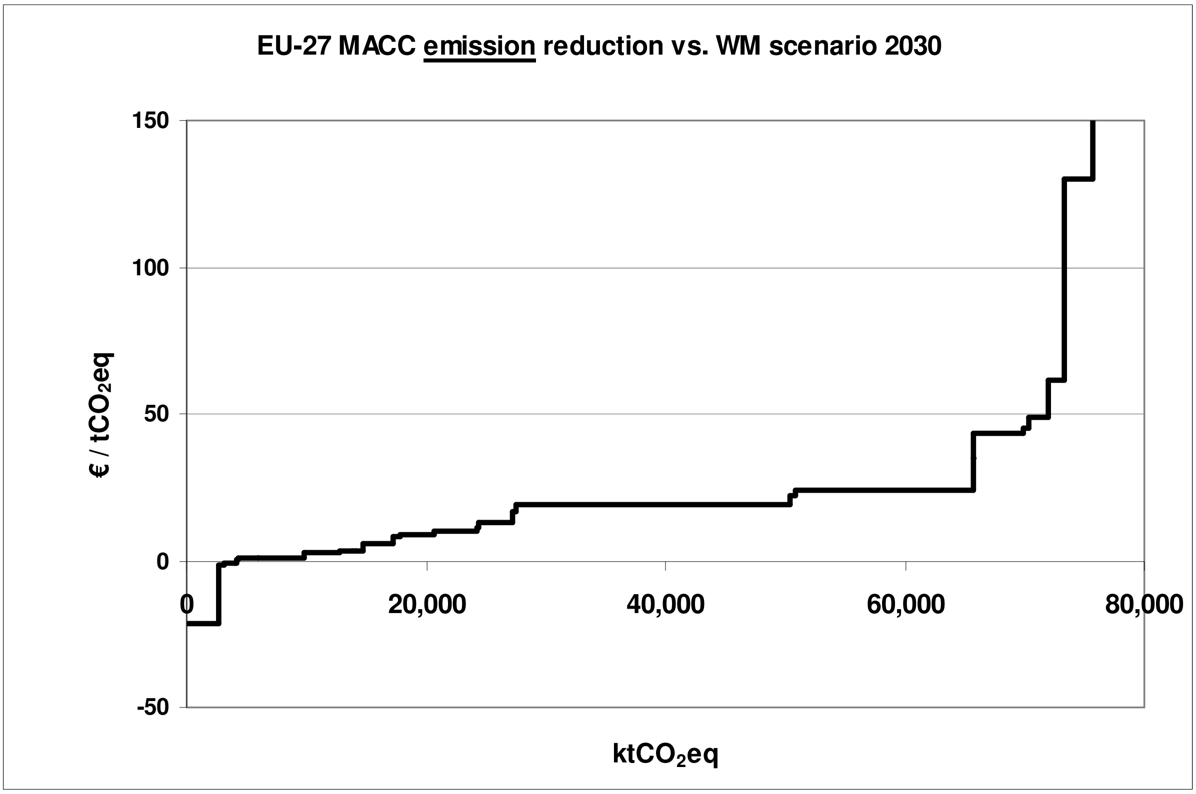

Figure ES-6: Marginal Abatement Cost Curve for F-gas emission reductions in EU-27 in 2030.

Options for further international action to reduce F-gas emissions

Scenarios project HFC consumption during the period 2010-2030 under business-as-usual (BAU) and technically feasible reductions of global HFC consumption in the same period in both developed and developing countries.

Growing use of HFCs and hence emissions are mainly a result of the phase out of ODS under the Montreal Protocol: HFC demand in developing countries is projected to increase drastically in the next decades, while HCFC demand will decrease (BAU scenario). HFC demand in developed countries is only slightly growing and likely to reach stable levels around 2030.

As F-gas markets are global markets, HFC production is often taking place in one country while HFC consumption and related emissions during and at the end of product life take place in other countries. Local or regional policy action can hence only address the contribution of HFCs to global warming to minor extent, while international action is thought to be able to achieve significant consumption and emission reductions at large scale.

Current policy discussions at international level treat the question on how to link the work on F-gases, in particular HFCs, done under the UNFCCC climate regime and further phase out of ODS under the Montreal Protocol more closely. The Montreal Protocol holds a special role as it addresses most industries and sectors which rely on F-gases while not addressing these gases. It could be possible to abate HFC emissions in a similar way as ozone-depleting substances by applying an approach similar to that of the Montreal Protocol.

Two existing proposals for HFC phase down under the Montreal Protocol resubmitted by Northern American (NA) countries and the Federated States of Micronesia (FSM) in 2011 are turned into the “NA scenario” and the “FSM scenario”.

Based on the findings on abatement technologies for each sector, potential HFC supply reduction scenarios for developed and developing countries are calculated: A reduction scenario (RED) is based on all technically feasible abatement options identified for each sector at the maximum penetration rates in a particular year. Another reduction scenario (RED10) is based on technically feasible abatement options at abatement costs <10 €/t CO_2 eq identified for each sector at the maximum penetration rates in a particular year.

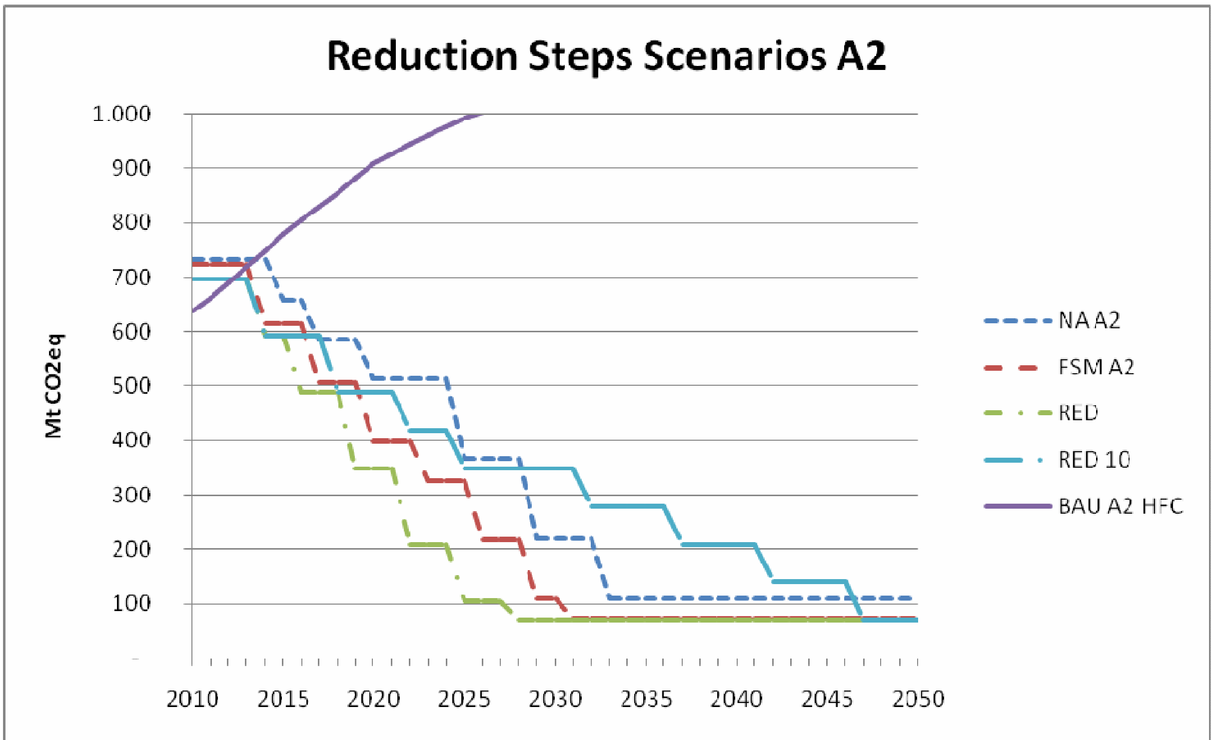

Figure ES-7: Comparison of scenarios for HFC phase down in developed countries.

The reduction scenarios, the NA scenario and the FSM scenario are compared (figure ES-7 for developed countries) with regard to the control schedules for developed and developing countries as well as their global HFC consumption reductions.

Options for further EU action to reduce F-gas emissions

The identification of policy options for further EU action is based on the project work and includes the forward looking options listed in Article 10 of the Regulation. The WM scenario calculated by the model AnaFgas serves as reference and allows comparison of different policy options.

Policy options for further action describe different ways forward and are, in most cases, mutually exclusive, although certain of the options and many of the sub-options might complement each other. The main options/ sub-options include:

Option A Business-as-usual (do nothing).

Option B Suspend provisions of the F-Gas Regulation. This option was discarded from further analysis because such approach would clearly not be in line with the EU's overall climate objectives.

Option C Non-regulatory approaches.

C-1: Environmental agreements and self-regulation.

C-2: Improved coordination.

C-3: Enhanced technical standards

Option D Further regulatory action (includes several sub-options addressing particular sectors, types of measures and/or types of F-gas emissions).

D-1: Include F-gases currently not covered in annex I of the F-gas Regulation.

D-2: Enhance application and monitoring of the Regulation.

D-3: Improve containment and recovery in certain sectors.

D-4: Ban the use or the placing on the market of open F-gas applications.

D-5: Ban the placing on the market of certain closed applications containing F-gases, where energy efficient and safe alternatives are available. This option considers potential bans for different closed applications of F-gases starting in the period 2015-2030.

D-6: Set quantitative limits for the placing on the market of F-gases in the EU-27. This option is based on stepwise limits to HFC supply, thereby drives the introduction of alternative technologies and hence reduces F-gas emissions.

D-7: Development and dissemination of BAT and BREF notes and documents.

D-8: Obligation to destroy HFC-23 by-product emissions from halocarbon production.

Option E includes market-based approaches.

E-1: Include additional activities under the EU-ETS.

E-2: Tax schemes.

E-3: Deposit and refund schemes.

In a screening, the policy options were assessed against several criteria such as effectiveness (threshold of 1 million t CO_2 eq), efficiency (threshold of 50 €/t CO_2 eq), technical constraints and other qualitative criteria. The screening resulted in a short list of key policy options, which are subject to the subsequent impact analysis (table ES-3).

Table ES-3: Overview of key policy options and their additional emission reduction potential in 2030 (kt CO_2 eq)

Proposed policy option	**Additional emission reduction potential in 2030 (kt CO_2 eq)**
Voluntary agreements	21,702
Improve containment and recovery under F-gas Regulation: Refrigerated trucks and trailers	1,430
Ban the placing on the market of certain open applications containing HFCs	5,190
Ban the use of SF_6 in open applications	250
Ban the placing on the market of certain closed applications containing F-gases	47,089
Limits for the placing on the market of HFCs in EU	71,740
Obligation for HFC-23 by-product destruction	370

All of these options could be supplemented by approaches under option D-2 aiming at improvement of the existing legislation and its application through additional information and guidance. Emission reduction potentials and abatement costs for such modifications are not quantifiable.

In order to achieve maximum abatement of F-gas emissions, a combination of the option "Limits for the placing on the market of HFCs in EU", the options "Ban the use of SF_6 in open applications" and "Obligation for HFC-23 destruction" was chosen as it provides the maximum emission reduction potential of ca. 72,500 kt CO_2 eq in 2030.

This combination is the basis of the third scenario "With additional measures" in the model AnaFgas. It is shown in figure ES-8, in comparison with the WOM and WM scenario.

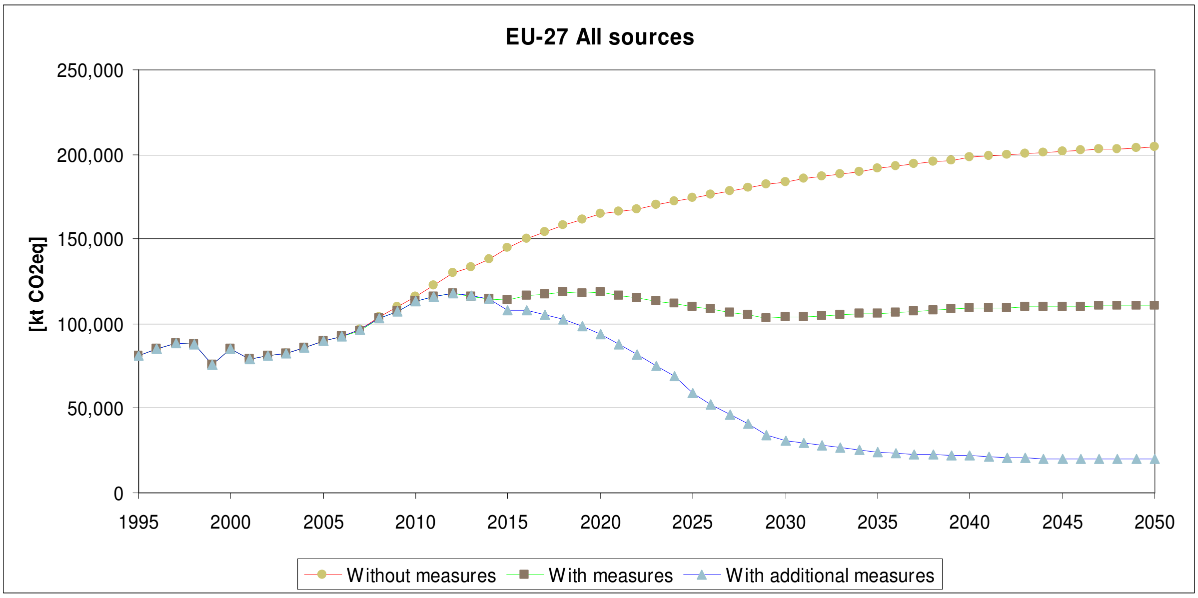

Figure ES-8: The three emission scenarios for EU-27 in the model AnaFgas.

Likely effects of the key policy options were considered in terms of their environmental, economic and social impacts on the basis of quantitative or qualitative analyses.

With regard to emission reductions, the option "quantitative limits for the placing on the market of fluorinated gases" shows the highest potential (direct: 71.7 Mt CO_2 eq; indirect: 1.6 Mt CO_2 eq), followed by the option "ban of the POM of certain closed applications containing F-gases" (direct: 47.1 Mt CO_2 eq; indirect: 0.7 Mt CO_2 eq) and the option "voluntary agreements" (direct: 21.7 Mt CO_2 eq; indirect: 0.5 Mt CO_2 eq). The abatement costs for these three policy options with high emission reduction effects are comparable and range at 14 - 17 €/ t CO_2 eq.

The direct net costs for affected sectors are the highest in the option "quantitative limits for the placing on the market of fluorinated gases" (1,083 M€/year), followed by the option "ban of the POM of certain closed applications containing F-gases" (675 M€/year). The investment costs are also the highest for the option "quantitative limits for the placing on the market of fluorinated gases" (5,613 M€/ year in 2030) and comparably high for the option "ban of the POM of certain closed applications containing F-gases" (2,860.2 M€/ year). Due to the fact that these options result in the largest new investments in the affected subsectors, they are expected to also have the highest positive effects on employment via the creation of new jobs.

1. Introduction

Fluorinated greenhouse gases (F-gases) are used in numerous applications and include three types of gases: HFCs, PFCs and SF_6. Their emissions are released from various sources (table 1-1).

HFC emissions account for large shares of F-gas emissions and are projected to increase in the next decades. HFCs were widely introduced as substitutes for ozone depleting substances (ODS) in recent years since the Montreal Protocol controls production and consumption of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) in order to reach global phase-out. Therefore, HFCs are used in the same sectors of application as CFCs and HCFCs, such as refrigeration and air conditioning equipment, foams and fire protection systems.

PFCs, in contrast, are mostly used and emitted during industrial processes such as semiconductor manufacture and aluminium production (inadvertent emissions). To limited extent, they are also used as solvents, fire fighting agents and refrigerants. Their contribution to total F-gas emissions has decreased in past years.

Emissions of SF_6 occur from certain industrial applications, e.g. magnesium casting, TFT-LCD and photovoltaic manufacture, but are also released from large banks contained in sound-proof windows and switchgear equipment for the transmission and distribution of electricity.

Table 1-1: Main sectors of intended application (and inadvertent production) of F-gases

HFCs	Refrigeration: Domestic refrigeration, commercial refrigeration, industrial refrigeration, transport refrigeration
	Air conditioning: Mobile air conditioning, stationary air conditioning, heat pumps
	Foam blowing: XPS foam, PU rigid foams, PU canned foam (OCF)
	Aerosols: Metered-dose Inhalers (MDI), technical aerosols, novelty aerosols
	Solvents
	Fire protection
	Manufacture of HCFC-22: HFC-23 as by-product (inadvertent production)
	others
PFCs	Semiconductor manufacturing
	Aluminium production (inadvertent production)
	Others: Fire protection, solvents, refrigerants
SF_6	Transmission and distribution of electricity
	Non-ferrous metal industry: Magnesium casting
	Secondary Aluminium cleaning
	Soundproof windows
	Particle accelerators
	Production of optical fibres
	Vehicle tyres
	Footwear
	TFT-LCD and photovoltaic
	others

F-gases are greenhouse gases and accelerate global warming. They often have high global warming potentials. They are addressed by international conventions such as the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, as well as by European policies and at national level in EU Member States and other countries internationally (chapter 3.2). The Kyoto Protocol promotes emission reductions of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

The EU committed to reduce overall greenhouse gas emissions by 8% compared to the base year 1990 during the first commitment period 2008-2012. In order to comply with these commitments, the European Commission identified and developed an EU strategy through the European Climate Change Programme (ECCP). In 2003, a legislative framework to reduce projected F-gas emissions by 23 million tonnes of CO_2 eq by 2010 (EU-15) was proposed. Based on this proposal, a package of two elements was adopted in 2006: Directive 2006/40/EC relating to emissions from air conditioning systems in motor vehicles, the so-called MAC Directive, and Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases, the so-called F-gas Regulation.

The F-gas Regulation applies since 4 July 2007 with the exception of Article 9 and annex II, which apply since 4 July 2006. The regulation has been implemented by 10 Commission Regulations adopted between December 2007 and April 2008, which establish certain technical elements of the provisions[4]. Provisions have been directly applicable in the Member States; however few elements needed implementation at EU or Member State level (chapter 4). Measures of the MAC Directive are expected to reduce F-gas emissions from 2011 onwards.

At international level, discussions on how to effectively reduce F-gas emissions also take place under the Montreal Protocol (chapter 7). The approach of the Montreal Protocol focuses on control and stepwise decrease of consumption and production. It presently applies to 96 chemicals including chlorofluorocarbons (CFCs), halons, hydrobromofluorocarbons (HBFCs), hydrochlorofluorocarbons (HCFCs), and others. Most of the fluorinated ozone depleting substances (CFCs, HCFCs) are being phased out which has resulted in a significant decrease of ODS production and supply all over the world since the 1980s. Developed countries ("A2 countries" in the terminology of the Montreal Protocol) have already completed the phase out of CFCs and will reach full phase out of HCFCs by 2020. Developing countries ("A5 countries" in the terminology of the Montreal Protocol), in contrast, have phased out CFCs by 2010 and will phase out HCFCs by 2030.

However, the phase-out of these substances has resulted in increased use of HFCs globally as they were developed as substitutes for ODS. Due to the potent global warming potentials of HFCs and the high growth rates of relevant sectors, this trend has caused concern internationally. Figure 1-1 illustrates the link between ozone depleting substances covered by the Montreal Protocol and HFCs and PFCs covered by the climate regime.

[4] Commission Regulations (EC) No 1493/2007, 1494/2007, 1497/2007, 1516/2007, 303/2008, 304/2008, 305/2008, 306/2008, 307/2008, 308/2008.

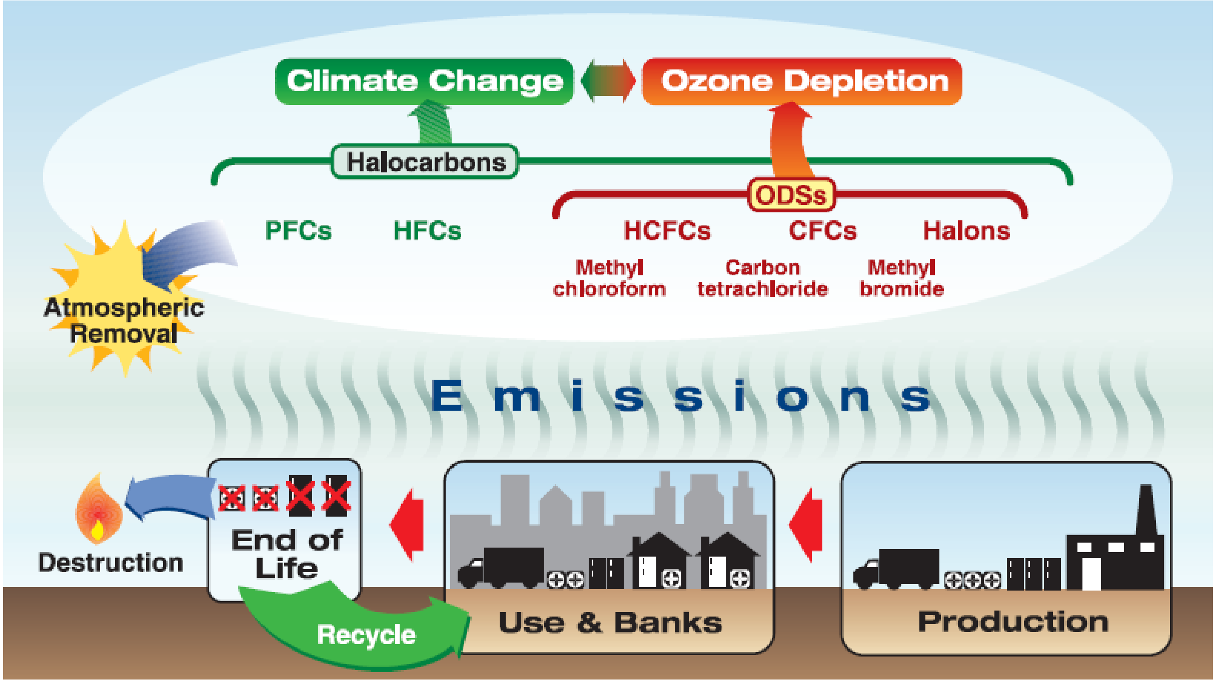

Figure 1-1: CFCs, HCFCs and halons contribute to climate change and ozone depletion while HFCs and PFCs contribute to climate change only and have been used as alternatives to ODS. Source: UNEP TEAP/IPCC SROC Report 2005.

Current international discussions are based on proposals by the EU, North American countries and the Federated States of Micronesia for action to address HFCs under the Montreal Protocol. Since 2009, two detailed proposals submitted under the Montreal Protocol by North American (NA) countries and by the Federated States of Micronesia (FSM) include schedules to limit and reduce the production and consumption of HFCs in the next decades.

In the context of this discussion, the current work provides relevant input such as a business-as-usual (BAU) scenario for future demand of HFCs by sectors and types of end-uses in A2 and A5 countries, as well as a detailed assessment of technical options for abatement to reduce HFC demand consumption including an analysis of marginal abatement costs for the time horizons 2015, 2020 and 2030. Scenarios further to those proposed already (FSM/NA) are based on the maximum technical feasibility of abatement of HFC demand consumption in different end-uses (RED scenario) and also take into account costs of abatement of HFC demand (RED10 scenario; abatement costs <10 €/t CO_2 eq) (chapter 7).

Article 10 of the Regulation requires the Commission to publish a report based on the experience of the application of the Regulation by 4 July 2011 also assessing the need for further action in the light of the evolving policy context. In this context the Commission is called upon to present appropriate proposals for revision of the relevant provisions of the regulation, where necessary. Aspects for review have been identified based on Article 10 and the results of work undertaken within the current project. These options and their key environmental, economic and social impacts in EU-27 are assessed (chapter 8).

The overall purpose of this project is to assist the Commission in reviewing Regulation (EC) No 842/2006 by providing technical data, analyses and general support. A service contract carried out by Öko-Recherche and partners since December 2009 includes the following tasks[5]:

- A review of relevant F-gas markets and policies internationally as well as in the EU-27, including investigation of possible interactions, complementarities or overlaps amongst the EU F-gas policy framework (F-gas Regulation and MAC Directive) and other EU or international policies.
- An assessment of the effectiveness of current EU F-gas policy, through the development of appropriate models and datasets for emission scenarios in EU-27 and an ex-post assessment of the key elements of the current EU F-gas policy.
- An assessment of the feasibility of emerging options for an international emission reduction arrangement for HFCs and, if appropriate, other F-gases by assessing the feasibility and cost-effectiveness of the replacement of F-gases, developing and comparing of scenarios for the control of consumption and/or production of HFCs and while considering any other elements that could be appropriate to complement a possible international reduction arrangement for HFCs.
- The development of options and recommendations for further action at EU level and an assessment of key impacts.

The project was guided by a Steering Group from the European Commission. In addition, an Expert Group consisting of experts on fluorinated gases from authorities in EU-27, industry and non-governmental organisations has commented and provided further input to the work. This process has enabled the authors of this report to substantially improve the model assumptions and background data.

[5] European Commission: Specifications to tender ENV.C.4/SER/2009/0033 Service contract to provide technical support for conducting a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases.

2. Methodology

2.1 Collection of data and information

The work undertaken is based on various sources of information in order to cover the different needs for quantitative or qualitative data, historic time series or trends and projections, policy measures including legislation, sectoral and country information, data for certain Member States, EU-27, developed countries, developing countries or the world.

2.1.1 Basic and background information

Existing and on-going studies and scientific articles serve as important sources of sectoral details and approaches, as well on global and regional concepts and trends. Major sources include recent reports by UNEP TEAP, the IPCC Special Report on Safeguarding the Ozone Layer and the Global Climate System as well as the IPCC 4th Assessment Report.

General expertise on F-gases, their alternatives and sectoral expertise are available through the project team lead by Öko-Recherche holding long-term experience and archives on the use of F-gases and methodologies required for the analysis to be undertaken.

Data from the Member States reported according to Article 6 of the F-gas Regulation have been complemented and cross-checked with the latest national communications under the UNFCCC[6]. In addition, national greenhouse gas inventory submissions by the Member States and the EU to the UNFCCC served as data input, in particularly CRF data were used for modelling purposes and are indicated in the model description (annex III).

2.1.2 Data on the status of implementation and application of the F-gas Regulation

An assessment of the status of implementation of the F-gas Regulation and the application of its most important measures in the Member States has been undertaken. It should be underlined that the implementation of the F-gas Regulation is delayed to some extent and not completed in all Member States yet. Therefore, this section is not an ex-post assessment in a strict sense but rather an assessment of the status of implementation and first results of the application of the Regulation.

The assessment analyses

- to what extent the current EU F-gas policy and in particular the relevant provisions of the F-gas Regulation have been implemented (chapter 4.1) and applied (chapter 4.2) in the EU-27 Member States and which costs arise from implementation and application of the Regulation (chapter 4.3).
- Whether qualitative and quantitative findings can already be made, whether the application of the F-gas Regulation has already lead to results in terms of its general objectives and whether it will continue to do so.

[6] Annex I parties to the UNFCCC were requested to submit their fifth national communications to the UNFCCC Secretariat by 1 January 2010 (Decision 10/CP.13 of December 2007).

The outcome of this assessment provides important background information for the identification of options for further action including through a potential revision of the F-gas Regulation (chapter 8). The survey is based on the following sources besides the evaluation of literature:

- Evaluation of a basic questionnaire (March 2010) which has been submitted to the **competent authorities in all Member States**. All Member States replied to this questionnaire and additional questions in oral and written form. Some of them also submitted more comprehensive documentation such as national assessments and studies already available. Although for some Southern and small Member States only limited data are available, the information on status of implementation and application of the F-gas Regulation in most of the EU-27 is quite detailed. The last survey amongst Member States (and industry) on the status of implementation and application of certification provisions of the Regulation dates from June 2011.
- **Stationary refrigeration, air conditioning and heat pump sector:** Evaluation of a questionnaire designed for industry stakeholders, who produce, design, install and maintain heating, cooling and refrigeration technologies (March 2010). These include 12 national and multinational companies who are members of EPEE (European Partnership for Energy and the Environment). The companies introduced their own knowledge and partly consulted their clients (operators). The questionnaire has also been answered by 4 national industry associations (AFCE/France, ATF/Italy, FETA/UK, and NRF/Poland). 20 completed questionnaires were analyzed encompassing details for 10 EU-Member States (Belgium, Denmark, France, Germany, Greece, Italy, Netherlands, Poland, Spain, and United Kingdom). EPEE submitted additional data on the status of implementation and application of the F-gas Regulation in the Member States including data on certification and training from 10 Member States.

  A consolidated report from the European-wide association of small and medium-sized service companies and contractors, AREA, has been evaluated within a discussion with AREA. This report is a summary of replies on a questionnaire designed for companies from the national AREA member associations and includes information on and by 18 EU-Member States (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Sweden, Slovakia, Spain, and United Kingdom).

  Evaluation of a consolidated report from ECSLA, the European Cold Storage and Logistics Association, including data from France, Germany, Greece, Netherlands, and Spain. The report is based on replies from ECSLA member associations to the questionnaire designed for companies from the stationary refrigeration, air conditioning and heat pump sector.

- **High voltage switchgear sector:** Evaluation of a questionnaire (March 2010) to industry which has been answered by national associations (Austria, France, Germany, Italy, and Spain) as well as the European umbrella organization T&D Europe. Data was obtained on all EU-Member States and additional background information from T&D Europe. The data were evaluated during a discussion with T&D Europe. The European association of network operators EURELECTRIC joined the responses of T&D-Europe. Additional information was submitted by the company EATON corporation.

– **Fire protection sector:** Evaluation of a questionnaire (March 2010) to the umbrella organizations EUROFEU and ASSURE. Replies and additional information were received from national associations of EUROFEU (Germany, Italy, the Netherlands, Spain, Sweden, and UK) as well as from companies from some Member States. The data were analysed in a meeting with EUROFEU, section Fire Extinguishing Installations. ASSURE submitted a consolidated report.

– **F-gas based solvents sector:** Information was provided by the manufacturer (DuPont) and by DEFRA (UK).

– **Manufacturers of F-gases:** Evaluation of replies from manufacturers of F-gases from the association EFCTC (European Fluorocarbon Technical Committee, CEFIC-member) and from EFCTC member companies to some questions of the questionnaire designed for companies active in the stationary refrigeration, air conditioning and heat pump sector.

– **Additional country information:** A separate survey of companies and organizations from the sectors of SRAC/HP, Fire Protection Systems, High-Voltage Switchgear and Mobile AC in the Baltic Member States Estonia, Latvia, and Lithuania was carried out by the EERC (Estonian Environmental Research Centre).

– **Cost data:** Information on costs came from the above mentioned sources, from certification bodies and from training centres from several Member States.

– **Methodological issues**: Discussions with representatives from the Dutch STEK organisation on methodological aspects of data calculation in the STEK system.

The level of detail and quality of responses to the questionnaires and follow-up questions varied considerably. Information from industry stakeholders for the stationary refrigeration, air conditioning and heat pump sectors are available from all Member States with the exception of Bulgaria, Cyprus, Luxembourg, Malta, Romania and Slovenia. Data for the sectors High-Voltage Switchgear and Fire Protection Systems is available from some Member States and mainly from industry. F-gas based solvents are not applied to a relevant extent in any Member State with the exemption of France and UK. The information from companies in this sector is limited to the one relevant manufacturer.

The data quality and comprehensiveness is relatively higher in the stationary refrigeration, air conditioning and heat pump sector and the high voltage switchgear sector, compared to the other sectors. All stakeholders involved in the investigation underlined with regard to the assessment of the effectiveness of the F-gas Regulation that the timeframe since the entry into force of the F-gas Regulation and since the start of its implementation and application is far too short to allow judgements in terms of quantitative data, in particular with regards to containment measures. Insofar qualitative information and subjective assessments had to be carefully considered.

Based on these sources the status of implementation of certain provisions of the F-gas Regulation and of its application were assessed at three points in time: 1st quarter 2010, January 2011 and July 2011.

2.1.3 Role of the Expert Group

An Expert Group established by the Commission to provide additional expertise during the preparatory phase of the review comprises representatives of competent authorities, of industry associations from all sectors and non-governmental organisations active in the field of fluorinated greenhouse gases. The Expert Group has been invited to comment on the data, assumptions and results derived throughout this project, on the basis of three Working Documents (September-October 2010, February 2011, May 2011) aiming at improving the quality of the final outcome. This report takes into account those comments, suggestions and input, as and where considered appropriate.

Where necessary, the project team has solicited direct follow-up input to the ongoing work by several members of the Expert Group and other experts.

2.2 Compilation of sectoral data and modelling

2.2.1 Compilation of data and development of models

Quantitative data were compiled for each sector relying on F-gases and for the halocarbon production and primary aluminium sectors in which F-Gases are emitted as by-products or as fugitive emissions. The classification of sectors follows the structure for the emissions reporting under UNFCCC (CRF tables) and includes the following subsectors:

- Domestic refrigeration (HFCs)
- Commercial refrigeration: Stand-alone equipment; Condensing units; Centralised systems (HFCs)
- Industrial refrigeration: Small refrigeration plants, Large refrigeration plants (HFCs)
- Refrigerated transport: Refrigerated vans; Refrigerated trucks & trailers; Refrigerated containers; Refrigerated fishing vessels (HFCs)
- Stationary air conditioning and heat pumps: Moveable air conditioners; Split air conditioners; Multi split air conditioners; Rooftop air conditioners; Displacement chillers; Centrifugal chillers; Heat pumps (heating only) (HFCs)
- Mobile AC: Passenger Cars; Trucks; Buses; Rail vehicles; Cargo ships; Passenger ships (HFCs)
- Foam sectors: One-component foam (canned); XPS and PU insulation foam for the construction sector; PU insulation foam for refrigeration applications; Non-insulating integral foams for automotive, furniture sectors, shoe soles, etc. (HFCs)
- Fire protection sectors: Fire protection (HFC-227ea and HFC-23)
- Aerosols: technical and novelty aerosols; MDIs (HFCs)
- Primary Aluminium production (PFCs)
- Semiconductor industry (PFCs)
- Electrical switchgear (SF_6)
- Magnesium casting and secondary Aluminium (SF_6)
- Soundproof glazing (SF_6)
- Car tyres (SF_6)
- Sport shoe soles (SF_6)
- Production of halocarbons (HFCs, PFCs, SF_6)

For each sector, historic data, expert estimates of the current situation as well as for short term and long term trends were compiled for EU-27, developed countries and developing countries.

2.2.2 The model AnaFgas

The model AnaFgas (Analysis of Fluorinated greenhouse gases in EU-27) is a bottom-up stock model to derive demand and emission scenarios for F-gases in relevant sectors and sub-sectors for the EU-27 Member States. It models demand for and emissions of HFCs, PFCs and SF_6 as well as HCFC-22 for the period 1995 to 2050 based on market data and estimates of the quantity of equipment or products sold each year containing these substances, and the amount of substances required in the EU to manufacture and/or maintain equipment and products over time.

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.

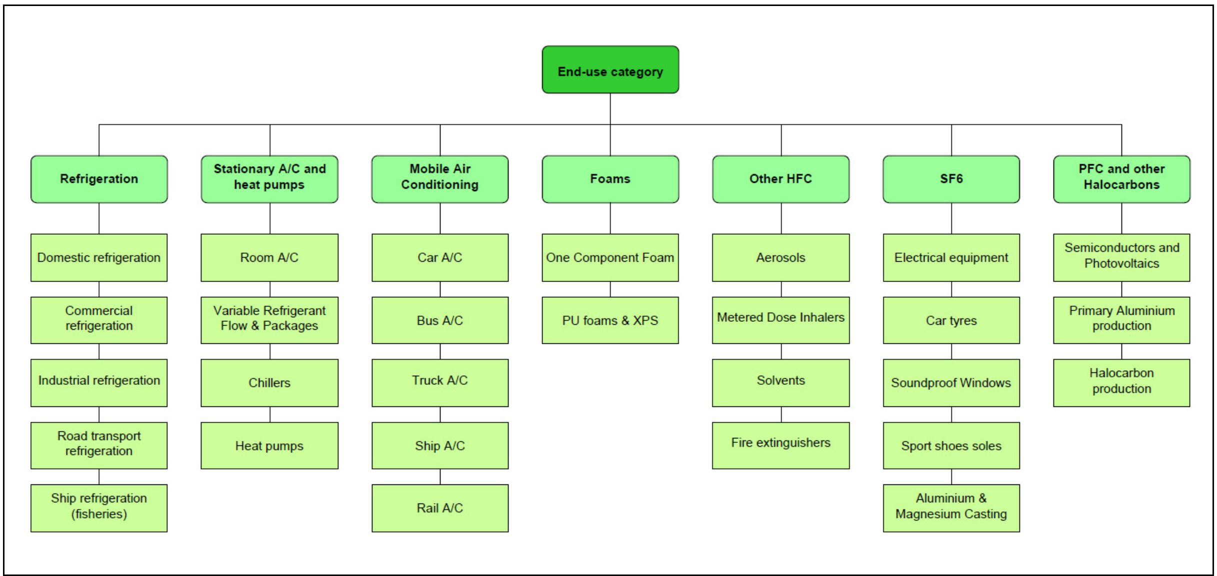

Figure 2-1: Scheme of the sectors and sub-sectors covered by AnaFgas

Through these emissions which occur during the lifetime of 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 tonnes or GWP-weighted (kt CO_2 eq).

Seven sectors with a total of 29 sub sectors are separately represented in the model (see figure 2-1). In total 21 different fluorinated gases (excluding ozone-depleting gases) are included in the model (11 HFCs, 5 PFCs, 2 unsaturated HFCs, 1 fluoroketone, SF_6, NF_3) and calculations can either be based on metric tonnes or global warming potential (GWP) (table 2-1).

In addition, the GWP included in the second, third or fourth IPCC Assessment Report (2nd, 3rd, 4th AR) can be chosen. Use and emissions are calculated annually for all years between 1995 and 2050.

***Table 2-1: List of gases and global warming potentials included in the model AnaFgas*[7]**

Industrial Designation or Common Name	Chemical Formula	GWP (100yr)		
		2nd AR	**3rd AR**	**4th AR**
Carbon dioxide	CO_2	**1**	**1**	**1**
HFC blends				
404A	44% 125, 4% 134a, 52% 143a	**3,260**	**3,784**	**3,922**
407C	23% 32, 25% 125, 52% 134a	**1,526**	**1,653**	**1,774**
507	50%125, 50% 143a	**3,300**	**3,850**	**3,985**
410A	50% 32, 50% 125	**1,725**	**1,975**	**2,088**
Substances controlled by the Montreal Protocol				
CFC-11	CCl_3F	**3,800**	**4,600**	**4,750**
CFC-12	CCl_2F_2	**8,100**	**10,600**	**10,900**
HCFC-22	$CHClF_2$	**1,500**	**1,700**	**1,810**
HCFC-141b	CH_3CCl_2F	**600**	**700**	**725**
HCFC-142b	CH_3CClF_2	**1,800**	**2,400**	**2,310**
Hydrofuorocarbons				
HFC-23	CHF_3	**11,700**	**12,000**	**14,800**
HFC-32	CH_2F_2	**650**	**550**	**675**
HFC-125	CHF_2CF_3	**2,800**	**3,400**	**3,500**
HFC-134a	CH_2FCF_3	**1,300**	**1,300**	**1,430**
HFC-143a	CH_3CF_3	**3,800**	**4,300**	**4,470**
HFC-152a	CH_3CHF_2	**140**	**120**	**124**
HFC-227ea	CF3CHFCF3	**2,900**	**3,500**	**3,220**
HFC-236fa	$CF_3CH_2CF_3$	**6,300**	**9,400**	**9,810**
HFC-245fa	$CHF_2CH_2CF_3$		**950**	**1,030**
HFC-365mfc	$CH_3CF_2CH_2CF_3$		**890**	**794**
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	**1,300**	**1,500**	**1,640**
Sulphur hexafuoride	SF_6	**23,900**	**22,200**	**22,800**
Nitrogen trifuoride	NF_3	**–**	**10,800**	**17,200**
PFC-14	CF_4	**6,500**	**5,700**	**7,390**
PFC-116	C_2F_6	**9,200**	**11,900**	**12,200**
PFC-218	C_3F_8	**7,000**	**8,600**	**8,830**
PFC-318	$c\text{-}C_4F_8$	**8,700**	**10,000**	**10,300**
PFC-3-1-10	C_4F_{10}	**7,000**	**8,600**	**8,860**
		Not listed in IPCC AR		
unsaturated Hydrofuorocarbons				
HFC-1234yf		**4**		
HFC-1234ze		**6**		
Hydrocarbons and other compounds - Direct Effects				
290 propane	C_3H_8	**3**		
600a isobutane	C_4H_{10}	**4**		
pentanes	C_5H_{12}	**5**		
fluoroketone FK 5-1-12	$C_6F_{12}O$	**1**		

[7] The GWPs of unsaturated HFCs in this list are not included in any IPCC report.

The model output can be expressed in three different ways (see figure 2-2):

1) emissions and use per chemical substance,
2) emissions and use per source, and
3) emissions and use per (sub-)sector.

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. For the purpose of projecting 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.

Refrigeration								
Country	EU-27							
GWP	Fourth AR		1995	2000	2010	2020	2030	2050
Without measures (Emissions)								
Total by Gas		[kt CO2eq]	1,628.1	13,471.1	39,346.9	52,883.7	54,832.9	56,861.5
HFC 134a		[kt CO2eq]	68.9	531.9	2,644.3	2,512.8	1,785.6	1,956.2
HFC 143a		[kt CO2eq]	344.4	7,219.3	21,537.6	30,007.6	31,907.4	33,025.1
HFC 125		[kt CO2eq]	228.2	4,783.0	14,424.6	20,290.6	21,139.8	21,880.3
HFC 32		[kt CO2eq]	0.0	0.0	27.5	72.6	0.0	0.0
R22		[kt CO2eq]	986.6	936.9	712.8	0.0	0.0	0.0
Total by Source		[kt CO2eq]	1,628.1	13,471.1	39,346.9	52,883.7	54,832.9	56,861.5
Manufacturing Emissions		[kt CO2eq]	13.9	8.3	0.0	0.0	0.0	0.0
Lifetime Emissions		[kt CO2eq]	1,614.2	13,462.8	35,704.7	44,584.2	47,078.9	48,614.9
Disposal Emissions		[kt CO2eq]	0.0	0.0	3,642.2	8,299.5	7,753.9	8,246.7
Total by Sector		[kt CO2eq]	1,628.1	13,471.1	39,346.9	52,883.7	54,832.9	56,861.5
Domestic Refrigeration		[kt CO2eq]	30.6	58.0	1,149.8	527.0	15.4	15.5
Commercial Refrigeration		[kt CO2eq]	66.9	9,118.2	24,473.3	32,301.2	34,001.8	34,815.2
Industrial Refrigeration		[kt CO2eq]	522.1	2,886.2	9,778.2	15,414.4	15,843.2	15,859.4
Road transport Refrigeration		[kt CO2eq]	1,008.4	1,408.8	2,932.5	3,437.3	4,066.7	5,325.7
Shipping Refrigeration (fisheries)		[kt CO2eq]	0.0	0.0	1,013.2	1,203.8	905.8	845.8

Figure 2-2: Model output by substance, source and sector.

Projections by 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 two different time periods:

- Near future (5-10 years) is modelled on known policies and measures, technological changes, substitution patterns and expected changes in use patterns, and
- 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. Specific information on each sector for EU-27 is summarized in the EU sector data sheets (annex V).

[8] IPCC/TEAP Special Report on Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorcarbons and Perfluorcarbons. 2005 Prepared by Working Group I and III of the Intergovernmental Panel on Climate Change, and the Technology and Economic Assessment Panel. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 488 pp.

The **scenarios** calculated by the model AnaFgas for EU-27 include the following scenarios:

- **Without measures (WOM) scenario:** A counter-factual demand and emission scenario for the EU-27 and each MS reflecting the situation that would likely have occurred since 1995 (baseline year for F-gases under the Kyoto Protocol) without the 2006 EU policy intervention (F-gas Regulation, MAC Directive). The projected 2050 quantities of use emissions are based on sub-sector specific growth assumptions, which in most cases do not include technological change or introduction of alternative fluids (“frozen technology”). Often the use level of the last year, or the trend over the last years before enforcement of the European F-gas legislation is extrapolated to the future. Details are given in the model description in annex III to this report.
- **With measures (WM) scenario:** A scenario of actual or baseline demand and emission trends for the period 1995-2050 taking into account the existing policies and measures to reduce F-gas use and emissions at EU-27 level and for each Member State. The ‘with measures’ scenario is based on the same underlying growth trends as the WOM scenario, but varies those parameters of the estimation that are influenced by the European legislation for the period since Member States started to implement the respective policies and measures. These parameters include leakage rates, recovery efficiency and the substitution of certain gases in certain applications which would not have occurred without a policy intervention.

By comparison of the WOM scenario and the WM scenario it is possible to estimate the impact of the F-gas Regulation on the current and future emissions.

With additional measures (WAM): A scenario for the demand and emission trends in the EU and Member States with additional measures to mitigate F-gas emissions. This scenario is developed in chapter 8 where options for such measures are presented and analysed.

2.2.3 Two scenarios for global HFC consumption

In addition to the EU scenarios of the model AnaFgas, two further scenarios are calculated and include a business-as-usual (BAU) projection of global HFC use for the period 2010-2030, and scenarios of reductions of global HFC consumption in the same period. Each scenario is calculated for both developed (A2) and developing countries (A5)[9]. Europe forms part of the group of developed countries.

- **Business as usual (BAU) scenario:** A global HFC consumption scenario reflecting the situation that will likely occur from 2010 onwards based on current industry trends. It includes the accelerated HCFC phase out under the Montreal Protocol in developing countries and integrates alternative technologies to the extent they likely replace conventional HFCs without additional policy measures[10].
- **Reduction (RED) scenario:** An abatement scenario reflecting the maximum technically feasible replacement of HFC technology by different types of abatement technology from 2010 onwards regardless costs. It is assumed that abatement options are chosen for all **new** equipment and production lines from 2010 onwards wherever feasible. A modification of this reduction scenario is RED10, which reflects replacement of HFC technology by different types of abatement solutions from 2010 onwards only when below an abatement cost threshold of 10 € / t CO_2 equivalent.

The two scenarios are put into the context of international action to reduce F-gas emissions by comparing them to the schedules of the amendment proposals on HFC phase down discussed under the Montreal Protocol (chapter 7). The difference between the baseline scenario (business-as-usual) and the reduction scenario defines the maximum potential to reduce HFC consumption until 2030 in A2 and A5 countries.

In contrast to AnaFgas, the calculation of the two global scenarios is not intended to estimate how containment and recovery measures reduce F-gas emissions but it shall help quantify the possible use of HFCs in their various applications.

Both business-as-usual and reduction scenarios are calculated bottom up on the level of sectors and sub sectors of HFC/HCFC application. The calculation includes for both A2 and A5 countries

- 7 sub sectors of stationary refrigeration
- 2 sub sectors of transport refrigeration
- 8 sub sectors of stationary air conditioning and heat pumps

[9] Developed countries are called A2 countries in this report based on the terminology of the Montreal Protocol. Developing countries are called A5 countries accordingly. Under the Montreal Protocol, the decision whether a particular country is considered A5 or Non-A5 country depends on the annual per capita consumption of ODS. Countries where the annual per capita consumption of ODS is <0.3 kg are considered developing countries (A5 countries). The Russian Federation, Eastern European transformation countries and certain Arab countries are hence classified as developed countries (A2 countries). This classification might not be consistent with the classification of developed and developing countries under other multilateral environmental agreements, e.g. the UNFCCC/Kyoto Protocol which refers to Annex 1 countries (developed countries) and Non-Annex 1 countries (developing countries).

[10] The EU MAC Directive, which leads to alternatives to conventional HFCs, is an existing political measure and therefore included in the BAU scenario.

- 3 sub sectors of mobile air conditioning
- 12 sub sectors of XPS/PU foam
- 2 sub sectors of fire protection
- 1 sector of aerosols[11].

At the sector level, the calculation of the business-as-usual scenario is based on following data which are collected for both A2 and A5 countries:

- New units per year[12]
- Total stock units
- Average technical characteristics per unit including lifetime, charge size, HFC/HCFC types, leakage rates, rated capacity, annual energy use, costs
- HFC/HCFC bank in 2006/2010
- Annual growth rates until 2030
- Possible change in refrigerant/blowing agent composition for new units

On the basis of these data the size of HFC bank and the annual use of HFCs for manufacturing (first fill) and servicing (refill) can be estimated. It is assumed that production capacities will follow the demand.

The calculation of the baseline scenarios was carried out by the sector experts in the project team widely using the relevant UNEP TEAP reports of RTOC, FTOC, and CTOC, and of the IPCC/TEAP SROC, evaluated market studies, and interviewed industry experts which provided first-hand information e.g. on cost.

For the reduction scenario, the calculation includes (a) identification of technically feasible abatement options for each sub sector, (b) assessment of their incremental cost compared to conventional HFC technology, and (c) analysis of application constraints and possible market penetration of alternative solutions.

A basic prerequisite for alternative technical options identified by the experts was energetic equivalence with conventional HFC technology. Only those abatement options are considered further that can show better or at least the same energy performance as the reference HFC technology. This criterion is important because additional energy consumption would negatively impact the total climate performance of a system (TEWI) up to the point where reductions of direct F-gas emissions by replacement of HFCs could be reversed by additional CO_2 emissions from energy use and production (indirect emissions).

This important methodological aspect and the work result are comprehensively presented in chapter 6 of this report; detailed information on all sector assumptions and abatement options is given in annex V (global data input sheets) and annex VI (Abatement technologies

[11] The BAU scenario and the Reduction scenario for HFCs include also MDIs but do not specifically analyse this sub sector. Reductions to the MDIs are not considered because substitution of HFCs in MDIs needs specialised investigation. Therefore in the models the BAU and RED scenarios for MDIs are identical. Health aspects related to the application of MDIs as compared to potential abatement technology should be investigated by experts from the medical and pharmaceutical industry. It should be mentioned that MDIs with ODS propellants are “essential uses” under the Montreal Protocol.

[12] In refrigeration and air conditioning and fire protection the units are discrete pieces of equipment. In the foam sector the “units” are production lines of average size, output and lifetime.

by sectors). The determined penetration rates represent best estimates. Further technical developments (e.g. hybrid systems) are not included as empirical data are lacking widely.

Differences between the EU scenarios and the global scenarios

Although the same approach (bottom up stock calculation) is applied to the scenarios for Europe (WOM and WM scenario), which are based on the model AnaFgas, and to the global HFC use scenarios (business-as-usual and reduction scenario), several important differences of content and background assumptions need to be noted, and are shown in tabular form below.

Table 2-2: Differences between the F-gas scenarios for Europe and the global HFC scenarios

	EU scenarios (AnaFgas)	**Global scenarios**
Content	Quantities for manufacturing and servicing. Emissions in use phase and at disposal	Quantities for manufacturing and servicing
Substances	HFCs, PFCs, SF_6, HCFC-22	HFCs and HCFCs
Sectors	40 sectors with HFCs, PFCs, SF_6 and production of halocarbons	21 HFC based key sectors
Foam sector differentiation	4 sectors (only of EU relevance)	2 x 9 sub sectors, in A2 and A5
Geographic scope	EU-27	Developed countries (A2; incl. EU-27) and developing countries (A5)
Leakage rates	In EU sometimes lower than in A2 (incl. USA and Japan) due to the application of containment provisions under the F-Gas Regulation	A2 average sometimes higher than in EU
Recovery efficiency	Considered	Not considered
Reduction measures	Containment and recovery, some use and placing on the market prohibitions by F-gas Regulation (WM scenario)	Application of alternative technical solutions with low GWP
Alternative technical solutions	Third scenario “With additional measures”	Reduction scenario RED
Containment and recovery	Content of WM scenario	Not considered
Cost estimates	For containment and recovery measures of F-gas Regulation (WM scenario), and for low-GWP alternative technologies	For alternative, low-GWP technologies
Baseline	Existing trend to alternative solutions only exceptionally considered	Alternative technologies partly included in BAU trend

2.2.4 The terms demand, supply and consumption

This study analyses and discusses emissions primarily from use and disposal of F-gas containing applications. The annual quantity of F-gases that flows into individual application sectors at the level of individual Member States, at EU level, and globally for A2 and A5 countries is calculated. In the sector by sector approach (bottom up) the annual F-gas flow is the amount required for new systems ("first fill")[13] plus the amount for refilling of existing closed systems during servicing ("refill") to compensate for leakage. The equation for demand is:

Demand (D) = $F_{\text{irst fill}} + R_{\text{efill}}$.

The annual demand for first fill and refill is completely based on sector specific charges and emission factors. Charges and emission factors, which are included e.g. in the model AnaFgas, are the only determinants of the demand of a particular sector, of a Member State, of the EU, or of A2 and A5 countries.

Based on the bottom-up approach used in this study, the definition of demand which includes first fill and refill does not depend on

- whether the F-gases are domestically manufactured or imported
- whether the F-gases are virgin material from chemical manufacture or used material from recycling or reclamation
- whether or not at end of equipment life used F-gases are released to the atmosphere or recovered for recycling or reclamation, or for destruction.

Qualitative difference between demand and consumption

The term demand which is calculated as the total of sectoral first fills and refills must not be confused with the term consumption as defined under the Montreal Protocol for ozone-depleting substances representing the supply in bulk quantities which serves the demand for bulk quantities. Consumption is clearly defined in Article 1 of the Montreal Protocol and has a particular meaning: It represents for a country the total amount of substances that are supplied to emissive end-uses and includes production of controlled substances plus imports minus exports of controlled substances, and minus the amount for destruction and the amount used as feedstock in the manufacture of other chemicals. Like exports, the latter are no part of the supply to emissive end-uses in the country.

The equation for consumption (under the Montreal Protocol) is:

Consumption (C) = $P_{\text{roduction}} + I_{\text{mports}} - E_{\text{xports}} - F_{\text{eedstock}} - D_{\text{estruction}}$.

Consumption is therefore not measured on a bottom-up basis like demand but from a top-down perspective. It defines for a country the overall emission potential ("potential emissions") regardless whether the produced and imported quantities of substances are used for first fill or for refill, and, vice versa, the term demand does not account for the distinction of the annual flow of substances into production, import, destruction or feedstock.

[13] The quantity per new system includes not only first fill into closed equipment of air conditioning, refrigeration, fire protection, and electrical switchgear or filling of aerosol and OCF cans, but also the quantity for the manufacture of XPS/PU foam and of semiconductors, as well as use as solvent or cover gas.

Quantitative differences between demand and consumption

The quantities of F-gases used as feedstock and subject to destruction are much lower than feedstock quantities and destroyed quantities of ozone-depleting substances. Under the Montreal Protocol, feedstock is primarily HCFC-22 as intermediate for PTFE plastics and represents a considerable part of the worldwide production of ODS. In contrast, the use of F-gases as feedstock plays a marginal role only. The same applies to destruction. Unlike the Montreal Protocol, which aims at complete phase-out of controlled substances, the Kyoto Protocol aims only at reduction, and the objective of the proposals for an international HFC agreement as an amendment to the Montreal Protocol (see chapter 7) is not phase-out but phase-down. So far, deliberate destruction of F-gases is not envisaged apart from contaminated quantities which cannot be recycled or reclaimed. Reuse, recycling and reclamation of F-gases are explicitly supported by the F-gas Regulation.

Considering the relatively low importance of destruction and feedstock for annual consumption of F-gases, the quantitative difference between consumption (including production and imports while excluding destruction and feedstock) and demand (including first fill and refill) is small. Both terms refer to amounts of almost the same size. As a consequence, it could be assumed that the first fill plus refill (demand) equals production plus import minus export (consumption).

There is, however, another fact which does not allow the equation of demand as calculated in the models of this study with consumption as defined under the Montreal Protocol. Consumption accounts for recycling and reclamation insofar as domestic recycling and reclamation for domestic reuse causes reduction of production and/or imports[14]. The higher the extent of recycling for domestic use is, the lower the need for imports or production for domestic use. In this study, for the term demand it does not matter whether the supply for first fill or refill is domestically produced, imported or recycled. It thus follows that the modelled demand for first fill and refill is higher than consumption/supply which includes production and imports minus exports when recycling for domestic reuse takes place in a country.

The equation for demand and consumption, specifically in this study is

Demand ($F_{irst\ fill}$ + R_{efill}) = Consumption ($P_{roduction}$ + I_{mports} – E_{xports}) + $R_{ecycling}$ (feedstock and destruction = 0).

As a consequence, in this report the term consumption is carefully used, even if all produced and imported F-gas quantities represent supply that serves the calculated demand. Consumption is a top-down category, which rarely matches the bottom up modelled demand.

First extension of the terms demand and supply (import of prefilled systems)

It has to be noted that the demand as well as the consumption of a country (or the EU) does not represent exactly the amount of substances which can potentially be emitted in the country if there is a considerable quantity of substances contained in imported or exported pre-charged equipment. The first fill of such equipment is carried out in one country but after installation of the equipment the quantity causes use-phase (and disposal) emissions in another country.

[14] In the theoretical limit, recycling can serve all first fill and refill (emissions = 0, first fill = amount for disposal), without any production or import of substances.

So far, first fill and refill as part of the demand as well as production and import as part of the consumption refer to F-gases in bulk quantities. In order to account for the emission potential of equipment which is first charged outside the country considered (e.g. the EU), the term demand as well as the term supply must also include F-gas quantities in imported pre-charged systems. As a result, the term supply no longer corresponds to the term consumption under the Montreal Protocol.

The demand includes not only first fill and refill of systems that are manufactured in the EU for domestic use but also first fill outside the EU in systems which are imported into the EU and the domestic refill into these imported systems during their use-phase and disposal.

The equation for the extended demand for F-gases (1st extension) in the EU is

Demand $_{ext1}$ = $F_{irst\ fill}$ of systems for domestic use + $F_{irst\ fill}$ of systems imported in the EU + R_{efill} of systems for domestic use + R_{efill} of imported pre-charged systems.

Correspondingly, the term for the respective supply changes and includes not only production and import (minus export, minus feedstock, minus destruction) in bulk quantities to serve the demand for first fill and refill of domestically manufactured systems and the refill of imported equipment but also the import of F-gases in pre-charged imported systems. However, this supply does not include the quantity of F-gases in pre-charged systems exported from the EU.

The corresponding equation for the extended supply of F-gases is

Supply $_{ext1}$ = $P_{roduction}$ + I_{mports} (bulk) – E_{xports} (bulk) – $F_{eedstock}$ – $D_{estruction}$.+ I_{mports} (pre-charged) – E_{xports} (pre-charged) .

In chapters 1-5 of this study no need arises to use the extended terms of demand and supply. This also applies to chapter 7 on a potential international HFC agreement, where the term consumption is used in its Montreal Protocol definition, bearing in mind that the annual HFC flow in A2 and A5 countries has been calculated in this study as a demand category, based on the estimation of first and refill in the individual application sectors.

In chapter 6, however, HFCs in imported pre-charged equipment as part of the supply (or first fill into imported pre-charged equipment as part of the demand) must be accounted for in one particular sector. This sector is stationary air conditioning where most systems of the moveable and split type for use in Europe are first filled in Asia. For this sector, the extended terms demand and supply are used.

Second extension of terms demand and supply (export of prefilled systems)

In chapter 8 on further EU action, amongst other policy options the possibility is discussed to reduce the demand for HFCs within the EU by limitation of the supply of HFCs. As this option refers to all HFC application sectors, the demand for first fill must include not only the domestic first fill in equipment for EU use, and the first fill into pre-charged equipment which is imported in the EU (= demand $_{ext}$), but also domestic first fill into equipment which is pre-charged for export. Domestic first fill for export equipment is relevant with regard to mobile air conditioners of motor vehicles (passenger cars, trucks, busses) and medical aerosols (MDIs). Like the refill in the first extension of demand, refill includes now both refill of systems manufactured in the EU for domestic use and refill into imported systems.

The equation for the second extension of demand for HFCs is

Demand $_{ext2}$ = $F_{irst\ fill}$ of systems for domestic use + $F_{irst\ fill}$ of systems imported in the EU + $F_{irst\ fill}$ of systems pre-charged for export from the EU + R_{efill} of systems for domestic use + R_{efill} of imported pre-charged systems.

The second extension of demand includes the first fill of pre-charged systems for export. It does not include the refill of those systems in the use-phase as this takes place in another country.

The supply of HFCs which serves the demand for the different types of domestic first fill and refill consists of bulk quantities from domestic production and/or imports of HFCs. This also applies to the supply for first fill of systems pre-charged for export. In addition, supply includes HFCs in imported pre-charged systems.

The equation for the extended supply of HFCs is

Supply $_{ext2}$ = $P_{roduction}$ + I_{mports} (bulk) – E_{xports} (bulk) – $F_{eedstock}$ – $D_{estruction}$.+ I_{mports} (pre-charged).

2.3 Measurability of emission reductions in 2011 and emission factors in AnaFgas

F-gas emissions are caused by the interplay of stocks and leakage which is expressed by emission factors. Hence two general policy strategies to reduce emissions are evident: reducing banks and reducing leakage rates. Both strategies are already implemented at European and Member State level:

- Containment strategies aim at reducing emission factors of new and existing equipment. The underlying principle is that F-gases do not cause environmental impact as long as they are contained within their applications.
- Substitution strategies aim at reducing the total bank of products and equipment containing F-gases, thereby targeting emissions at the source.

The choice between containment and substitution strategies has been considered to be a choice between minimizing short-term or long-term emissions[15], although this evaluation finds that this does not apply in the case of the F-Gas Regulation (see chapter 5).

2.3.1 Lack of empirically verified data on emission factors

In order to determine the containment of various measures set out by the F-gas Regulation, emission factors in relevant sectors and sub sectors need to be determined and compared to emission factors prior to the introduction of these measures. Emission factor reductions in the time period since entry into force of the F-gas Regulation in mid 2006 are hard to quantify. This section assesses whether the different reporting and monitoring systems for F-gas use and emissions established within EU-27 are suitable to indicate reductions of F-gas emissions in recent years.

By 2008, use-phase emissions accounted for 90% of all emissions; only 10% were disposal emissions (source AnaFgas). An assessment of the effectiveness of the F-gas Regulation hence needs to ask particularly whether and to which extent reductions of use-phase emissions can be empirically verified. It must be pointed out that absolute emissions do not only reflect the development of leak tightness but also the development of the underlying bank which is influenced by the number of installations, charges, installed shares of alternative refrigerants, economic cycle, etc. The appropriate indicator of changing leakage rates are changes of emission factors. Different reporting and monitoring systems for F-gas use and emissions are assessed with regard to this type of information.

Data from CRF tables

EU Member States annually report amounts of F-gases for new products, in the stocks and in products at decommissioning as well as the emissions from these to the UNFCCC and the European Commission. The common reporting format (CRF) distinguishes six refrigeration sub sectors: domestic refrigeration, commercial refrigeration, industrial refrigeration, transport refrigeration, stationary air conditioning, and mobile air conditioning.

[15] Hekkenberg, M. & Schoot Uiterkamp, A.J.M. 2007: Exploring policy strategies for mitigating HFC emissions from refrigeration and air conditioning; International Journal of Greenhouse Gas Control I, pp.298-308.

The F-gas Regulation focuses on stationary systems only rather than transport refrigeration and mobile air conditioning. Furthermore the key containment provisions of the F-gas Regulation (Article 3) do not apply to stationary equipment containing charges <3 kg. Therefore, use-phase emissions from domestic refrigeration, which are already quite low, are not likely to decrease further as a result of the Regulation. Commercial and industrial refrigeration and stationary air conditioning[16] are the main sectors where emission reduction might occur and could possibly be identified.

By April 2011, CRF tables for 2008, the last year reported so far, were available from all 25 Member States who are obliged to reporting (excluding Malta and Cyprus). This implies that reported data only cover the early period of application of the F-gas Regulation. Analysis of the national reports does not provide sufficient information in this regard: 10 Member States do not report about any of the 3 relevant sectors, another 9 Member States report on only 1 of the 3 sectors. Data on emissions from industrial refrigeration and air conditioning are widely lacking, as well as emissions from refrigerants other than R-134a. CRF tables from 7 Member States refer to each of the three sectors[17] individually and include the reports from Austria, Denmark, Estonia, France, Germany, the Netherlands and the UK. Incomplete information is, however, not the main reason why the existing CRF tables do not indicate possible emission reduction from 2006 onwards.

The methodology of CRF reporting does not require annual empirical survey, but calculations of reported emissions are based on fixed sector-specific emission factors. In most national submissions, emission factors have been kept constant since 1995. Some countries have updated (mostly lowered) the factors, often based on national studies, but only at intervals of several years[18], which is not expected in the next few years in most cases. Emission factors for the same sectors vary widely between Member States, e.g. in commercial refrigeration from 5% to 22%. Hence CRF reporting, in its present state, is not an appropriate tool for reliable indication of short-term changes of emissions.

Data from national F-gas surveys

In a number of Member States the total national consumption of F-gases is assessed annually and usually based on statistics on external trade and domestic chemical production. The data are entered in CRF tables as so-called “potential emissions”, in addition to so-called “actual emissions”. These “top-down” data sets are useful tools for a rough plausibility

[16] In commercial refrigeration charges <3 kg are also used. Equipment charged <3 kg is even more common in stationary air conditioning where moveable and split room air conditioners, and heat pumps are charged below the threshold for application of Art 3. The model, developed in this study, accounts for these facts but CRF tables do not. Nevertheless, emission estimation for the entire sectors makes sense when looking for a possible reduction trend from 2006 onwards.

[17] It must be noted that the Netherlands do not break stationary refrigeration and air conditioning into sectors, and do not distinguish between different HFC types. They report only an “unspecified HFC mix” in CO_2 equivalents. This is done also by UK. Authorities from the Netherlands argue that breaking down the number would increase uncertainty significantly taking into account the activity data based on which the emission estimates have been assessed. The figures have been verified by the amount of refrigerants sold in the Netherlands for the specific sectors.

[18] UK reduces the emission factors for stationary refrigeration and air conditioning every year by the same amount, implying a steep decrease in the overall emission factor from 22.6% to 10.6%, between 1995 and 2008. We do not consider this reduction empirically backed up but based on plausibility assumptions of the inventory compilers. The Netherlands have used an emission factor of 5% which was established in 1999 and remained unchanged since then.

check of the bottom up data in the tables. However, the different types of F-gases cannot be assigned to particular applications. The F-gas reporting according to Art 6(1) of the F-gas Regulation[19], which represents a survey of the above mentioned type on an EU wide level, tries to compensate this lack of information through the question to producers, importers and exporters about the intended application categories. However, the relevant category "Refrigeration and Air Conditioning" is too wide to allow emission reduction estimates in the sectors that are subject to containment provisions of the F-gas Regulation.

In a few countries, surveys on refrigerants are carried out. For instance, in France the branch association of companies in the refrigerant sector, SNEFCCA, has compiled a complete time series of data on the national consumption of R-22 and of the HFC refrigerants R-134a, R-404A/507, R-407C and R-410A for the period 2000-2009. As the HFC-blends and R-22 do not occur in mobile air conditioning, they can be assigned reliably to refrigeration and stationary air conditioning. It must be pointed out that national or EU wide surveys of the above mentioned types may be useful in some respects but cannot provide insight in emissions directly because they do not distinguish between F-gas use for new equipment and use for servicing needs.

In the following, examples for national surveys are briefly discussed. National empirical surveys on the use of HFCs as refrigerants, foam blowing agents and aerosols have been carried out in the Netherlands, Germany and Austria for several years. F-gas quantities used for new equipment and for servicing are distinguished which allows the allocation of particular types of refrigerants to stationary or mobile applications. This type of survey can provide insight in emission trends, and could also be used to monitor short-term emission reductions in the sectors subject to key containment provisions of the F-gas Regulation. Similar monitoring and reporting systems are intended or being established in some Eastern European Member States (Bulgaria, Estonia, Hungary, Lithuania and Poland).

Case: STEK system in the Netherlands

Certified companies, who represent virtually the total number of companies active in the refrigeration sector of the Netherlands, report the quantities of HCFC and HFC refrigerants used in a year for new tailor-made installations and for refills into existing tailor-made and pre-charged equipment to the STEK organisation. It is possible to separate the refrigerants for mobile air conditioning so that the refills into stationary refrigeration and air conditioning equipment can be calculated (even though the reported refills still include the relatively small sector of transport refrigeration and the very small sector of domestic refrigeration). Under the generally accepted assumption that refills equate use-phase emissions, a time series of the HCFC/HFC emissions from the relevant sectors can be shown for 1998-2007. However, further data are not available yet.

The reports cannot be used to update emission factors because they do not include the refrigerant banks. 1999 is the only year when the size of the bank was estimated in a comprehensive survey[20]. Since then, only absolute emissions are surveyed which do not differentiate between changes in leakage rates and changes in the refrigerant bank. HCFC emissions follow a downward trend, HFC emissions have increased since 2001 (figure 2-3).

[19] See also chapter 4.2.7 on reporting requirements.

[20] ITM Research, Monitor Koudemiddelenstromen 1999, Amsterdam, May 2001. This important document, on which all STEK emission factor estimates since 1999 are based, and which forms the general basis for the expected emission reduction effects through the F-gas Regulation, is only available in Dutch language.

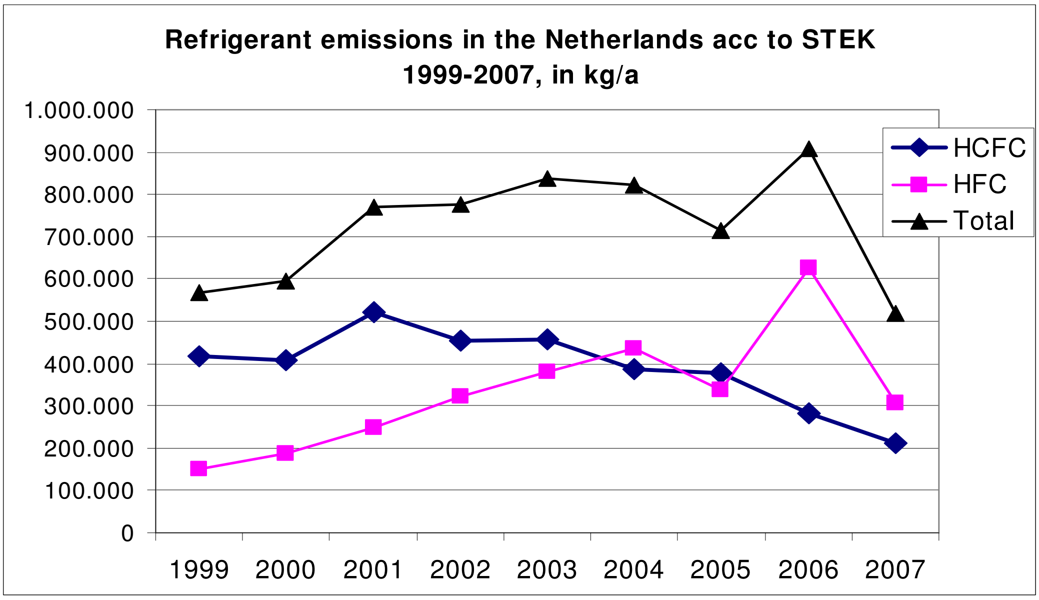

Figure 2-3: Refrigerant emissions in the Netherlands in 1999-2007. The graph shows the refills (=use-phase emissions) for all stationary equipment containing charges >3 kg. HCFC emissions (R-22) decreased from 400 t to 200 t, HFC emissions increased from 150 to 300 t in the same time. The upper curve displays the overall emissions; its shape reflects changes in the bank size much more than in leakage rates[21].

Total refrigerant emissions (HCFCs + HFCs) had increased until 2006, as a result of growing banks[22], and decreased significantly in 2007. Without data on further years, the decline in 2007 cannot be considered the beginning of downward trend. Although emission factors are not updated in the STEK system a trend in absolute emissions can be seen.[23]

The STEK system is suitable to provide data on absolute use-phase emissions over a long time in the sectors subject to key containment measures of the F-gas Regulation. However, the Dutch emission figures ironically cannot be used as indicators of the effect of the F-gas Regulation. Containment measures of the STEK system and the F-gas Regulation are largely identical, which implies that the Netherlands have been subject to them not as recently as 2006 but for much longer. A decline in F-gas emissions after 2006 would not indicate effects of the F-gas Regulation but relate to other influencing factors.

Case: National F-gas survey in Germany

In 2006, a comprehensive and legally binding annual survey of the F-gas use in all industrial sectors (approx. 50) was introduced in Germany[24] and is carried out by the Federal Board of

[21] In the data analysis by STEK for Öko-Recherche “Emissions in the Netherlands - based on STEK figures, Baarn, 20 May 2010” the trend is explained by “smaller volume per installation, more newly pre-charged installations, introduction of alternative refrigerants (instead of F-gases)”.

[22] See footnote before, and communication of Dan De Bruyckere (STEK) to Öko-Recherche, Brussels, 4 May 2010 and 18 January 2011.

[23] In the Netherlands, figures from the STEK foundation have only been used for verification of the emissions calculated under UNFCCC for some years and are not part of the QA/QC of the national inventory. Also the STEK information is based on assumptions of the installed base (as well as the CRF data, based on the NOKS study of 1999/2000). However it appears according to the authorities from the Netherland that the outcomes of the different data sources have been following similar trends during the past period.

[24] Law on Environmental Statistics (Umweltstatistikgesetz) of 16 August 2005.

Statistics. The questionnaire on HFCs/PFCs distinguishes between refrigerants, foam blowing agents, aerosols, and other, and classifies the refrigerant use by first fill into new equipment, first fill in converted equipment and by refill in existing equipment. Data analyses allow separating mobile applications from stationary applications so that use-phase emissions from stationary refrigeration and air conditioning can be analysed by individual HFC and PFC types.

Like the STEK system, the German statistics do not allow an assessment of the size of the banks, which would be needed to establish emission factors and could be used to indicate effects of containment measures. Furthermore, the German data focus on F-gases. The time series 2006-2009 shows a clear increase of absolute emissions of HFC refrigerants from 985 t (2006) to 1,049 t (2007), to 1,103 t (2008), and to 1,221 t (2009)[25]. This trend, however, does not reflect higher leakage rates or growing banks but first of all the replacement of R-22 by HFCs in the banks. A trend in containment cannot be identified since R-22 is not monitored. Once no R-22 equipment is covered by the reporting any more, the underlying approach could be used to estimate the trend in absolute use-phase emissions and effects of the F-gas Regulation. This could be possible for the reporting years from 2014 onwards.

Case: F-gas reporting system in Austria

The Austrian Ordinance on HFCs, PFCs and SF_6 requires companies who manufacture, maintain and service stationary refrigeration and air conditioning equipment and other sectors (foams, aerosols, solvents, fire protection, high-voltage switchgear, manufacturing of electronics) to report annually used HFC and PFC quantities to the competent ministry since 2003. The reporting includes quantities for new fill and re-fill and disposal, and is basically suited to monitor emission trends over time.

Like the German survey, the Austrian reporting system does not provide data on refrigerant banks and hence does not allow empirical calculation of emission factors. Furthermore, the Austrian system does not cover HCFCs, which impedes realistic estimation of emission factors. The main problem related to the Austrian reporting system, however, is the low level of compliance. The share of companies in the stationary refrigeration and air conditioning sector who do report is estimated to range at 30% at maximum and has been steadily decreasing since 2003. The data of submitted company reports cannot be considered representative because the share of their F-gas quantities in the total F-gas quantities can only be estimated roughly.

Case: New monitoring and reporting systems in Eastern European Member States

Some new Member States who entered the EU since 2004 are currently establishing or planning F-gas monitoring and reporting systems which allow calculation of emission rates based on empirical data. The systems shall primarily build a link to national F-gas emission inventories according to Article 6(4) of the F-gas Regulation[26]. The key component of these systems is a central database of all stationary refrigeration and air conditioning equipment with charges >3 kg, which allows determination of the refrigerant bank. Annual use of F-gases and ODS are to be reported to the database by operators and service companies, as

[25] By far mostly used refrigerants in the stationary sectors are R-404A/507, R-134a, R-407C, and R-410A, with together 97% share in the total.

[26] Article 6(4) requires Member States "to establish reporting systems for the relevant sectors referred to in the F-gas Regulation, with the objective of acquiring, to the extent possible, emission data".

well as the quantities for recovery, recycling, reclamation and destruction. Such systems are planned or being established in Bulgaria, Estonia, Hungary, Lithuania and Poland.

The most ambitious monitoring system for the refrigeration and air conditioning sectors exists in Hungary: It is being established since 2009 and is operated by the Hungarian Monitoring and Certification Body (HMCB). The renewal of company certification by HMCB is conditional upon reporting. By mid-2010 about 70% of the companies concerned had reported for the previous year. Over 21,000 refrigeration circuits >3 kg are registered in the electronic data base and it is intended to extent the database to all types of mobile AC systems. Electric switchgear and fire protection systems are not covered.

HMCB recently presented an evaluation of the leakage rates of 11,000 refrigeration systems[27] (table 2-3). The average leakage rate in 2009 amounted to 10% for stationary refrigeration and air conditioning equipment >3 kg. A time series which could reliably establish a real trend in leakage rates would require datasets for additional years. The new Hungarian monitoring systems can indicate the development of leakage rates caused by the F-gas Regulation over time. However, verification of an impact of the Regulation on general leak tightness would be expected to be possible only a couple of years later.

Table 2-3: Installed F-gas refrigerant banks and leakage rates in 11,000 refrigeration systems >3 kg in Hungary 2009. Source: HMCB, September 2010

Refrigerant	bank /kg	Leaked /kg	leakage rate /%
R-134a	45,807.5	2,108.0	4.6
R-404A	194,998.1	21,023.1	10.78
R-407C	68,221.5	8,016.1	11.75
R-410A	10,303.8	468.0	4.54
R-413A	116.1	8.0	6.89
R-507	216.0	20.0	9.26
Others	169.9	255.4	150.0
Total	**319,833**	**31,898.5**	**10.0**

The new monitoring systems are not only appropriate to support national CRF reporting but are also appropriate to verify possible containment effects of the F-gas Regulation in the next years. It is essential that the systems include a comprehensive database of the F-gas bank contained in operating refrigeration equipment (charges >3 kg).

Data from selected installations

Currently estimates of the trends of emission factors in stationary refrigeration and air conditioning seem to be possible on sub-national level only. At present, data on banks and emissions exist for individual installations only. These data are based on the recording of refrigerant charges, added and recovered refrigerant quantities according to Article 3(6) of the F-gas Regulation[28]. The introduction of recording in most Member States has taken some

[27] Zoltán Attila (Hungarian Monitoring and Certification Body: Országos Monitoring és Képesítö Testület), Fgas Certification and Monitoring. Implementation of the ODS and FGG regulations in Hungary. ECOCOOL'10, Budapest 16/09/2010.

[28] Recording requirements of Article 3(6) follow the approach of the STEK system in the Netherlands. Records (“logbooks”) are obligatory there since 1994, first for ODS, and later also for F-gases. This also applies to Sweden, where records must be kept since the 1990s, not only for stationary but also for mobile equipment with refrigerant charges >3 kg (refrigerated vehicles and air conditioned buses).

time to become established. In early 2010, about half of the operators in EU-27 did not maintain records as required. Large differences between geographic regions and between large and small operators need to be noted (see chapter 4).

The records can also serve as information basis for the monitoring of emissions and the calculation of emission factors on the basis of empirical data. National legislation planned or in force in certain Member States requires operators of equipment (F-gas charges >3 kg) to report to authorities which run centralized equipment registers (e.g. Poland, Hungary as described above). However, this is not the case in all Member States. It should be noted that such centralized systems are not supported by all Member States due to the high administrative efforts for establishment of such databases and input of data, which sometimes are not electronically available.

Hence the main obstacle to the use of records as monitoring instrument for emission factors is not only their limited dissemination and the slow pace of their introduction, but the significant amount of time and effort needed for their evaluation. Few assessments of records have been undertaken to date[29,30] as the workload for the analysis of handwritten records is high. In contrast, evaluation of electronic records is much easier. However, even in case of identical software programmes for all users (contractors, operators, etc.), records are not kept in central databases. Data delivery for research purposes is voluntary apart from exceptions in the Member States mentioned above, and service companies and operators are often found to be reluctant to release data for centralized analysis for confidentiality reasons.

The difficulties related to central evaluation of records from individual installations are illustrated by an example from Germany: The Association of German Refrigeration and Air Conditioning Companies (VDKF) developed the recording software „VDKF-LEC Leakage & Energy Control" in 2004/2005, and requested the German service companies to apply the tool for all upcoming European and national reporting and monitoring requirements. At the end of 2008, about 700 of the 2,100 contractors were licensed users of the programme. The first data evaluation for refrigerant banks and emissions could be carried out in 2008, on the basis of only 31 companies who had made their 2006 data available to the VDKF[31]. By 2010, the number of users has grown to more than 840 (including some operators of large facilities). However, no further evaluation has been performed due to a lack of awareness of

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Record keeping for mobile refrigeration and air conditioning systems is also mandatory in the Netherlands under the STEK system.

29 In the Netherlands the only assessment of logbooks in the history of STEK dates back to 1999/2000: ITM Research, op. cit. Contrary to common opinion this study is mainly based on questionnaires, not on records ("logbooks") of individual installations. Logbooks had been used complementarily only. "In many cases it was not the questionnaire but a copy of the log book that was sent back. Contrary to what we had expected, the log books turned out to be in many different formats. In cases where there was uncertainty about the data to fill in, contact was sought with the respondent" (Translation for this study by Jason Anderson).

30 Assessment of records in Sweden: For a study for the European Commission, Öko-Recherche analysed in 2006 ca. 2,000 report forms on inspections of mobile air conditioners of 309 buses and coaches in a specialised garage in South-East Sweden during the period 1996-2005. The evaluation took 3 months time of two researchers. See: Establishment of Leakage Rates of Mobile Air Conditioners in Heavy Duty Vehicles, Part 2 Buses and Coaches (ENV.C.1/SER/2005/0091r), prepared for DG Environment), January 2007.

31 The results are published in the technical journal DIE KÄLTE + Klimatechnik, 11/2008. Bank 58,488 kg; refills: 1,980 kg; average leakage rate 3.4%.

operators and contractors for such analyses, and concerns about confidentiality[32], even if data were used in encoded form, and the additional work necessary for the assessment.

Despite confidentiality concerns, two Austrian companies active in the servicing of supermarket refrigeration and AC systems and one large German industrial company made data available to the project team in the context of this work, which allow compilation of time series.

Case: Supermarket systems 1

Banks and use of HFCs for refill are shown in table 2-4 for the period 2005-2010. The time series of the emission factor (bottom line) shows a downward trend until 2007. The refill rate increased again in 2008 and declined in 2010. 2009 data have not been available (IT-problems, data loss). One of the reasons for the peak refills in 2008 was total refrigerant loss of one installation (R-404A).

Table 2-4: Refrigerant banks and refills of an Austrian service company for supermarkets, 2005-2010, in kg[33]

<table>
<tr><th></th><th colspan="2">2005</th><th colspan="2">2006</th><th colspan="2">2007</th><th colspan="2">2008</th><th colspan="2">2010</th></tr>
<tr><td>No of supermarkets</td><td colspan="2">56</td><td colspan="2">56</td><td colspan="2">50</td><td colspan="2">44</td><td colspan="2">41</td></tr>
<tr><td></td><td>bank</td><td>refill</td><td>bank</td><td>refill</td><td>bank</td><td>refill</td><td>bank</td><td>refill</td><td>bank</td><td>refill</td></tr>
<tr><td>R-22</td><td>2,190</td><td>31</td><td>2,190</td><td>192</td><td>1,460</td><td>148</td><td>876</td><td>285</td><td>584</td><td>10</td></tr>
<tr><td>R-134a</td><td>292</td><td>15</td><td>292</td><td>1.5</td><td>146</td><td>1.5</td><td>146</td><td>16</td><td>146</td><td>2</td></tr>
<tr><td>R-404A</td><td>528</td><td>185</td><td>528</td><td>30</td><td>528</td><td>41</td><td>528</td><td>301</td><td rowspan="2">6160</td><td rowspan="2">767</td></tr>
<tr><td>R-507</td><td>6,336</td><td>1,467</td><td>6,336</td><td>1,339</td><td>6,336</td><td>1,073</td><td>5,984</td><td>1,209</td></tr>
<tr><td>R422D</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>146</td><td>66</td></tr>
<tr><td>Total</td><td>9,346</td><td>1,698</td><td>9,346</td><td>1,563</td><td>8,470</td><td>1,264</td><td>7,534</td><td>1,811</td><td>7,036</td><td>845</td></tr>
<tr><td>EF total</td><td colspan="2">18.2%</td><td colspan="2">16.7%</td><td colspan="2">14.9%</td><td colspan="2">24.0%.</td><td colspan="2">12,0%</td></tr>
</table>

Aside the 2008 values, which are the highest in the 6-years-period, the time series shows a certain decrease in emission factors, from 18.2% to 12.0%. The sample, however, is rather small and limited to one servicing company. Therefore, the trend cannot yet be extrapolated to all EU-27. The example illustrates that such time series should be longer and need to be based on a larger number of installations.

Case: Supermarket systems 2

Another international service company provided data on leakage rates (refill rates) from over 1,100 discount markets, supermarkets and hypermarkets with a total bank of ca. 201 t of HFCs and HCFCs. Data from 2004 and 2009 could be compared. The leakage rates (i.e. refill for loss of refrigerant during use, including accidents) of one quarter of the installed stock (new systems) were reduced by almost 50% through technical measures and regular leakage control measures like those prescribed in Article 3 of the F-gas Regulation.

[32] Communication of Volker Hudetz from VDKF (Bonn, Germany) submitted on 27 August 2010.
[33] The sample includes only equipment that has been serviced over all six years. Therefore the total decreases by retired installations. In 2007, 5 R-22 and 1 R-134a installations were decommissioned; in 2008, 4 R-22 systems and 2 R-507 systems, and in 2010 2 R-22 installations and 1 R-507 installation. In 2010 1 system was converted from R-22 to R422D. Data for 2009 has not been available. The name of the company is not disclosed (confidential information).

Table 2-5: Refrigerant banks and refills of an international operating service company for supermarkets, 2004-2009, in kg

Number of systems	Average charge/system (kg)	Refill rate (%)		
		All systems in 2004	All systems in 2009	New systems (25% of all systems) 2009
1,124	179	17.9	15.3	7.7

The name of the company is not disclosed (confidential information).

Emission rates of the total stock (old and new systems) were reduced from 17.9% (2004) to 15.3% (2009). However, emission reductions result only from decreasing emission factors (-50%) of new systems while emissions from old equipment have not been lowered, so far. Assuming systems lifetime of 10-12 years, emission factors of the total equipment stock might be reduced by 50% in 2015.

Case: Refrigeration and air conditioning systems in a large industry group

A large international industry group systematically collects data from refrigeration and air conditioning equipment containing charges from <3 kg to >300 kg. In 2008, more than 1,200 systems containing HCFC and HFC refrigerants were included and in 2010 the system had been expanded to more than 1,500 systems (+23%). Refrigerant losses (quantities refilled) decreased from 2008 to 2009 by almost 50% and increased again in 2010 to 190% of the quantity in 2008. Although the systems are well maintained and provisions of the F-gas Regulation are fully applied, these data show no trend. The time series are too short to draw serious conclusions.

2.3.2 Assumptions on emission factors in AnaFgas

The lack of empirically verified data on emission factors, which are sufficiently long, leads to the need for expert assumptions on changes of emission factors subsequent to the introduction of the F-gas Regulation. In the model AnaFgas, the following assumptions on impacts of provisions of different measures have been established for the WM scenario, which the application of the measures of the F-gas Regulation.

Containment measures according to Article 3: For stationary refrigeration, stationary air conditioning, fire protection systems and electrical switchgear containing charges >3 kg, it is assumed that containment measures carried out by certified personnel (Article 3) lead to a stepwise decrease in the use-phase emission factors by 40% in total during the period 2010 to 2015. From 2015 onwards, the emission factor is kept constant until 2050.

This reduction of the emission factor is not validated by empirical data but constitutes an estimate for possible emission reductions if the F-gas Regulation will be fully applied in EU-27. The estimate of a decrease of emission factors by 40% is based on reports referring to the Dutch STEK system, which is the model behind the key containment provisions of the F-gas Regulation with regard to the stationary refrigeration and AC sector. These assumptions about decreasing emission factors have also been used in a preparatory study for the

European Commission in 2003[34]. It is reported that the measures set out by STEK have cut the annual leakage rate in the Netherlands from more than 11% to less than 5% within 5 years in this sector. The IPCC/TEAP SROC Report assumes a similar reduction potential in 2015 in the mitigation scenario.

Moreover, the assumed 40% decrease of the use-phase emission factor does not account for the different extent of containment activities carried out in certain sectors prior to the F-gas Regulation. The actual increase in containment activities varies between sectors.

Recovery measures according to Article 4 (1): For all types of equipment covered by Article 4(1) on recovery by certified personnel, it is assumed that recovery efficiency increases. Disposal emission factors in stationary refrigeration and air conditioning are estimated to stepwise decrease by ca. 33% in high-charged equipment and by 50% in small systems, from 2010 to 2015. From 2015 onwards, the reduced emission factor is kept constant until 2050.

This reduction of the emission factor is not validated by empirical data either, but needs to be considered an estimate for possible emission reductions if the F-gas Regulation will be fully applied. It should be noted that information on recovery, recycling, reclamation and destruction of F-gases and/or equipment containing F-gases is available to very limited extent in most Member States and for EU-27.

[34] Enviros, 2003: Assessment of the Costs & Impact on Emissions of Potential Regulatory Frameworks for Reducing Emissions of HFCs, PFCs & SF_6, report on behalf of the European Commission.

2.4 Emission factors used in this report

Emission factors are essential for the quantitative assessment of emissions both in the counterfactual scenario (WOM) and in the scenario including measures of the F-gas Regulation and the MAC Directive (WM scenario). All emission factors used in the model AnaFgas are presented in overview tables (table 2-6 and 2-7).

Table 2-6 presents the emission factors applied to stationary refrigeration, air conditioning and heat pumps and to mobile air conditioning in the WOM and WM scenario of AnaFgas.

Table 2-7 shows the emission factors in the other F-gas sectors.

In both tables the model emission factors are compared with the relevant recommendations of the IPCC Guidelines for National Greenhouse Gas Inventories 2006, in the column on the right. In addition, table 2-6 shows use-phase emission factors for the two global consumption scenarios. Disposal emission factors are not considered there because disposal is not relevant when modelling consumption which includes first fill and refill only.

In the foam sector, use-phase emission factors are also not relevant for the global scenario because emissions from foam are not refilled.

Table 2-6: Emission Factors for refrigerants [%] in WOM and WM scenario (AnaFgas) for Europe compared with the two global scenarios of this study (chapter 7) and the IPCC 2006 Guidelines. (Empty cells in the WM scenario mean no change vs. WOM scenario. Empty cells in other columns indicate that there is no emission factor available.)

Refrigeration, AC and heat pump sub sectors	Type of emission factor	EU WOM scenario and WM scenario pre-2010	EU WM scenario post-2015	Global consumption scenarios (A2)	IPCC GL 2006
Domestic Refrigeration	Lifetime factor	0.3 (default)	0.3	*0.3*	*0.1-0.5*
	Disposal factor	40	30		*30-100*
Industrial Refrigeration	Lifetime factor	10	6	*8*	
	food industry	9	5.4	*8*	
	other industry	12	7.2	*8*	*7-25*
	Disposal factor	30	20		*10-100*
Commercial Refrigeration	Lifetime factor				
	Centralised systems	15	9	*15*	*10-35*
	Condensing units	10	6	*10*	*[10-35]*
	Stand-alone; hermetics	1	1	*1*	*1-15*
	Disposal factor				
	Centralized systems	30	20		*30-100*
	Condensing units	50	25		*30-100*
	Stand-alone; hermetics	70	35		*30-100*
Transport Refrigeration	Lifetime factor				
	Trucks, Trailers	20		*20*	*15-50*
	Vans	30			*15-50*
	Disposal factor	30			*30-100*
Fishing vessels	Lifetime factor	40			
	Disposal factor	30			
Heat Pumps	Lifetime factor	3.5	3.5	*5*	*1-10*
	Disposal factor	70	35		*20-100*
Moveable AC	Lifetime factor	3	3	*5*	*1-10*
	Disposal factor	70	35		*20-100*
Split AC	Lifetime factor	5	5	*5*	*1-10*
	Disposal factor	70	35		*20-100*
Multi-split AC	Lifetime factor	8	5.6	*8*	*1-10*
	Disposal factor	30	20		*20-100*
Rooftop AC	Lifetime factor	5	3	*5*	*1-10*
	Disposal factor	30	20		*20-100*
Chillers (incl. centrifugal)	Lifetime factor	4	2.4	*5*	*2-15*
	Disposal factor	30	20		*5-100*
Passenger Car AC	Lifetime factor	10		*10*	*10-20*
	Disposal factor	70			*50-100*
Truck AC	Lifetime factor	10/15			*10-20*
	Disposal factor	70			*50-100*
Bus AC	Lifetime factor	15		*15*	*10-20*
	Disposal factor	30			*50-100*
Rail AC	Lifetime factor	7			
	Disposal factor	30			
Ship AC	Lifetime factor	40			
	Disposal factor	30			

Table 2-7: Emission Factors in other sectors in the WOM and WM scenario of the model AnaFgas compared with IPCC 2006 Guidelines. (Empty cells in the WM scenario mean no change vs. WOM.)

Sub sectors	Type of emission factor	EU WOM scenario and WM scenario pre-2010	EU WM scenario post-2015	IPCC GL 2006
OCF	Lifetime factor	100	100	95-2.5-2.5
XPS	Manufacturing 152a	100		50-25-25
	Manufacturing 134a	30		25
	Lifetime factor 134a	0.75		0.75
PU rigid	Manufacturing 134a	10		10 (tier 1)
	Manufacturing 245fa/365mfc	10/15		4-15
	Lifetime factor 134a	4.5		4.5 (tier 1)
	Lifetime factor 245fa/365mfc	1/1.5		0.25-1.5
PU integral skin	Manufacturing	100		95-2.5-2.5
Aerosols, Solvents	Lifetime factor	100	100	50-50
Fire extinguishers	Lifetime factor 227ea/23	2.5	2.3	1-3
	Lifetime factor 236 (portable)	>5	4	2-6
	Disposal factor	10	9	
Switch gear	Manufacturing	5	5	7/8.5
	Lifetime factor	1	0.7	0.2/2.6
	Disposal factor	5	1.5	
Soundproof glazing	Manufacturing	33	33	33
	Lifetime factor	1	1	1
	Disposal factor	100	100	100
Shoe soles, Car tyres	Disposal factor	100	100	100
Aluminium smelting	Manufacturing	1.5		
Magnesium casting	Manufacturing	100	5.4 (134a/SF_6)	100
Photovoltaic	Manufacturing	4		4

2.5 Identification of policy options

Policy options for further international and EU action to reduce F-gas emissions are assessed in chapters 7 and 8. The impact of certain policy options on F-gas use and emissions is calculated in the WAM scenario for EU-27, based on the model AnaFgas, and the two global scenarios, based on assessment of sector experts, described in section 2.2.

2.5.1 Policy options at international level

Under the Montreal Protocol, it is currently discussed on how to link the work on HFCs done under the Kyoto and post-Kyoto regime and further phase out of ODS more closely.

Two proposals for an amendment of the Montreal Protocol in this respect have been resubmitted in 2011, one by the Federated States of Micronesia and one by the Northern American countries USA, Canada and Mexico. Both proposals suggest control of production and consumption of HFCs. These proposals are presented in chapter 7 of this report.

Elements for further action at international level to reduce F-gas emissions focus on HFC phase down scenarios.

2.5.2 Policy options in EU-27

The identification of policy options for further EU action addressing emissions of fluorinated greenhouse gases is based on the modelling work and the assessment of the projected effectiveness of the F-gas Regulation and includes the options listed in Article 10.

The scenario integrating all measures introduced by the MAC Directive and the F-gas Regulation (WM) reflects the current situation and illustrates the F-Gas emission development under option A of this report (no policy action, see chapter 8).

The options identified finally lead to a third scenario with additional measures (WAM) addressing future F-gas emissions. The development of emissions in this third scenario depends on the choice of policy options (see chapter 8).

3. F-gas markets and policies

3.1 Global and European F-gas markets

3.1.1 Montreal Protocol as main driver of growing use of HFCs

Control of production and consumption of fully halogenated ozone-depleting substances (CFCs) under the Montreal Protocol started in the early 1990s. Subsequently, the chemical industry in the USA, Western Europe and Japan invested in large scale in the production of HFC-134a (GWP 1,430; ODP 0) as the main replacement for CFC-12 (GWP 10,900; ODP 1), which had been the most important CFC for decades.

The relevant market for HFC-134a was and still is the mobile air conditioning sector and to smaller extent refrigeration, while large parts of the refrigeration sector and the stationary air conditioning sectors have been relying on HCFCs (R22). The three main sectors using refrigerants, i.e. refrigeration, mobile and stationary air conditioning, currently use approximately two thirds of the global annual HFC/HCFC-production at almost equal parts.

HFC-134a successfully replaced ODS also in medical and technical aerosols, and later-on in XPS foam blowing. In the early 1990s, further HFC species came to the market as replacements for fully halogenated ODS. These included HFC-227ea and HFC-236fa, which were introduced as substitutes for halons in fire protection equipment, and HFC-43-10mee as alternative to CFC-113 in solvents applications. The market potential of these HFC species was of limited size, since the sectors of fire protection, solvents, aerosols and to less extent the foam sector[35], which accounted for half of the ODS production in the 1980s, did not experience a similar transition to HFCs, but mostly conversion to hydrocarbons or not-in-kind technologies. Overall, the market for HFCs does not match the former size of the ODS market.

The only field of ODS application with a high replacement rate (relation of HFCs to former ODS) turned out to be the refrigeration and air conditioning sectors. This was partly due to the fact that most halocarbons, which are fluorinated gases with and without chlorine in the molecule, are not flammable like hydrocarbons or ammonia. Nevertheless, the sub sector of domestic refrigeration gradually changed to hydrocarbons, first in Europe and subsequently at international level.

3.1.2 HCFC phase-out drives use of HFC refrigerant blends

A couple of years after the decision to fully phase-out halogenated ODS a new decision was taken to also control and phase out HCFCs under the Montreal Protocol. As pure HFC species could not reach the refrigeration performance of R22, blends containing two or three of the HFC types HFC-32, HFC-125, or HFC-143a, i.e. R407C, R404A, or R507 were offered as HCFC substitutes. Some years later another blend, R410A, came to the market. However the phase out schedule allowed developed countries more than 15 years to continue the use of HCFCs, and developing countries over 35 years (2030). This schedule is the main reason

[35] In the polyurethane foam sector; introduction of HFC blowing agents substituting the prevailing HCFC-141b took a longer time than the introduction of the R-22 replacing refrigerants. HFC-245fa and HFC-365mfc started production first after 2000, when the advanced HCFC prohibition in Europe had already entered into force.

why the new HFC based refrigerant mixtures soon brought to the market as HCFC replacements did not gain substantial market shares for a long time.

Sales of HFC refrigerant blends and thus the production of HFC-125, HFC-143a, and HFC-32 have significantly increased from 2000 onwards, first in Europe, then in Japan, and with some delay in the remaining industrialised countries including the USA. Since 2005, growth in HFC production of the Western and Japanese chemical companies has mainly been driven by refrigerant blends which have already exceeded the decrease in the HCFC-22 refrigerants[36]. In this study it is estimated that the global demand for HFC-32 and HFC-125 will soon exceed the demand for HFC-134a.

3.1.3 Strong increase of HFC production in developing countries

Two global trends have strongly influenced current HFC markets are expected to continue doing so in the future under business-as-usual:

(1) Strong growth in use of refrigerant blends and small growth in use of HFC-134a;

(2) Slight increase in HFC production in developed countries and strong increase in developing countries, mainly in Asia where growing demand for HFCs is projected.

Production of HFC-134a by Western and Japanese chemical companies, which had steadily been increasing since 1991, stopped growing in 2004 and had been decreasing until 2009 (see table 3-1).

In 2009, AFEAS[37] stopped collecting data on halocarbon production explaining that the member companies "accounted for less than half of global sales". The interpretation of industry experts is that developing countries, primarily China, started and quickly increased domestic production of HFC-134a[38] not only to cater for domestic demand but also for the world market. China, which is today by far the largest producer of HCFCs, will presumably gain world market leadership also in HFC blend components, primarily because of the high demand for HFC blends by the stationary air conditioning sector.

Table 3-1 illustrates three different aspects of the halocarbon production of the Western and Japanese manufacturers.

- First, HFC-134a production decreases from 2004, after continuous growth from 1995.
- Second, production of HCFC-22 dropped by 40%, beginning in 1999/2000 (left column).
- Third, the decrease in HCFC-22 was counteracted by additional production of the refrigerant blend components HFC-125 and HFC-143a.

Together with HFC-32, (data is not included in the table for confidentiality purposes), the growth of HFCs for blends exceeded the decline of HCFC-22 completely. In contrast, the sharp drop in HCFC-141b, which serves as a PU foam blowing agent, is not at all compensated by HFCs (HFC-245fa and HFC-365mfc) (not shown for confidentiality reasons).

[36] In contrast, the sharp drop in HCFC-141b is not offset by new HFCs (HFC-245fa and HFC-365mfc).
[37] AFEAS is an organisation of Western and Japanese Chemical companies.
[38] The present production numbers are not known outside of China. Expert estimates range from 20,000 to 100,000 metric tons per year.

Table 3-1: Global annual production reported by AFEAS companies* (metric tons). Source: AFEAS 2009. Data does not include China and India.

	HCFC-22	HCFC-141b	HFC-134a	HFC-125	HFC-143a
1995	243,468	113,154	73,769		
1996	267,523	121,085	83,674	0	794
1997	246,937	122,356	97,949	296	339
1998	271,980	129,037	112,174	698	557
1999	248,552	130,415	131,710	1,243	750
2000	239,197	132,476	130,056	7,400	5,396
2001	213,328	121,757	133,956	12,583	9,151
2002	193,955	116,673	156,987	16,190	9,656
2003	187,262	74,596	166,899	22,631	12,972
2004	189,545	40,417	173,851	32,734	14,053
2005	176,373	25,619	169,999	31,819	16,321
2006	165,478	22,548	156,573	38,537	16,257
2007	165,862	21,835	158,161	42,573	18,325

* Note that data on HFC-32 are not published. In our estimate, the trend of is similar to that of HFC-143a, which means considerably growing.

Figure 3-1 illustrates the historic development of the global halocarbon market (fluorinated gases with and without chlorine) over 40 years and includes also a projection established by the project team until 2030, which shows a downward trend for HCFCs and CFCs since the end of the 1990s. From 2000 onwards, the growth of HFCs is strongly supported by components for refrigerant blends substituting HCFC-22, while the global market of HFC-134a is projected to grow only slowly.

The pie charts below figure 3-1 illustrate the changes of end-use applications of halocarbons. While refrigerants, foam blowing agents, aerosol propellants and solvents were consumed at almost equal parts during the 1980s, refrigerants account for three quarters of the worldwide production and sales at present and most likely also in the future.

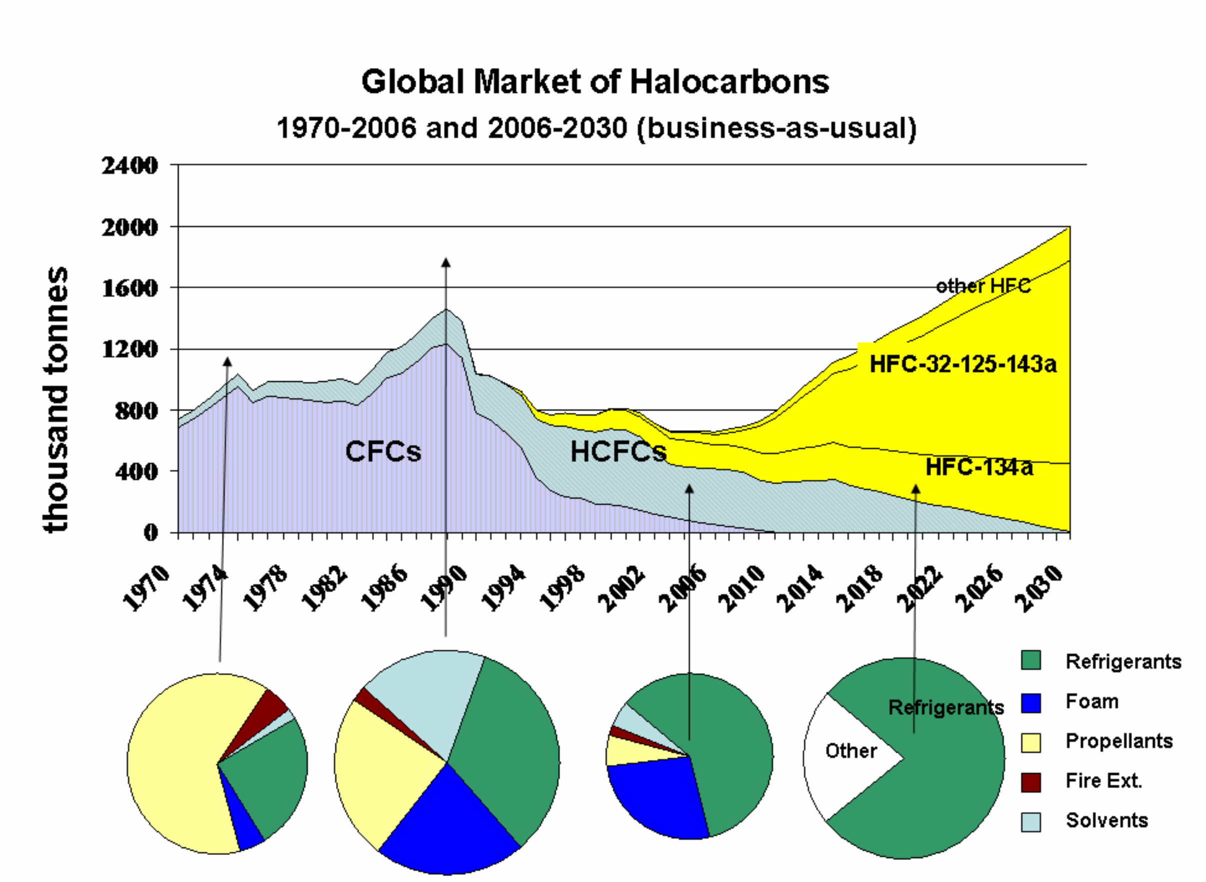

Figure 3-1: Global market for halocarbons including ozone-depleting gases like CFCs and HCFCs from 1970 to 2030 (incl. own forecast). After 1990, CFCs show rapid decline, not fully replaced by HCFCs. From 2000, HFCs replace HCFCs and will grow continuously until 2030. From 2004 onwards, the increase in HFC sales is no longer driven by HFC-134a but by those HFCs that form R-22 substituting refrigerant blends, primarily HFC-32 and HFC-125. Over the five decades, refrigerants have become the most important application of halocarbons. The quantities are presented in metric tons, which makes the trend clearer than CO_2 equivalents. Source: AFEAS until 2006, 2030 projection by Öko-Recherche.

The shift between the halocarbon species from CFCs to HFC blend components is one important trend. The second main trend, the structural market shift from developed countries to developing countries, is illustrated in the next graph (figure 3-2) which presents a projection elaborated within this project for the halocarbon demand by A2 (developed countries) and A5 countries (developing countries) until 2030 (detailed information on these projections are included in chapter 7).

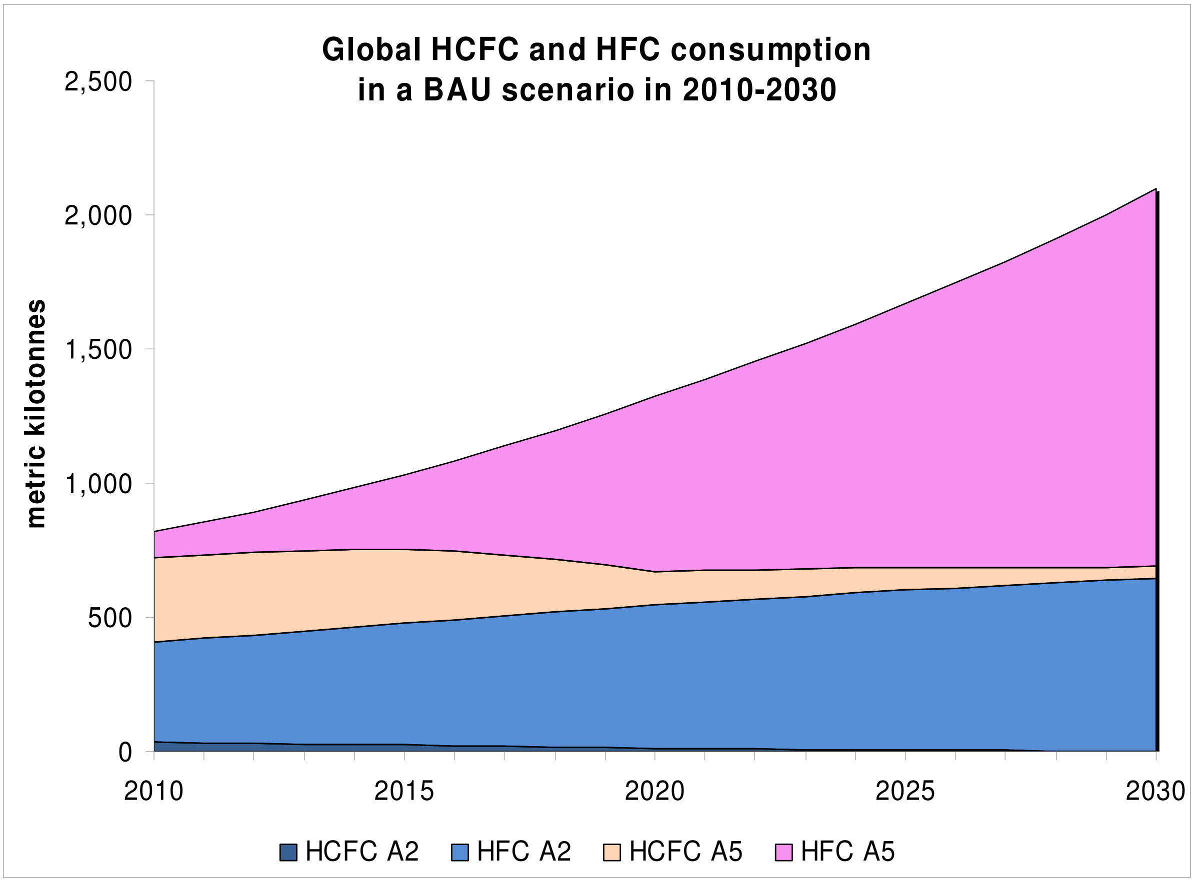

Figure 3-2: Business-as-usual projection of the global sales (metric kilo tonnes; kt) of HFCs and HCFCs until 2030 by the authors of this study. While demand and sales of HFCs grow moderately in developed countries (A2), demand and sales will rise steeply in developing countries (A5).

In this business as usual scenario, the global demand will more than double over the next twenty years, from 800 kilo tonnes (2010) to 1,300 kilo tonnes (2020) and even 2,000 kilo tonnes (2030)[39]. The market growth in A2 countries is slow as markets are being saturated widely. The global increase will almost completely be driven by A5 countries as of 2020. Quantitative demand for HFCs in A5 countries will by far exceed the demand of A2 countries in 2030. This development will be the result of overall population and economic growth, expressed through a strong demand for refrigeration and stationary air conditioning applications.

3.1.4 Slow market growth in developed countries: F-gas demand in EU-27

Since F-gases were included in the basket of greenhouse gases covered by the Kyoto Protocol in 1997, measures to improve containment, leak tightness and recovery have gained importance, and alternative fluids and not-in-kind technologies are increasingly discussed, developed and applied.

- Higher awareness of personnel and technical or regulatory measures improve leak tightness of equipment, and contribute to reduction of operating emissions. E. g. the

[39] For details see chapter 7 of this report.

EU legislative framework addressing F-gases from 2006 requires strict containment measures. This decreases demand from the aftermarket.

- Recovery at end-of-life shows first signs of progress.
- Hydrocarbons, ammonia and CO_2 (subcritical and transcritical use) are penetrating into the sectors of refrigeration and, in part, stationary air conditioning.
- Several European countries impede the use of F-gases through regulatory and fiscal measures[40]; e.g. the EU legislative framework addressing F-gases from 2006 eventually bans the use of HFC-134a in the large sector of mobile air conditioning of passenger cars.

These measures show impact upon the future demand for F-gases, in particular HFCs. After successful implementation of the HCFC-phase-out, there are signs that the growth in demand for HFCs slows down.

Table 3-2: Sales[41] of F-gases (metric tonnes) by F-gas types in EU-27 in 2007-2010 based on reported data (Art 6 of the F-gas Regulation)

Sectors	**2007**	**2008**	**2009**	**2010**
	t	**t**	**t**	**t**
HFC-134a	51,693	48,123	42,005	45,373
HFC-32	4,186	5,545	4,328	5,408
HFC-125	12,933	15,427	13,438	18,308
HFC-143a	9,605	10,487	8,940	10,118
HFC-152a	4,301	2,782	5,182	6,213
HFC-227ea	0,857	2,336	2,075	2,199
HFC-365mfc	n.r.	3,785	3,054	3,554
SF_6	2,223	3,011	1,928	1,851
- thereof to electrical equip.	*1,568*	*2,386*	*1,284*	*1,614*
Other	7,338	2,547	4,164	4,645
Total sales	**93,127**	**94,043**	**85,114**	**97,669**

Note: F-gas quantities in pre-charged equipment are not included here, but are discussed in chapters 4 and 8.

Table 3-2 shows a slight increase in total F-gas sales from 2007 to 2008, and a sharp decline of 10% in 2009. The severe drop in 2009 is clearly a result of the economic crisis in that year, because in 2010 the total sales increased again, to a level which is 5% higher than in 2007.

Looking at the sales of HFC-134a only which is by far the most important single F-gas type, representing more than half of the F-gas market, one can see that the demand declined more sharply than the total F-gas demand in the period 2007-2009, and the re-rise in 2010 was lower than that of most other HFCs. From 2007 to 2010 the sales reduction was 12%. In contrast, sales of the blend components HFC-32, HFC-125, and HFC-143a strongly increased in the same period of time by 26% and over compensated the reduction in sales of HFC-134a.

[40] See chapter 3.2.

[41] Sales include only F-gases in containers or cylinders (bulk quantities). Import in prefilled equipment like stationary air conditioners is excluded even though they significantly contribute to emissions in Europe (see chapter 2). Source: 2007-2009: http://ec.europa.eu/clima/studies/f-gas/docs/statistical_factsheet_2010_en.pdf. Data for 2010 are preliminary, subject to validation.

The demand for other F-gases like HFC-227a (fire protection) and HFC-365mfc (PU foam) is stable, while sales of HFC-152a (XPS insulation foam) are rising. SF_6 is the only F-gas with a clear down trend; the sales dropped 2007-2010 by 17%. As the demand from the most important SF_6 sub sector, electrical switchgear, was stable, the sales drop can be attributed to prohibitions of several open applications by the F-gas Regulation (magnesium die casting, sport shoe soles, car tyres; soundproof windows).

For the future, stagnation of the EU market of F-gases is anticipated. Mobile air conditioning (first fill and refill) is by far the most important single F-gas sector, accounting for two thirds of the annual sales of HFC-134a (ca. 35 kt per year). Restrictions in the mobile air conditioning sector (MAC Directive) are likely to impact the overall HFC-134a market substantially, in particular as both XPS foam and aerosol sectors will not remain stable HFC sales areas in the long run. It is not certain whether demand for the blend components HFC-32, HFC-125, and HFC-143a will actually balance the reduction of demand for HFC-134a once the R-22 phase-out is completed.

Figure 3-3 indicates that the EU demand for virgin and recycled F-gases would increase by 25,000 t (+30%) within 40 years under the WOM scenario which disregards all 2006 EU F-gas legislation. However, the application of the MAC Directive and the F-gas Regulation lead to a reduction by 14% in 2050 vs. 2010, to 72,000 t.

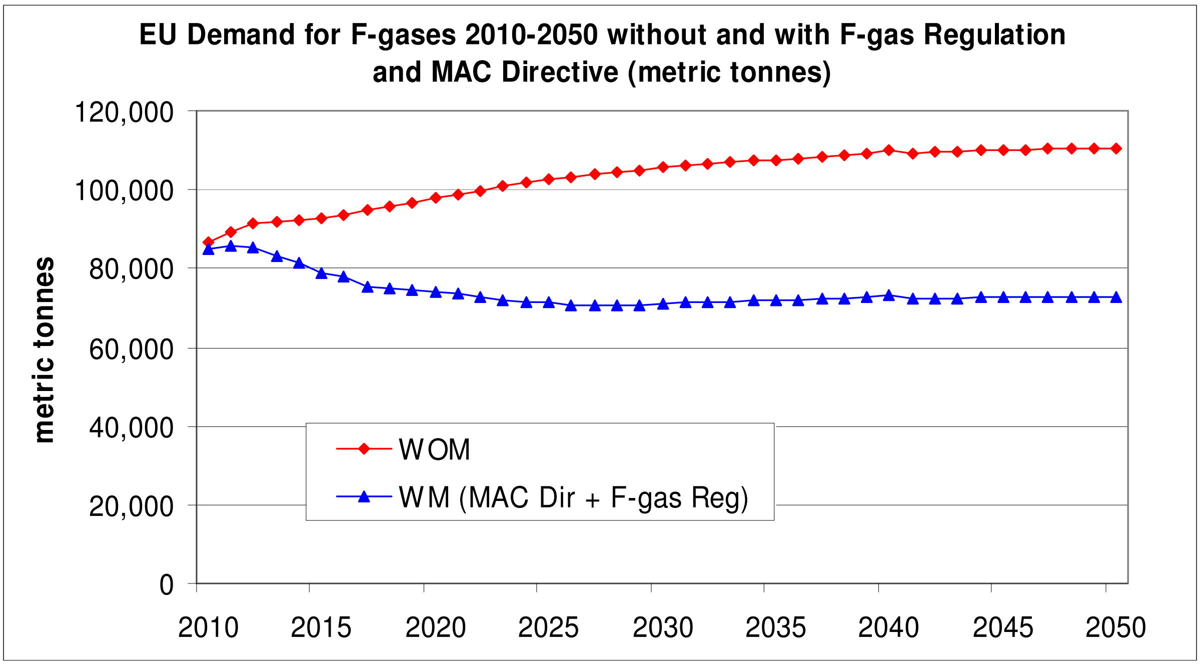

Figure 3-3: Demand for virgin and recycled F-gases (metric tonnes) in the EU-27 under the WOM scenario and the WM scenario, which includes MAC Directive and F-gas Regulation. Under the 2006 F-gas legislation the demand for F-gases will significantly decrease until 2025, and remain stable afterwards. (Source: model AnaFgas)

In the period 2005-2009, 2 of the 4 plants for HFC-134a production have been closed (Italy, UK), and the closure of one of these facilities lead to discontinuation of the production of HFC-125, which had been captured as by-product. Although traditionally European HFC demand is covered to large extent by imports, mostly from the USA, the reduction in EU HFC production capacities seems to be based on projections of the HFC market potential in Europe.

3.1.5 HFC markets in North America, Japan, and Asia-Pacific

In other regions of the world, the market trends differ from those in Europe.

In the USA, the production of F-gases is more than twice as high as in Europe and the domestic demand is much larger, in particular for refrigeration and mobile air conditioning. Stationary air conditioning is also important and represents a strong market for HFC blends. The phase-out of HCFC-22 and transition to HFC blends is still in progress. Regulatory measures for containment or prohibition of F-gases currently do not exist. Alternative fluids and not-in-kind technologies do not yet attract such high interest as they do in Europe for most applications[42].

In Japan, the phase-out of HCFCs follows a tight schedule similar to that in Europe. The market potential for HFC blends replacing R-22 is not fully saturated yet. Like the USA, Japan has a large sector of stationary air conditioning, which generates high demand. In contrast, the potential for the use of HFC-134a in mobile air conditioning is unlikely to increase. The Japanese PU industry recently decided to waive HFCs in spray foam (the largest sub segment of foam in Japan)[43].

The most evolving markets for F-gases in the future are the developing countries, in particular China. In China the use of HFC-134a in mobile air conditioning is still in its initial stages within the car industry. The stationary refrigeration sector is still ahead of HCFC-22 phase out and thus the transition to HFC blends. The large-scale production of room air conditioners for the domestic and the world market causes high demand for HFC blend components, in particular for HFC-32 and HFC-125 used for production of the refrigerant blend R410A. In China an unknown but growing number of small HFC plants emerge competing with the Western and Japanese chemical companies to meet this growing demand. In addition, low-GWP refrigerants such as propane (R290), iso-butane (R600a), carbon dioxide (R744) or ammonia (R-717) and foam blowing agents such as pentanes or organic solvents plus CO_2 attract interest in developing countries, partly supported by the Montreal Protocol.

From a global perspective, the development of global F-gas markets is not consistent. On the one hand new demand arises, and on the other hand the market potential of HFC technology is limited by national and international regulatory action. Alternative fluids and not-in-kind technologies are increasingly available, usually at low cost.

It must be pointed out that even very strict regulatory measures on the use of F-gases, like the EU ban for HFC-134a in air conditioning systems in passenger cars do not necessarily influence the global HFC market.

Furthermore, the development of alternatives to HFCs with low global warming potential, such as unsaturated HFCs like HFC-1234yf or HFC-1234ze (see chapter 5.4), and numerous blends of unsaturated HFCs and HFCs is ongoing. However, quantitative data on production and market potential of these substances and preparations are not available yet.

[42] In industrial refrigeration ammonia plays a greater role in the USA than in Europe.

[43] Japan Urethane Industries Institute (JUII): “Phase-out of hydro fluorocarbons (HFC) as a blowing agent of Polyurethane (PU) rigid spray foam for the residential building insulation” by the end of August, 2010; press release 26th January 2010.

3.2 Policies addressing F-gas emissions

F-gas policies analyzed at international, European and Member State level as well as at national level in countries outside of EU-27 were identified. The underlying approaches include regulatory action, market-based mechanisms and voluntary initiatives.

3.2.1 International level

Multilateral Environmental Agreements (MEAs)

The EU has ratified several international conventions, which impact use and emissions of F-gases while not addressing them exclusively.

The **United Nations Framework Convention on Climate Change** (UNFCCC) and its **Kyoto Protocol** are covering HFCs, PFCs and SF_6 emissions since 1997. Measures for monitoring and reporting of emissions apply and they are subject to greenhouse gas emission reduction targets. The Kyoto Protocol lays down such national targets for developed countries (Annex I countries) until 2012, which also include F-gas emissions. Through Council Decision 2002/358/EC[44], the European Community and its Member States accepted the Kyoto Protocol and committed to reduce overall greenhouse gas emissions by 8% compared to the base year 1990 during the commitment period 2008-2012.

While COP 15 failed to produce an international agreement involving binding greenhouse gas emissions reduction targets, most Annex I countries pledged quantifiable emission reductions under the **Copenhagen Accord**[45], and several developing countries submitted nationally appropriate mitigation actions (NAMAs) listed in Appendix II of the Accord. In total, countries which submitted pledges under the Copenhagen Accord account for ca. 80% of global greenhouse gas emissions. For most countries, pledges under the Copenhagen Accord are quite similar to those made prior to COP 15, for example, the EU pledged to reduce GHG emissions by 20% compared to 1990 levels and to cover 20% of energy consumption by renewables. On condition that other major emitting developed and developing countries commit to do their fair share under a global climate agreement, the EU offered a more ambitious reduction target of 30%. The European Commission has analyzed the effects of moving unilaterally to an unconditioned 30% reduction target but maintains that the conditions to do so are not met yet[46]. The recent roadmap for moving to a competitive low carbon economy in 2050[47] confirmed the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990.

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[44] Council Decision 2002/358/EC concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the fulfillment of commitments thereunder.

[45] UNFCCC 2009: Decision 2/CP15 Copenhagen Accord of 18 December 2009.

[46] European Commission: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage. COM(2010)265final, 26.05.2010.

[47] European Commission: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A roadmap for moving to a low carbon economy in 2050. COM(2011)112final, 08.03.2011.

European policies addressing all types of GHG emissions including F-gases will hence need to be adapted in order to meet these new commitments.

In addition to the UNFCCC, the Montreal Protocol on ozone depleting substances under the Vienna convention is linked to F-gases which were introduced as substitutes to ODS. This link is reflected in a series of decisions of the Meetings of the Parties to the Montreal Protocol taken in recent years (table 3-3).

Current discussion treats the question on how to link the work on HFCs done under the Kyoto and post-Kyoto regime and further phase out of ODS under the Montreal Protocol more closely. Two proposals for an amendment of the Montreal Protocol in this respect have been re-submitted in 2011, one by the Federated States of Micronesia (FSM) and one by Northern American countries including the USA, Canada and Mexico (NA). Both proposals suggest control of production and consumption of HFCs and are currently being discussed at international level. Detailed analyses of these proposals are outlined in chapter 7 of this report.

The **Basel Convention** of 1989 on the control of transboundary movements of hazardous wastes and their disposal entered into force in 1992. It defines hazardous wastes and establishes a global control system for transboundary shipment of hazardous wastes in order to improve waste management and minimize risks for health and the environment.

As for applications of F-gases, this convention is relevant with regard to imports and exports of used equipment and products containing F-gases, for example household refrigerators, freezers and air conditioning equipment, to and from EU-27 either during or at the end of product life. The Basel Convention came into force in EU in 1994 and has been transposed in European legislation (see chapter 3.3.2) and Member State national legislation.

In recent years, the cooperation with the Vienna Convention/ Montreal Protocol was enhanced: The Secretariat of the Basel Convention participated in meetings of the Open-ended Working Group of the Parties and Meetings of the Parties to the Montreal Protocol, and a workshop on management of ozone depleting substance banks and implications for climate change in 2009[48].

[48] Open-ended Working Group of the Basel Convention, Seventh Session May 2010: International cooperation and coordination: review of the implementation of decision IX/11. Document UNEP/CHW/OEWG/7/17.

Table 3-3: Decisions under the Montreal Protocol illustrating the link between the UNFCCC and the Vienna Convention

Decision	Issue
MOP decision X/16 (1999)[49]	Implementation of the Montreal Protocol in the light of the Kyoto Protocol: - Report by the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol on implications to the Montreal Protocol of the inclusion of HFCs and PFCs in the Kyoto Protocol, critical and desirable uses of HFCs, and replacement potential of HCFCs by HFCs. - Start of formal interaction with the Intergovernmental Panel on Climate Change (IPCC) and first workshop.
MOP decision XIV/10 (2002)	Relationships between efforts to protect the stratospheric ozone layer and efforts to safeguard the global climate system: issues relating to hydrofluorocarbons and perfluorocarbons: Common special report of the IPCC and the TEAP.[50]
MOP decision XIX/6 (2007)	Adjustments to the Montreal Protocol with regard to Annex C, Group I substances (hydrochlorofluorocarbons): Accelerated phase out of production and consumption of HCFCs. Preparation of funding criteria by the Executive Committee which include i.a. "substitutes and alternatives that minimize other impacts on the environment, including on the climate, taking into account global warming potential, energy use and other relevant factor" (11b).
MOP decision XX/8 (2008)	Workshop for a dialogue on high global warming alternatives for ozone depleting substances. - TEAP report on alternatives to HFCs and HCFCs including use patterns, costs and market penetration of alternatives[51]. - Report by the Ozone Secretariat on current control measures, limits and reporting requirements for high-GWP alternatives for ODS[52]. - Dialogue on high GWP alternatives to ODS organized by the Ozone Secretariat to discuss technical and policy issues on how the Montreal Protocol experience can be used to address the impact of HFCs and maximize the ozone and climate benefit of the HCFC early phase out[53].
ExCOM Decision 60/44 (2010)	Agreed funding criteria for HCFC phase out in the consumption sector in A5 countries were adopted by the Executive Committee: "Funding of up to a maximum of 25% above the cost effectiveness threshold will be provided for projects when needed for the introduction of low global warming potential (GWP) alternatives" (Annex I (f) (iv)).

[49] Document UNEP/OzL.Pro11/2 of 19 July 1999.
[50] IPCC/ TEAP 2005: Special Report – Safeguarding the Ozone Layer and the Global Climate System: Issues related to Hydrofluorocarbons and Perfluorocarbons.
[51] TEAP Task Force decision XX/8 report: Assessment of alternatives to HCFCs and HFCs and update of the TEAP 2005 Supplement report data. May 2009.
[52] Document UNEP/OzL.Pro/Workshop.4/2 of 19 May 2009.
[53] The Workshop was held in Geneva in July 2009.

Market based mechanisms

In the context of the Kyoto Protocol, three market-based mechanisms were established, which cover all types of greenhouse gases including F-gases.

- The **International Emissions Trading (IET)** describes a regime that allows Parties subject to quantified emissions limitation or reduction commitments ("caps") to buy and sell emission credits among them. Authorities assign certain numbers of emission credits to each participating entity. Entities whose emissions exceed the amount of credits assigned to them, must buy additional credits to cover their actual emissions.
- The **Clean Development Mechanism (CDM)** allows developed countries to finance projects avoiding greenhouse gas emissions in developing countries and receive credits for doing so.

  As of 1 March 2011, F-gas emissions are addressed under several methodologies applying to different sectors[54]:

    25 CDM projects address HFC emissions: Incineration of HFC-23 from HCFC-22 production (20), recovery of HFC-134a in residential refrigerators (1) and avoidance of HFC emissions in PU foam manufacture (4).

    7 CDM projects address PFC emissions: Emission reduction from primary aluminium smelting facilities (7).

    14 CDM projects address SF_6 emissions: Emission reductions in electrical grids (6) and during the manufacture of LCD screens (4), prevention of emissions from venting following tests of gas insulated electrical equipment (1) and replacement of SF_6 by an alternate cover gas in magnesium industry (3).

  Most of the CDM projects addressing F-gas emissions take place in Asia, some in Latin America.
- The **Joint Implementation Mechanism (JI)** refers to projects in developed countries reducing net greenhouse gas emissions in another developed country in order to receive credits.

  As of 1 March 2011, F-gas emissions are addressed under several methodologies applying to different sectors[55]:

    6 JI projects address HFC emissions: Co-destruction of HFC-23 and SF_6 at a polymer plant (1; Russia); HFC-23 destruction (2; Russia); thermal oxidation of the gas effluents of from manufacture of trifluoroacetic acid (1; France).

    2 JI projects address PFC emissions: Emission reductions at primary aluminium smelting facilities (2; Germany, Russia).

The European Emissions Trading System will be outlined in subchapter 3.2.2.

[54] UNEP Risoe: CDM/JI pipeline analysis and database. http://cdmpipeline.org/
[55] See above.

Voluntary programmes and initiatives

In the environmental field, decision-makers increasingly opt for alternative forms of regulation including voluntary agreements and other industry self-regulation, instead of using traditional legislative instruments.

International voluntary action addressing use and emissions of F-gases has been taken by different industries:

Semiconductor industry: An international voluntary agreement of the semiconductor industry (including all the countries where production is located) includes the commitment to reduce absolute total emissions of HFC-23, PFCs, SF_6 and NF_3 by 10% by 2010 (baseline 1995). This target has been reached and a new voluntary agreement for the post-2010 period is currently being elaborated[56].

LCD industry: This voluntary agreement of the LCD industry (located in Japan, Korea and Taiwan) from 2003 intends to reduce aggregate absolute PFC and SF_6 emissions from LCD fabrication facilities to at least 0.82 million tonnes CO_2 eq by 2010.

Aluminium industry: Global agreement to reduce PFC production emissions by 50% per tonne of production by 2020 (baseline 2006).

Refrigeration: In November 2010, the Consumer Goods Forum, an organization of 400 global consumer goods manufacturers and retailers, announced an initiative to phase out the use of HFC refrigerants as of 2015 where natural refrigerant alternatives “are legally allowed and available for new purchases of point-of-sale units and large refrigeration installations”.

Global initiatives such as “Refrigerants, Naturally!” and “The Natural Voice” provide platforms for companies committing to the use of natural refrigerants and thereby prevention of emissions of ozone-depleting substances and fluorinated greenhouse gases.

3.2.2 European level

Regulatory measures

In the context of additional commitments for GHG emission reductions, a new stage of European climate and energy policy has been initiated when the so called **“climate and energy package”** was agreed in 2008. It consists of four pieces of legislation: a revision of the 2003 Emissions Trading Directive, a Decision on sharing the effort on GHG emission reductions in the non-Emissions Trading System (ETS) sectors among Member States (406/2009/EC), a new and comprehensive Renewable Energy Directive (2009/29/EC), and a Directive on carbon capture and storage (CSS).

The Effort Sharing Decision 409/2009/EC lays down binding national GHG emission reduction targets in the sectors not covered by the European Emissions Trading System (EU-ETS), i.e. all sectors relying on F-gases except for aluminium casting and related PFC emissions. These national targets were set for the period 2013-2020 in order to contribute to the overall reduction objective by 2020. The reference year is 2005 and the targets take into account the Member States’ per-capita GDP.

[56] Confirmed by ESIA (Shane Harte) via Email on 16.02.2011.

An important element is the revised Renewable Energy Directive 2009/28/EC, which lays down mandatory national targets for the Member States' use of renewable energy in electricity, heating, cooling and transport, which are adding up to 20% of the EU's total energy consumption by 2020.

A potential review of the F-gas Regulation and/or the MAC Directive will need to take into account this context of commitments for GHG emission reductions (see chapter 3.3.3). Interactions with European legislation relevant in the context of F-gases are set out in chapter 3.3.

Market based mechanism

The European Emissions Trading System (EU-ETS) is a "cap and trade" program and commenced operation in 2005. It currently only covers CO_2 emissions from installations from more than 10,000 energy-intensive facilities across EU-27 including oil refineries, power plants over 20 megawatts in capacity, coke ovens, and iron and steel plants, along with cement, glass, lime, brick, ceramics, and pulp and paper installations.

Within the "climate and energy package", the European Emissions Trading Directive was subject to revision (Directive 2009/29/EC). From 2013, the scope will be extended to other sectors and gases and will then also include PFC emissions from the aluminium sector. Other F-gases and/or sources of emissions are not addressed by the EU-ETS in the period until 2020.

Furthermore, caps placed on industrial emissions under the EU-ETS create a link between European and international market-based mechanisms as demand for credits generated through CDM and JI projects under the Kyoto Protocol is created. Exchange and substitution of international emission reduction certificates is limited by the setting of a facility-related upper limit for the use of CDM/JI credits[57].

However, the first phase of EU-ETS (2005-2007) has suffered from the high number of allowances resulting in little demand and low prices for offsets. For the second phase (2008-2012), different caps apply, which might eventually lead to increasing demand for international credits as it might be cheaper for industry to import emission reduction credits from CDM/JI projects than achieving emission reductions domestically.

For the third phase in the period 2013-2020, the Effort Sharing Decision (406/2009/EC), which is also part of the "climate and energy package", has introduced more flexibility for the Member States in how to achieve their national GHG emission reduction targets. The share of international emission offsets will also be limited, while the exact percentage compared to the 2005 baseline remains to be determined.

Emission offset credits generated through HFC-23 destruction projects through the CDM are currently being discussed. The EU Climate Change Committee, which includes representatives from the Member States, voted for a ban of such credits from the EU-ETS from May 2013.

[57] Linking Directive 2004/101/EC connects European Emissions Trading and the Kyoto Protocol mechanisms.

Voluntary programmes and initiatives

The following list gives some examples of voluntary programmes and initiatives but does not intend to give a complete overview.

General: In Europe, voluntary action can be taken by industry sectors or within the European Eco-Management and Audit Scheme. The EMAS scheme (Eco-Management and Audit Scheme) is a voluntary environmental management system, under which companies and other public organisations evaluate, manage and continuously improve their environmental performance. EMAS has been operative since 1995 and the latest revision (EMAS III) came into effect on 11 January 2010 (Regulation (EC) No 1221/2009). The core indicators for environmental performance include several aspects relevant for use and emissions of F-gases (Annex IV C):

- Emissions: Total annual emission of greenhouse gases and total annual air emission.
- Waste: Total annual generation of waste and total annual generation of hazardous waste.
- Energy efficiency: Total annual energy consumption with percentage of renewable energy use.
- Material efficiency: Annual mass-flow of different materials used.

Semiconductor industry: European semiconductor industry has agreed to a European emission reduction target in order to meet the global reduction target (1995-2010).

3.2.3 Member State level

Regulatory measures

Early national policy measures addressing F-gases were based on existing ODS legislation, which was extended to F-gases or applied to sectors relying on both ODS and F-gases.

In France, recovery of CFCs, HCFCs and HFCs was mandatory from 1992 onwards[58]. In Sweden, personnel and companies had to be trained and accredited by the Swedish Board of Accreditation and Conformity Assessment (SWEDAC) since 1992. Since 1992, the Danish KMO system and the Dutch STEK system have been working on the prevention of emissions of all types of halogenated refrigerants and on training and certification of personnel and companies.

After the European commitments for reduction goals of GHG emissions under the Kyoto Protocol, the EU Burden Sharing Decision (Council Decision 2002/358/EC)[59] redistributed the target among the Member States. Subsequently and in addition to European legislation, Member States have individually implemented their measures addressing GHG emissions. They might hence have been ahead of the EU concerning the reduction of certain emissions. Early legislation on F-gas emissions entered into force in Denmark (March 2001) and Austria (December 2002). On the basis of the clause laid down in Article 9(3) of the F-gas

[58] Decree of 7 December 1992.

[59] This agreement is based on an arrangement under Article 4 of the Kyoto Protocol whereby Annex I Parties can fulfil their emission targets jointly by pooling their individual emissions in a common 'bubble.' The EU (EU-15) has used this provision and sub-divided its target of -8% into differentiated targets for each Member State that take account of their different national circumstances.

Regulation, these Member States were allowed to maintain their stricter provisions until 2012[60].

For the accounting of F-gas emissions in the national GHG emission reduction targets, the baseline year in EU-15 generally is 1995 (except for Austria, France, and Italy: 1990).

Some Member States decided to establish provisions of national legislation which are stricter than the requirements of the F-gas Regulation with regard to scope and mechanisms of different measures.

Measures stricter than the F-gas Regulation that have been imposed by national legislation include for example

- **Lower minimum charges:** Equipment containing lower minimum charges of F-gases than set out by the F-gas Regulation is subject to rules for containment in Denmark (minimum charge of 2.5 kg) and France (minimum charge of 2 kg).
- **Mandatory leakage checks for mobile equipment:** Leakage checks of certain types of mobile equipment are mandatory in Germany (refrigerated trucks containing charges of >3 kg of F-gases), Sweden (refrigeration and AC systems installed on ships containing charges of >10 kg of F-gases), and the Netherlands (mobile refrigeration and AC equipment including ships according to schedule set out by the F-gas Regulation).
- **Maximum annual leakage rates** for stationary equipment have been established in Germany (refrigeration and AC equipment; depending on charge and date of manufacture), Belgium (new equipment: 5%) and Luxembourg (5%).
- **Mandatory storage of equipment records** is required in Czech Republic (5 years), France (5 years), the Netherlands (5 years) and Germany (5 years). Electronic recording is mandatory in Hungary and Slovakia.
- **Registration of equipment** in a database for monitoring and enforcement purposes in Hungary (cooling circuits), Slovenia (charges >3 kg of ODS or F-gases), Estonia (charges >3 kg of F-gases).
- **Mandatory reporting of records** of equipment containing charges of >10 kg of F-gases to local authorities is required in Sweden (charge, F-gas quantities refilled and recovered, dates and results of mandatory leakage checks, contact details of servicing company, discarded equipment); mandatory reporting of equipment records by operators and service companies (charges >3 kg) is planned or in place in some Member States (e.g. Hungary, Poland) and intends to build a link to national F-gas emission inventories according to Article 6(4) of the F-gas Regulation (also see chapter 2).
- **Producer responsibility schemes** requiring producers and suppliers of F-gases to take back recovered bulk F-gases for further recycling, reclamation and destruction are in place in Sweden (legally binding for fluorinated greenhouse gases since 2007, for ODS since 1989) and Germany (legally binding since 2008).

[60] Recital (11) to articles of the F-gas Regulation: "*Annex II to Decision 2002/358/EC lays down different targets for individual Member States and Member States have adopted different strategies to achieve these targets. Member States should be able to maintain existing national measures adopted in order to meet those targets for a limited period of time in accordance with Article 95 of the Treaty*."

- **Certification of groups of personnel and companies** not subject to certification requirements of the F-gas Regulation, e.g. in the Netherlands personnel and companies servicing mobile equipment containing charges of F-gases >3 kg are subject to certification. In France, certification requirements were extended to companies of the MAC sector.

Furthermore, it should be noted that other European legislation implemented at national level might also address F-gases and set stricter requirements than related European rules. For example,

- Take back systems for domestic and small commercial refrigeration and AC systems need to be developed and implemented at national level under the WEEE Directive (see chapter 3.3.2). In the Netherlands, national rules have extended this take back scheme to large commercial and industrial refrigeration and AC systems.
- The European Directive on integrated pollution prevention and control (IPPC Directive) requires industrial and agricultural activities with high pollution potential to have a permit. In the Netherlands, maximum F-gas emission thresholds were established in the permits for aluminium industry, semiconductor industry, HCFC-22 manufacturing facilities.

Under the 2008 climate and energy package, new national GHG emission reduction targets have been laid down through the Effort Sharing Decision 409/2009/EC. These legally binding national targets were set for the period 2013-2020 in order to contribute to the EU's overall reduction objective by 2020. They are based on the reference year 2005 and set the framework for further EU and national policy measures.

Market-based mechanisms

In addition to regulatory measures, financial incentives established at Member State level can reduce demand and improve containment and recovery of F-gases.

A recent study on behalf of the EU Commission[61] (2010) assessed taxes on virgin refrigerant sales and rebates on the return of used refrigerants for destruction as a policy option for promoting the recovery and destruction of ODS/HFCs from banks. It is suggested to promote reclamation for reuse in certain cases instead of strict destruction since it was often more cost effective and less energy-intensive to reclaim used refrigerant than to produce virgin refrigerant. Moreover, if the reclamation of used refrigerant could displace the production of new refrigerant in EU or abroad, this was an important benefit that should not be overlooked.

For recovery of F-gases from products and equipment at end of life, a lack of economic incentives, in particular for smaller companies, has been identified as main influencing factor in a recent study for the European Commission[62], "as currently the only driver compelling

[61] ICF International: Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-gases) Banked in Products and Equipment; Final Report prepared for the European Commission, May 2010; p. 57.

[62] ICF International, *ibid.* p. 54. Other barriers perceived by stakeholders include legal issues arising from waste shipment legislation (Regulation (EC) No 1013/2006) and unclear roles and responsibilities for recovery of F-gases from large equipment in some Member States.

recovery at end of life is compliance with EC and national regulations”. This finding has also been confirmed by stakeholders contacted within this project.

Reclamation of F-gases is a complex technical process which leads to higher costs for reclaimed substances than for virgin gases.

The types of financial incentive schemes established in certain Member States include:

- Taxes and tax rebates
- Deposits and refunds

If linked to the climate impact of the specific substance (GWP), financial incentives might also support the choice of low or zero GWP alternatives.

Experiences from several Member States are available: Denmark (deposit-refund scheme since 1992; tax since 2001), Slovenia (tax since 2009) and Sweden (deposit scheme; legally binding producer responsibility scheme since 2007). Sweden is planning to introduce a tax on import and production of HFCs, Poland will impose a tax on F-gas quantities placed on the market.

The schemes applied in Denmark and Slovenia are chosen as case studies since they have been in place for several years already.

Case: Deposit-refund scheme and tax in Denmark

A **deposit-refund scheme** has been established in Denmark through the Danish Refrigeration Installers’ Environmental Scheme (KMO system) in 1992 in order to work on the prevention of emissions of all types of halogenated refrigerants and on training and certification of personnel and companies. Major measures of this voluntary scheme include:

- Only service companies being members of KMO can purchase new refrigerants from importers of synthetic refrigerants (no domestic production).
- End users pay a fee for refrigerants charged into the equipment, of which certain shares remain with the service company (expenses for training, recovery equipment) and the KMO (funding of secretariat, infrastructure for reclamation and destruction, refund).
- The service companies receive a refund when returning used refrigerants to KMO reclamation and destruction facilities. The level of the refund depends on purity of the recovered refrigerant.
- KMO undertakes reclamation and destruction of used refrigerants. Reclaimed gases are sold to service companies for ca. DKK 4/ kg (ca. €0.5) and contribute to the funding of KMO.

Data on recovery of HFCs for reuse and recycling on-site are not available. Preliminary data show a stable share of returned refrigerants by KMO Members for reclamation and destruction compared to refrigerant sales (table 3-4).

Table 3-4: Estimated refrigerant sales to KMO Members (including all types of synthetic refrigerants) and returned quantities for reclamation and destruction in Denmark (t)

	Refrigerant sales by KMO Members	Refrigerants returned to KMO	%
1998	ca. 400-500 t	ca. 23 t	ca. 5
2010	ca. 300 t	ca. 9-15 t	3-5

Based on previous experiences made with a **tax** on new CFCs from 1989 onwards, Denmark also introduced a tax on F-gases in March 2001 through the "Law on Tax on certain ozone depleting substances and certain industrial greenhouse gases".

The tax on F-gases is based on the Danish CO_2-tax per t CO_2 eq which applies to potential emissions. The base tax per t CO_2 eq emitted will be increased from DKK100 (ca. €13.50) to DKK150 (ca. €20) from January 2011 onwards[63]. Fluorinated greenhouse gases and blends with high GWP are hence subject to higher taxation than low GWP gases (table 3-5). The maximum tax is currently DKK400/ kg (ca. €53).

Table 3-5: Examples of Danish tax for specific substances (DKK/kg; €/kg)

F-gas type	**Tax per kg (DKK)**	**Tax per kg (€)**
HFC-134a	130	ca. 17
R-404A	378	ca. 50
R-407C	165	ca. 22
PFCs	400	ca. 53
SF_6	400	ca. 53

As Denmark does not produce any F-gases domestically, taxes are generally imposed on imports of bulk F-gases and F-gases contained in products but several exemptions apply for F-gas quantities contained in equipment[64]. The tax is also applicable to servicing quantities. Quantities contained in pre-charged refrigeration and air conditioning equipment, switchgear (<36 kV), XPS foam, mobile air conditioning equipment in cars, buses and trucks, are exempted from this tax.

It was estimated in an Effort Analysis that the tax in combination with the effect of bans introduced through regulation will lead to emission reductions of 49 kt CO_2 eq in 2001, 150 kt CO_2 eq in 2005 and 370 kt CO_2 eq in 2010 as compared to a business as usual scenario. The socio-economic reduction costs were estimated at ca. DKK200/ tonne CO_2 (ca. €27/ tonne CO_2), costs and effects of taxes and regulations were not calculated separately.[65]

Absolute quantities of F-gas imports decreased since introduction of the tax and regulatory bans (metric tonnes; table 3-6)[66,67]. Reclaimed quantities of F-gases are not subject to taxation which potentially provides an incentive for reclamation.

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[63] Ministry for Climate and Energy 2009: Denmark's Fifth National Communication on Climate Change under the United Nation's Framework Convention on Climate Change and the Kyoto Protocol; p.151.

[64] List of exemptions: https://www.retsinformation.dk/Forms/R0710.aspx?id=18091 (last checked on 04.03.2011).

[65] Ministry for Climate and Energy 2009: Denmark's Fifth National Communication on Climate Change under the United Nation's Framework Convention on Climate Change and the Kyoto Protocol; p.150.

[66] Plan Miljo 2010: The greenhouse gases HFCs, PFCs and SF_6; Danish consumption and emissions 2008; Report for the Danish Ministry of the Environment.

Table 3-6: Import of HFCs (pure and blends), PFCs and SF_6 to Denmark 1995-2009 (t)

	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
HFCs	745	1,027	676	713	510	702	484	559	402	399	363
HFC-134a	*565*	*711*	*473*	*402*	*241*	*307*	*235*	*281*	*161*	*165*	*175*
HFC-404A	*119*	*193*	*126*	*189*	*145*	*253*	*162*	*176*	*130*	*114*	*107*
PFCs	1.5	6.9	3.7	2	0.5	0.3	0.5	0	0.7	0.8	0.9
SF_6	17	9	4.7	1.4	2.2	2.3	3.6	4.2	5.4	5.9	4.3
Total	763.5	1042.9	684.4	716.4	512.7	704.6	488.1	563.2	408.1	405.7	368.2

Table 3-7: Emissions of HFCs, PFCs and SF_6 in Denmark 1995-2009 (kt CO_2 eq)[68,69]

	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
HFCs	217.8	606.2	649.6	675.3	699.7	754.1	801.0	822.0	848.7	851.3	797.6
HFC-134a	*194.4*	*320.7*	*341.4*	*355.0*	*334.4*	*353.2*	*344.3*	*343.2*	*346.9*	*342.9*	*n.a.*
HFC-404A	*15.3*	*239.6*	*236.8*	*256.5*	*290.0*	*312.7*	*351.1*	*375.4*	*391.6*	*393.0*	*n.a.*
PFCs	0.5	17.9	22.1	22.2	19.3	15.9	13.9	15.7	15.4	12.8	14.2
SF_6	107.3	59.2	30.4	25.5	31.9	33.1	21.8	36.0	30.3	31.6	36.7
Total	325.6	683.3	702.1	723.0	750.8	803.1	836.7	873.7	894.3	896	845

n.a.: not available yet

F-gas emissions increased since 2001[70], mostly driven by HFC-404A, which is used as substitute for R-22 (GWP 3260; IPCC 2nd AR), and HFC-134a (GWP 1300; IPCC 2nd AR) and reached a peak in 2008 (table 3-7). Emissions in 2009 decreased and ranged at about the level of emissions in 2005. Although F-gas imports and F-gas emissions decreased, large quantities are still placed on the market[71]. It seems that the level of taxes might be low compared to continued use of HFCs in large refrigeration and air conditioning systems, which hence might not provide sufficient incentive for all operators to opt for low or zero GWP alternatives. Furthermore, several tax exemptions are to be noted. Reported emissions also reflect the long lifetime of the equipment stock containing F-gases. The revenues from the tax have partly been used to support research and development of technologies not relying on F-gases.

Case: Tax scheme in Slovenia[72]

In 2008 Slovenia adopted a regulation on an environmental tax on the use of fluorinated greenhouse gases, which entered into force on 1 January 2009[73]. The tax is calculated on

[67] Plan Miljo 2010: The greenhouse gases HFCs, PFCs and SF_6; Danish consumption and emissions 2009; Draft Report for the Danish Ministry of the Environment (preliminary data for 2009).
[68] Plan Miljo 2010: The greenhouse gases HFCs, PFCs and SF_6; Danish consumption and emissions 2008; Report for the Danish Ministry of the Environment.
[69] Denmark: National Inventory Report 2009.
[70] It should be noted that PFC emissions from aluminium industry are not subject to taxation.
[71] Imports also include substances which are exempted from tax.
[72] Input provided by Dr. Tanja Markovič Hribernik, University of Maribor, Faculty of Business and Economics, Slovenia, via Email on 1 June 2011.

the basis of pollution units, which refer to CO_2 equivalents, The Slovenian government defines the price per pollution unit each year; for 2009, 2010, and 2011 the price per pollution unit remained the same and was €0.0125.

When it introduced the tax on the use of F-gases, the Slovenian government anticipated a transition period during which the tax burden would gradually increase in the following manner:

– For 2009, 10% of the full price per pollution unit (or 1/10 of the full price per pollution unit; €0.0125 × 0.1 = €0.00125)

– For 2010, 20% of the full price per pollution unit (or 1/5 of the full price per pollution unit; €0.0125 × 0.2 = 0.0025)

– For 2011, 40% of the full price per pollution unit (or 1/2.5 of the full price per pollution unit; €0.0125 × 0.4 = €0.005)

– For 2012, 80% of the full price per pollution unit (or 1/1.25 of the full price per pollution unit; €0.0125 × 0.8 = €0.01)

– For 2013 onwards, the full price per pollution unit (= €0.0125)

The level of the tax depends on the purpose of the use of F-gases: The first fill of pre-charged equipment and stationary equipment is taxed 5% while F-gas quantities used for servicing and maintenance of equipment are taxed 100%.

First data on F-gas quantities used and tax revenues show high increase of the use of F-gases and related increase of tax (table 3-8).

Table 3-8: Quantities of F-gases used in Slovenia and related tax revenues in 2009 and 2010. Source: Customs Administration of the Republic of Slovenia (General Customs Directorate)

	2009	**2010**
Total quantity of F-gases (kg)	187,057.05	277,465.90
- Use for the production of equipment containing F-gases (kg)	79,451.00	87,352.00
- Use for first installation of stationary equipment (kg)	10,098.60	15,275.10
- Use for maintenance of existing equipment (kg)	97,507.45	174,838.80
Environmental tax paid (€)	86,893.00	510,640.03

Current problems of the scheme relate to the fact that taxes do not apply in neighbour countries within the EU and outside of the EU and that it is possible for companies to buy F-gases there at lower prices. Furthermore, tax rebates for recovered F-gases for reclamation and destruction are not part of the scheme. Amendments of the existing regulation are being discussed in order to improve effectiveness of the tax scheme.

Voluntary programmes and initiatives in Member States

Certain industries established voluntary agreements at national level in some Member States. The following list gives some examples but does not intend to give an exhaustive account:

[73] Government of the Republic of Slovenia: Regulation on Changes and Amendments to the Regulation on the Environmental Tax for Polluting the Air with Carbon Dioxide Emissions, *Official Gazette of the Republic of Slovenia* 78/08, 2008.

Producers of refrigeration, air conditioning and heat pump equipment: Voluntary take-back schemes established by industry for end of life equipment such as commercial and industrial air conditioning systems (Greece, UK, Belgium), heat pumps (Belgium).

Producers of fluorinated gases: Voluntary take-back schemes established by industry for recovered bulk F-gases are established in the Netherlands (following a mandatory take-back scheme for ODS, which has been in place since the early 1990s) and in France (deposit-refund scheme covering ODS and HFCs, which has been in place since 1993).

Fire protection industry: Prior to the F-gas Regulation, voluntary agreements on monitoring of HFC and PFC emissions, leak detection and containment processes were in place in the Netherlands[74] (since 1999) and the UK (since 1994, renewed in 1997)[75]. The agreements were outdated by the F-gas Regulation.

A voluntary agreement by industry in Germany on the phase out of the use of HFC-23 as fire extinguishing agent from 2006 has been withdrawn by industry as one manufacturer of HFC-23 equipment exerted pressure.

Semiconductor industry: Global and European agreement to reduce emissions of HFC-23, PFCs, SF_6 and NF_3 (1995-2010), which has been transferred into national targets for all Member States where production is located.

Switchgear industry: Voluntary agreements addressing use and emissions of SF_6 exist in France (2005-2010; renewed agreement expected for the period 2011-2016), Germany (since 1996/ renewed in 2005), Spain (2008-2012). Measures of the earlier voluntary commitments preceded the provisions of the F-gas Regulation and were established through industry standards. Further emission reductions through the F-gas Regulation are not expected as these industry standards already have established the same measures as the regulation.

Aluminium industry: A voluntary commitment by the only French producer of primary aluminium entered into force in May 1996 and aimed at reductions of absolute CF_4 emissions (t) by 63% and specific CF_4 emissions (kg/t) by 73% until 2000 (baseline 1990).

A voluntary commitment had been made by the German primary aluminium industry in 1997 and aimed on reduction of absolute and specific PFC emissions (CF_4, C_2F_6) by 50% until 2005 (baseline 1990). In 2001 the emissions were already 85% below the baseline. So far, the voluntary agreement has not been renewed.

3.2.4 National level outside of EU-27

Policies addressing F-gas emissions are common in some countries outside of the European Union where HFCs were introduced several years ago as a consequence of ODS phase out under the Montreal Protocol.

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[74] „Code of Practice for the use of HFC and PFC fire extinguishing agents", concluded by the Ministry of Environment and VEBON (Association of Safety Companies in the Netherlands), August 1999.

[75] „Voluntary Agreement between the UK Government and the Fire Industry concerning the use of HFCs and PFCs for fire protection" concluded by the Department of Environment and Fire Industry Council, September 1994, renewed in 1997.

These countries include developed countries such as the United States of America, Australia, Japan, Norway, and Switzerland, which are all listed in Annex 2 of the Montreal Protocol ("A2 countries"). The approaches chosen comprise regulatory measures, partly linked to market-based instruments such as taxes.

National policies addressing emissions of HFCs, PFCs and SF_6 are hardly known from developing countries ("A5 countries" under the Montreal Protocol) except for few cases, e.g. Croatia (provisions on monitoring of imports under national ODS legislation were extended to imports of HFCs; fees for ODS and HFC destruction apply at the time of purchase).

Regulatory measures

In **Switzerland**, the Swiss Ordinance on Risk Reduction relates to the use of certain particularly dangerous substances, preparations and articles[76] (SR 814.81), last amended in 2005[77]. The term "substances stable in air (SSA)"[78] includes HFCs with GWP in the range of 140-11,700, all PFCs, SF_6 and NF_3. HFC-152a is hence not covered. The Ordinance establishes a general prohibition for SSA but allows exemptions for specific sectors listed in annexes. The ban applies to residential refrigerators, freezers, dehumidifiers and air-conditioners. Production and placing on the market of air conditioning systems in motor vehicles are exempt as long as no substitutes are available.

The ban applies to foams unless insulation is not possible with other materials. For the solvents sector, exemptions from the general prohibition apply to SSA used for surface treatment in installations with automatic closing systems opening only when the SSA concentration is <1 g/ m^3 at a mass flux of the SSA of <100 g/ h (according to the requirements of the Clean Air Ordinance, Annex 2, No 87). Aerosol products containing HFCs are generally banned. Exemptions exist for MDI, one component foams and sprays used for the cleaning of equipment under electric tension. Swiss legislation is stricter than EU legislation for technical aerosols containing HFCs as they are subject to a ban.

With regard to the refrigeration and air conditioning sector, the following requirements apply for installations containing charges of SSA >3 kg: Annual controls for tightness, mandatory maintenance of records, authorization requirements for new installations[79], public registration of equipment containing ODS and SSA.

In **Japan**, current legislation on ODS and F-gases focuses on recovery and recycling of refrigerants, such as the Home Appliance Recycling Law, which entered into force in 2001. It applies *inter alia* to household air conditioners, refrigerators and freezers. The Fluorocarbons Recovery and Destruction Law entered into force in 2002 (amended in 2006) and requires recovery of CFCs, HCFCs and HFCs from commercial refrigeration and air conditioning systems during servicing (since 2006) and at end of life (since 2002) in order to ensure proper destruction. The End-of-Life Vehicle Law was promulgated in 2002 and entered into force in 2005. It aims at recycling of vehicle components and recovery of ODS and F-gases from mobile air conditioning systems in all vehicle types.

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[76] Ordinance on Risk Reduction related to Chemical Products (ORRChem).

[77] http://www.bafu.admin.ch/chemikalien/01389/01404/index.html?lang=en; communication from the Swiss Bundesamt für Umwelt (Federal Office for the Environment), via Email

[78] The basic definition refers to „fluorinated VOC with vapor pressure of at least 0.1 mbar at 20°C or a boiling point lower than 240°C at 1013.25 mbar with T >2 years" (Annex 1.5 of the Ordinance).

[79] For further information on authorization: www.pebka.ch

In **Australia**, the Ozone Protection and Synthetic Greenhouse Gas Management Regulations 1995 (last amended in 2010) establish licensing requirements for the placing on the market of F-gases: Licensing requirements apply to import, export and manufacture of HFCs and PFCs, (“controlled substances licenses”) and the import of refrigeration and air conditioning equipment containing HFCs or HCFCs (“pre-charged equipment license”). A controlled substances license is required to manufacture HFCs and PFCs and for the import and export of any amount of HFCs and PFCs. A non-refundable application fee of AUD $15,000 (ca. €11,000) is payable with the application. Holders of a HFC or PFC controlled substance license are required to maintain records, provide quarterly reports to the Department of Environment and pay a levy based on the quantity of substances imported at the end of each quarter. The levy is AUD $165/ t (ca. €120/t) for HFCs and PFCs.

In the **USA**, proposals for domestic climate legislation currently pending Congress decision include the American Clean Energy and Security Act (formerly known as the Waxman-Markey bill) and the American Power Act (known as the Kerry-Lieberman discussion draft) and introduce cap and trade mechanisms. Both set out separate chapters with supply caps on all HFCs and maximum allowable amounts of HFC supply. Reduction steps are relative to the baseline of aggregate US consumption of HFCs and HCFCs, averaged in the period 2004-2006 and differ between the proposals. Regulatory measures already in place include rules established by the US Environmental Protection Agency (EPA) and the Greenhouse Gas Reporting Program, which requires *inter alia* magnesium production and HCFC production facilities to calculate and report their GHG emissions to EPA (first reports on 2010 are due in 2012).

Market-based instruments

In **Norway**, a tax on HFCs and PFCs was introduced on 1 January 2003 and currently amounts to NOK204.99 per t CO_2 eq (ca. €25) of gas imported or produced (in bulk and in pre-charged equipment) (approximately the tax rate on mineral oil in Norway). From 1 July 2004, this tax was supplemented by a reimbursement scheme which applies to all HFCs and PFCs delivered for destruction and prescribes about a similar rebate. HFCs are not produced domestically.[80] The tax and reimbursement scheme are reported to have resulted in better maintenance and improved routines during discharge of old equipment. It also gives a strong incentive for choosing HFCs with low GWP or alternative substances and processes, which is reflected by lower imports of F-gases with high GWP (figure 3-4).

An evaluation report states that “the introduction of tax seems to have decelerated the yearly growth rate of imports by inducing a change in technology towards equipment using less chemical per unit, and by augmenting the use of alternative refrigerants like ammonia and CO_2. These changes are mainly occurring in medium sized equipment, such as air conditioning and refrigeration/freezing installations in supermarkets, hotels, restaurants, etc. "The price increase of chemicals has made changing technology good economy.”[81]

[80] Ministry of Environment 2009: 5th National Communication of Norway under the UNFCCC and the Kyoto Protocol; p.38.
[81] Katherine Loe Hansen 2008: Statistics Norway, Department of Economic Statistics, Environmental Statistics – Emissions from consumption of HFCs, PFCs and SF_6 in Norway; p.3.

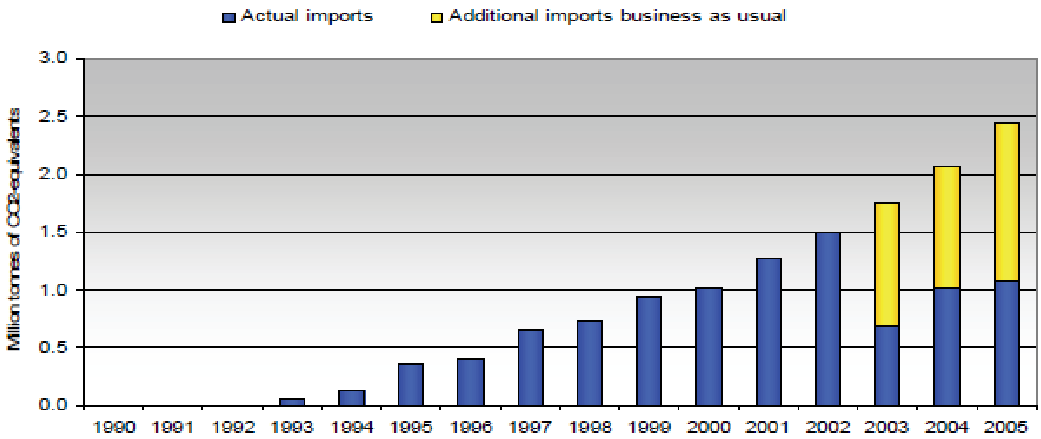

Figure 3-4: Actual imports of F-gases as compared to projected imports in a business as usual scenario in the period 1993-2005 in Norway (MT CO_2 eq)[82].

Although emissions are still growing, since the introduction of the tax, the growth trend in HFC and PFC emissions changed from exponential to linear[83] (table 3-9).

The estimated revenue of the tax amounts to 210 Million NOK in 2010 (ca. 25.7 Million €). The tax is adjusted annually.

Table 3-9: Emissions of F-gases in Norway (t CO_2 eq)[84]

Emissions (t CO_2 eq)	**1995**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
HFCs	15.1	124.8	157.6	188.9	215.2	240.7	274.4	303	328.7
PFCs	301.4	198.0	199.4	215.3	135.7	131.5	124.3	110.7	119
SF_6	25.4	39.1	33.1	10	9.8	11.5	13.1	8.9	3.2

[82] Katherine Loe Hansen 2008: Statistics Norway, Department of Economic Statistics, Environmental Statistics – Emissions from consumption of HFCs, PFCs and SF_6 in Norway; p.4.
[83] Ministry of Environment 2009: 5th National Communication of Norway under the UNFCCC and the Kyoto Protocol; p.10.
[84] Ministry of Environment 2009: 5th National Communication of Norway under the UNFCCC and the Kyoto Protocol; p.23.

Voluntary programmes and measures

In **Australia**, the Greenhouse Gas Abatement Program (GGAP)[85] is a voluntary approach introduced by the Commonwealth in order to support activities likely to result in emission reductions. 3 projects under this programme focussed on the use and emissions of HFCs, including “destruction of synthetic gases from refrigeration”, “inventories and projections of ozone depleting and synthetic greenhouse gases used in Montreal Protocol industries” (2002) and “synthetic gas use in non-Montreal Protocol industries” (2002; magnesium production, aluminium smelting, electricity transmission).

In the **USA**, voluntary partnerships between industries and the US EPA are the major tool for reducing F-gas emissions: Since 2003, a voluntary code of practice intends to reduce HFC and PFC emissions from fire protection and is based on a partnership between the US EPA and several industry associations active in the sector. Voluntary recommended practices for household refrigerator and freezer producers intend to minimize HFC emissions (foam and refrigerants) during manufacture of appliances[86]. For other types of refrigeration and air conditioning equipment, responsible use guidelines also aim at reduced manufacturing emissions[87]. PFCs and SF_6 emissions from aluminium manufacture, magnesium production, semiconductor and electric power industries. Another voluntary program with HCFC-22 producers has reduced HFC-23 by-product emissions through process optimization and thermal oxidation (HFC-23 Emission Reduction Program). Disposal emissions from appliances are addressed by the Responsible Appliance Disposal Program of the US EPA since 2006.

In **Japan**, a voluntary agreement of the Japanese Urethane Industry for a phase-out of HFCs as blowing agents of PU rigid spray foam for residential building insulation by end of August 2010. The Industrial Network for Fluorocarbon Recovery Promotion has encouraged recovery of fluorocarbon refrigerants during repair and maintenance of equipment since the mid 1990s.

In **Norway**, a voluntary agreement from 2002 between the Ministry of Environment and the most important users and producers of SF_6 insulated switchgear aims at emission reductions by 13% in 2005 and 30% in 2010 (baseline 2000). The increased focus on emissions has led to less leakage during production and use. Emissions from electrical equipment were almost halved from 2000 to 2005[88].

[85] http://www.environment.gov.au/atmosphere/ozone/sgg/index.html (last checked on 7 September 2010).
[86] Association of Home Appliance Manufacturers and US EPA 2005: Recommended practices for minimizing HFC emissions from refrigerator-freezer factories.
[87] Air conditioning and Refrigeration Institute and US EPA: Responsible use guide for minimizing fluorocarbon emissions in manufacturing facilities.
[88] Statistics Norway/ Department of Economic Statistics, Environmental Statistics, Katherine Loe Hansen 2008: Emissions from consumption of HFCs, PFCs and SF_6 in Norway.

3.2.5 Norms and standards

A standard is a technical document designed to be used as a rule, guideline or definition, and standardization is the voluntary process of developing technical specifications based on consensus among all interested parties (industry including Small and Medium-sized Enterprises, consumers, trade unions, NGOs, authorities, etc).[89] Therefore standards are here considered to be voluntary but can become mandatory when referred to by national or European legislation.

For all sectors relying on F-gases a number of international, European and national standards exist. Although they are voluntary to use and do not impose any regulation, in practice many governments, industry groups and trade associations require products or services to adhere to a standard before they can be placed on the market.

A European Standard automatically becomes a national standard in all Member States, but remains voluntary to use. Through the development of European standards and the withdrawal of conflicting national standards, standardization has played a leading role in the achievement of a Single Market for goods. European Standards are highly important for manufacturers inside and outside Europe as they increase product safety and quality and lower transaction costs and prices. A standard codifies best practice and is usually state of the art relating to products, services or systems.

Products and equipment relying on F-gases are addressed by various international, European and national standards, which set out specifications, performance requirements, and safety measures. Standards relating to the control of F-gas emissions exist at international, European and national level. For simplification, the following overview mostly refers to EU level as examples. Standards are relevant in the following sectors so far:

<u>Refrigeration and air conditioning:</u> The main standard for refrigeration systems and heat pumps is the norm EN 378[90] which includes safety and environmental requirements for all refrigeration air conditioning and heat pump equipment (domestic, commercial, industrial).

Other standards apply to certain sub sectors or specific topics only, for example:

- EN 60335-2-40[91] set out safety requirements for any air conditioning and heat pump appliances.
- EN 60335-2-89[92] specifies safety requirements for electrically operated commercial refrigerating appliances that have an incorporated compressor or that are supplied in two units for assembly as a single appliance in accordance with the manufacturer's instructions (split system). Appliances in scope of this standard include refrigerated display and storage cabinets, refrigerated trolley cabinets, service counters and self-service counters, blast chillers and blast freezers.

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[89] European Commission: European standardization policy, 2010; http://ec.europa.eu/enterprise/policies/european-standards/standardisation-policy/index_en.htm

[90] EN 378: Parts 1-4 Refrigerating systems and heat pumps – safety and environmental requirements (2008).

[91] EN 60335-2-40: Household and similar electrical appliances - Safety - Part 2-40: Particular requirements for electrical heat pumps, air conditioners and dehumidifiers.

[92] EN 60335-2-89: Household and similar electrical appliances - Safety - Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant unit or compressor (2010).

- EN 13313[93] specifies activities related to the refrigeration circuits of equipment and associated competence profiles. It also establishes procedures for assessment of the competence of personnel and could thus serve as input for personnel certification schemes in the Member States (see chapter 4).
- EN 16084[94] specifies qualifications for the tightness of joints and components.

Foams: Standards are specific to particular types of foams and define performance criteria. Important standards in this sector include for example:

- EN 13165[95] defines quality requirements for factory-made rigid PU foam panels which are mostly used to insulate flat roofs, ceilings, floors and walls as well as in low-energy houses.
- EN 14315[96] applies to spray foam and sets out specifications for the foam before installation and after.
- EN 13164[97] sets out specifications for XPS foam products.

High voltage switchgear: Existing standards introduced maximum leakage rates for medium and high voltage electric power equipment and instrument transformers. In this way, awareness of equipment manufacturers has been raised and has lead to significant emission reductions previous to the F-gas Regulation. Important standards include:

- IEC 62271-1[98] defines maximum leakage rates: For closed pressure systems, which refers to modern high voltage electric power equipment, standardized leakage rates amount to 0.5% and 1% per year and per gas filled compartment. For sealed pressure systems, mostly modern medium voltage electric power equipment, tightness is specified for their expected operating life as defined by the manufacturer in order to avoid refill. The leakage rate of these systems is considered <0.1% per year ("sealed for life").
- IEC TR 62271-303[99] defines tightness classes of equipment by referring to IEC 62271-1.
- IEC 61869-1[100] enters into force in 2012, applies to newly manufactured instrument transformers and defines the leakage rate of SF_6 transformers as <0.5% per year.
- Two standards refer to the quality of SF_6: IEC 60376 indicates that the gas is new and IEC 60480 set out that the gas is recycled and minimum specifications apply.

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[93] EN 13313: Refrigeration systems and heat pumps – Competence of personnel (2010).
[94] EN 16084: Refrigeration systems and hear pumps – Qualification of tightness of components and joints (2010).
[95] EN 13165 Thermal insulation products for buildings - Factory made rigid polyurethane foam (PUR) products. Specification (2009).
[96] EN 14315 Thermal insulating products for buildings – In-situ formed sprayed rigid polyurethane foam (PUR) products – Part 1: Specification for the rigid foam spray before installation. Part 2: Specification for the installed insulation products.
[97] EN 13164 Thermal insulation products for buildings- Factory made extruded polystyrene foam (XPS) products– Specification.
[98] IEC 62271-1 Common specifications.
[99] IEC TR 62271 High voltage switchgear and controlgear – Part 303: Use and handling of sulphur hexafluoride (SF_6) (2008).
[100] IEC 61869 Instrument transformers – Part 1: General requirements.

Fire protection: Standards anticipated important containment measures in this sector such as leakage checks and records, set maximum leakage rates for certain types of containers and give specifications of leakage detection systems. Relevant standards include:

- ISO 14520 requires regular leakage checks and service records to be maintained by the service companies since 2000.
- EN 12094-4[101] sets a maximum leakage rate of 0.5% of the mass contents on the smallest cylinder and fill when cycled between -20℃ and +50℃ over 102 days. EN 12094-10[102] is relevant for systems using a cylinder low pressure switch.
- The standard EN 15004 came out in 2008. EN 15004-1[103] relates to design, installation and maintenance of fixed gas extinguishing systems. EN 15004-4[104] refers to fire fighting systems and leakage detection systems for HFC-125 extinguishant; EN 15004-5[105] refers to fire fighting systems and leakage detection systems for HFC-227ea extinguishant; EN 15004-6[106] refers to fire fighting systems and leakage detection systems for HFC-23 extinguishant.

Standards can support reductions of F-gas emissions by transferring best practices to markets and thereby replacing previous technologies and methods. Regulatory mechanisms often refer to existing standards, which anticipated legislation, e.g. Article 3(5) of the F-gas Regulation refers to the ISO 14520 standard.

With regard to flammable refrigerants, it should be noted that international standards limit the charge sizes for equipment placed in occupied spaces (e.g. IEC and EN 60335-2-24[107] set the maximum charge for hydrocarbon refrigerants in domestic refrigeration at 150 g)[108]. Furthermore, national standards might set bans in certain cases, e.g. in France the use of flammable refrigerants in public buildings is not allowed due to local building and fire safety standards.

While standards play an important role for safe handling of F-gases, their alternatives and product safety within Europe and in the world, analyses of the impact of particular norms and standards on F-gas emissions from certain appliances are not known and have not been carried out in the context of this project.

Aspects where implications of standards are taken into account include:

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[101] EN 12094 Fixed fire fighting systems – Part 4: Components for gas extinguishing systems. Requirements and test methods for container valve assemblies and their actuators (2004).

[102] EN 12094 Fixed fire fighting systems - Components for gas extinguishing systems - Part 10: Requirements and test methods for pressure gauges and pressure switches (2003).

[103] EN 15004 Fixed firefighting systems - Gas extinguishing systems – Part 1: Design, installation and maintenance (ISO 14520-1:2006, modified).

[104] EN 15004 Fixed firefighting systems - Gas extinguishing systems – Part 4: Physical properties and system design of gas extinguishing systems for HFC-125 extinguishant (ISO 14520-8:2006, modified).

[105] EN 15004 Fixed firefighting systems - Gas extinguishing systems – Part 5: Physical properties and system design of gas extinguishing systems for HFC-227ea extinguishant (ISO 14520-9:2006, modified).

[106] EN 15004 Fixed firefighting systems - Gas extinguishing systems – Part 6: Physical properties and system design of gas extinguishing systems for HFC-23 extinguishant (ISO 14520-10:2005, modified).

[107] IEC and EN 60335-2-24: Household and similar electrical appliances – Safety – Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers.

[108] Chapter 6 takes existing standards into account. Also see explanations for particular sectors in annex IV: Global DIS, and annex V: EU sector sheets.

- Additionality of measures required by the F-gas Regulation and related additional costs for operators of equipment (chapter 4.3)
- Selection of abatement options: Charges of flammable substances as alternatives to F-gases (chapter 6 and related annexes).

3.2.6 Impact of policies addressing F-gas emissions

Since most ozone depleting substances are also potent greenhouse gases, the phase out of ODS under the Montreal Protocol has contributed largely to reducing global GHG emissions. It is estimated that the decrease of annual ODS emissions under the Montreal Protocol range around 10 Gt CO_2 eq of avoided global warming emissions annually. These emission reductions were about five times larger than the annual emission reduction target for the first commitment period of the Kyoto Protocol (2008-2012).[109]

In contrast to the success of the Montreal Protocol, international efforts under the Kyoto Protocol only had limited impact on F-gas emissions.

In developing countries, emission reductions being achieved through CDM projects on F-gases in the first commitment period (2008-2012) amount to <5 Gt CO_2 eq in total, largely (>90%) resulting from HFC-23 destruction projects. JI projects yield emission reductions of ca 12 Mt CO_2 eq during the same period which are also caused by HFC-23 destruction to large extent. Regulatory action aiming at monitoring and reducing HFC, PFC and SF_6 use and emissions were identified in several developed countries and contribute to specific GHG emission reduction targets under the UNFCCC/Kyoto Protocol. It should be pointed out that Europe has established, worldwide, the only comprehensive regulatory framework addressing use and emissions of HFCs, PFCs and SF_6 from various sectors and at different stages of equipment lifetime.

Voluntary approaches by industry were found to complement or replace regulatory action in some countries and sectors and contribute to global F-gas emission reductions. In some sectors, the identified voluntary approaches preceded provisions of the F-gas Regulation (e.g. leak checks in fire protection) and in other sectors they continue to be the only type of measure addressing F-gas emissions (e.g. PFC emissions from semiconductor industry).

Voluntary approaches can allow for flexible and adjusted adaptation to technological options and market sensitivities[110] and are sometimes taken to anticipate regulatory action. However, voluntary agreements are self-regulatory practices and are not legally binding at Community level. Furthermore, voluntary approaches are often considered to lack transparency, ambition, legitimacy and efficacy. Major drawbacks include limited participation, lack of independent control of compliance and enforcement (lack of consequences in case of non-compliance) and the rather industry-centered perspective[111].

Voluntary agreements hence need to be considered a rather “soft” instrument to raise general awareness and address sectors not covered by mandatory regulation. Voluntary approaches are estimated too weak if emission reduction targets and compliance with international commitments need to be achieved.

[109] WMO/UNEP 2010: Scientific Assessment of Ozone Depletion: 2010, p.3.
[110] European Commission: http://ec.europa.eu/energy/efficiency/agreements_en.htm (last checked on 08.03. 2011).
[111] European Consumers’ Organisation 2006: Voluntary Environmental Agreements.

3.3 Interactions of other policies with EU F-gas policy framework

The identification and analysis of interactions, complementarities and overlaps between EU F-gas policy and other European policies focuses on regulatory measures, since they usually represent the most important type of instrument at European level.

It should be noted that the national implementation of other European policies might be stricter than the European legislation and cause additional interactions, complementarities and overlaps. However, such interactions at national level were not investigated within this study due to large differences between Member States and even regions within Member States (e.g. in Belgium).

The list of policies does not intend to give a complete overview of all regulatory measures relevant in the context of F-gases but aims to identify the key interactions to the extent possible.

3.3.1 ODS policy

- **General links**

Under the **Vienna Convention**, the **Montreal Protocol** on ozone depleting substances is closely linked to F-gases. Since 1981, it controls production and consumption of ozone depleting substances (ODS). Presently, the regulations apply to 96 chemicals including chlorofluorocarbons (CFCs), halons, hydrobromofluorocarbons (HBFCs), hydrochlorofluorocarbons (HCFCs), and others. The phase out of fluorinated ozone depleting substances such as CFCs and HCFCs in developed countries (“A2 countries”) and developing countries (“A5 countries”) under the Montreal Protocol has globally created demand for substitutes. HFCs were developed as replacements for ODS to be used in the same sectors of application and are being produced and marketed on large scale since the early 1990s (see chapter 3.1). Therefore, the Montreal Protocol has highly influenced global HFC emissions.

ODS policy at international and European level is aiming at ozone layer protection through phase out of ozone depleting substances. In addition, the EU legislation is also aiming at emission reduction. As most ODS also show high global warming potential, the Montreal Protocol has significantly contributed to both ozone layer and climate protection.

The ODS **Regulation (EC) No 1005/2009** (replaced (EC) No 2037/2000) is implementing the Montreal Protocol and has certainly contributed to raise general awareness and improve capacities of personnel and companies through training measures. As usually the same companies deal with both ODS and F-gases, ODS policies now also support F-gas policies as awareness of service personnel and manufacturers for the environmental impact of their activities had increased already.

The ODS Regulation (Article 23) requires leakage control of stationary equipment or systems to be undertaken at specific frequencies based on fluid charges (Table 3-10), which is quite similar to the scheme set out by the F-gas Regulation (Article 3). The installation of leakage detections systems, however, is not mandatory under the ODS Regulation.The remaining

HCFC systems have to be replaced in the coming years due to the prohibition to use recovered HCFC for their maintenance, effective as of 1 January 2015.

Table 3-10: Overview of requirements of Regulation (EC) No 1005/2009 and Regulation (EC) No 842/2006 with regard to regular leakage control of stationary equipment and systems

Frequency of leak checking required by regulations	ODS		F-gases	
	System charge Normal	**System charge Hermetically sealed**	**System charge Normal**	**System charge Hermetically sealed**
None	**<3 kg**	**<6 kg**	**<3 kg**	**<6 kg**
Annually	3 kg – 30 kg	6 kg – 30 kg	3 kg – 30 kg; 30 kg – 300 kg if automatic leak detection system in place	6 kg – 30 kg; 30 kg – 300 kg if automatic leak detection system in place
6 monthly	30 kg – 300 kg	30 kg – 300 kg	30 kg – 300 kg; >300 kg if automatic leak detection system in place	30 kg – 300 kg; >300 kg if automatic leak detection system in place
Quarterly	>300 kg	>300 kg	>300kg	>300kg

In contrast to the F-gas Regulation, which does not set a time limit for the repair of detected leakage, under the ODS Regulation, detected leakage has to be repaired as soon as possible and in any event within 14 days.

ODS recovery and destruction by approved technologies are required by Article 22, which refers to refrigeration, AC, heat pump and fire protection equipment, equipment containing ODS solvents as well as products containing ODS, such as foams. This provision thus supports the management of foams containing ODS while the F-gas Regulation does not specify recovery of HFCs from foams.

Recording requirements under the ODS Regulation (Article 23(2)) differ from provisions of the F-gas Regulation as records do not include the quantity and type of refrigerants installed in stationary refrigeration, air conditioning and heat pump equipment and systems. Labelling requirements pursuant to Article 11(6), however, do include these data.

The Montreal Protocol also sets out reporting obligations relevant for the sectors relying on F-gases, since F-gases are often used as substitutes for ODS. Reporting requirements include data on annual production, imports and exports of ODS, including quantities of the feedstock production, and the amounts of ODS destroyed through approved technologies.

As CFC and HCFC phase-out are largely completed in Europe, reporting obligations are assumed to refer nowadays mostly to amounts of HCFCs produced for export, for feedstock and other exempted use (i.e. essential laboratory and analytical uses and critical uses of halons) and the quantities of ODS that were destroyed. The ODS Regulation implements the reporting requirements under the Montreal Protocol at European level through even stricter provisions. Article 26 requires annual reporting by the Member States to the Commission. The information to be submitted relates to the quantities of methyl-bromide authorized and halons installed, as well as to cases of illegal trade of ODS.

Article 27 imposes reporting requirements on undertakings which have to submit a list of data on each controlled substance and each new substance to the Commission and the competent authority of the Member State concerned. The data to be reported vary depending on the type of undertaking. For example, producers must report quantities produced, placed on the market, as well as quantities recycled, reclaimed and destroyed, and stocks. Undertakings in the ODS database that did not produce, import, export or destroy ODS in the previous year are required to return a “nil” form. The recasted ODS regulation (EC) No 1005/2009 also introduced new requirements for destruction plants to report ODS quantities destroyed directly to the European Commission, including quantities contained in products or equipment.

- **Implications**

As many measures of ODS policy and F-gas policy (e.g. awareness raising, training, certification) affect the same companies active in service and destruction, further streamlining and synergies should be explored in order to build on previous experience.

Reclamation and destruction of ODS and F-gases often take place in the same facilities or companies. Reporting requirements for ODS destruction could be extended to F-gases in order to gain information on the effectiveness of provisions on F-gas recovery and recycling and related disposal emissions.

With regard to the policy options explored, this could apply inter alia to reporting obligations for destruction plants on the quantities destroyed.

3.3.2 Waste policy

In the context of recovery, recycling, reclamation, destruction (RRRD) of F-gases and products and equipment containing F-gases, links between the F-gas Regulation and waste policy are to be noted.

Article 4 of the F-gas Regulation requires operators of stationary equipment to arrange proper recovery of fluorinated greenhouse gases by certified personnel in order to ensure recycling, reclamation or destruction of F-gases. The stationary equipment in scope of this provision includes cooling circuits of refrigeration, air conditioning and heat pump equipment, equipment containing F-gas based solvents, fire protection systems and fire extinguishers as well as high voltage switchgear. It also applies for the recovery of residual F-gases in end-of life containers where technically feasible and other products and equipment, including mobile equipment (unless serving military operations). Article 4 applies to all equipment and products covered irrespective of the quantity of fluorinated greenhouse gas they contain.

- **General links**

The new legal framework on waste, **Directive 2008/98/EC on waste**, which entered into force in December 2010 (previously Directive 2006/12/EC) addresses the whole waste cycle and emphasizes the role of recovery and recycling. Member States are required to ensure waste recovery, and to collect waste separately “if technically, environmentally, and economically practicable”, and to not mix it with other waste or material with different properties (Article 10). Measures to “promote high quality recycling” and “separate collections of waste where technically, environmentally and economically practicable and appropriate to meet the necessary quality standards for the relevant recycling sectors” shall be taken (Article 11).

The definition of waste[112] is clearly met by recovered F-gases which are no longer needed and cannot be recycled or reclaimed. In contrast, this definition is not met for F-gases subject to recycling and reclamation. However, used bulk HFCs is considered hazardous waste in the Waste List Decision 2000/532/EC. In most cases used SF_6 intended to be reclaimed is considered as a product while only SF_6 intended for destruction is deemed to be waste.

Directive 2008/98/EC requires recovery of 70% of construction and demolition waste by 2020 (by weight). This will have implications for the treatment of construction foam, which is currently not known to be typically separated from other materials at end of life. Separating foams containing ODS/F-gases at demolition of buildings and ensuring proper recycling or destruction is estimated to present significant challenges, in particular in cases where the type of blowing agent in the insulating foam is not discernable.[113] Compared to appliance foam, construction foams have lower levels of recovery potential due to higher annual emission rates, longer lifetime and higher losses of blowing agent during separation and removal[114].

According to the Waste Framework Directive, requirements for the management of hazardous waste include control of hazardous waste and traceability from production to final destination (Article 17), the prohibition to mix hazardous waste with other categories of hazardous waste or other waste, substances or materials, which bans diluting of hazardous substances (Article 18), special labelling requirements (Article 19), as well as the maintenance of records and their storage for a certain time period (Article 35).

Recovered F-gases for reclamation need to be declared as hazardous waste although they will be recycled or reclaimed. In addition, for transportation of recovered F-gases classified as hazardous waste further provisions apply, e.g. under **Regulation (EC) No 1013/2006 on shipments of waste**. These become particularly relevant in case Member States without reclamation and destruction facilities intend to export used F-gases for reclamation and/or destruction purposes to other Member States. In the case of Poland, national legislation is known to not treat recovered F-gases intended for reclamation as waste, which facilitates their handling as restrictions for hazardous do not apply. Recovered substances are only considered waste if reclamation is not possible due to low purity.

Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures (CLP Regulation) standardizes criteria for classification of substances and mixtures and requires the labelling of hazardous substances at manufacture, import and use. The Regulation aims to ensure protection of human health and the environment as well as the free movement of substances, mixtures and articles. Since waste is excluded from the scope of this Regulation (Article 1(3)), provisions do not apply to recovered F-gases for disposal. Nevertheless, it applies to F-gases for recycling and reclamation, as well as virgin, recycled and reclaimed gases and mixtures. The regulation makes use of two tools for the communication of hazards of substances and mixtures provided for in Regulation (EC) No 1907/2006 (REACH Regulation): labels and safety data sheets.

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[112] Article 3(1) of the Waste Framework Directive: "Waste" means any substance or object which the holder discards or intends or is required to discard.
[113] ICF International: Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (Fgases) Banked in Products and Equipment; Final Report prepared for the European Commission, May 2010; p.37.
[114] ICF International, ibid, p.39.

Since, as identified later in this report (chapter 4.2.6), reclamation and destruction facilities for ODS and F-gases are lacking in several Member States, used bulk F-gases and waste electrical and electronic equipment containing F-gases are shipped across borders. Therefore, at international level, a link to the **Basel Convention** on the control of transboundary movements of hazardous wastes and their disposal should be noted (see section 3.2). Discarded equipment containing CFCs, HCFCs, and HFCs is covered under the convention (Annex V).

Regulation (EC) No 1013/2006 on shipments of waste transposes the Basel Convention by establishing procedures and control regimes for the shipment of waste between Member States, within EU-27 or via third countries, for the import and export of waste in/from EU-27 and for waste on transit through the Community. As all HFCs (including those contained in equipment) for disposal are considered and treated as hazardous waste (Title II, Art 3(1) b iii.), their shipment has to be based on prior written notification and consent.

In addition to waste policies already mentioned, special links between the F-gas Regulation and waste policies appear for equipment and products containing F-gases and bulk F-gases recovered from products and equipment.

- **Links for equipment and products containing F-gases**

Two pieces of waste legislation need to be noted such as the WEEE Directive and the ELV Directive.

Directive 2002/96/EC on waste electrical and electronic equipment (WEEE Directive, as amended) addresses large and small household appliances, including household refrigeration and AC appliances, and small commercial refrigeration equipment containing ODS or gases with GWP >15. It requires treatment before disposal of waste household appliances and small commercial refrigeration equipment, separate collection and treatment of ODS in accordance with Regulation (EC) No 1005/2009, as well as treatment of refrigerant and foam contained in appliances.

The WEEE Directive is linked to the F-gas Regulation as it refers to equipment containing gases with GWP >15. All fluorinated gases subject to the F-gas Regulation have higher GWPs. The provisions of both legislative acts hence overlap with regard to recovery of F-gas refrigerants from domestic refrigeration, air conditioning and heat pump equipment. The F-gas Regulation complements the provisions of the WEEE Directive by introducing qualification requirements for personnel[115].

The WEEE Directive goes beyond the provisions of the F-gas Regulation since it requires, in its Annex on selective treatment, foams used as insulation material in domestic and small commercial refrigeration appliances to be treated. Recovery of F-gases used as blowing

[115] Commission Regulation (EC) No 303/2008 explains the special requirements for qualification of personnel undertaking recovery of F-gases from equipment covered by the WEEE Directive and containing charges <3 kg. If personnel

- is undertaking recovery in premises covered by a particular permit for WEEE treatment and
- is employed by the company holding the permit and
- have completed a training course according to Category III verified by an attestation of competence issued by the permit holder,

other certification requirements of the Regulation do not apply. It is explained that the level of qualification for personnel recovering refrigerant in plants for WEEE treatment is lower compared to that needed by personnel carrying out in-site recovery, because of the type of automated recovery equipment available in such plants.

agents is not required by provisions under Article 4 of the F-gas Regulation. However, the labelling provisions of the F-gas Regulation (Article 7) support recovery and proper treatment of F-gas insulation foams as they require marking equipment with a label saying “foam blown with fluorinated greenhouse gases”, which applies to refrigeration equipment when such equipment also contains F-gas refrigerants.

Although the WEEE Directive and the F-gas Regulation have been coexisting for some years, few quantitative data on their combined impact in terms of waste management and related emission reductions of ODS and F-gases are available.

In the model AnaFgas, it is assumed that the disposal emission factor of the sectors covered under the WEEE Directive will decrease as recovery efficiency increases (chapter 2). As for decommissioning facilities, the costs for personnel certification are also taken into account.

Directive 2000/53/EC on end-of life vehicles (ELV Directive) requires Member States to ensure that end-of-life vehicles are dismantled and hazardous materials are removed (Art 6). Air conditioning system fluids must be removed, collected and stored separately before the vehicle is shredded (Annex I, Art 6). The directive also requires recovery of foams at end of life for proper disposal.

The ELV Directive is linked to the F-gas Regulation as it requires recovery of refrigerants (i.e. HFC-134a) from air conditioning systems contained in end of life vehicles. This provision partly overlaps with Article 4 of the F-gas Regulation which requires F-gases contained in mobile equipment unless it is serving military operations to be recovered by appropriately qualified personnel[116] “to the extent that it is technically feasible and does not entail disproportionate cost” in order to ensure recycling, reclamation or destruction. The F-gas Regulation exceeds the scope of the ELV Directive since it requires recovery not only at end of life but also during servicing and maintenance. By introducing qualification requirements for recovery of F-gases from AC systems contained in passenger cars, the F-gas Regulation complements the provisions of the ELV Directive in order to minimise F-gas emissions during recovery.

Another provision on recovery of foams from ELV vehicles usually does not interact with the F-gas Regulation since most types of foam currently used in automotive industry do not contain F-gases.

So far, no quantitative data on the combined impact of the ELV Directive and the F-gas Regulation or the MAC Directive on emission reductions exist[117].

For future management of F-gas banks contained in equipment, experiences from environmentally sound management of ODS banks under the Montreal Protocol should be considered in order to identify further potentials for streamlining legislation and management processes.

[116] Minimum requirements for training programmes and attestation of personnel recovering certain fluorinated greenhouse gases from air conditioning systems in motor vehicles falling within the scope of Directive 2006/40/EC are set out by Commission Regulation (EC) No 307/2008.

[117] This might partly be due to the fact that used passenger cars at the end of their registered lifetime in one Member State are often exported to other Member States or out of EU-27 and used as second hand cars for some more years.

- **Links for bulk F-gases recovered from products and equipment**:

When servicing of equipment is undertaken on-site and the recovered F-gas is not suitable for recycling, the gas should be collected and stored in special containers for subsequent reclamation or destruction. Only small quantities of F-gases are reclaimed since they need to be sorted by type and reclamation of blends is technically complicated (see chapter 4.2.6 on RRRD). For servicing companies it is often impractical to store small quantities of recovered F-gases separated by type. Therefore, most recovered F-gases not suitable for on-site recycling are mixed and considered waste.

- **Implications**

Recovery for recycling, proper reclamation and destruction of F-gases by certified personnel according to Article 4 of the F-gas Regulation is not explicitly promoted by current definitions and provisions of European waste legislation. Small contractors in the refrigeration and air conditioning sector are not incentivized to undertake recovery for proper reclamation and destruction since collection, transport, storage and eventual shipment of used F-gases classified hazardous waste result in costs and effort for servicing companies.

Existing legislation for the management of F-gases contained in domestic appliances as well as air conditioning systems of end of life vehicles preceded and now complements the F-gas Regulation. However, data on waste streams in these sectors are rare or not available for EU-27.

While considering the benefits of the horizontal approach of European waste legislation, a general lack of information on current waste management practices with regard to F-gas reclamation and destruction needs to be stated. Large quantities of used F-gases are presumably not collected separately for treatment and/or not treated in specialized facilities.

3.3.3 Climate & energy and industrial emissions policies

Strong links between climate and energy policies and the EU F-gas policy have been identified and might impact F-gas emissions.

- **General links**

Parties to the **United Nations Framework Convention on Climate Change (UNFCCC)** must submit national reports on the implementation of the Convention to the Conference of the Parties (COP). The required contents of national communications and the timetable for their submission are different for Annex I (developed countries) and non-Annex I Parties (developing countries).

By 15 April each year, Annex I Parties must provide annual national GHG inventories covering emissions and removals of direct GHGs (including CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) from several sectors[118] and for all years from the baseline to the most recent year. Inventory submissions are divided in two parts: the Common Reporting Format (CRF) which includes standardized data tables, and the National Inventory Report (NIR), a comprehensive description of the results, applied methodology, the data sources etc.

[118] These sectors include the following main source categories: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land-Use Change and Forestry, Waste, Other, CO_2 emissions from Biomass, International bunkers and Multilateral Operations. F-gas emissions are to be reported from the sector “industrial processes”.

In addition to the annual inventories, Annex I Parties are also required to submit national communications periodically. Annex I Parties to the UNFCCC that have also ratified the Kyoto Protocol must include supplementary information in their national communications and annual inventories to demonstrate compliance with the Protocol's commitments.

Commitments made by the EU (see chapter 3.2) result in the need for monitoring and regular assessment of greenhouse gas emissions in the EU. **Decision 280/2004/EC concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol**[119] represents the basis for the compilation of the EC inventory in accordance with the UNFCCC and Kyoto Protocol, which includes emissions of HFCs, PFCs and SF_6. Although each of the Member States is preparing GHG emission inventories in order to fulfil reporting obligations to the UNFCCC, the information gained through the reporting of production, import and export of F-gases according to Article 6 of the F-gas Regulation can rarely be linked to the information contained in the inventories (see chapter 2). Article 6(4) of the F-gas Regulation aims to address this problem by requiring Member States to establish monitoring systems for F-gas emissions.

Furthermore, **Directive 2008/1/EC concerning integrated pollution prevention and control** (IPPC Directive) requires industrial and agricultural activities with a high pollution potential to have a permit. This permit can only be issued if certain environmental conditions are met. Hence companies are obliged to take responsibility for preventing and reducing pollution they may cause. The decision to issue a permit contains certain specific requirements including also the monitoring of substances released. Emission Limit Values (ELVs) for pollutants are based on best available techniques (BATs[120]), which take into account the balance between costs and environmental benefits.

In 2010, the Council of the EU adopted Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (Recast) (the IED).[121] The IED recasts seven existing Directives related to industrial emissions, including the Directive concerning integrated pollution prevention and control (IPPC), into a single and coherent legislative instrument. Currently, around 50,000 installations are covered by existing industrial emissions legislation in sectors like metal production, chemical manufacture, poultry and pig farming, waste incineration and large combustion plants.

The Directive does not set standards or thresholds for the prevention or control of emissions, or other environmental aspects, but requires Member States to refer to Best Available Techniques (BATs) conclusions, which form a part of BAT reference documents (BREFs), for setting permit conditions. Furthermore, Article 15 of the Directive requires emission limit values set in permits to be set at a level that ensures that emissions from the installation are in line with the BAT Associated Emission Levels provided in the BAT conclusions. Deviations from these levels are only permitted when local and technical characteristics would make it disproportionally costly. BREFs and BAT conclusions under IED are given a clear role in the setting of permit conditions and, in particular, the setting of emission limit values.

[119] Decision 280/2004/EC is currently under revision.

[120] BAT are defined as "the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole".

[121] OJ L334, 17.10.2010, p. 17.

Emission limit values refer to polluting substances with the exception of greenhouse gases if the emission trading scheme applies. A permit issued in compliance with the IED is hence not obliged to contain emission limit values for greenhouse gases if these are subject to an emission trading scheme and provided that there is no local pollution problem. Hence emissions from aluminium industry could be addressed through BREFs but PFC emissions would not be in the focus of the permit as they will be included in the EU-ETS from 2013.

Currently, several BREFs address industries relevant in the context of F-gases:

"Smitheries and Foundries"[122] (05.2005; review in 2012): Special attention is given to the melting process of magnesium which relies on the use of SF_6 and SO_2 cover gases to prevent the oxidation (or burning) of molten magnesium. Since SF_6 is more easily to handle than the toxic SO_2, it became the preferred cover gas after its introduction in the mid 1970s. The BREF states that BAT is to use SO_2 as a covering gas for magnesium melting in installations with an annual output of >500 t, regardless of whether the plant is to be newly built or still runs with SF_6 (p.183). For small plants (<500 t Mg parts output/year) BAT is to use SO_2 or to minimize the use of SF_6. In the case where SF_6 is used, the BAT associated consumption level is <0.9 kg/t casting for sand casting and <1.5 kg/t casting for pressure die-casting (Executive Summary, p. ix). The BREF also states that alternative cover gases to replace SF_6 such as HFC-134a and Novec612 had been developed and tested but had not found industrial implementation so far (p. 334). This information is outdated[123] with respect to HFC-134a and is likely to be changed during the review process of the BREF.

"Non-Ferrous Metal Industries" (12.2001, review ongoing) also recommends replacing SF_6 as cover gas in magnesium industry (p. 596; 612) and refers to the Foundries BREF.

"Energy Efficiency"[124] (02.2009) follows a horizontal approach and thus addresses all IPPC sectors. The general BAT are intended to serve as reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation (p. 269). The BREF underlines that heat pumps rely on refrigerants with greenhouse gas emissions in case of leakage or at decommissioning (p. 171). In the same sense and with regard to large scale chilling systems, it is highlighted that the refrigerants should not only have zero ozone-depleting potential, but also low global warming potential and lower energy demand in use (p. 307).

It should be noted that the BREF on ***"Industrial cooling systems"***[125] (12.2001; review in 2011) excludes industrial refrigeration with refrigerants and therefore is not relevant.

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[122] European Commission: Integrated Pollution Prevention and Control – Reference Document on the Application of Best Available Techniques in the Smitheries and Foundries Industry, May 2005. ftp://ftp.jrc.es/pub/eippcb/doc/sf_bref_0505.pdf

[123] Öko-Recherche 2009: Service contract to assess the feasibility of options to reduce emissions of SF_6 from the EU non-ferrous metal industry and analyse their potential impacts; Final Report, prepared for the European Commission.

[124] European Commission: Integrated Pollution Prevention and Control – Reference Document on the Application of Best Available Techniques for Energy Efficiency, February 2009. ftp://ftp.jrc.es/pub/eippcb/doc/ENE_Adopted_02-2009.pdf

[125] European Commission: Integrated Pollution Prevention and Control – Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems, December 2001. ftp://ftp.jrc.es/pub/eippcb/doc/cvs_bref_1201.pdf

With regard to the different industrial sectors emitting F-gases, permits are required e.g. for aluminium manufacturing facilities (PFC emissions), semiconductor industry facilities (PFC, SF_6, NF_3 emissions) and halocarbon production facilities (HFC-23 emissions).

In the context of pollution control, **Regulation (EC) No 166/2006 on the establishment of a European Pollutant Release and Transfer Register (PRTR)** should be mentioned. This regulation implements the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention), which was signed by the EC in 1998, and the UNECE Protocol on Pollutant Release and Transfer Registers, signed in 2003. It requires operators of certain industry facilities to annually report amounts of pollutant release to competent authorities (Article 5) starting from 2007. Subsequently, Member States are obliged to provide the data to the Commission by electronic transfer (Article 7).

The pollutants addressed by the Regulation also include HFCs (threshold of 100 kg for release to air/year) and SF_6 (threshold of 50 kg for release to air/year) (Annex II). These reporting requirements apply for example to manufacturing facilities of chemicals and F-gas destruction facilities. The data provided through the database could hence be used for cross-checking with reported data on F-gas emissions.

The revised **EU-ETS Directive** (Directive 2009/29/EC) is a core piece of the European climate and energy package (see chapter 3.2). It includes PFC emissions from the aluminium industry in emissions trading from 2013 onward. It is assumed that this decision will support the introduction of technological improvements aiming at emission reductions. This is expected to cause a decrease in PFC emissions of ca. 1.3 million t CO_2 eq by 2020.

Furthermore, it is expected that a proposal on excluding emission offset credits generated through CDM projects on HFC-23 destruction from the EU-ETS from 2013 will be adopted in 2011.

The **Renewable Energy Directive 2009/29/EC** is also part of the European climate and energy package (see chapter 3.2) and promotes the use of renewable energy sources.

As heat pumps are considered to be using renewable energy from heat sources in the air, water or the ground, their installation has been fostered through this directive and additional market incentive programmes in several Member States. The number of heat pumps installed in EU-27 has been growing significantly in the last few years and is expected to continue increasing further. Projections of the model AnaFgas take this development into account.

Article 14(3) of the Renewable Energy Directive requires Member States by 31 December 2012 to develop specific certification schemes for installers of heat pumps (in accordance with Annex IV). The requirements of the certification system are more specific than those of the F-gas Regulation but do overlap with regard to containment.

In this context, the European eco label for heat pumps[126] is promoted (Decision 2007/742/EC). The list of criteria includes inter alia one point on “limitation of the use of substances harmful to the environment” and specifies that the GWP of the refrigerant should be ≤2,000. If the GWP of the refrigerant is <150, the minimum requirements for energy efficiency in heating and cooling mode are reduced by 15%. In this Act, GWP values are

[126] Eco label for heat pumps: http://ec.europa.eu/ecolabel (last checked 15 March 2011).

those in Annex I of the F-gas Regulation (according to 3rd AR of the IPCC). This implies that heat pumps running on the currently common refrigerant R410A (GWP 2,088 according to 4th AR of the IPCC; GWP 1,890 according to 3rd AR) are currently eligible the eco label.

The recast of the **Ecodesign of Energy using Products Directive 2009/125/EC (EuP Directive)** (previously 2005/32/EC) is a framework directive and aims at improved product design with regard to increased energy efficiency and environmental safety of energy related products. The use of energy related products has an impact on energy consumption. One large group of energy related products are energy using products (e.g. boilers, computers, industrial fans etc). Other energy related products can contribute to energy saving (e.g. windows, insulation material etc.) and have been included lately in the scope of the recast directive. Means of transport are not covered by this framework directive.

The framework directive does not set binding requirements on products by itself, but through implementing measures for each product group. Article 16(1) of the directive, requires the Commission to set out a working plan including an indicative list of energy-using products which will be considered in priority for the adoption of implementing measures in the period 2009-2011. Earlier legislation for minimum energy performance standards will be integrated and existing labelling requirements remain in force.

Certain product groups which are covered by the current working plan set out by the Commission include equipment relying on F-gases:

- Air conditioning and ventilation systems;
- Refrigerating and freezing equipment including e.g. service cabinets, walk-in cold rooms, chillers, ice-makers, ice-cream and milkshake machines.

Other product groups relying on F-gases which have been treated by preparatory studies already include:

- Domestic refrigerators and freezers: Commission Regulation (EC) No 643/2009 implements ecodesign requirements for household refrigerating appliances;
- Room air conditioners;
- Laundry driers.

With regard to F-gases, it should be underlined that improvements of energy efficiency may influence the refrigerant charge size of systems, and thus the emissions[127].

Complementary legislation includes Directive 2010/30/EU on the indication by labelling and standard product information of the consumption of energy and other resources by energy related products.

Manufacturers and importers of products need to ensure that their products meet the requirements of the EuP Directive and relevant implementing measures. Design and construction of products must comply with the eco-design requirements (which should ideally be based on harmonized standards existing for the products), undertake conformity assessments, issue technical documents and Declaration of Conformity, and label the product with the CE marking.

[127] Ecodesign criteria agreed as of July 2011 have been considered in the assessment of abatement options (chapter 6 and annex VI).

Another important contribution to EU's emission reduction targets is expected from the **Energy Performance of Buildings Directive (EPB Directive)** (recast 2010/31/EU; previously 2002/91/EC). Its objective is to promote the energy performance of buildings in EU taking into account outdoor climatic and local conditions as well as indoor climate requirements and cost-effectiveness. With regard to F-gases, it is particularly relevant for insulation foams. Due to the requirement of improved insulation, the use of construction foam might increase and the use of HFC-365mfc and HFC-245fa as foam blowing agents could potentially grow. However, as this growth is neither certain nor quantifiable the model AnaFgas does not include an assumption reflecting this potential impact in the long term.

It should be noted that the EPB Directive requires Member States to establish "regular inspection of the accessible parts of air conditioning systems of an effective rated output of more than 12 kW" (Article 15[128]). The Directive points out that this inspection of AC systems should be carried out in accordance with the inspection of leakages referred to in the F-gas Regulation. In fact, this link is relevant for equipment containing charges >3 kg, which applies to air conditioning systems of an effective rated output of more than ca. 15 kW such as multi-split and VRF systems, and chillers.

As stated by the relevant standard EN 15240[129], the inspection is mainly based on examination of existing documentation, visual inspection and checks whether the equipment is well maintained and serviced regularly and that all components are functioning correctly. According to the EPB Directive, inspection reports need to be issued subsequent to the inspection (Article 16) and inspections are to be carried out "in an independent manner by qualified and/or accredited experts" (Article 17).

National requirements for qualifications of such experts become a key issue when considering overlaps of inspections under the EPB Directive and leakage checks under the F-gas Regulation.

- **Implications**

In some cases, F-gas policies and various pieces of climate and energy legislation complement each other. For example, PFC emissions from the aluminium industry, which are not addressed by the F-gas Regulation, will be integrated into the EU-ETS from 2013. This is assumed to promote the introduction of abatement technologies in aluminium production facilities and emissions are expected to decrease significantly.

Further harmonization of EU F-gas policy and other pieces of climate and energy legislation would be useful. For example, the EuP Directive is accompanied by implementing measures for different energy related product groups. These establish specific ecodesign requirements for products which contribute to energy consumption and energy savings. In practice, the implementing measures focus on products which have a high potential for reducing greenhouse gas emissions at low cost, through reduced energy demand. Improvements of energy efficiency may influence the refrigerant charge size of systems, and thus F-gas

[128] Article 15(1) also sets out: "The inspection includes an assessment of the air conditioning efficiency and the sizing compared to the cooling requirements of the building. The assessment of the sizing does not have to be repeated as long as no changes were made to this AC system or as the cooling requirements of the building in the meantime. Member States may reduce the frequency of such inspections or lighten them, as appropriate, where an electronic monitoring and control system is in place".

[129] EN 15240: Inspection of air conditioning systems (2007-08).

emissions. Yet, no specific trend has been identified whether the efficiency of a given system with a given refrigerant capacity will improve with more or less refrigerant mass.[130] While the EuP Directive primarily focuses on energy consumption and related direct CO_2 emissions, synergies with other environmental legislation (e.g. F-gas Regulation, WEEE Directive) are to be explored and enforced.

The Renewable Energy Directive promotes the installation of heat pumps in order to reduce direct emissions released through incineration of fossil energy sources. As heat pumps contain and emit F-gases throughout their lifetime and at the end of their life, F-gas emissions from heat pumps are expected to increase. The encouragement of measures to limit F-gas emissions from this application should be supported.

The EPB Directive could potentially contribute in increasing use of HFCs (365mfc, 245fa) as foam blowing agents. However, foam with low-GWP blowing agents such as hydrocarbons is known to provide the same energy performance as HFCs, if the thickness is increased. Thus, this interaction is not expected to impact F-gas emissions in the long-term. Furthermore, inspections of AC systems >12 kW as required by the EPB Directive (Article 15) might also contribute to improved leak tightness irrespective of the charges and appropriate choice of AC equipment. Yet this impact on F-gas emissions can hardly be quantified.

3.3.4 Policies related to safety

Several pieces of legislation address safety issues related to the use of F-gases as refrigerants, propellants etc. and might also apply to alternatives to F-gases.

Regulation (EC) No 1907/2006 concerning the registration, evaluation, authorisation and restriction of chemicals (REACH) aims at protection of human health and the environment through better and earlier identification of the properties of chemical substances. It entered into force in 2007 and will be implemented gradually until 2018. REACH streamlines several pieces of EU chemical legislation into one directive creating a single regulatory system for all chemicals.

It covers all chemical substances including F-gases, whether on their own, in preparations or contained in equipment. Manufacturers and importers are required to register substances on their own (i.e. pure substances) and in preparations in quantities of >1 t per year according to a timetable (Article 6) and provide safety information for chemicals to properly manage the risks of using them (Articles 10-14).

The **ATEX Directive 94/9/EC on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially Explosive Atmospheres,** applies to the environment in which equipment is installed but does not refer to certain substances contained in the systems. For example, it would apply to a refrigeration plant containing any flammable gases located in a refinery.

The **Pressure Equipment Directive (PED) 97/23/EC** became mandatory in 2002 and applies to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure greater than 0.5 bar gauge including

[130] Energy efficiency can be increased by use of larger conventional heat exchangers which typically contain greater refrigerant charge mass (due to increased internal volume), or alternatively by use of so-called mini channel heat exchangers which contain less refrigerant. The latter option, which is still more expensive, would benefit from higher refrigerant cost.

vessels, piping, safety accessories and pressure accessories. Only products fulfilling the Essential Safety Requirements may be introduced to EU markets and put into service. Not all pressure equipment is covered by this directive as the Transportable Pressure Equipment Directive (TPED) and the Simple Pressure Vessels Directive (SPVD) both cover certain equipment and products.

Important tools to demonstrate compliance with the Essential Safety Requirements are “harmonized standards”, i.e. EN standards harmonized against the PED Directive (published in the Official Journal). Harmonized standards are expected to conform to the Essential Safety Requirements stated in the PED Directive and include for example EN 378-1/2/3/4 (refrigeration systems and heat pumps), EN 14276-1 (vessels), EN 14276-2 (piping), EN 12284 (valves), EN 12263 (safety pressure switches).

It should be noted that the application of harmonized standards remains voluntary. Manufacturers may choose to apply other technical solutions that provide compliance with the Essential Safety Requirements. A notified body is involved to perform an audit for verification of compliance.

The PED Directive defines a number of classifications for pressure equipment, based on their hazard level which is determined on the basis of stored energy (pressure-volume product) and the nature of the contained fluid (fluid group I: dangerous fluids, which are toxic and/or flammable and/or explosive; e.g. R717, R600; fluid group II: all other fluids including HFCs and HCFCs).

3.3.5 Consideration of interactions within the project work

The analysis of interactions between the European legislation on F-gases and legislative acts from other fields has led to identification of possible areas of overlaps and certain aspects, which might impact future F-gas emissions. Some of the aspects identified are already incorporated into the datasets underlying the model AnaFgas, other aspects, however cannot be quantified in terms of their effects on F-gas emissions.

Certain areas where interactions of the EU F-gas policy with other policies have complicated the application of provisions or caused confusion are addressed to some extent in the assessment of policy options for a potential review of the F-gas Regulation (chapter 8).

4. Application of the EU F-gas Regulation

Provisions of Regulation (EC) No 842/2006 are directly applicable in all Member States. However, a few elements needed implementation through EU and/or national legislation. These are the provisions on certification/ attestation systems according to Article 5(2) and on penalties according to Article 13. For both aspects, national legislation had to be established and the Commission had to be informed about.

This chapter investigates implementation of those provisions and application of the F-gas Regulation: “Implementation” refers to the legal establishment of provisions at Member State level, where required. The relevant notifications of the Member States to the EU Commission serve as indicators. “Application” refers to the actual realization of the measures of the F-gas Regulation in the Member States.

The costs associated with the F-gas Regulation result mostly from their application and enforcement in the Member States (certification, containment, recovery measures etc.) and are listed in chapter 4.3.

4.1 Status of implementation of certain provisions of the F-gas Regulation in EU-27

The status of implementation has been investigated during the first quarter of 2010 and again in January and July 2011 in all Member States and relevant industries through questionnaires and interviews.[131] The evaluation showed that the implementation of the relevant provisions of the F-gas Regulation was progressing but remained incomplete at all times. Thus, the analysis cannot be considered an ex-post assessment of implementation but an interim assessment of the status of ongoing implementation (and application) of the F-gas Regulation.

4.1.1 Requirements for implementation of Article 5

Training, qualification and certification of personnel and companies involved in the handling of fluorinated gases is a central aspect of the F-gas Regulation to reduce emissions of F-gases by prevention of leakages (i.e. leakage checking by certified personnel, Article 3(2)) and by putting in place appropriate arrangements for the proper recovery of F-gases (recovery to be done by certified personnel, Art 4(1), respectively by “appropriately qualified personnel”, Article 4(3)).

[131] The status of implementation of Articles 5 (2) and 13 has been investigated based on the notifications of the Member States to the European Commission in early 2010, in January 2011 and in July 2011. Additional information was submitted by Member States via questionnaires. The status of application of the certification provisions (Article 5) has been investigated during the first quarter 2010 and January 2011 in all Member States and industry. It was updated as of July 2011 by questionnaires to all Member States (SRAC and MAC sector) and industry (FPS, HVS). Information on the status of application of the provisions of Article 3 (containment) and 4 (recovery) is based mostly on the first inquiry among Member States and industry (first quarter 2010). Data on the status of application of Article 6 provisions refer to 2007-2010 and are based on the respective reports to the Commission and additional information from Member States and industry. Information on the application of labelling provisions (Article 7) and bans (Articles 8 and 9) is based on information from industry and special investigations as outlined in chapter 4.2.8 and 4.2.9 (reference date 2010/2011).

The obligations of the operators of equipment according to Article 3 (containment) and Article 4 (recovery) became directly applicable in the Member States when the F-gas Regulation entered into force. Training and certification of personnel play a particularly important role for effective application of the provisions of the F-gas Regulation.

According to Article 5(2), by July 2008, Member States had to establish or adapt their training and certification requirements for both companies and relevant personnel involved in installation, maintenance or servicing of the equipment and systems covered by Article 3(1) as well as for personnel involved in the activities provided for in Article 4. Minimum requirements as referred to in paragraph 1 of Article 5 and conditions for mutual recognition are laid down in the following implementing Commission Regulations:

- Regulation (EC) No 303/2008: Certification of companies and personnel with regards to stationary refrigeration, air conditioning and heat pump equipment containing certain fluorinated greenhouse gases;
- Regulation (EC) No 304/2008: Certification of companies and personnel with regards to stationary fire protection systems and fire extinguishers containing certain fluorinated greenhouse gases;
- Regulation (EC) No 305/2008: Certification of personnel recovering certain fluorinated greenhouse gases from high-voltage switchgear;
- Regulation (EC) No 306/2008: Certification of personnel recovering certain fluorinated greenhouse-gas based solvents from equipment;
- Regulation (EC) No 307/2008: Minimum requirements for training programmes with regards to air conditioning systems in certain motor vehicles containing certain fluorinated greenhouse gases.

The Member States had to notify the Commission of their training and certification programmes. They must recognize the certificates issued in other Member States in accordance with the implementing Regulations and not restrict the freedom to provide services or the freedom of establishment for reasons relating to the issuance of certifications in another Member State.

According to Article 5(3), the operator of the relevant application had to ensure that the technical personnel involved has obtained the necessary certification referred to in Art 5(2), which implies appropriate knowledge of the applicable regulations and standards as well as the necessary competence in emission prevention and recovery of F-gases and safe handling of the relevant type and size of equipment.

According to Article 5(4), by 4 July 2009, Member States had to ensure that the companies involved in carrying out the activities provided for in Articles 3 and 4 shall only take delivery of fluorinated greenhouse gases where their relevant personnel held the certificates mentioned in Article 5(2).

To enable the training and certification of personnel currently active in the sectors of stationary refrigeration, air conditioning and heat pumps as well as fire protection systems and fire extinguishers without interrupting their professional activity, the Regulations (EC) No 303/2008 and (EC) No 304/2008 allow Member States to make use of interim certification of personnel and companies. The interim certificates expired on 4 July 2010 for the fire protection sector and on 4 July 2011 for the stationary refrigeration, air conditioning and heat pump sector at the latest.

Temporary interim-certification of personnel could have been issued based on approval of past employment ("professional experience")[132] or existent, comparable certification ("existing qualification schemes")[133]. Interim certificates for companies are issued to companies certified under existing certification schemes[134] or to companies employing personnel holding a certificate[135].

In contrast to interim certification, final ("full") certification relies upon the existence of a certification body. The establishment of certification bodies and attestation bodies must have been notified to the Commission and implementing provisions should have been adopted at national level where appropriate. Final personnel certification is issued after theoretical and practical examination organised by an evaluation body. In Member States where an existing examination-based certification system covers the minimum skills and knowledge, a certification body may issue a certificate to the holder of this qualification without repeating examination.

In the case of training attestations for personnel recovering F-gases from air conditioning systems in motor vehicles, Regulation (EC) No 307/2008 also allowed a transitional period until 4 July 2010 at the latest, for which personnel holding an attestation issued under existing qualification schemes or with professional experience should have been deemed appropriately qualified.

If F-gas based solvents were not used in a Member State, this Member State could have decided not to designate the requested certification or evaluation body until the need for such certification arises. In this case, Member States must already provide for the necessary arrangements under their national legislation in order to ensure the timely issuance of such certificates in case such certification would be requested in the future.

[132] In this case the personnel should have been issued with an interim certificate document by an entity designated by the Member State. See Regulation (EC) No 303/2008, Art 6(3) and Regulation (EC) No 304/2008, Art 6(3).

[133] Personnel holding an attestation issued under existing qualification schemes could have been deemed holders of an interim certificate and don't need an additional document. See Regulation (EC) No 303/2008, Art 6(2) and Regulation (EC) No 304/2008, Art 6(2).

[134] Such companies could have been deemed holders of an interim certificate. (EC) No 303/2008, Art 9(2), (EC) No 304/2008, Art 9(2).

[135] In this case the companies need an interim certificate issued by an entity designated by the Member State. (EC) No 303/2008, Art 9(3), (EC) No 304/2008, Art 9(3).

4.1.2 Implementation of Art 5(2): status of notification by Member States

The notification obligations of the Member States regarding training and certification systems in the various sectors are laid down in detail in the respective Regulations[136]. Table 4-1 summarizes important deadlines for notifications.

Table 4-1: Training and certification systems – obligation of the Member States for notification

Date	Subject	Regulation (EC) No
4 July 2008	Intention to apply an interim certification system for personnel and/or companies	303/2008 304/2008
	Identification of existing qualification systems or conditions based on professional experience on the basis of which personnel are deemed appropriately qualified	307/2008
4 January 2009	Entities entitled to issue interim certificates; Certification bodies for personnel and companies	303/2008 304/2008
	Certification bodies for personnel	305/2008
	Certification bodies for personnel or decision not to designate any certification bodies	306/2008
	Attestation bodies for personnel	307/2008

A delay in the notifications indicates difficulties encountered within the implementation process in the Member States. The following development since 2009 can be noted:

Until January 2009 only 3 and until January 2010, only 12 Member States had submitted final notifications for all sectors, one Member State had notified partly (France).

Stationary refrigeration, air conditioning and heat pumps are common applications in every Member State, as is the necessity for recovery of F-gas from AC systems in motor vehicles (based on European legislation; see chapter 3). Nevertheless, as of 30 April 2010 about 40% of the Member States (10 out of 27) had not yet notified the required certification and attestation systems for these sectors. These 10 Member States account for about 44% of the 2008 F-gas emissions from commercial refrigeration, industrial refrigeration and stationary air conditioning (calculated by the model AnaFgas). The Member States who had not implemented the provisions on training and certification at that time thus include not only small countries with low emissions.

The status **as of 4th July 2011**, i.e. two and a half years after the deadline for final notifications of January 2009, is summarized in the following tables 4-2 and 4-3 and in the figures 4-1 to 4-3.

- **Stationary refrigeration, air conditioning and heat pumps**: 20 Member States were in compliance with the notification obligations. They provided final notification of their certification bodies for personnel and companies to the Commission.

- **Fire protection**: 19 Member States were in compliance with the notification obligations. One of these Member States (DK) decided not to designate evaluation/certification bodies, as the use of F-gases for fire protection is prohibited in the country.

[136] Commission Regulations (EC) No 303-307/2008.

– **High voltage switchgear**: 19 Member States were in compliance with the notification obligations: 17 Member States had notified their training and certification schemes. Two Member States decided not to designate evaluation/certification bodies.[137]

– **F-gas based solvents**: 19 Member States were in compliance with the notification obligations: 11 Member States provided final notification of their certification bodies for personnel recovering F-gas based solvents. 8 Member States decided not to designate evaluation/certification bodies.[138] 17 Member States[139] declared that F-gas based solvents were not in use at the time. Use of F-gas based solvents is prohibited in Denmark.

– **Air conditioning systems contained in motor vehicles:** 20 Member States were in compliance with the notification obligations. They provided final notification of their attestations bodies for personnel recovering F-gases from AC systems in motor vehicles.

– 18 Member States had notified **interim certification schemes**, amongst them 3 which had not yet notified final certification (Luxembourg, Poland and Portugal).

– 4 Member States did not notify interim certification schemes and had **not yet notified** final certification (Greece, Italy, Latvia, and Malta).

[137] These Member States are Denmark and Estonia.
[138] These Member States are Austria, Czech Republic, Denmark, Estonia, Ireland, Lithuania, the Netherlands, and Romania.
[139] These Member States are Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Hungary, Ireland, Lithuania, Latvia, Malta, the Netherlands, Romania, Slovakia, Slovenia, and Sweden.

Table 4-2: Status of notification of certification bodies according to (EC) No 303/2008-307/2008 as of July 2011

	Final notification of certification/attestation bodies under Regulation (EC) No					**Interim certification notified**	**Without notification of interim/final certification**
	303/2008 (SRAC/HP)	304/2008 (FPS)	305/2008 (HVS)	306/2008 (solvents)	307/2008 (MAC)		
AT	X	X	X	N[2]	X	X	
BE	X	X	X	X[2]	X	X	
BG	X	X	X	X[2]	X	-	
CY	X	X	X	X[2]	X	X	
CZ	X	X	X	N[2]	X	X	
DE	X	X	X	X	X	X	
DK	X	N[1]	N	N[1, 2]	X	X (only 303)	
EE	X	X	N	N[2]	X	X	
EL	-	-	-	-	-	-	X
ES	X	X	X	X	X	X	
FI	X	X	X	X	X	X	
FR	X	-	-	-	X	X (only 303)	
HU	X	X	X	X[2]	X	X	
IE	X	X	X	N[2]	X	X	
IT	-	-	-	-	-	-	X
LT	X	X	X	N[2]	X	-	
LU	-	-	-	-	-	X (only 303)	
LV	-	-	-	-[2]	-	-	X
MT	-	-	-	-[2]	-	-	X
NL	X	X	X	N[2]	X	X	
PL	-	-	-	-	-	X	
PT	-	-	-	-	-	X	
RO	X	X	X	N[2]	X	-	
SE	X	X	X	X[2]	X	X	
SK	X	X	X	X[2]	X	-	
SI	X	X	X	X[2]	X	-	
UK	X	X	X	X	X	X	
total	**20**	**18**	**17**	**11**	**20**	**18**	**4**

X: Final notification submitted; N: Member States decided not to designate evaluation/certification bodies. [1] In DK use of fluorinated greenhouse gases in the fire protection sector and as solvents is prohibited. [2] No use of solvents (17 Member States). Source: EC and EU-27 authorities.

Two and a half years after the due date, 19 Member States were in full compliance with the notification obligations. Final notifications of certification bodies were completely or partly lacking in 8 Member States i.e. in 30% of the EU-27 Member States (table 4-3).

Table 4-3: Status of notification of certification bodies according to (EC) No 303/2008-307/2008 as of July 2011 (number of Member States)

	In compliance with notification obligations			**Final notification not submitted**
	In total	Certification/ attestation bodies identified	Decision not to designate evaluation/ certification bodies	
Stationary refrigeration, air conditioning, heat pumps (EC) No 303/2008	20	20	-	7 (EL, IT, LU, LV, MT, PL, and PT)
Fire protection (EC) No 304/2008	19	18	1 (DK)	8 (EL, FR, IT, LU, LV, MT, PL, and PT)
High-voltage switchgear (EC) No 305/2008	19	17	2 (DK, EE)	8 (EL, FR, IT, LU, LV, MT, PL, and PT)
Solvents (EC) No 306/2008	19	11	8 (AT, CZ, DK, EE, IE, LT, NL, and RO)	8 (EL, FR, IT, LU, LV, MT, PL, and PT)
Mobile air conditioning (EC) No 307/2008	20	20	-	7 (EL, IT, LU, LV, MT, PL, and PT)

Source: EC and EU-27 authorities

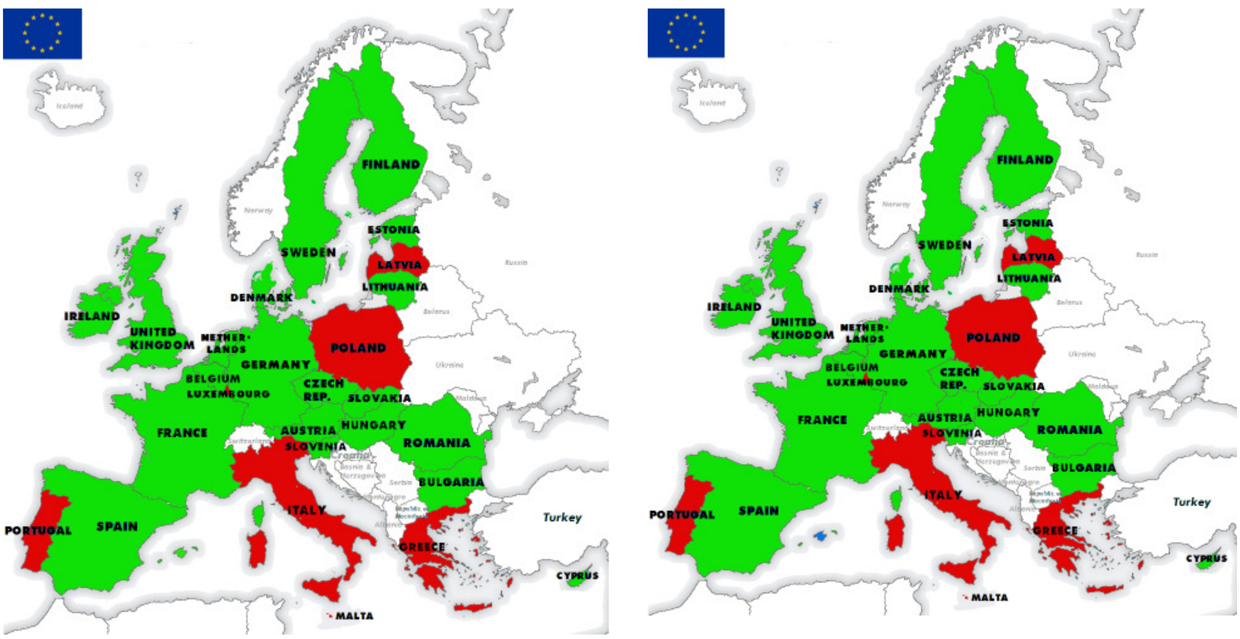

Figure 4-1: Status of notification of certification bodies in the stationary refrigeration, air conditioning and heat pump sector (left; 303/2008) and of attestation bodies in the mobile air conditioning sector (right; 307/2008) in July 2011. Green: 20 Member States in compliance with notification obligations. Red: 7 Member States not yet in full compliance.

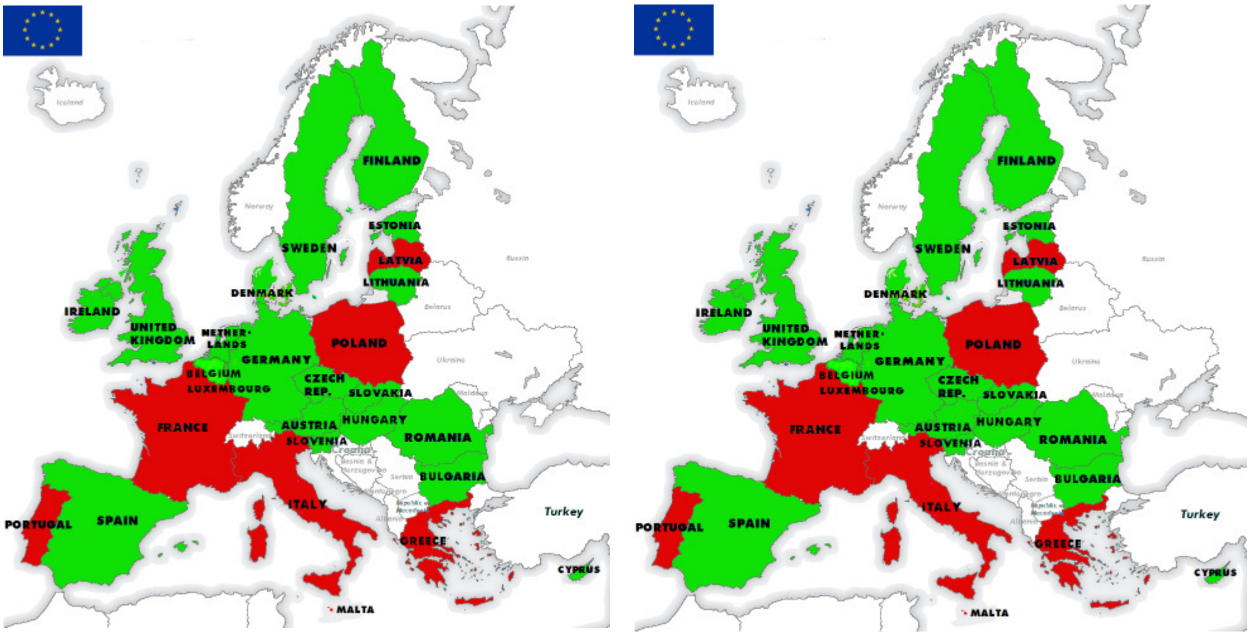

Figure 4-2: Status of notification of certification bodies in the fire protection sector (left; 304/2008) and the high-voltage switchgear sector (right; 305/2008) in July 2011. Green: 19 Member States in compliance with notification obligations. Red: 8 Member States not yet in full compliance.

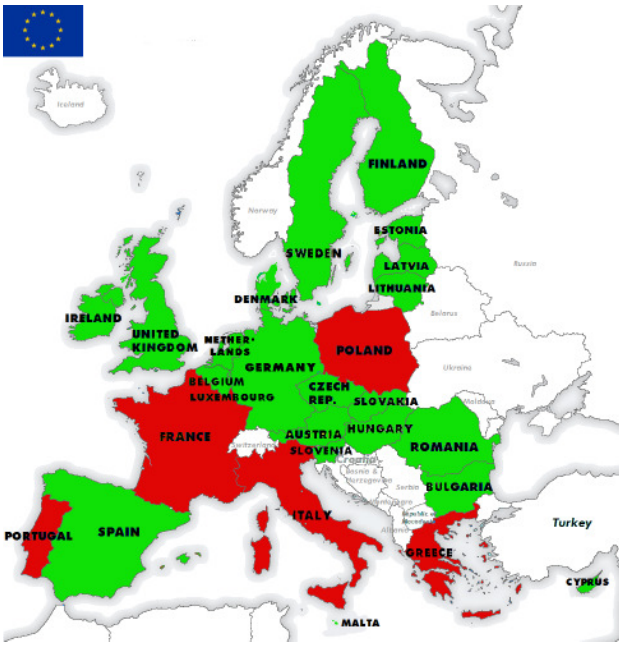

Figure 4-3: Status of notification of certification bodies in the solvents sector (306/2008) in July 2011. Green: 19 Member States in compliance with notification obligations. Red: 8 Member States not yet in full compliance.

As of 4th July 2011, relevant national legislation was adopted in Portugal, Latvia and (with regard to Commission Regulations (EC) No 304/2008, 305/2008 and 306/2008) in France.

However, these Member States had not yet notified the designation of the respective certification bodies to the Commission. In most of these Member States the certification bodies had been identified already.

4.1.3 Implementation of Article 5(2): reasons for delay

A significant delay can be identified when looking at the status of implementation of Article 5(2) according to the notification obligations of the Member States as of July 2011, i.e. 30 months after the deadline for notifications.

The identification of the reasons for the delay in implementing the requirements of Article 5(2) and for the problems associated with the delay has to consider the different conditions in each Member State. These include:

- Structural and cultural differences in the political-administrative and legislative system of the Member States, which impact priority and speed of implementing the F-gas Regulation.
- Different baseline conditions regarding the vocational training systems and the existence of certification systems in sectors before entry into force of the F-gas Regulation.
- Differences in the number of staff involved and companies concerned in the various sectors and Member States, and differences in the availability of infrastructure (training institutions, examination bodies) in the Member States.

In addition, it seems that political and administrative effort for coordination in the Member States in order to establish structures for the implementation of the F-gas Regulation have been largely underestimated especially concerning:

- The need for extensive discussion on the implementation of the minimum requirements in training programs, and examination requirements.
- The need for clarification of the recognition of existing qualifications, and of the harmonization with existing certification systems in the stationary refrigeration, air conditioning and heat pump sector as well as the mobile air conditioning sector.
- The need for extensive and time-consuming coordination between political institutions, industrial associations and further stakeholders.
- The lack of training facilities and providers and the time and effort to put them in place. This is particularly a problem of small Member States and particularly affects the F-gas applications with few specialized personnel and hence low demand for training/certification (Cat III in the stationary refrigeration, air conditioning and heat pump sector, fire protection, high voltage switchgear, solvents). For example, it is pointed out that the organisation and conduct of trainings for the fire protection sector is not profitable for the relevant institutions if the demand for such training is too low.

4.1.4 Status of implementation of Article 13 (penalties)

According to Article 13 of the F-gas Regulation, Member States should have laid down rules on penalties applicable to infringements of the provisions of this Regulation and shall take all measures necessary to ensure that such rules are implemented. Member States should have notified the rules on penalties to the Commission by 4 July 2008.

As of 4th July 2011, 23 Member States had notified that rules on penalties were set out at national level. Notifications were still lacking from the other 4 Member States[140] (Fig. 4-4).

The implementation of the provisions on penalties according to Article 13 is also delayed even though, in fewer Member States, compared to training and certification according to Article 5. 9 out of the 23 Member States which have notified already did so in 2009, 2010 or 2011 i.e. after the deadline laid down in Article 13.

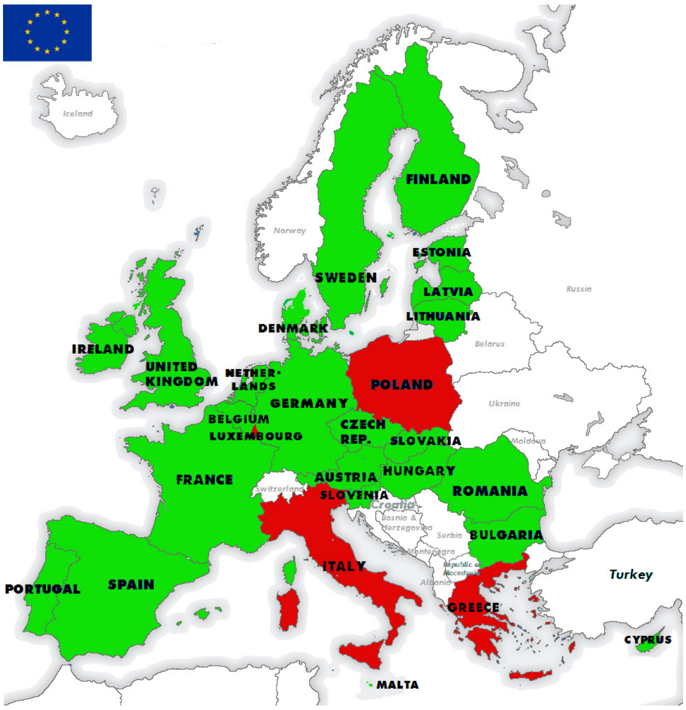

Figure 4-4: Status of notification of penalties according to Art 13, as of July 2011. Green: 23 Member States in compliance. Red: 4 Member States not yet in full compliance.

[140] These Member States are Greece, Italy, Luxembourg, and Poland.

4.2 Application of the provisions of the F-gas Regulation

The progress of application of the F-gas Regulation in the Member States is analyzed with regard to major provisions:

- Training and certification requirements (Article 5)
- Containment provisions (Article 3)
- Requirements for proper recovery of F-gases (Article 4)
- Reporting obligations (Article 6)
- Labelling requirements (Article 7).
- Bans (Article 8 and 9)

Where appropriate, the assessment considers each sector separately: Stationary refrigeration, air conditioning and heat pumps, fire protection, high voltage switchgear, F-gas based solvents, mobile air conditioning.

4.2.1 Certification requirements and availability of training centres in Member States

Training requirements, programmes and bodies are not specified by the F-gas Regulation. But they are critical for the application of the provisions of Article 5 on certification and need to be in place in the Member States. Usually the organisations designated as certification bodies are not the same institutions which provide the necessary training.[141] The availability of training centers for different sectors in the Member States has been assessed in early 2010.

According to (EC) No 303-306/2008, certification bodies shall issue a certificate to personnel in each sector who have passed a theoretical and practical examination organized by an evaluation body covering the minimum skills and knowledge set out by the relevant regulation. Evaluation bodies need to be recognized or certified at national level.

However, neither the F-gas Regulation nor Regulations (EC) No 303-306/2008 contain provisions on how to gain minimum skills and knowledge. It is thus possible to pass the examinations without previous participation in trainings.

Where an existing examination-based certification system covers the minimum skills and knowledge set out by the Regulations and meets their requirements with regard to certification and evaluation bodies, a certificate may be issued to the holder of previous qualification without repeated examination.

Nevertheless, in practice, final certification according to Regulations (EC) No 303-307/2008 requires the establishment of infrastructure for training in all Member States because most

[141] Two examples illustrate this aspect: Bulgaria notified for the stationary refrigeration, air conditioning and heat pump sector a personnel and a company certification body (Bulgarian Branch Chamber of the Machine Building). This certification body does not provide training. This is done by five professional training centres within the country. Germany notified only for personnel certification in the stationary refrigeration, air conditioning and heat pump-sector more than 200 certification bodies which are with two exceptions not identical to the more than 20 professional training centres.

personnel subject to certification requirements need training. This aspect is highly important in terms of costs.

In the stationary refrigeration, air conditioning and heat pump sector, larger groups of qualified personnel (i.e. not beginners) can be certified without additional training only in few Member States, where training and certification schemes already existed prior to the F-gas Regulation. These Member States include Austria (ca. 50% of personnel subject to certification requirements), Germany (ca. 50% of personnel subject to certification requirements), Denmark (about 80%)[142] and the Netherlands (100% due to the STEK system).

In all other Member States, certification based on Article 5(3) of Regulation EC (No) 303/2008 is only possible to very limited extent or not at all. Therefore, training programmes are necessary to teach the minimum skills. In most Member States with high numbers of personnel to be certified, the share of personnel participating in training measures is estimated to range between 90% (France, Spain, Sweden[143], UK) and 100% (e.g. Italy).

In the fire protection sector, the high-voltage switchgear sector and the F-gas-based solvent sector, all personnel need to take relevant trainings before the exams, which lead to certification.

For training attestation according to (EC) No 307/2008, an exam is not required. In case personnel hold training attestations issued under existing qualification schemes, attestation bodies may issue training attestations to the holders of such qualification without repeating the training course. However, it is estimated that nearly all personnel subject to attestation provisions will need to follow trainings for attestation.

Table 4-4 presents data on the availability of training centres per Member State, which are ready to run courses on the relevant skills and knowledge for F-gas certification as soon as national legislation on certification/attestation is in place. This includes training centres in Member States without final notification and/or without adoption of their national legal implementing provisions. The objective is to give an overview on the availability and development of training infrastructure in the Member States regardless of legal status.[144]

The availability of the necessary infrastructure for application of the certification requirements of the F-gas Regulation in the main sectors (stationary refrigeration, air conditioning and heat pumps; mobile air conditioning) is sufficient in almost all Member States.

According to expert information from industry (AREA, EPEE members) from 15 Member States the number of training centres and/or training courses for the stationary refrigeration, air conditioning and heat pump-sector rose in Member States where implementation of these provisions was completed[145].

[142] In DK, Cat. I acc (EC) 303/2008 is identical with the "kølemontør" category under the existing certification system.
[143] In Sweden the existing certification scheme covers minimum requirements according to (EC) No 303/2008. Nevertheless almost all personnel participate in trainings prior to final certification.
[144] In house training is not covered by the table.
[145] These include 10 out of the 15 Member States on which information was available: BE, DE, DK, FR, FI, HU, IE, SE, SK, and UK.

Table 4-4: Availability of training centres ready to run F-gas certification after implementation of Art 5(2) of the F-gas Regulation as of January 2010.

	Stationary refrigeration, air conditioning and heat pumps	**Stationary fire protection systems and fire extinguishers**	**High-voltage switchgear**	**Equipment containing F-gas based solvents**	**Air conditioning in motor vehicles**
AT	X	X	-	-	X
BE	W.R.: X F.R.: X B.R.: -	W.R.: - F.R.: X B.R.: -	W.R.: - F.R.: X B.R.: -	W.R.: - F.R.: - B.R.: -	W.R.: - F.R.: X B.R.:-
BG	X	-	-	-	X
CY	X	-	X	-	X
CZ	X	X	X	-	X
DE	X	X	X	X	X
DK	X	n.a.	-	n.a.	-
EE	X	X	-	-	X
EL	No data	No data	No data	No data	No data
ES	-	-	X	-	-
FI	X	-	-	-	-
FR	X	X	X	-	X
HU	X	X	X	-	X
IE	X	-	-	-	X
IT	X	X	X	-	X
LT	X	-	-	-	-
LU	No data	No data	No data	No data	No data
LV	X	-	-	-	X
MT	X	-	-	-	X
NL	X	X	X	-	X
PL	X	X	X	-	-
PT	-	-	-	-	-
RO	X	X	X	-	X
SE	X	-	X	-	X
SK	X	X	-	-	X
SI	X	X	-	X	X
UK	X	X	X	X	X

X: available; -: not available; n.a.: not applicable, F-gas use prohibited. B.R.: Brussels Region; F.R.: Flemish Region; W.R.: Walloon Region. Source: EU-27 authorities, industry.

The Netherlands represent an exception as the STEK Regulation existed prior to the F-gas Regulation and hence only some changes of the existing training centres and curricula were required. In some Member States where notification or national legal implementing provisions were pending, industry assured that training courses meeting the requirements of the F-gas Regulation may be performed already (without the possibility to issue the respective certificate) e.g. Poland (stationary refrigeration, air conditioning and heat pump-sector sector) and France (switchgear sector).

4.2.2 Application of certification requirements by sectors

The status of certification according to the requirements of the F-gas Regulation (table 4-5) is analysed by sectors as of July 2011.

Table 4-2 and 4-3 on the status of notifications and table 4-4 on availability of training centres in the Member States provide important background information.

This practice of training and certification varies between individual sectors and Member States. A number of Member States did not have qualification or certification systems in place when the F-gas Regulation entered into force. In those Member States the creation of certification systems according to the requirements of the F-gas Regulation could not rely on existing occupational qualification or certification. In Member States with already existing qualification schemes, the certification system required by the F-gas Regulation could be built on existing schemes provided that these schemes and the skills and knowledge covered by them include the minimum standards envisaged by the F-gas Regulation.

The information on personnel and companies in EU-27 subject to certification requirements and the number of personnel and companied who have been certified to date are based on information from industry and competent authorities in some Member States. Data were extrapolated for EU-27 by means of population data.

Certification of personnel is required in all sectors (in the MAC sector: attestation). In the stationary refrigeration, air conditioning and heat pump sector as well as the fire protection sector, company certification is also required.

Stationary refrigeration, air conditioning and heat pumps

Status of definitive certification of personnel: As of 4 July 2011, 20 Member States had notified their certification bodies (see table 4-2 and 4-3), and 7 not yet (Greece, Italy, Latvia, Luxembourg, Malta, Poland, and Portugal). The period during which interim certificates could be used expired, at the latest, on the same date. The total number of personnel that need to be certified in EU-27 (table 4-5) is estimated at about 228,000.[146]

99,500 persons were certified in the 19 Member States who had submitted detailed information. This refers to ca. 59% of personnel subject to certification requirements in this sector and in these Member States (total: ca. 169,500). It is assumed that about 15% of personnel subject to certification requirements in the other Member States where no detailed information was available from were fully certified (8,700 persons, mostly in Spain).

On this basis it is estimated that the share of certified personnel in this sector amounted to about 47.5% in EU-27 as of July 2011.

[146] This estimate is based on data from industry and competent authorities from 19 Member States (AT, BE, BG, CY, CZ, DE, DK, EE, FI, FR, HU, IE, IT, NL, RO, SE, SK, SI, and UK). Data were extrapolated for the remaining Member States. Population in the 19 Member States who submitted detailed information represent about 78% of the total population in EU-27.

Table 4-5: SRAC sector – Status of certification according to (EC) No 303/2008 (July 2011)

	Population (million)	Total personnel subject to certification requirements	Fully certified personnel		Total companies subject to certification requirements	Fully certified companies	
			Absolute number	% share		Absolute number	% share
AT	8.3	2,500	1,500	60.0	1,000	600	60.0
BE	10.6	4,000	3,400	85.0	900	720	80.0
BG	7.7	2,000	1,738	86.9	120	88	73.3
CY	0.8	1,000	850	85.0	350	315	90.0
CZ	10.3	2,700	2,200	81.5	275	230	83.6
DE	82.3	28,000	23,800	85.0	5,750	4,025	70.0
DK	5.4	4,000	2,200	55.0	1,000	1,000	100
EE	1.3	450	45	10.0	250	15	6.0
FI	5.3	4,900	1,960	40.0	2,050	1.025	50.0
FR	63.4	45,000	25,917	57.6	18,000	12,688	70.5
HU	10.1	4,500	900	20.0	1900	380	20.0
IE	4.3	1,900	950	50.0	700	490	70.0
IT	59.1	30,000	0	0	9,000	0	0
NL	16.3	11,800	11,649	98.7	850	850	100
PL	38.2				6,000	0	0
PT	10.6				1,700	0	0
RO	21.6	60	30	50.0	30	18	60.0
SE	9.0	5,700	5,600	98.2	900	768	85.3
SK	5.4	900	675	75.0	300	240	80.0
SI	2.0	600	487	81.0	300	257	86.0
UK	60.9	19,500	15,584	79.9	6,000	4,500	75.0
sub-total		169,510	99,485	58.7	57,375	28,209	49.2
other*		58,250	8,700	15.0	7,717	0	0
total	**495.2**	**227,760**	**108,185**	**47.5**	**65,092**	**28,209**	**43.3**

Source: EU-27 authorities, industry. * Other MS (extrapolated): Personnel certification: EL, ES, LT, LU, LV, MT, PL, PT (population = 111.1 million); company certification: EL, ES, LT, LU, LV, MT (population = 62.3 million).

Large differences between Member States need to be noted: Only in 15 Member States[147], the share of certified personnel was ≥50% in July 2011 (i.e. at the end of the interim period). The high share of certified personnel in the Netherlands has been inherited from the former STEK-system and related certification requirements.

<u>Status of definitive certification of companies:</u> The total number of companies subject to certification requirements in this sector in EU-27 is estimated at ca. 65,000 (table 4-5). By the end of the interim period on 4 July 2011, all of these companies needed to be certified.[148]

Detailed information on final company certification is available from 21 Member States and includes ca 28,200 companies (ca. 49% of all 57,300 companies subject to certification requirements in these Member States). Five out of the remaining 6 Member States (with the exception of Spain) had not yet notified certification bodies (see table 4-3); from Spain no data on definitive company certification were available. Therefore, it is assumed that the total

[147] These include AT, BE, BG, CY, CZ, DE, DK, FR, IE, NL, RO, SE, SK, SL, and UK.

[148] The estimate is based on data from industry and competent authorities from 21 Member States (AT, BE, BG, CY, CZ, DE, DK, EE, FI, FR, HU, IE, IT, NL, PL, PT, RO, SE, SK, SI, and UK). The data have been extrapolated for the remaining Member States. Population in the 21 Member States who submitted detailed information represents about 87.4% of the total population in EU-27.

number of fully certified companies in EU-27 as of 4th July 2011 is about 28.200 or 43.3% of all companies subject to certification requirements in this sector.

The status of company certification differs largely between Member States. 18 Member States confirmed that at least some of the companies in this sector were fully certified. In 16[149] Member States the share of certified companies was ≥50% in July 2011 (i.e. at the end of the interim period).

Fire protection

Status of final certification (personnel and companies): Interim certification for the fire protection sector expired on 4 July 2010.

On 4 July 2011, 18 Member States had submitted their final notification of certification bodies. In Denmark, the use of F-gases in fire protection systems has been prohibited since January 2006 (Statutory Order No 552/2002). Final notifications for this sector were still lacking from 8 Member States (tables 4-2 and 4-3).[150] In some Member States, where final notification for this sector is pending, training facilities for personnel certification in this sector already exist (e.g. FR, IT, PL; cf. table 4-4).

In cooperation with experts from EUROFEU and based on data reported by Member States, the total number of personnel and companies to be certified in the fire protection sector in EU-27 has been estimated at 4,500 persons and the number of companies to be certified at 1,300 (Table 4-6).[151]

In January 2011, less than one third of personnel (28%) and about 7% of companies had been fully certified.

By July 2011, the relevant industry association EUROFEU had no further information on personnel and company certification. This indicates that the certification process within this sector is progressing slowly. It is thus assumed that the number of fully certified personnel and companies in January 2011 did not rise by more than 20% in the period from January to July 2011. As of July 2011, a share of one third of fully certified personnel and 9% of fully certified companies can be estimated (table 4-6).

Table 4-6 shows that the number of personnel and companies to be certified varied largely between Member States depending on the extent of the use of HFC fire extinguishing agents, the size of companies and market structure as well as national regulations.

Already about 950 personnel certificates had been issued in the UK, which is due to the rule that not only personnel of fire extinguishing companies but also personnel of fire alarm and detection (FA&D) companies are subject to certification requirements. This is a national particularity and does not apply in other Member States. Certification quotas of 50% and more for personnel and companies are reported from BG, CZ, FI, NL, and SK. In the UK only the share for personnel certification ranges at similar levels and in Germany the share for company certification.

[149] These are AT, BE, BG, CY, CZ, DE, DK, FI, FR, IE, NL, RO, SE, SK, SI, and UK.

[150] These Member States are EL, FR, IT, LU, LV, MT, PL, and PT.

[151] This estimate is based on data from industry and competent authorities from 22 Member States. Data were extrapolated for the remaining Member States (HU, IE, LT, LU, MT, and RO). Population in the 22 Member States who submitted detailed information represent about 93% of the total population in EU-27.

Table 4-6: FPS sector – Status of certification according to (EC) No 304/2008 (January and July 2011)

	Population (million)	Total personnel subject to certification requirements	Fully certified personnel		Total companies subject to certification requirements	Fully certified companies	
			Absolute number	% share		Absolute number	% share
Data January 2011							
AT	8.3	36	0	0	9	0	0
BE	10.6	20	9	45.0	6	1	17.7
BG	7.7	40	23	57.5	15	10	66.7
CY	0.8	2	0	0	2	0	0
CZ	10.3	75	70	93.3	4	3	75.0
DE	82.3	150	50	33.3	8	4	50.0
DK	5.4	0	0		0	0	
EE	1.3	40	0	0	15	0	0
EL	11.2	150	0	0	100	0	0
ES	44.5	600	0	0	400	0	0
FI	5.3	15	15	100	2	2	100
FR	63.4	500	0	0	20	0	0
IE	4.3	80	0	0	40	0	0
IT	59.1	750	0	0	200	0	0
LV	2.3	35	0	0	10	0	0
NL	16.3	80	57	71.3	10	10	100
PL	38.2	300	0	0	10	0	0
PT	10.6	150	0	0	100	0	0
SE	9.0	20	0	0	5	0	0
SK	5.4	73	63	86.3	9	8	88.9
SI	2.0	20	0	0	5	0	
UK	60.9	1000	950	95.0	175	50	28.6
sub-total	459.2	4136	1245	30.0	1143	88	7.7
other*	36.0	278			81		
Total	**495.2**	**4414**	**1237**	**28.0**	**1223**	**88**	**7.2**
Estimate July 2011**			**1485**	**33.6**		**110**	**9.0**

Source: EU-27 authorities, EUROFEU. * HU, LT, LU, MT, and RO (population = 36 million). ** Estimate: number of personnel/companies certified as of January 2011 plus 20%.

High-voltage switchgear

Personnel carrying out recovery of F-gases from high-voltage switchgear have to be certified according to (EC) No 305/2008.[152]

By July 2011, 17 Member States had provided notification to the Commission of their certification systems for this sector (cf. tables 4-2 and 4-3).[153] 8 Member States had not

[152] The Regulation does not provide an explicit "interim certification system". However, according to Art 3(3) of this Regulation, Member States may decide that personnel undertaking the described activity before 4 July 2008 shall be deemed certified (transitional regulation) up to 4 July 2009 at the latest.
[153] These Member States are AT, BE, BG, CY, CZ, DE, ES, FI, HU, IE, LT, NL, RO, SE, SK, SI, and UK (table 4-2).

notified yet[154]. Two Member States (Denmark and Estonia) explained their decision not to set up a national certification system and use the possibility of certification abroad.[155]

<u>Status of definitive certification of personnel:</u> In cooperation with experts from T&D Europe and based on data reported from Member States the total number of personnel to be certified in the High Voltage Switchgear sector in EU-27 has been estimated at 3,000 persons (Table 4-7).[156]

Table 4-7: HVS sector – Status of certification according to (EC) No 305/2008 (July 2011)

	Population (million)	Total personnel subject to certification requirements	Fully certified personnel	
			Absolute number	% share
AT	8.3	45	34	75.6
BE	10.6	45	23	51.1
BG	7.7	20	9	45.0
CY	0.8	6	3	50.0
CZ	10.3	60	60	100
DE	82.3	1150	1148	99.8
DK	5.4	60	40	66.7
EE	1.3	10	2	20.0
EL	11.2	10	1	10
ES	44.5	80	9	11.3
FI	5.3	50	42	84.0
FR	63.4	210	0	0
HU	10.1	10	0	0
IE	4.3	35	35	100
IT	59.1	250	21	84.4
LT	3.4	10	2	20.0
LU	0.5	10	7	70.0
LV	2.3	10	0	0
MT	0.4	2	0	0
NL	16.3	126	126	100
PL	38.2	50	7	14.0
PT	10.6	15	4	26.7
RO	21.6	10	0	0
SE	9.0	100	42	42.0
SK	5.4	100	91	91.0
SI	2.0	40	30	75.0
UK	60.9	450	404	89.8
total	**495.2**	**2964**	**2140**	**72.2**

Source: EU-27 authorities, T&D Europe.

[154] These Member States are EL, FR, IT, LU, LV, MT, PL, and PT.
[155] In contrast, training centres have already been in place and operating in some of the Member States in which the certification system still had to be installed and thus participation in training courses was not yet compulsory. For example, in France, 170 persons out of 210 persons to be certified had passed a training course already in November 2010. However, as regulations for this sector had been lacking, it was not possible to issue personnel certificates. Information provided by T&D Europe.
[156] This estimate is based on information from industry and competent authorities from all EU-27 Member States.

The share of certified personnel out of all personnel subject to certification provisions in this sector is estimated at 72%, which is much higher than in other sectors. Nevertheless, differences between Member States are also significant: In 14 Member States the rate is <50%, in 13 Member States ≥50%.

The high level of certification results from some peculiarities of the high voltage switchgear sector:

– A high degree of concentration of equipment manufacturers in EU-27, close cooperation between equipment manufacturers and utilities; close cooperation of the industry with regard to training and certification; training and certification schemes are often linked to equipment manufacturers and servicing companies. As major equipment manufacturers are based in Germany, almost 50% of all personnel certificates were issued in Germany (including >200 certificates for personnel from 18 other Member States).

– The majority of personnel to be certified are active in Germany, France, Italy, the Netherlands and the UK. 82% of the certified personnel are from three countries (DE, NL, and UK). In these Member States, high certification quotas of 90-100% had been achieved. In contrast, final certification had not yet started in France and Italy.

– Certification in other Member States is of high importance in this sector. From at least two thirds of the EU-27 such cross-border certification has been reported. It shows that also personnel from Member States without notification and/or without training and certification system in place can be certified. More than 200 technicians from 18 Member States have been certified in Germany in late 2010[157]. Out of the 970 personnel certificates issued in EU-27 for personnel not originating from Germany 22% were issued in Germany.

– A delay in implementing the required certification system does not necessarily mean a lack of training. The standard of qualification and training within the high-voltage switchgear industry is high since voluntary agreements aiming at reductions of SF_6 emissions from equipment had been in place in some Member States (DE, ES, and FR; see chapter 3.2) before the F-gas Regulation entered into force. These voluntary approaches also included training and qualification of personnel. T&D Europe underlines that manufacturers of high-voltage switchgear equipment and utilities already had their system to train people in charge of handling SF_6. “SF_6 training is only part of a larger training package given to personnel handling HV equipment.” (T&D Europe)

F-gas based solvents

As of 4 July 2011, 11 Member States had notified for this sector.

F-gas based solvents are not in use in at least 17 Member States (cf. tables 4-2, 4-3)[158]. In one of them (DK) the use of F-gas based solvents is prohibited. This matches the information given by the manufacturer of the main HFC solvent, DuPont. The company communicated sales to 9 Member States in 2008 (see Annex III. 20).

On the basis of Art 6(2) of Commission Regulation (EC) No 306/2008, if F-gas based solvents are not used in a Member State, the Member State may decide to not designate the

[157] Larger groups came from DK (40), CZ (28), IE (35), AT (18), FI (16), and IT (14).
[158] These are AT, BE, BG, CY, CZ, EE, HU, IE, LT, LV, MT, NL, RO, SE, SK, and SI.

requested certification or evaluation body until the need for such certification arises. In this case Member States shall provide for the necessary arrangements under their national legislation in order to ensure the timely issuance of such certificates in case such certification would be requested in the future. 8 Member States made use of this option.[159]

Final notifications or statements concerning the solvents sector (with regard to Article 6(2)) were lacking from 8 Member States. Only one active training centre according to (EC) 306/2008 was identified and is located in the UK.

Status of certification of personnel: F-gas based solvents are used at least in 3 Member States including France, Poland and UK. The number of personnel subject to certification requirements is estimated at 160 persons in these Member States out of which ca. 100 persons are active in UK (table 4-8).[160] In France, where also high quantities of HFC-based solvents are used, no training and certification body could be identified in 2011. Therefore, relevant personnel will likely be trained abroad in the future. In Poland one company using F-gas based solvents will organize in-house training.

Out of the remaining 7 Member States Germany and Finland explained that F-gas based solvents played no important role. Thus it is assumed that at maximum 170 persons are subject to certification provisions.

In total, over 50% out of the 170 persons subject to certification requirements have been certified already (all in UK).

Table 4-8: Solvents sector – Status of certification according to (EC) No 306/2008 (July 2011)

	Population (million)	Total personnel subject to certification requirements	Fully certified personnel	
			Absolute number	% share
FR	63.4	50	0	
PL	38.2	10	0	
UK	60.9	100	92	
Sub-total	162.5	160	92	57.5
"no use"*	119.2	0	-	-
Other**	213.5	10	0	
total	**495.2**	**170**	**92**	**54.1**

Source: EU-27 authorities. *17 Member States; **DE, EL, ES, IT, FI, LU, and PT.

Recovery of F-gases from AC systems in motor vehicles

Personnel carrying out recovery of F-gases from air conditioning systems in motor vehicles falling within the scope of Directive 2006/40/EC must hold a training attestation according to (EC) No 307/2008.[161]

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[159] These Member States are AT, CZ, DK, EE, IE, LT, NL, and RO (cf. table 4-2 and 4-3).
[160] Defra/UK, 2 November 2010.
[161] According to Art 2(3) of this Regulation, Member States had the possibility to decide that until 4 July 2010 at the latest, personnel holding an attestation issued under existing qualification schemes for the activity within the scope of this regulation or personnel with professional experience in this activity acquired before 4 July 2008 should be considered appropriately qualified to carry out the mentioned activity (transitional arrangement).

Status of personnel attestation: As of July 2011, 20 Member States had been in compliance with notification obligations; final notifications and the possibilities for attestation of personnel were missing from 7 Member States (cf. tables 4-2 and 4-3).[162]

Table 4-9: MAC sector – Status of attestation according to (EC) No 307/2008 (July 2011)

	Population (million)	Total personnel subject to certification requirements	Fully certified personnel	
			Absolute number	% share
AT	8.3	3,500	1,750	50.0
BE	10.6	8,000	6,000	75.0
CY	0.8	360	140	38.9
DE	82.3	70,000	49,000	70.0
DK	5.4	7,000	3,500	50.0
EE	1.3	430	258	60.0
FI	5.3	6,350	6,350	100.0
FR	63.4	40,000	40,000	100.0
HU	10.1	3,000	600	20.0
IT	59.1	58,000	0	0
NL	16.3	7,400	7,350	99.3
SE	9.0	2,500	2,500	100
SK	5.4	900	675	75.0
SI	2.0	2,000	510	26.0
UK	60.9	50,000	26,656	53.3
sub-total	340.2	259,440	145,289	56.0
other*	155.0	100,801	10,080	10.0
total	**495.2**	**360,241**	**155,369**	**43.1**

Source: EU-27 authorities. *: BG, CZ, EL, ES, IE, LT, LU, LV, MT, PL, PT, and RO (population = 155.0 million).

The total number of personnel to be certified in the MAC sector in EU-27 (cf. table 4-9) has been estimated at about 360,000 persons.[163] In the 15 Member States who had submitted detailed information, it is known that by July 2011 ca. 145,000 persons held their final attestation, which equals ca. 56% of the personnel subject to attestation requirements. In the other Member States, some of which have not notified yet, it is expected that about 10% of the total personnel subject to attestation requirements hold attestations. Therefore, the total share of personnel holding attestations in EU-27 is estimated at about 43%.

In the mobile air conditioning sector, large differences between Member States are to be noted. While the level of attestation is high (50->90%) in 12 out of the 15 Member States with detailed data, it is comparably low (<50%) in 3 of them. In at least 7 Member States, attestation does not take place yet (attestation bodies not yet notified).

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[162] These are EL, IT, LU, LV, MT, PL, and PT. (In Denmark, attestation bodies had been identified but not notified, and training and attestation were carried out in 2010 already.)

[163] This estimate is based on data from industry and competent authorities from 15 Member States. Data were extrapolated for the remaining 12 Member States (BG, CZ, EL, ES, IE, LT, LU, LV, MT, PL, PT, and RO). Population in the 15 Member States who submitted detailed information represent about 69% of the total population in EU-27. The estimate determines the number of service workshops and the stock of servicing equipment for mobile air conditioning systems contained in motor vehicles and was carried out in order to complement data from Member States.

4.2.3 Other issues related to Article 5

Training and certification abroad: Notification of certification bodies and the use of training facilities in other Member States are only important in the high voltage switchgear sector. As outlined above, this is the sector with the largest share of foreign certification relevant for two thirds of the Member States. Until 30 November 2010, more than 200 certificates for personnel from other 18 Member States were issued in Germany (10% from all certificates issued in EU-27). This is due to the small number of personnel to be certified in this sector in most Member States, the rather high costs for special equipment and related high costs for certification as well as the close cooperation of switchgear manufacturers and utilities.

In other sectors training and certification in other Member States play a minor role. In few cases, small Member States notified certification bodies in other Member States or personnel from small Member States were trained and certified in other Member States. In the solvents sector, France is considering this possibility. In the stationary refrigeration, air conditioning and heat pump sector, certain companies operating in several Member States also took the opportunity to train and certify their personnel together with personnel from the parent company in one Member State.

In all sectors, training and certification in other Member States is de-facto limited by language barriers.

Recognition of certificates: There is no information on serious problems related to the recognition of certificates. In few cases minor problems were highlighted concerning the following issues:

- Language problems related to certification abroad and certificates, which were issued abroad (requirement for translation of certificates into national language).
- Insufficient transparency of compliance of certificates gained abroad with the EU minimum requirements.

Validity of certificates: The Commission Regulations (EC) No 303-307/2008 which establish the minimum requirements for certification of personnel and companies do not specify a validity period for the certificates. The Member States may decide whether the validity of the certificates should be limited and what the validity period should be.

Out of 20 Member States who had submitted final notifications, 10 had decided to limit the validity of personnel and company certificates (table 4-10). The validity period of personnel and company certificates vary widely:

Personnel certification is valid for 5 years in 7 Member States and for 3 years in 1 Member State (Slovakia) but this does not always apply to all sectors.

In France, the validity of personnel certificates according to Regulations (EC) No 303/2008, No 304/2008 and No 307/2008 (attestation) is not limited but checked every 5 years during regular audits which link company certification to certification of personnel. In Belgium and UK, only personnel certificates in the stationary refrigeration, air conditioning and heat pump sector are of limited validity. In the UK, personnel certificates with limited validity and certificates with unlimited validity coexist.

Article 5(4), delivery of F-gases only to certified personnel: According to Article 5(4) and by 4 July 2009, Member States shall ensure that the companies involved in carrying out the activities provided for in Articles 3 and 4 shall only take delivery of F-gases where their relevant personnel is certified. While the implementation of provisions according to Article 5(2) (certification) and Article 13 (penalties) is a prerequisite for the application of this provision, no reliable indicators are available to assess its status of application. Member States[164] refer to the respective provisions of national legislation, to national authorities, which are obliged to control compliance with the provisions of the F-gas regulation and to legislation on penalties according to Article 13 in case of non-compliance. Some Member States have set further national stipulations, which pledge the F-gas distributors to deliver appropriate refrigerants only to appropriately certified enterprises (FR; ES). In France, distributors of fluorinated gases are obliged to check whether the operator that takes delivery of F-gases is certified or not. To facilitate this check, the lists of certified companies are published on the internet. Penalties apply to F-gas distributors *and* the operator in case of F-gas delivery to a non-certified customer.

Joint certification systems for F-gases and ODS: According to the ODS Regulation (EC) No 1005/2009 (recast which replaced Regulation (EC) No 2037/2000), Member States shall define minimum qualification requirements

- for personnel carrying out leakage detection and repair activities in the refrigeration, air conditioning and heat pump sector and
- for personnel carrying out leakage detection and repair activities in the fire protection sector and
- for personnel involved in RRRD of ODS.

Under the ODS Regulation, training courses without examination and certification are normally carried out in the Member States. However, in some Member States (e.g. Czech Republic, Hungary, Poland) certification of personnel is required for these activities and a joint certification system for both F-gases and ODS is (CZ, HU) or will be (PL) in force. In Member States which did not implement personnel certification requirements in the context of (EC) 1005/2009 the certification according to F-gas Regulation may be classified as further training covering the requirements of the ODS-Regulation (e.g. Germany).

[164] In the questionnaire under paragraph 4.7, Member States were asked for control mechanisms in order to monitor compliance with the provisions according to Articles 5(3) and 5(4).

Table 4-10: Limitation of the validity of certificates/attestations (January 2011)

	Personnel certificates/attestations	Company certificates
BE	5 years (only SRAC)	3 years (only SRAC, Flemish Region)
BG	5 years always	5 years always
EE	5 years always	5 years always
FR	5 years (only HVS, solvents)	5 years (always incl. MAC)
IE	-	1 year always
NL	-	4 years always
SE	5 years (only SRAC, HVS)	5 years (only SRAC)
SK	3 years always	1 year always
SI	5 years always	-
UK	5 years (only SRAC, one certification body)	3 years (SRAC); 5 years (FPS)
MS without notification		
LV	5 years (planned)	5 years (planned)
PT	planned	Planned
PL	5 years (planned, always, excl. MAC)	5 years (planned)

Validity of company certification according to Regulations 303/2008 and 304/2008 is limited in 9 Member States, 3 other Member States plan to introduce such provisions.

In France, certification requirements were extended to companies of the MAC sector (Regulation (EC) No 307/2008). In Belgium, only one region (Flemish Region) introduced company certificates of limited validity according to Regulation (EC) No 303/2008.

4.2.4 Summary: Status of certification

Based on the information presented above, table 4-11 gives an overview of the status of certification for each sector in July 2011. In EU-27, about 600,000 persons are subject to certification and attestation requirements according to Regulations (EC) No 303-307/2008.

About 60% of the personnel subject to certification/ attestation requirements work in the mobile air conditioning sector (ca. 360,000 persons), 38% in the stationary refrigeration, air conditioning and heat pump sector (ca. 230,000 persons). The remaining 2% consists of personnel active in the fire protection sector (ca. 4,500 persons), the high voltage switchgear sector (ca. 3,000 persons) and the F-gas based solvents sector (up to 200 persons).

In July 2011, the share of personnel holding final certification/attestation out of the personnel subject to certification/attestation requirements, as of 4 July 2011, is estimated at ca. 48% in the stationary refrigeration, air conditioning, heat pumps sector and at ca. 43% in the mobile air conditioning sector. The average values for both large sectors for EU-27 include large differences between Member States: While in some Member States the provisions for final certification of Article 5 of the F-gas Regulation are neither implemented nor applied yet, in some other Member States (more than 50% of the personnel with definitive certification/ attestation in 15 Member States), final certification/attestation is progressing well.

Table 4-11: Status of certification according to (EC) No 303-307/2008 (July 2011)

Sectors	**Certification/attestation of Personnel**				**Certification of Companies**	
	Total personnel subject to certification requirements		Fully certified personnel	Member States with >50% personnel fully certified	Total companies subject to certification requirements	Fully certified companies
	Absolute number	% by sector	% share		Absolute number	% share
SRAC/HP	228,000	38.3	48	15	65,000	43
FPS	4,500	0.8	34	6	1,300	9
HVS	3,000	0.5	72	14	-	-
Solvents	170	<0.1	54	(1)	-	-
MAC	360,000	60.4	43	15	-	-
total	**595,670**	**100**			**66,300**	

The share of personnel already certified in the fire protection sector is estimated at 34% in EU-27. The differences between Member States are larger than described for the stationary refrigeration, air conditioning, heat pumps and mobile air conditioning sectors. The share of certified personnel is much higher in the high voltage switchgear sector, which is linked to some particularities of this special industry (inter alia high level of previous qualification concerning the handling of SF_6, high degree of concentration and cooperation between companies). However, the differences between Member States are also significant and low certification rates would be found in about half of the Member States. The F-gas based solvents sector takes a special role: These solvents are only used in few Member States and personnel had been certified only in UK so far.

Company certification is only required for the stationary refrigeration, air conditioning and heat pump sector as well as the fire protection sector. The number of companies working in the stationary refrigeration, air conditioning and heat pump sector is estimated at 65,000 out of which ca. 43% hold final company certification in July 2011. In the fire protection sector, the number of relevant companies is estimated 1,300 of which less than 10% held final company certification in July 2011.

In general, it has to be noted that the status of certification depends not only on the compliance of industry to the provisions of the Regulation but also on the activity of Member States in implementing the Regulation, its enforcement and control.

In the stationary refrigeration, air conditioning and heat pump sector, the interim period for certification ended on 4 July 2011. Until then, most Member States had not reached full certification of personnel and companies as required. However, it should be noted that the qualification of personnel is in fact higher than indicated by the average certification quota. This relates to the delay of notification of certification bodies in some Member States while trainings of personnel according to the F-gas Regulation have been carried out already.

4.2.5 Application of containment provisions (Art 3)

Article 3 (containment) of the F-gas Regulation covers the following applications:

- stationary refrigeration, air conditioning and heat pump equipment (including their circuits), and
- stationary fire protection systems.

The article establishes measures to prevent leakage of fluorinated gases and to repair any detected leakage as soon as possible. Operators of such equipment are required:

- to ensure regular leakage checks,
- to install leakage detection systems (in applications containing ≥300 kg fluorinated greenhouse gases) and
- to maintain records ("logbooks") on quantities and type of F-gases installed, added and recovered and on other relevant information.

Article 3(2): Leakage checks

Article 3(2) requires operators of the above mentioned applications referred to in paragraph 1 of Article 3 to ensure that leakage checks are carried out by certified personnel complying with the requirements of Article 5 of the F-gas Regulation, and according to a specific schedule:

- applications containing ≥3 kg of fluorinated greenhouse gases: at least once every 12 months;
- applications containing ≥30 kg of fluorinated greenhouse gases: at least once every 6 months;
- applications containing ≥300 kg of fluorinated greenhouse gases: at least once every 3 months.

Where a properly functioning appropriate leakage detection system is in place, the frequency of the checks required shall be halved (applications ≥30 kg and ≥300 kg, Art 3(4)).

Equipment with hermetically sealed systems, which is labelled as such and contains less than 6 kg of fluorinated gases is exempt from these provisions.

Regular leakage checks according to Article 3(2) became compulsory as of July 2007.

Stationary refrigeration, air conditioning and heat pumps

In general, before the entry into force of the F-gas Regulation leakage checks at large systems with particularly high emission factors (commercial and industrial refrigeration) were carried out more or less regularly in the framework of service contracts in the stationary refrigeration, air conditioning and heat pump sectors. However, this was not a common practice in small systems and appliances (charges <30 kg). There is no quantitative data available on the extent of leakage controls prior to the entry into force of Regulation (EC) No 842/2006.

In some Member States regular leak checking is enhanced by national legislation:

- According to Austrian legislation[165], regular checks have been obligatory "for many years" (at least annually). Following the Regulation's entry into application, intervals have to be shorter, depending on charge.
- In Bulgaria regular leakage checks of F-gas refrigeration and air conditioning systems ≥3 kg are compulsory at least annually since 2002[166].
- Germany reported a delay for the refrigeration and air conditioning sector because the national requirements for personnel carrying out leakage checks were not laid down before 1 August 2008. However, it was also stated that annual checks have always been compulsory for stationary fire extinguishers in order to maintain insurance coverage[167].
- Danish legislation[168] requires that pressurized refrigeration and heat pump equipment containing charges >1 kg is subject to periodic examinations.
- French national legislation[169] prescribes periodical control of the installation for stationary refrigeration, air conditioning and heat pump equipment containing charges of ODS or F-gases >2 kg in order to prevent leakage (at the same frequencies as in Regulation (EC) No 842/2006).
- The Netherlands underline that for stationary refrigeration and air conditioning systems "the same regime has been in place … since 1997" and that the frequency of leakage checks performed is generally well in line with the requirements of the F-gas Regulation (>90% as reported in 2007 and 2008). With regard to the fire protection sector, due to insurance and safety policy in the Netherlands a safety check regime is required in line with the provisions of the F-gas Regulation.
- According to the Swedish authorities, annual checks of stationary refrigeration, air conditioning and heat pump equipment have been required since 1989.

These Member States are among the group of countries which notified (interim) certification schemes relatively early (except Bulgaria). They all had finally notified in 2009.

Representatives of the stationary refrigeration, air conditioning and heat pump industry[170] were asked in a more detailed way about their experiences with leakage checks. Information

[165] Austrian Kälteanlagenverordnung BGBL. Nr. 305/1969.

[166] Amendment to the Bulgarian Ordinance on ODS, State Gazette No 96/2002.

[167] A few years ago shorter intervals depending on the size of the system had been laid down by the licensing institution VDS Schadenverhütung GmbH.

[168] Danish Executive Order No. 100 issued by the Danish Working Environment Authority (in force since 15 February 2007).

[169] French arrêté of 7 May 2007.

[170] Data from AREA, EPEE and ECSLA. The "Air conditioning and Refrigeration European Association" (AREA) is an organisation of air conditioning, refrigeration and heat pumps contractors in Europe. The association is active in 20 European countries and represents according to their own information more than 9,000 companies, mainly small to medium sized enterprises. EPEE – "European Partnership for Energy and the Environment" – is an industrial association composed of internationally operating companies who produce, design and install heating, cooling and refrigeration technologies. ECSLA: European cold storage and logistics Association.

has been provided by small and medium contractors in this sector from several Member States[171].

- Industry estimates that since 2009 leakage checks in equipment containing charges of ≥30 kg are carried out more or less regularly. The industry associations have no empirical data but rely on experience and the qualitative judgement of their members.

- Prior to entry into force of the F-gas Regulation, in this sector fewer checks were carried out, unless there was a specific problem e.g. decrease of performance leading to investigative work and suspicion of refrigerant shortage. AREA estimates that with regard to equipment containing refrigerant charges ≥30 kg "the number of leak checks increased substantially" since 2009.

The association AREA communicated the status of compliance in different sub sectors as follows.

Table 4-12: Status of compliance with requirements for leakage checks according to Article 3(2) by sectors and sub sectors

Sectors	**Compliance with requirements of Article 3(2) of Regulation (EC) No 842/2006**
Supermarkets	
„major supermarkets"/big chains	Mostly compliant
Smaller supermarkets	Less compliance
Small commercial applications	Mostly very little regular checking
Large commercial applications	
Hospitals, public buildings	More likely to fully comply
Private sector	Depends (on nature of the business, whether other regular checks are made compulsory or not, maintenance contract exist etc.)
Industrial applications	More likely to comply (often other mandatory inspections, tighter rules and regulations)

Source: Questionnaire to contractors, AREA 2010

Table 4-12 shows that compliance with obligations for leak checks can be expected to a higher degree for large companies and for large equipment (large supermarkets, major public and private enterprises such as hospitals, industrial facilities) rather than for small shops or small equipment.

Further findings of the survey confirm that the reality and the trend of frequency of leak checks differ between small and large industries and between regions.

- Small industries (small contractors, charges from ≥3 kg to ≥30 kg): In the past the frequency of leak detection did "depend on the leaks" or on the maintenance contract. In the past 10 years (before and after entry into force of the F-gas Regulation) the number of leak checks increased only slightly.

- Larger industries (Internationally operating manufacturing and service companies, charges from ≥3 kg to ≥300 kg): Frequencies of leakage checks are reported to be more or less in compliance with the F-gas Regulation only in some Member States (e.g. Germany, the Netherlands, and Great Britain). From other Member States (e.g.

[171] These Member States include: AT, BE, CZ, DK, DE, EL, ES, FI, FR, HU, IE, IT, NL, PL, PT, SE, SK, and UK.

EL) low awareness and no enforcement is reported. For the first group of Member States a slight increase in leak checks is registered (e.g. DE, FR, UK; Baltic; in the Netherlands the number of leak checks remained stable, for Poland an significant increase is estimated.)

– As for the cold storage and logistics sector, ECSLA reports that most companies in France, Germany, Netherlands and Spain carry out regular leakage checks twice a year, in France and Germany since approximately 2000. The number of leak checks remained stable in France, Germany, and the Netherlands over the past ten years and increased slightly in Spain (+10%).

Based on the information available and with regard to early 2010 it can be concluded that leak checks in this sector must increase by at least 50-100% to meet the requirements of Art 3(2).

Fire protection sector

In this sector, the above mentioned schedule for leakage checking is compulsory. Article 3(5) of the F-gas Regulation specifies that if an existing inspection regime is in place to meet ISO 14520 standard, these inspections may also fulfil the requirements as long as the inspections are at least equally frequent.

In contrast to the provisions of the F-gas Regulation, ISO 14520[172] is a voluntary international standard which was introduced in 2000. This norm requires systems (including systems with F-gas charges < 3 kg) to be checked regularly. It was widely adopted as European norm EN 15004[173]. According to ISO 14520 and EN 15004 all systems shall be thoroughly inspected at least annually. At least every 6 months, the contents of the containers shall be checked. If the halogenated extinguishing agents are filled into the containers and losses of more than 5% or a loss in pressure (adjusted for temperature) of more than 10% occur, the container shall be refilled or replaced.

Representatives of the fire protection[174] industry were asked in a more detailed way about their experiences with regard to leakage checks. In the fire protection sector leakage control is widespread to ensure proper functioning of the systems.

Data on the percentage of fire protection systems subject to regular leakage checks as of January 2010 have been provided by the fire protection industry[175] for Germany and the UK (table 4-13).

Table 4-13: Status of regular leakage checks according to Art 3 for fire protection systems

	Percentage of systems with regular leakage checks in compliance with Art 3 [%]		
	Systems ≥3 kg	Systems ≥30 kg	Systems ≥300 kg
DE	50	70	90
UK	100	100	100

Source: Questionnaire to fire protection industry

[172] ISO 14520: Gaseous fire-extinguishing systems - Physical properties and system design.
[173] EN 15004: Fixed fire fighting systems - Components for gas extinguishing systems.
[174] Data is from EUROFEU (a section of Fire Extinguishing Installations) for Germany and UK and from two companies from Italy and Estonia. EUROFEU represents National Trade Associations of the European fire protection industry from a total of 10 EU Member States, amongst them 5 with a section „Fire Extinguishing Installations“(BE, DE, FR, NL, and UK). ASSURE. European Association for Responsible Use of HFCs in Fire Fighting did provide a general statement.
[175] Input from EUROFEU, section Fire Extinguishing Installations.

UK experts report that this high level of compliance was related to the routine of application of ISO 14520 and state that leakage checks were undertaken every 6 months. For Germany, industry indicates mostly annual or semiannual leakage checks for all types of equipment (charges from ≥3 kg to ≥30 kg). Industry claims that the frequency of leakage checks remained relatively stable since the entry into force of the F-gas Regulation (EUROFEU: DE, IT, UK; ASSURE).

Available information indicates that leakage checks must increase by at least 25% in this sector to meet the requirements of Article 3(2). This information corresponds to statements made by experts from industry (EUROFEU).

Article 3(3): Leakage detection systems

Operators of the applications referred to in Article 3(1), containing F-gas charges ≥300 kg, shall, according to Article 3(3), install leakage detection systems. These leakage detection systems shall be checked at least once every 12 months to ensure that they are working properly. In the case of fire protection systems installed before 4 July 2007, leakage detection systems shall be fitted by 4 July 2010.

According to Article 3(4) the frequency of the checks required for applications containing ≥30 kg and ≥300 kg of fluorinated greenhouse gases – Article 3, paragraphs 2(b) and (c) – shall be halved where a properly functioning appropriate leakage detection system is in place.

The installation of leakage detection systems required by the F-gas Regulation became compulsory as of July 2007 (exception: fire protection systems installed before 4 July 2007, as mentioned above).

Stationary refrigeration, air conditioning and heat pumps

In this sector around 20 % of commercial centralized refrigeration systems, i.e. the small and large industrial refrigeration units and AC centrifugal chillers are concerned by Article 3(3) (according to the model AnaFgas).

The mainly small to medium sized contractors in this sector have no detailed information on the extent of installed leakage detection systems and estimate that only few systems may have been introduced in this sector. Also, large internationally operating manufacturing and service companies report relatively small numbers of installed leakage detection systems. They characterize the use of such systems in Great Britain and France as mediocre, and in the Netherlands, and Germany even less.[176] Data from other Member States were not available. However, most of the companies describe an increasing trend since the entry into force of the F-gas Regulation.

Authorities from some Member States expressed the need for more guidance on technical specifications of leakage detection systems.[177] The main issue seems not to be the availability of detection systems but their accuracy. Enquiries show that there is still uncertainty amongst operators about what types of leakage detection systems are accepted

[176] In contrast, the cold storage industry is according to the Branch association ECSLA well equipped with leakage detection systems, and in most cases these have been in place for a long time (data from Germany, France, Greece, the Netherlands, and Spain).
[177] These Member States include BE, DE, FR, and PT.

by the authorities. Due to this uncertainty, systems are not installed and so the frequency of checking procedures pursuant to Article 3(4) cannot be halved.

According to the information available leakage detection systems are rarely installed in this sector. Therefore, the cost assessment is based on the assumption that installation of leakage detection systems at equipment containing charges ≥300 kg is generally required in this sector to meet the provisions of Article 3 (3) of the F-gas Regulation.

Fire protection sector

More experience on the use of leakage detection systems for the fire protection sector [178] is available in some Member States. Large stationary fire protection systems were already subject to leakage checks stipulated by property insurances before entry into force of the F-gas Regulation[179].

The percentage of fire protection systems with leakage detection systems installed according to Article 3(3) of the F-gas Regulation (i.e. applications containing ≥300 kg of fluorinated greenhouse gases, erected after 4 July 2007) was indicated by industry at 99% in Germany and at 75% in UK. Hence, such detection systems are “widespread”. The UK-representatives stated the view that it is “sometimes difficult to install leakage detective systems retrospectively on older systems”.

At the same time the survey with experts from industry (EUROFEU) showed that ISO standard 14520 is prevalent throughout Europe in this sector. This applies to standard EN 12094, too (also see chapter 3).[180]

Thus, it is assumed for the cost assessment that the installation of leakage detection systems at fire protection systems is not necessary.

[178] “All containers used to store extinguishing agents in fixed fire protection systems are required to have a leakage detection system fitted as standard. (…) These leak detectors are of two kinds: the majority are pressure gauges but weight monitoring systems are also used, so that the detector indicates either a loss of pressure or weight if a leakage occurs, depending on the type used.
New fire protection systems over 300 kg manufactured since 2003 have alarm systems fitted that automatically alert the operator if a leak occurs. (…) Some older systems also have retrospectively fitted alarms. However, under Article 3 of the Regulation, operators of fixed fire protection systems containing more than 300 kg of HFCs have until 4th July 2010 to fit an alarm system. These larger systems are in a minority and our impression is that retrospective fitting of alarm devices to older systems (some of which already have them) is proceeding to schedule.”
ASSURE, Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases. Response to Öko-Recherche GmbH Questionnaire on Fire Protection Systems, May 2010. For technical aspects cf. BFPSA (British Fire Protection Systems Association), Guidance Note EC Regulation No 842/2006 on Certain Fluorinated Greenhouse Gases, 7-08-06, p. 6.

[179] Examples: Austria and Germany: checks by weighing the containers; monitoring the gas supply by pressure measurements has also been permitted for some time.

[180] EN 12094: Fixed fire fighting systems - Components for gas extinguishing systems. Of special relevance is Part 4: Requirements and test methods for container valve assemblies and their actuators.

Article 3(6): Records

Operators of the applications referred to in Article 3(1) containing F-gas charges ≥3 kg shall maintain records on the quantity of F-gases installed, added, and recovered. They shall also maintain records of other relevant information described in detail in Article 3(6) and in Article 2 of (EC) No 1516/2007 (stationary refrigeration, air conditioning, heat pumps) and (EC) No 1497/2007 (fire protection sector). These records shall be made available upon request to the competent authority and to the Commission.

Status of record keeping and analysis of records by Member States

The survey undertaken within this project investigated the status of record keeping by operators and whether the authorities request these records for control purposes.

Records are kept either on paper and/or electronically[181].

The survey shows that authorities although they request records for control purposes usually do not analyse the records in a systematic and comprehensive manner. The authorities from 16 Member States report that they requested in the past "representative samples of records … in order to review them" (table 4-14) at least "during inspection campaigns", "in some cases" or "only when the compliance of the operator is being checked". The checks are conducted by environmental inspectorates, local health authorities, occupational health authorities, fire brigades (in case of the fire protection sector) etc. 10 Member States answered that they have not requested records for inspections so far (2 Member States: no data).

Table 4-14: Analysis of records according to Article 3(6) by EU-27 authorities

	Number of Member States		
	Yes	No	Not reported
Records requested	16	10	1
Records analysed	4	21	2
National assessment report	2	24	1

Source: Questionnaires to EU-27 authorities.

Only 4 Member States explained that they had analysed the records to some extent.[182] Finally, 2 Member States have prepared national assessment reports on the results of their inspections in former times (the Netherlands, NOKS-report from 2000) or recently (Latvia), but these reports are not based on systematic evaluation of record keeping by the operators of the equipment. 2 Member States are planning such assessments (Germany and Luxembourg).

Analyses of records show – as far as results are reported – that they do not always include all necessary data and often are not completed correctly. The quality of record keeping depends not only on the awareness of the operators and qualification/certification of personnel but also on enforcement and control by authorities. This correlation is also confirmed by industry.[183]

[181] Records: In 11 Member States only or "mostly" on paper; in 12 Member States records both on paper or in electronic format are possible, in 2 Member States only electronic records. 2 Member States have recently introduced electronic records. No data from 2 Member States.
[182] These Member States are BE (Flemish Region), BG, LV, and NL.
[183] Statement from AREA: "In general, the lower the enforcement, the more customers are reluctant to spend any money on having logbooks prepared."

Stationary refrigeration, air conditioning and heat pumps

The survey among industry (1st quarter of 2010) revealed that frequency and quality of record keeping vary strongly by size and type of companies and shows high differences between regions.

– Record keeping is more common or widespread amongst supermarket operators (chains, franchised stores), major public institutions like hospitals and in general in industry (food processing, chemical and pharmaceutical, cold stores and logistics etc.).

– Records are rare among operators of small supermarkets (groceries, convenience shops), shops with light commercial equipment (e.g. bakeries, butchers, restaurants, flower shops), shopping malls, leisure institutions (sports, cinema etc.), and office buildings (banks, insurances), hotels or canteens.

– An estimate of the percentage of operators maintaining records is shown in table 4-15. It summarises estimates from five Member States, based on the expertise from seven companies. The share is relatively high among operators of equipment in the sector of industry (40->80%), large supermarkets (40->80%), large commercial applications (hospitals, banks, insurances etc.: 40-70%) and rather low among operators of small shops and businesses relying on small commercial equipment.

Table 4-15: Shares of operators maintaining records according to Article 3(6)

"Do the operators who are customers of your company and who own systems above 3 kg charge have logbooks on their installation?"	DE*	UK**	FR***	ES*	EL*
Supermarkets					
Large (chains)	5	5	3-4	3	3
Small (franchised stores; groceries, convenience stores etc.)	n.a.	2	2	1	1
Small commercial applications	3	1	1-2	1	1
Large commercial applications					
Hospitals, banks, insurances, hotels, shopping malls	4-5	4	3-4	4	4
Canteens, Leisure (sports, cinema)	4	2-3	n.a.	1	1-2
Industrial applications	4-5	5	4-5	3-5	4-5

* Clients of one company; ** clients of three companies; *** one company plus AFCE. n.a.: no answer
1: Few operators (<20%) have records; 5: All operators (≥80%) have records.
Source: 7 installer and service companies and national associations (EPEE member)

– According to large internationally operating manufacturing and service companies in this sector, ca 50% of their customers in France and UK maintain records. Belgian contractors from the small and medium sub sector (charges of ≥3 kg to ≥30 kg) likewise confirm that <50% of their clients maintain records.

– One internationally operating manufacturing and service company provided an estimate of frequency of record keeping in percentage of operators for some Member States (own clients of the company excluded) as follows: The Netherlands = 100%, Germany = 70%, Great Britain = 60%, Spain = 10%, Greece = nearly 0%.

– Records often are not kept in an accurate manner. Table 4-16 shows the judgement of industry experts on the quality of records kept by operators in 3 Member States (UK, FR, IT). The data represent the top level of accuracy, because these installers and service companies and associations mostly work for medium and large operators which were generally found to be more compliant than small companies.

Table 4-16: Quality of records (FR, UK and IT) – expertise from stationary refrigeration, air conditioning and heat pump industry

"How precisely are the logbooks filled in with regard to":	FR	UK	IT
- Dates and results of leakage inspections and servicing	4-5	4-5	3
- Refrigerant type and quantity by refrigerant circuit	4-5	4-5	1
- Quantities recovered/added during service, repair, disposal	4	4	3
- Identification of company, technician, certifications	4-5	4	5*

1: not precise (<20%); 5: very precise (≥80%); * no certification in place
Source: Seven installer and service companies and national associations (EPEE member)

Records from cold storage industry are assumed to be precise or very precise, according to the relevant association (ECSLA members, FR, DE, NL, and ES).

Fire protection sector

The fire protection industry from Great Britain and Germany (installers and service companies) estimate that about 50% of the operators of systems (charges ≥3 kg) maintain records according to Article 3(6) of the F-gas Regulation. Industry comments that the low but increasing figure represents the ongoing replacement of existing records according to ISO 14520 by those containing the text required by Regulation (EC) No 842/2006.[184]

Awareness of operators of obligations according to Article 3

The awareness of the operators is important for all measures of containment.

It was generally communicated by industry stakeholders that operators' compliance and awareness of the requirements of the F-gas Regulation is highly dependent on enforcement by authorities.

Stationary refrigeration, air conditioning and heat pumps

Based on discussions with industry experts from small and medium-sized contractors as well as from large international service companies in this sector, about 50% of the operators do not know about their obligations.

A clear difference in awareness between large companies and operators of large plants (industry, large supermarkets, and large commercial applications) on the one hand and small companies and operators of small equipment on the other hand has been stated. The awareness is low in the sector of small equipment with low refrigerant charges, but relatively high among operators with large equipment.

Differences between segments/applications of F-gases are indicated in table 4-17:

[184] "ISO 14520 required records of service to be kept for HFC fire protection systems from 2000. There is very little difference between the log books previously required under ISO 14520, and those currently required by EC 842/2006. However, the industry is currently undertaking the transition from previous log books to those that contain the wording according to EC 842/2006. The majority of systems now have the current log book in place." ASSURE, Review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases. Response to Öko-Recherche GmbH Questionnaire on Fire Protection Systems, May 2010.

Table 4-17: Awareness of operators of obligations according to Art 3

"Are the operators aware of their obligations?"	**DE***	**UK****	**FR*****	**IT******	**ES***
Supermarkets					
- Large (chains)	5	5	4	4	3
- Small (franchised stores; groceries, convenience stores etc.)	4	2	2	1	1
Small commercial applications	4	1-2	1	1	1
Large commercial applications					
- Hospitals, banks, insurances, hotels shopping malls	4-5	4-5	4	4	4
- Canteens, Leisure (sports, cinema)	4	3	3-4	2-3	1-2
Industrial applications	5	5	5	4-5	4

* HVAC/HP, clients of one company; **SRAC/HP, clients of three companies; *** SRAC/HP, one company plus one national association; **** one national association.
1: Few operators (<20%) aware of their obligations; 5: All operators (≥80%) aware of their obligations.
Source: 7 installation and service companies and national associations (EPEE member)

Similar data are reported by service companies from the Baltic (Estonia) and by contractors from Belgium. Both underline that operators of major applications (such as supermarkets, retails, industrial applications) are more aware of their obligations than operators of small applications (small shops), and they maintain records and perform leak checks more regularly than operators of small applications.

Table 4-17 indicates a north-south gradient in terms of awareness.

Table 4-18, based on additional information, also shows significant differences between Member States.

Table 4-18: Awareness of operators of their obligations according to Art 3 (6 Member States)

Percentage of operators "aware"	**>60% ("4")**	**>40% ("3")**	**>20% ("2")**	**<20% ("1")**
France, Great Britain, Germany	X			
Italy		X		
Spain			X	
Greece				X

1: Few operators (<20%) aware of their obligations; 5: All operators (≥80%) aware of their obligations.
Source: 7 installation and service companies and national associations (EPEE member).

The same is reported about the cold storage and logistics industry: High awareness (>80%) in Germany and the Netherlands, less awareness (>60%) in France and low awareness (<20%) in Spain. The association presumes that awareness is much higher within large companies (>50 employees) than in small ones (data submitted by ECSLA).

Awareness of the provisions of the F-gas regulation is generally considered to be better amongst contractors than among operators.[185] Staff of specialized technical companies (contractors) have better knowledge and higher awareness than staff from companies that

[185] In 2008, in Ireland's SRAC sector, awareness of the F-gas regulation was regarded fairly well amongst contractors ("well aware": 50%) although it was generally felt that most customers had a very poor understanding of the requirements ("well aware": 5%; "not aware": 66%). Awareness was considered to be high amongst multi-national end user companies but not so high at smaller companies. DOEHLG F-gas report 2008: Department of the Environment, Heritage and Local Government: Study on Meeting the Requirements of European Regulation 842 on Certain Fluorinated Greenhouse Gases (F-Gases). A Report by Enviros Consulting Ltd., Dublin 2008, p. 40.

work only occasionally in this sector (mechanical and electrical contractors). Such companies often install AC systems during construction projects, but rarely work in service and maintenance.

It has been reported that the awareness of requirements related to containment measures and record keeping was higher in industrial facilities, especially facilities licensed under Directive 2008/1/EC concerning integrated pollution prevention and control (IPPC Directive), than in small commercial applications (e.g. retail).

Fire protection sector

For the fire protection sector, it is assumed that about two-thirds of the operators in the UK and Germany (from where data has been available) know their obligations (estimate from EUROFEU).

Status of application of containment measures

All in all, the reported qualitative estimates show that the state of application of the provisions on containment widely differs within EU-27. Delay of the application of relevant requirements of the F-gas Regulation is found in most Member States. The extent to which containment measures according to Article 3 are applied in the individual Member States and in the individual stationary applications of F-gases after entry into force of Regulation (EC) No 842/2006 depends on several factors:

- Entry into force of national legislation for certification of personnel and companies;
- Status of implementation of other F-gas related legislation, e.g. IPPC Directive which requires licensing of industrial facilities with high pollution potential;
- Structural disparities between sectors of F-gas applications (SRAC/HP sector: industry, big supermarket chains, large commercial applications vs. small shops, light commercial applications, etc.; the fire protection sector: operators with maintenance contracts vs. service by demand etc.);
- Knowledge/awareness of operators and service companies about the requirements of the F-gas Regulation;
- Intensity of enforcement of the F-gas Regulation and the extent of control and sanctioning in case of infringements.

<u>Leak checks</u>: Leak checks according to Article 3(2) at stationary refrigeration, air conditioning and heat pump equipment are not performed consistently in all Member States. Experts from industry note comparably high compliance of operators of large equipment and low compliance of operators of small equipment.

In Member States, where regular leak checks have already been undertaken on the basis of technical standards, voluntary commitments, or legal obligations, the frequency of leak checks according to Article 3 is higher compared to other Member States.

Industry stakeholders assume that since entry into force of the F-gas Regulation the frequency of leak checks has increased to some extent, however, with considerable differences between Member States. Quantitative information supporting this assumption is not available.

For the fire protection sector a comparably high level of compliance is reported. Leakage checks have already been carried out for a long time on the basis of specific technical requirements (e.g. ISO 14520) and hence an increase of the frequency specifically caused by the F-gas Regulation is not observed.

<u>Leakage detection systems</u> according to Article 3 (3) have been installed rarely so far in the SRAC/HP-sector, pursuant to information from industry experts. Apparently, upgrading of older equipment with leak detection systems takes place to a small extent only. In contrast internationally operating installers and service companies report a trend which indicates slight increase. Only the cold storage industry claims high numbers of equipment with leakage detection systems, which have already been in place over a long time period.

The fire protection sector reports a high rate of installed leakage detection systems. For two Member States a rate of 75% (UK) and 99% (DE) is reported for installations erected after 4 July 2007. Upgrading is often considered difficult. The sector explains the high equipment rate with long term experience of the industry concerning relevant requirements. ISO standard 14520 is prevalent throughout Europe in this sector.

Record keeping and quality of records: Industry communicates that in the stationary refrigeration, air conditioning and heat pump sector no more than half of the operators maintain records. The compliance level by sub-sectors and Member States is similar to that of leakage checks: high percentages are typical for industry, large supermarkets and large commercial applications, low percentages are typical for small enterprises and light commercial equipment. There is also a north-south gradient in the frequency of record keeping. The quality of records, where they exist, is often criticized because of insufficient accuracy.

In the fire protection sector, records have been kept so far in accordance with ISO 14520. Industry communicates that about half of the companies have not yet changed to records according to F-gas Regulation.

Awareness of the operators: According to the information from small and medium-sized contractors, as well as from large international service companies in the SRAC/HP-sector, as many as half of the operators do not know about their obligations. Firstly, there is a clear difference in awareness between large companies and operators of large plants (industry, large supermarkets, and large commercial applications) and small companies and operators of small equipment. Secondly, it is understandable that staff of specialized companies have better knowledge and higher awareness than staff from companies that work only occasionally in this sector (mechanical and electrical contractors). Thirdly, a clear north-south gradient in terms of awareness is reported.

For the fire protection sector, it is estimated that about two-thirds of the operators in UK and Germany (from where data has been available) are aware of their obligations.

Control and enforcement: It was generally communicated by industry experts that operators' compliance with and awareness of the requirements of the F-gas Regulation and its containment provisions is highly dependent on enforcement by the authorities. According to information from authorities, records from operators ("logbooks", usually in paper form, but often electronic) have been requested randomly for control in more than half (16) of the Member States in the past few years. There is de facto no comprehensive evaluation of these records in the Member States.

4.2.6 Application of recovery provisions (Article 4)

Article 4(1) requires recovery of F-gases from stationary applications by certified personnel. Paragraph 1 covers the following stationary applications:

- Cooling circuits of refrigeration, air conditioning and heat pump equipment;
- Equipment containing F-gas based solvents;
- Fire protection systems and fire extinguishers;
- High-voltage switchgear.

The article applies to all equipment covered by its provisions irrespective of the quantity of F-gases they contain. Operators of these types of stationary equipment are required to establish arrangements for proper recovery of F-gases (i.e. collection and storage of F-gases from equipment or machinery) by personnel certified according to Article 5 to ensure their recycling, reclamation or destruction.

Recovery for the purposes described in Article 4 shall take place before the final disposal of that equipment and, when appropriate, during its servicing and maintenance.

The purpose of the provisions of Article 4 is the following: Firstly to avoid emissions at recovery by qualified personnel. And secondly, that the quantity of recovered F-gas and the quantity of F-gas returned for recycling/reclamation/destruction is increased and F-gas emissions are thereby reduced. The intention of Article 4 is to contribute to emission reduction during recovery and through extension of recovery. The main objective is the reduction of disposal emissions.

Recovery, recycling, reclamation and destruction – practice and infrastructure

The term “recovery”, as used in the F-gas Regulation,[186] does not exclusively refer to the removal of F-gas from the equipment with the objective to supply it to an external recycling/reclamation/destruction facility. The term also stands for temporary removal of the F-gas during service or maintenance before reuse in the same equipment (“on site recycling”). To give an example: SF_6 is removed from high-voltage switchgear equipment during mid-term maintenance, cleaned and afterwards refilled in the same equipment. This operation falls under “recovery” for onsite recycling and has to be performed according to Article 4 by certified personnel.[187]

The quantities recovered and subsequently recycled on site are normally not included in statistics on recovery and recycling. Quantities referred to as “recovered” in statistics are only quantities which have been definitely transferred to facilities for recycling/reclamation/destruction.

Quantities recovered and recycled on site should be included in the equipment records required by Art 3.

Little is known about the mass flows of recovered quantities before disposal of equipment.

[186] (EC) No 842/2006, Art 2, Definitions: “14. ‘Recovery’ means the collection and storage of fluorinated greenhouse gases from, for example, machinery, equipment and containers”.
[187] Certificates issued under (EC) No 305/2008 concern personnel recovering F-gases from high-voltage switchgear, not personnel involved in installation, maintenance or servicing of the equipment.

The emission factors assumed in the model AnaFgas (annex III) for end of life (WOM scenario) show that the recovery efficiency before disposal is presently ≤50% in many sectors. Recovery rates are relatively high, up to 70% in larger installations and for equipment which is maintained systematically. Barrault and Clodic (2008) estimate that 2% or less of refrigerant is recovered from small equipment at end of life. For larger equipment they estimate a recovery rate of 70-80%.[188]

Likewise, nothing is known about F-gas quantities which have been recovered prior to disposal of equipment, and are reused for recharging other equipment instead of being properly recycled, reclaimed or destructed. In Austria, for example, that amount is estimated by industry experts at about 2 % of the total market for HFCs in the stationary refrigeration, air conditioning and heat pump sector.

Legal Framework

The legal framework for proper recovery of F-gases includes European and national legislation on waste/hazardous waste including national legislation on WEEE (see section 3.3.2 on policy interactions).

Used HFCs and SF_6 are classified as hazardous waste[189]. According to the F-gas Regulation, the operator of equipment is responsible for the recovery of the F-gas and its proper transfer to a company for recycling/reclamation/destruction.

In some Member States specific arrangements for the recovery of F-gases have been established based through additional national requirements including the responsibility of manufacturers and distributors of F-gases to take those back after use (e.g. France, Germany, Sweden). In practice many of the distributors take back recovered F-gases and provide their customers with special recovery cylinders.

Common practice of recovery

Companies and contractors describe the common practice of recovery *in general* as the following: The personnel handling/servicing/maintaining the systems containing F-gas (machinery, equipment, containers) collect F-gas quantities from the system undergoing service or disposal and store it in a container. The recovered and stored F-gas is – usually after a basic cleaning process (filtering) – used for refilling of the system (i.e. recycling) or – not treated at all and sent to a facility for reclamation or destruction.

Differences between Member States regarding recovery result from legal circumstances (status of implementation/application of the F-gas Regulation including particularities of national legislation and voluntary agreements) and from the availability of technical requirements and logistics for the reclamation and destruction of F-gases within the Member States.

Availability of infrastructure for reclamation and destruction

Table 4-19 and figure 4-5 present data on the availability of operating[190] F-gas reclamation and destruction facilities in the EU-27 based on information from authorities and industry and

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[188] S. Barrault/D. Clodic, Quantités récuperées et projection futures, Colloque AFCE, 9 Oct 2008.

[189] HFC: Waste category 140601*; SF_6: Waste category 160504*.

[190] In some cases companies had the licence to destruct F-gases but did not operate for cost reasons (amount of F-gas offered for destruction too low compared to operating costs). Companies with several facilities normally concentrate OCF/F-gas for destruction at one site.

on data from ICF 2008/2010. In EU-27, 41 facilities for reclamation of F-gases and 24 facilities for destruction of F-gases exist as of beginning of 2010.

The figures in table 4-19 are lower than the data from ICF[191] which seem to contain a number of collecting points for F-gases. These collecting points are facilities which accept F-gases for reclamation/destruction without being equipped for the technical process of reclamation/destruction themselves. They collect and store the material and supply (mostly export) it to other facilities for reclamation/destruction. Likewise, decommissioning sites for refrigerators are able to recover but not to destroy F-gases. The overview shows that 12 of the 27 Member States do not have reclamation facilities and 15 Member States do not have destruction facilities within their territory.[192]

There is no information about which F-gases by type are accepted for reclamation by these facilities.

Figure 4-5: Availability of reclamation and destruction facilities for F-gas refrigerants (April 2010). Blue/green striped: Reclamation + destruction. Green: only Reclamation. Blue: only Destruction. Red: No facilities available.

[191] ICF International: Analysis on the Recovery of Fluorinated Greenhouse Gases in EU-27 in the Period 2004-2007 and Determination of Options for Further Progress, October 2008, p. 18; Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-Gases) Banked In Products and Equipment, Prepared by: ICF International, March 2010 – Final Report.

[192] ICF assumes for 2008 and for 2010 that 10 Member States are without a reclamation facility. With regard to F-gas destruction, ICF assumes, in 2008 11 Member States without a facility and in 2010 15 Member States. The number of F-gas destruction facilities indicated in the ICF studies halved from 2008 to 2010.

Table 4-19: F-gas reclamation and destruction facilities 2010

	Number of reclamation facilities	Number of destruction facilities
AT	0	0
BE	3	1
BG	2	0
CY	0	0
CZ	5	1
DE	3	5[2]
DK	0	2
EE	0	0
EL	1[1]	0
ES	4	0
FI	0	1
FR	5	3
HU	3	2
IE	0	0
IT	3	3
LT	1[1]	0
LU	0	0
LV	0	0
MT	0	0
NL	3	0
PL	1	1
PT	0	0
RO	1	1
SE	1	2
SI	0	0
SK	0	0
UK	5	2
Total	41	24

[1] License since March 2010 (Greece) and June 2010 (Lithuania)
[2] One company with 4 facilities referred to as 1 facility (only 1 out of the 4 facilities is operating).

Status of RRRD by sectors

Stationary refrigeration, air conditioning and heat pumps

Recovery of F-gases from cooling circuits of refrigeration, air conditioning and heat pump equipment is normally done by contractors carrying out installation, service and maintenance of the equipment. Larger operators may have their own service.

Recycling – reclamation – destruction

Recycling normally takes place on site and is carried out by the same contractors, i.e. service and maintenance companies. It is done to clean the refrigerant by removing oil and other pollution and by drying the refrigerant. Special equipment and standards for recovery and recycling exist.[193] F-gas quantities recovered and recycled onsite are not part of reported data on recovery. In addition to onsite recycling, a simple recycling process different from reclamation can also be done by specialised companies. From the total amount of HCFC and HFC refrigerants, which were reported by manufacturers and distributors as recycled, reclaimed or destructed in France in 2008, only 0.1% was classified as recycled.[194]

The number of specialised companies involved in recovery and onsite recycling of F-gases is large. AREA reported a number of around 45,000 small and medium-size contractors in the stationary refrigeration, air conditioning and heat pump sector from 16 Member States. For France alone, AFCE adds to this number another 10,000.[195] We expect that the total number of specialised companies carrying out activities related to refrigerant circuits in this sector in the EU-27 can be estimated at >100,000. A high proportion of them are small businesses. The average number of employees within these small businesses is about 10 in Germany and 3 in Italy, for example. According to our survey at least two thirds of the contractors are involved in onsite recovery and recycling.

In contrast to recycling, reclamation involves chemical reprocessing of the recovered used F-gas to essentially its virgin specifications in order to meet a specified standard or performance. This is a technically much more elaborate and costly, analytically controlled process (filtration, distillation, adsorption and other separation technologies), which cannot take place onsite, but only in special reclamation facilities (manufacturers, wholesalers). In general, only pure recovered refrigerants can be reclaimed since separation of refrigerant blends is technically difficult and very costly. According to ICF 2008, facilities were unable to reclaim about one third of gases collected (main reasons: mixtures; high oil content)[196]. Field instruments to analyze refrigerants are available, however are not very widespread for cost reasons in some of the Member States.

Since reclamation can be carried out in appropriate facilities only, it is possible to record and report reclaimed amounts in statistics. The percentage of reclaimed CFC/HCFC/HFC

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193 ISO 11650 „Performance of refrigerant recovery and/or recycling equipment". Cf. UNEP, 2010 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, Draft, chapter 11.

194 ADEME, Rapport annuel sur la mise en oeuvre de l'Observatoire des flux de fluids frigorigènes. Données 2008, Janvier 2010, p.32.

195 AREA Reply to Öko-Recherche Questionnaire on F Gas Review, 16 April 2010 ; AFCE (Alliance Froid Climatisation Environnement), François Heyndrickxs, written communication, 14 April 2010.

196 ICF International: Analysis on the Recovery of Fluorinated Greenhouse Gases in EU-27 in the Period 2004-2007 and Determination of Options for Further Progress, October 2008, p. 21.

refrigerants was just under 82% of the total amount of recycled, reclaimed or destroyed refrigerant in France in 2008.[197]

Destruction of F-gases by incineration takes place mostly in specialized waste incineration plants equipped with high temperature incinerators. In addition, other technologies can be applied (reactor cracking; plasma arc technology).[198]

Since non-combustible F-gases, delivered in cylinders, have to be dosed for high-temperature decomposition and fed in the combustion process without emission loss, devices for connecting the gas cylinders are required. Only a few plants which are principally able to destruct F-gases by high-temperature incineration have the necessary appliances for feeding-in gases. This is usually dependent on the volume of the quantity of waste gases supplied.

Recovery – quantitative data

Quantitative data on recovered F-gas refrigerants hardly exist. Some data is available from France and UK. Data from service companies recovering F-gases for reclamation/destruction, and from companies executing the reclamation and destruction, are not included into centralized databases in the Member States.

The French Association of companies active in the refrigerant sector, SNEFCCA[199], reports annually on refrigerant purchasing and recovery in SRAC sector. The data for the years 2001-2009 are included in table 4-20 and relate to the recovery of CFCs, HCFCs and HFCs. The amount is based on the annual use of HCFCs and HFCs. The percentage of recovery is 4-6% in the annual purchase of refrigerants. Since 2006, a slight increase of the percentage of F-gas recovery can be observed.

Table 4-20: Annual purchase and recovery of HCFC- and HFC-refrigerants in the French stationary refrigeration, air conditioning and heat pump sector 2001-2009 (t and %)

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Purchase (HCFC + HFC)	11,293	11,829	11,572	12,580	13,120	12,131	12,810	12,570	11,965
Recovery CFC + HCFC + HFC	478	486	690	570	545	565	585	610	720
Recovery (%)	4.2	4.1	6.0	4.5	4.2	4.7	4.6	4.9	6.0
Destruction in % of recovery	65.5				47.7	56.6	53.8	44.3	45.8

Source: SNEFCCA 2010

The statistics published by ADEME for the first time for 2008 on refrigerant sales in France, include information from 83% of French refrigerant manufacturers and distributors (table 4-21). They indicate sales of about 9,800 t of HCFCs and HFCs on the French market in 2008. The quantities of CFCs, HCFCs and HFCs returned is 361 t or 3.7% of the refrigerant purchase.[200] The proportion of the "treated" (= destruction + reclamation + recycling)

[197] ADEME 2010, p. 32 (quantities reported by distributors and manufacturers). The total amount of these refrigerants recycled, reclaimed or destroyed was 451 t (cf. table 4-21).

[198] ADEME 2010, p. 32.

[199] SNEFCCA: Syndicat National des Entreprises du Froid, d'Equipements de Cuisines Professionnelles et du Conditionnement de l'Air. The number of companies of the industry is indicated with 3,100. Cf. www.snefcca.com.

[200] The greatest proportion is R22 and R11. The share of HFCs out of the returned quantity is 41%.

refrigerant is 4.6%. Out of this quantity, ~18% were destroyed, ~82% were reclaimed. The percentage of recycling of ca. 0.1% was almost negligible.[201]

Table 4-21: Recovery, reuse and treatment of refrigerants in the French stationary refrigeration, air conditioning and heat pump sector 2008 (t and %)

	Sales	charge	recovered	reused on-site	„treated“
Producer / distributor					
metric tonnes	9,787	-	361	-	451
%	100	-	3.7	-	4.6
43 operators					
metric tonnes	-	80	3.9	7.1	21
%		100	4.9	9	26

ADEME 2010

For the same year, reports have been delivered by 43 operators (<1% of the total number of operators with attestation).[202] They communicated a recovery of 4.9% compared to the quantity of refrigerant charged into equipment. 80% of the recovered fluid was returned to dealers. 21 t were treated by the operators.

Comparatively high is the amount of refrigerants that have been recovered and recycled on-site (reused on-site) which ranges at 7.1 t or ca. 9% of the 80 t reported as filled-in.

The recovery data from ADEME are in the same order as the SNEFCCA data. They don't show a trend of quantities recovered and are therefore not yet suitable to draw conclusions on the effectiveness of the F-gas Regulation.

In UK, the percentage of used HCFC- and HFC-refrigerants returned for reclamation or destruction compared to the annual purchase increased from 2007 to 2009 from about 10% to about 12% (table 4-22). The increase is due to increasing quantities of R-22 returned for reclamation, and does not refer to increasing quantities of returned F-gases.

Table 4-22: Annual purchase and recovery of HCFC and HFC refrigerants in UK (t and %)

	2007	**2008**	**2009**
Purchase (HCFC + HFC) (t)	9,655	9,320	9,792
Recovery HCFC + HFC (t)	979	971	1207
Recovery HCFC + HFC (% of purchase)	10.1	10.4	12.3
Refrigerants destroyed	587	507	436
Refrigerants reclaimed	392	460	764
R-22 reclaimed	205	210	522
HCFC + HFC recovered without R-22 reclaimed	774	721	685

The data on recovery of HCFC- and HFC-refrigerants available today show a low level of recovery and only a slight increase of recovered quantities which is primarily due to increase of HCFC-22 quantities returned for reclamation[203]. This indicates little effectiveness of recovery measures according to Article 4.

[201] The difference between 361 t "recovered" and 451 t "treated" in 2008 is due to treatment of 90 t of refrigerants recovered *before* 2008 (ADEME 2010, p. 31).
[202] These 43 operators had purchased 111 t of refrigerant and filled 80 t in SRAC systems.
[203] This is confirmed also for the Netherlands where HFCs today account for <10% of the substances taken back by producers within a take back scheme, while the majority is HCFC-22. (Personal communication, Linde Gas Netherlands, 16 June 2011).

Fire Protection Systems

The fire protection sector is characterized by the following particularities:

The extinguishing agent is stored in a container and will be released in case of fire. Unlike in the stationary and mobile refrigeration and air conditioning sector and the high voltage switchgear sector, on site refilling and on site recycling do not take place. After intended release in the event of fire or in case the equipment is malfunctioning (leakage, pressure drop), the containers are returned to the manufacturers. Re-charging, repair work and recovery is always done off site by specialist personnel.

As long as the extinguishing agent is contained, it does not get polluted by impurities, and reclamation is not relevant. The industry points out that recovery and recycling of F-gas fire extinguishing agents has been only carried out to a small extent, since HFCs in fire protection have only been in use since the mid 1990s. As the lifetime is 15 years or longer, most systems are still in use.

According to the industry, no data (apart from internal company records) on recovered F-gas quantities and F-gas quantities transferred to the manufacturer for recycling/destruction are available.

Recovery, recycling and destruction of F-gas fire extinguishing agents already took place before the F-gas Regulation came into force. There is no evidence of an increase in recovery, recycling and destruction in response to the implementation of the F-gas Regulation.

High-Voltage Switchgear

SF_6 is used as an insulating gas in electrical equipment for the transmission of electricity with a rated voltage of >1 kV (high-voltage (HV) switchgear) such as switchgear, instrument transformers, gas insulated transmission lines, high-voltage bushings, capacitors and power transformers. According to the industry (T&D Europe), since 1995 the HVS industry has developed measures to systematically reduce SF_6 emissions. National voluntary agreements to reduce SF_6 emissions exist at least in France (2005), Germany (1996; 2005), and Spain (2008).

In general, the use and handling of SF_6 in electrical equipment >1 kV includes the following characteristics:

With regard to recovery and direct reuse on site (recycling), it is known that during maintenance of HV switchgear equipment, recovery of SF_6 occurs from closed pressure systems >52 kV including immediate reinjection of the recycled SF_6 into the system after maintenance operations.

For repair and maintenance of HVS >52 kV in Germany it is estimated that more than 90 % of the SF_6 quantity recovered will be recycled on site and reinserted into the HVS (SF_6 quality according to IEC 60480). Sealed pressure systems (<52 kV) do not need recovery during normal operations life, only before disposal. According to industry (T&D Europe), no database on quantities recycled on site exists.

Recovery for external recycling and for reclamation/destruction: SF_6 is removed either on site and returned e.g. to a gas manufacturer or the SF_6 charged equipment is completely transported to gas or equipment manufacturers for recovery of F-gas quantities. After a gas analysis according to IEC 62271-303, the gas may be reused if the quality is in accordance with IEC 60480 (recycling) or it is reclaimed or destroyed. On the European level, according to T&D Europe, statistics on quantities are only available to companies involved (gas manufacturers, distributors or reclamation/destruction companies).

Facilities for reprocessing (reclamation) of SF_6 are available in Germany and France. Facilities for the destruction of SF_6 are available in Germany, France and the UK. Other facilities are not known; therefore recovered SF_6 is often subject to cross border shipment. Since 1990, Solvay (SF_6 producer) has established a "ReUse" concept (reclamation and destruction) for SF_6.[204] This concept offers appropriate packaging and transport, analysis of used SF_6, re-introduction of the used F-gas into the SF_6 production process (annual quantity of approximately 40 t) or destruction by incineration. Several companies in France, Netherlands, Belgium, Austria, Finland, Spain, Great Britain, Italy and Greece participate.

Some quantitative information on SF_6 recovery, reclamation and destruction is available from Germany. The German voluntary commitment[205] on SF_6 in HVS includes detailed reporting on RRRD to the German EPA.

The vast majority of operators and manufacturers in Germany take part in the SF_6 "ReUse" system of Solvay. Since the investment costs for mobile equipment to reclaim SF_6 on site are very high, reclamation of used SF_6 by SF_6 producers is the common practice.

The quantity of SF_6 which was supplied for reclamation and destruction by HVS manufacturers and operators from Germany in the "ReUse" system did slightly increase between 2005 and 2009 (table 4-23). This applies primarily to the amount of SF_6 to be destroyed. About one-third of the total quantity was delivered by German operators and two-thirds by German manufacturers (2008/2009).

Table 4-23: High-voltage switchgear – SF_6 reclamation and destruction 2005-2009 (Solvay ReUse system, Germany)

	Reclamation	Destruction	Total
2005	7.80	1.90	9.70
2006	10.20	0.11	10.31
2008	9.40	0	9.40
2009	9.23	2.52	11.75

Source: Solvay Fluor GmbH

The trend for SF_6 is as follows. Since the voluntary agreements from 2005 and 2008 included already detail commitments to RRRD, the F-gas Regulation will probably not lead to significant changes. The SF_6 quantities for disposal in Germany will increase from 2015 onwards for HVS >52 kV, and for HVS <36 kV from 2020 onwards because of the long lifetime of the equipment (ca. 40 years, see annex III).

The national associations of the HVS industry and at least one HVS equipment manufacturer claim that national and European waste legislation hampered the cross border transport of used SF_6 within EU-27, because its shipment would be allowed only when declared as

[204] Cf. http://www.solvay-fluor.com/docroot/fluor/static_files/attachments/sf6_e.pdf, p 42f.

[205] Voluntary Commitment of SF6 Producers, Manufacturers and Users of Electrical Equipment >1kV for Transmission and Distribution of Electric Power in the Federal Republic of Germany on SF6 as an insulating and arc extinguishing medium, 1st edition: 1996, current version: 2005. Federal Ministry for the Environment: http://www.bmu.de/klimaschutz/downloads/doc/35655.php.

waste, and would hence hinder reclamation and promote domestic incineration of SF_6. This is, however, difficult to understand, since SF_6 has to be declared as waste in both cases (reclamation/destruction), and in many countries no possibility for incineration exists. Therefore, a preference to destruction for this reason alone is not very likely.

F-gas based Solvents

F-gas based solvents[206] are mainly used for degreasing of metal prior to precision coating and in the optics and electronics sector. Equipment can have charges of 50 to 1,200 litres. Used solvent is heated to remove impurities (distillation) and the recovered solvent is reused. The residue is sent for incineration. Normally it consists of 75% oil/impurities and 25% of solvent.

As of July 2011, 17 Member States communicated that F-gas solvents are not used in their country (table 4-2). The quantity used before in 9 Member States was <300 t (model description in annex III). The main countries using F-gas based solvents in EU are France and the UK. A UK DEFRA report estimates that the bulk of the annual sales are used to replace the contaminated residue solvent. Further information on the recovery/recycling/reclamation/destruction (RRRD) of F-gas based solvents is not available. Recovery for recycling or reclamation of F-gas based solvents is unlikely.

Control and enforcement by authorities

Competent authorities from EU-27 Member States were asked about control mechanisms in order to monitor compliance with the provisions of Article 4. Most of them referred to provisions on control and sanction in the national legislation on F-gases and in the waste legislation. Inspection campaigns are reported from less than half of the Member States.[207] Other desktop control instruments mentioned are checking of system dossiers, reporting obligations etc. But in general it seems that no systematic monitoring of the compliance to the recovery provisions is carried out, as expressed explicitly by one Member State (DE).

[206] These are blends from which HFC is only a component. Cf. for the following: DuPont, Vertrel – Specialty Fluids, 2007; DEFRA, Impact Assessment of the Fluorinated Greenhouse Gases Regulation 2009, November 2008; DuPont, Pascal Faidy, pers. comm. by Email, 28 April 2010.

[207] These Member States include Belgium, Cyprus, Czech Republic, Denmark, Estonia, Germany, Hungary, Ireland, Latvia, the Netherlands, and Slovenia.

4.2.7 Application of reporting provisions (Article 6)

Article 6(1) of the F-gas Regulation requires entities in the European Union (EU) which produce and/or import and/or export more than one metric tonne per year of F-gases or preparations (blends) containing F-gases, to submit a report by 31 March each year for the previous calendar year, starting in 2008. The companies must submit their report to the Commission, sending the same information to the competent authority of the Member State concerned.

Reporting includes bulk shipments, including F-gases shipped with the equipment for the purpose of charging that equipment. It excludes quantities contained in imported or exported equipment (i.e. pre-charged equipment).[208] Producers, importers and exporters shall communicate any quantities reclaimed or destroyed within the Community or exported for recycling, reclamation and/or destruction (cf. Regulation (EC) No 1493/2007).

Results of the first four reporting years

The F-gas reporting system builds upon the reporting system for substances that deplete the ozone layer (ODS) according to Article 19 of the Regulation (EC) No 2037/2000[209]. The majority of companies obliged to reporting according to the F-gas Regulation have several years of experience in collection and submission of relevant ODS data.

Reporting according to Article 6(1) takes place since 2008 for calendar year 2007. Table 4-24 shows the F-gas quantities reported by producers, importers and exporters for the years 2007-2010. The 2010 data are preliminary data.

Table 4-24: Reported quantities of F-gases according to Art 6(1) for the period 2007-2010 (metric tonnes)

	2007		2008		2009		2010**	
	t	%*	t	%*	t	%*	t	%*
EU Production	58,037	100	41,647	71.8	35,123	60.5	46,459	80.1
EU Imports	59,647	100	68,721	115.2	58,904	98.8	70,052	117.4
EU Exports	23,654	100	19,373	81.9	17,162	72.6	22,074	93.3
EU Sales	93,126	100	94,043	101.0	85,230	91.5	97,697	104.9
RRRD in EU***	426	100	343	80.5	173	40.6	n.a.	
Export for RRRD***	12	100	48	400	-	-	n.a.	

n.a. = not yet available. 2007 = 100%; ** 2010: preliminary data; *** RRRD includes only quantities from companies obliged to report acc. to Art 6(1), not accounting for specialised RRRD facilities, which process by far the largest part of returned F-gas quantities.

Quality of reported data

Analyses of the reports from companies for calendar year 2007, 2008 and 2009 have been undertaken on behalf of the European Commission[210]. Some aspects relevant for the assessment of the quality of the reporting system are outlined here.

[208] (EC) No 1493/2007, Annex part 1, Introduction, 2nd paragraph.
[209] In 2009, this Regulation was recast by Regulation (EC) No 1005/2009.
[210] Touchdown Consulting sprl 2008: Analysis of Data Reported by Companies in the European Community on the Production, Import and Export of Fluorinated Greenhouse Gases in 2007.

– **Completeness**. The total number of reporting companies for each reported calendar year was: 76 for 2007, 80 for 2008 and 88 for 2009. 19 companies that had reported for 2007 did not submit a report for 2008. Conversely, 18 companies reported for 2008 for the first time. Some of these companies stated that they had not been aware of their reporting obligation for 2007. Companies from 9 different Member States have not submitted reports in one or more years during the period 2007-2009 (2007 and 2008: 6 MS, 2009: 5 MS). Companies from 3 Member States (AT, LU, and SK) have not submitted reports in any year in the entire period 2007-2009.

  In case some companies had not fulfilled their reporting obligations, reported data on import/export would be somewhat lower as in reality. As imports exceed exports significantly (table 4-24), the sales volumes to the EU market would be slightly underestimated. In our view, this hypothetical case is not considered to have a serious impact on the total F-gas sales data in the EU.

– **Compliance with reporting obligation**. In 2007, seven of 76 companies, and in 2008, 25 of 80 companies represented more than 95% of the total HFC sales to the EU market. The remaining companies accounted for less than 5% of sales and exports.[211]

  It is likely that large companies comply with the reporting obligations more consistently than small enterprises. However, relatively lower participation of small companies would not significantly distort the picture. Even if 54 additional small companies (i.e. two more small companies from each Member State) had not reported, the total outcome would increase by only a few percent.

– **Accuracy of sales estimates**. A small difference exists between the reported data on production, import and exports on the one hand and estimated sales to intended applications on the other hand. The sales were estimated higher by 3.4% in 2008 and by 11% in 2009.

  The error may be caused by overly high expectations for sales held before the economic crisis. It might also be possible that the recording is not accurate at each of the companies. The difference, however, is well within acceptable order.

The overall finding is confirmed that the reported figures are dominated by the accuracy and completeness of the companies with the greatest quantities of F-gas sales and exports on the European market.

Control and enforcement by authorities

The producers, importers and exporters shall send the same reports to the competent authorities of the Member State. Responses from questionnaires by competent authorities from EU-27 show that authorities from 13 Member States (ca. 50%) have checked the details

Touchdown Consulting sprl 2009: Analysis of Data Reported by Companies in the European Community on the Production, Import and Export of Fluorinated Greenhouse Gases in 2008.
Austrian EPA 2010: Fluorinated greenhouse gases 2009 – Data reported by companies on the production, import and export of fluorinated greenhouse gases in 2009.

[211] TouchDown Consulting sprl, 2008, p. 18; 2009, p. 23.

of the reports; 10 authorities have not yet looked into them. (4 did not answer the relevant question.)

The authorities of the Member States were also asked whether all companies in their country subject to reporting requirements do actually report. When F-gas producers operate in the country, the question was consistently answered "yes". Regarding importers and exporters the answer was "yes" in two thirds of the cases. Enforcement measures were not mentioned.

Reporting of recycling, reclamation and destruction

Reporting according to Art 6(1) includes the F-gas quantities for recycling, reclamation, and destruction, to be communicated by producers, importers, and exporters.

The provisions continue identical provisions set out in the former ODS Regulation (EC) No 2037/2000 (recast: Regulation (EC) No 1005/2009) relating to “controlled substances”. The companies subject to reporting of recycled, reclaimed and destroyed quantities under the F-gas Regulation are usually the same companies that have already been subject to reporting under the ODS Regulation. Therefore, the system is well established.[212]

It must be pointed out that the information on recovery, reclamation and destruction of F-gases gained through the F-gas reporting system is of very limited use for an overview of the total quantities recycled, reclaimed or destroyed within the EU or exported from the EU.

Reported RRRD includes only quantities from the companies obliged to report according to Art 6(1), and does not account for specialised RRRD facilities, which reclaim or destroy by far the largest part of returned F-gas quantities. For the year 2008, only four companies reported reclamation and destruction of HFC-134a, and three companies reported destruction of SF_6. As shown in table 4-19 the number of specialised reclamation facilities in the EU is at least 41, and the number of destruction facilities is at least 24. Unlike the data of production and sales, the data on RRRD are not representative of the EU total. However, they can be used as supplementary to data from the specialised facilities, if the European Commission wants to obtain a complete picture of the overall RRRD quantities within the EU.

Therefore, chapter 8 suggests the possibility of introducing reporting obligations for destruction facilities similar to the provisions under the ODS Regulation (EC) No 1005/2009.

Conclusion on the application of the F-gas reporting provisions

The reporting system according to Article 6(1) of the F-gas Regulation is well-established. It benefits from the preceding reporting system on ODS, which had been established in the 1990s for the majority of the present participants. Assuming that all large producers/importers/exporters fulfil their reporting obligation, the reported sales and

[212] The recast ODS Regulation (1005/2009) requires higher reporting demands of producers, importers, and exporters (Art 26 and 27). The ODS data to be reported vary depending on the type of undertaking. For example, producers must report quantities produced, placed on the market, as well as quantities recycled, reclaimed and destroyed, and stocks. Undertakings in the ODS database that did not produce, import, export or destroy ODS in the previous year are required to return a “nil” form. The recast regulation also introduced new requirements for destruction plants to report quantities destroyed, including quantities contained in products and equipment, directly to the European Commission.

production quantities of F-gases are well within acceptable statistical error range. Control and enforcement mechanisms seem to be not fully active at this point in time. Reporting of recycled, reclaimed, or destroyed quantities as it currently stands is of limited value.

One-tonne threshold

Article 10(2)f of the F-gas Regulation requires a review of the “one tonne quantitative limit” for the reporting obligation. Chapter 8 discusses this aspect in the context of improved reporting systems.

The reporting obligation under Art 6(1) covers only entities which produce and/or import and/or export more than one metric tonne per year of F-gases or preparations containing F-gases. This one tonne limit hardly distorts the total data outcome as it is shown by the following calculation: If ten companies[213] in each of the 27 Member States would import or export a non-reportable quantity of F-gases <1 t, the missing amount would total 270 t at the maximum. This amount equals 0.3% of the effectively reported sales quantities (85,180 t) or 0.5% of the reported import quantities (58,848 t) in 2009.

The low impact of the one-tonne-limit and the validity of the assumption of ten companies per Member State may be illustrated by data from two EU Member States, which serve as example:

- The Estonian customs authorities collect data on all quantities of HFCs imported from and exported to countries which are not member of the EU, without any threshold. Evaluation of the customs records reached the same conclusion as the calculation above. Individual quantities below 1 tonne add up to a total share of ~ 0.3% in the annual volume of foreign trade. Estonia is an importer of large HFC quantities, especially of HFC-152a, because manufacturing of OCF foams plays an important role.
- In Germany 35 companies import annually about 10,000 t F-gases from in- *and* outside the EU. In 2007 and 2008 10-11 out of the 35 companies reported according to Art 6. If each of the remaining 25 companies imports 1 t at maximum from outside the EU this would result in 25 tons or 0.25% of the total import. (But in fact only some of them are expected to do so.) 11 out of 35 companies represent about 30% of all importing companies. The total figure of European companies reporting according to Art 6 is about 80. If these represent 30% of the total number of companies, the remaining 70% would be about 270 companies.

Import and export of F-gases contained in pre-charged equipment

Under Article 6(1), importers and exporters are not obliged to report on F-gas quantities contained in equipment. The lack of information on these quantities might have more serious consequences for the data quality than missing information on quantities below one-tonne-limit.

[213] On average only 4 companies per Member State do report. 10-30% of them represent more than 95% of the HFC sales of the European market. The number of 10 additional companies per Member States is rather high compared to the real number of F-gas importing/exporting companies.

Pre-charged equipment in large numbers imported to or exported from outside EU-27 is found in the following sectors:

- Mobile air conditioning (import and export of motor vehicles)
- Stationary air conditioning (import of factory-made devices)
- One component foam (export of cans)
- High-voltage switchgear (export of SF_6-filled systems)
- Metered Dose Inhalers (export of aerosol cans).

A survey-based estimate of the amount of F-gases in pre-charged equipment is shown in table 4-25[214].

Table 4-25: Import and export of F-gases contained in pre-charged equipment, which is currently not covered under reporting obligations in 2008. GWP values according to 3rd IPCC Assessment Report

		Import		Export	
Sector	**F-gas**	**metric t**	**CO_2 eq (Mt)**	**metric t**	**CO_2 eq (Mt)**
Automotive	HFC-134a	1,694	2.20	2,389	3.11
Stat Air Con	R-410A	7,002	13.83	negl.	negl.
OCF	HFC-134a	0	0	2,100	1.99
MDI	134a, 227ea	0	0	3,135	4.15
Switchgear*	SF_6	negl.	negl.	460	10.21
Total		**8,697**	**16.03**	**8,084**	**19.46**

Source: AnaFgas and specific research by Öko-Recherche. * Exports from Germany and Spain. negl.: negligible.

- The largest quantities of F-gases imported are contained in pre-charged stationary air conditioners. Almost 90% of split systems of different types are imported from East Asia (Japan, China). Export of stationary air conditioning equipment is of negligible size.
- As for mobile air conditioning, quantities of F-gases exported are higher than quantities imported.
- The EU is the world largest producer of one-component foam. About one third of the production is exported, to large extent to Russia.
- The EU is the world largest filler of metered dose inhalers. Almost two-thirds of the production is exported worldwide.
- The EU is the world largest exporter of switchgear equipment. To ship, medium voltage systems are completely factory-filled with SF_6 while the large high-voltage equipment is filled to atmospheric pressure only and is filled up to operating pressure at the place of

[214] The data are based on Öko-Recherche interviews in the course of this study with Daikin Europe (stationary air conditioning), ACEA (foreign trade with motor vehicles), Mexichem (MDI), T&D Europe (electrical switchgear) and an Öko-Recherche study on OCF for the German EPA (2009).

destination[215]. In terms of CO_2 eq, SF_6 in pre-charged electrical equipment represents by far the largest single F-gas quantity in the foreign trade of the EU.

In 2008, exports of F-gas contained in pre-charged equipment amounted to ca. 8,000 tonnes and imports of F-gas contained in pre-charged equipment ranges at about 8,700 tonnes. Imported quantities of F-gases contained in pre-charged equipment represent almost 13% of the total import of bulk F-gases covered under reporting obligations. Export of F-gases contained in pre-charged equipment represents ca. 42% of the exported quantities reported under Art 6(1).

In 2008, the most important F-gases in imported equipment were HFC-32 and HFC-125 which are the two components of the refrigerant blend R-410A. Each of them accounted for 40% of the F-gas quantities (in metric tonnes) in imported pre-charged equipment. HFC-134a in mobile air conditioning represented the remaining 20%.

As for exports, HFC-134a accounts for more than 92% of the total quantity of F-gas contained in pre-charged equipment, HFC-227ea and SF_6 represent the remaining percentage.

Although in metric tonnes, imports and exports in charged equipment numerically balance each other almost, and thus do not significantly change the reported overall emission potential of the EU-27 in metric tonnes, the consideration of pre-charged F-gases significantly shifts the composition of the emission potential by individual F-gas types.

The distortion of the reported emission potential is even more evident when looking at the global warming potentials. A clear difference between import and export in 2008 was found which amounts to 3.4 million t CO_2 eq (import: 16 million t CO_2 eq; export: 19.4 million t CO_2 eq). This is primarily a result of the high GWP of SF_6. Certain quantities of SF_6 are exported in pre-charged switchgear equipment.

The composition and the amount of F-gases in imported and exported equipment vary from year to year, depending on the economic activities inside and outside EU-27. The relevance of data reported under Article 6(1) for the calculation of potential F-gas emissions, would be higher if F-gases contained in pre-charged equipment were included in these reporting requirements.

A review option on including F-gases contained in pre-charged equipment in the reporting obligations according to Article 6 is included in chapter 8.

Reporting systems of Member States for emission data

According to Art 6(4) of the F-gas Regulation, Member States shall “establish reporting systems for the relevant sectors referred to in this Regulation, with the objective of acquiring, to the extent possible, emission data”.

In our interpretation, which conforms to the position of the most Member States asked in the survey undertaken, this provision does not necessarily require the establishment of new monitoring and reporting systems in addition to existing national systems for CRF reporting

[215] Separate gas containers, which are often shipped with the equipment for charging on-site, are covered by reporting.

to the UNFCCC. In general, Article 6(4) remains rather unclear to Member State authorities. Additional efforts of Member States are considered useful only if they would lead to monitoring systems for emissions which allow verification of emission trends and emission factors over time.

In chapter 2.3 on the measurability of emission reductions caused by containment measures of the F-gas Regulation, appropriate approaches for this purpose which already exist or are planned in EU-27 have been discussed. So far, attempts to build up appropriate electronically based monitoring systems have been made only in a few Member States.[216] In most cases these systems are not yet fully in place. Only one Member State, Hungary, uses records maintained under Art 3(6) to estimate emissions (Stationary refrigeration, AC and heat pump sector and mobile AC sector). This system is still under development and cannot yet be used for CRF reporting.

[216] These Member States are Bulgaria, Estonia, Hungary, Lithuania, and Poland.

4.2.8 Application of labelling provisions (Article 7)

Labelling provisions according to Article 7 apply since 1 April 2008. Article 7 states that products and equipment containing F-gases shall not be placed on the market unless the F-gas type according to chemical nomenclature and quantity can be identified on a label which is placed near the charging or recovery points for F-gases on the equipment. These labelling provisions apply to the following types of equipment and include equipment containing F-gas charges <3 kg:

- Refrigeration and air conditioning products and equipment (other than those contained in motor vehicles), heat pumps, fire protection systems and fire extinguishers containing PFCs, HFCs or preparations containing PFCs or HFCs.
- Switchgear which contains SF_6 or preparations containing SF_6.
- All F-gas containers.

Hermetically sealed systems shall be labelled as such. Furthermore, it is required that instruction manuals of the equipments contain information on F-gases and their global warming potentials.

With regard to the mobile refrigeration and air conditioning sector, it should be noted that Article 7 covers also products and equipment installed in rail vehicles, ships and agricultural machinery. As for F-gas containers not placed on the market, e.g. large ISO tanks used by chemical producers or importers for distribution of F-gases but eventually returned to them, labelling requirements according to Article 7 might not apply. However, a case-by-case analysis will be needed in order to assess specific circumstances. Guidance by the EU Commission on the interpretation of Article 7 also includes the encouragement of voluntary labelling schemes at national level, in particular for recovery cylinders.

According to Art 7(1) information on the fluorinated greenhouse gases, including their GWP shall be given in the instruction manuals provided for such products and equipment.

Altogether labelling requirements affect around 50.000 companies in the SRAC sector (OEM and contractors assembling in site components), about 100 F-gas suppliers including suppliers of cylinders for FPS and about 25 manufacturers of HVS equipment.

Article 7(3) requires the Commission to establish the form of the label and additional labelling requirements. Commission Regulation 1494/2007 defines the information to be contained on the label, the form of the label and the placing of the label.

It should be noted that refrigeration, air conditioning and heat pump equipment insulated with foam blown with fluorinated greenhouse gases need in addition to be marked with a label saying “foam blown with fluorinated greenhouse gases” before being placed on the market.

Concerning the language of the label, Article 2(4) allows Member States to require that label information is available in their official language when products and equipment are first placed on their territory in the Community market. The choice of the targeted markets within EU-27 is expected to lead manufacturers and importers to adapt to language needs.

The Commission provided guidance with regard to text and placing of the label on the equipment. As an example, a possible label for is given below (figure 4-6). Nevertheless, several industries and Member States highlighted the need for further guidance.

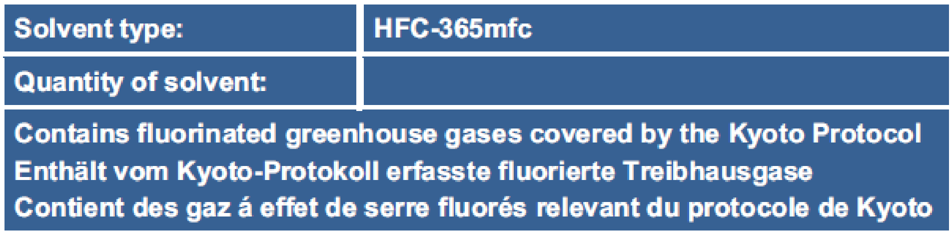

Figure 4-6: Example for a possible label for F-gas based solvent containers[217].

Industry efforts focus on harmonization of labels, in particular in sectors where products and equipment are marketed across Europe, and integration of the additional labelling requirements into other labels. For example, a label for switchgear containing SF_6 fulfilling the requirements of Article 7 and a relevant industry standard[218] has been developed by T&D Europe (figures 4-7, 4-8, 4-9).

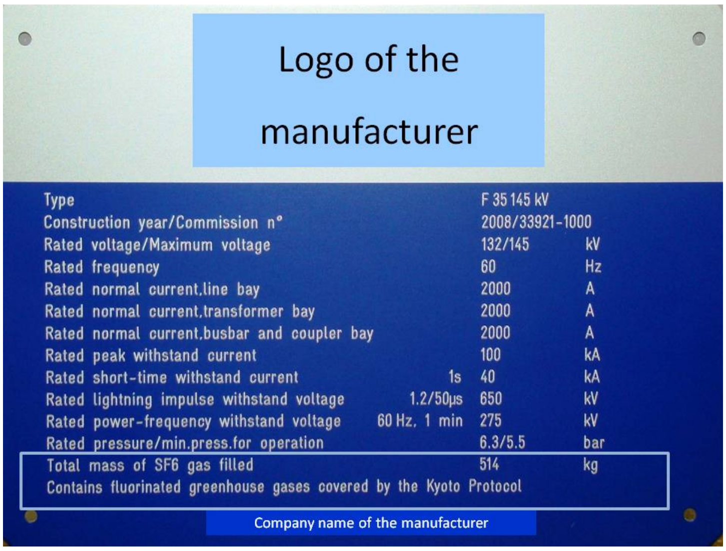

Figure 4-7: Label for high voltage switchgear >52 kV fulfilling requirements of Article 7 of the F-gas Regulation and a relevant industry standard.

Figures 4-8 and 4-9: Additional multilingual labels are placed near the servicing access of switchgear <52 kV (left) and >52 kV (right).

[217]European Commission 2009: Information for operators and technical personnel working with equipment containing fluorinated greenhouse gases – equipment containing fluorinated F-gas based solvents.
[218] IEC 62271-200 (2003).

For household appliances, in particular hermetically sealed heat pump tumble dryers containing HFCs, the idea of a harmonized label was discussed by industry but found to be rather complicated. Since most manufacturers are active in all Member States, a label containing the required text in all 24 official languages was considered confusing. Instead, the industry association CECED considered a harmonized pictogram which is voluntary to use by manufacturers and indicates that the system contains F-gases[219].

Manufacturers of other hermetically sealed household appliances such as domestic refrigerators and freezers as well as room air conditioners have not yet considered a harmonized label.

While products and equipment placed on the market prior to April 2008 is not subject to labelling provisions, it can be recommended to operators to label all equipment. Labelling plays an important role during installation, servicing and maintenance of equipment and helps to find out whether the equipment is covered by the F-gas Regulation. In addition, labelling will also provide significant support for future environmentally sound management of F-gas banks i.e. safe handling at disposal.

Other labelling requirements set out by European or national legislation might apply for certain types of equipment and include e.g. pictograms according to the WEEE Directive or the CE conformance mark according to Council Decision 94/465/EEC.

The application of labelling provisions in the different sectors has been delayed to some extent. At the due date of 1 April 2008, small manufacturers only active in one Member State were hence not in all cases compliant with the requirements of the F-gas Regulation. Large manufacturers of electrical switchgear equipment were to large extent compliant with labelling requirements at the end of 2008 at the latest.

Lack of compliance with labelling provisions was also indicated for imported equipment from outside of EU-27, in particular Asia. Importers might often not be aware of their obligations under the F-gas Regulation, are rarely members of European associations and hence do not refer to guidance documents distributed by industry associations. The lack of control and enforcement stated previously has also been confirmed with regard to labelling.

An option to further enhance labelling requirements is suggested in chapter 8.

[219] CECED: Instructions for identifying tumble dryers containing fluorinated refrigerants (Draft of 10 March 2011).

4.2.9 Application of bans (Articles 8 and 9)

Article 8 prohibits the use of SF_6 for two types of open applications: Large magnesium die casting facilities with SF_6 use >850 kg/year from 1 January 2008 and the use of SF_6 for vehicle tyres from 4 July 2007. The use of SF_6 for both applications has decreased significantly since the start of the bans.

As for magnesium die casting, the companies concerned substituted their use of SF_6 as cover gas of 24 t in 2007 by HFC-134a and SO_2 according to a recent study on behalf of the EU Commission[220]. Two companies located in Germany substituted SF_6 only in the first half of 2008 by HFC-134a; therefore the remaining SF_6 quantity in this year amounted to 3.1 t.[221]

SF_6 use for the filling of vehicle tyres amounted to ca. 5 t in 2006 (model AnaFgas). Two thirds of this quantity was used in Germany, since introduction of this technology in 1984. For Germany, SF_6 data for 2007-2009 are available from the Board of Statistics' database which refers to sales of gas distributors to car workshops. Table 4-26 indicates some residual use of SF_6 in 2008-2009 despite the ban as of 4 July 2007. In 2010 the quantity was nearly 0. This data can serve as indicators for EU-27.

Table 4-26: SF_6 use (metric tons) of Mg die casting facilities (>850 kg/y) and for the filling of vehicle tyres in 2007-2010

	2006	2007	2008	2009	2010
Mg die casting >850 kg (EU-27)	31	23	3.1	0	0
Vehicle tyres (Germany – 2/3 of EU-27)	3.0	0.8	0.5	0.5	~0

Article 9 prohibits the placing on the market of F-gases in a number of applications, which are listed in Annex II to the F-gas Regulation and include open applications and such closed applications, for which F-gas recovery at end of life is technically not possible.

OCF (ban as of 4 July 2008 except when required to meet national safety standards), novelty aerosols (ban as of 4 July 2009) and sound proof windows (full ban as of 4 July 2008) are the most important F-gas applications in terms of sales quantities (table 4-27).

Table 4-27: F-gas sales (metric tons) to applications subject to bans pursuant to Article 9 of the F-gas Regulation in 2006-2009

	2006	2007	2008	2009
OCF (HFC-134a)	1,200	1,100	950	400*
Novelty aerosols (HFC-134a)	500	380	260	91*
Soundproof glazing (SF_6 **)	12	9	7	3.3

* In preparations with GWP <150. ** Data for Germany (50% of EU-27 sales)

With regard to PU canned one-component-foam (OCF) it can be stated that ca 10% of OCF cans sold in 2006 contained HFC-134a (of 11.3 million cans sold each contained ca. 110 g of

[220] Öko-Recherche 2009: Service contract to assess the feasibility of options to reduce emissions of SF_6 from the EU non-ferrous metal industry and analyse their potential impacts. Final Report, on behalf of the European Commission.

[221] Öko-Recherche 2010: Inventory compilation of F-gases 2009. Data on HFCs, PFCs, and SF_6 for the national emissions reporting under the Framework Convention on Climate Change for the reporting year 2009. On behalf of the German EPA.

HFC-134a), in total ca. 1,200 t (AnaFgas). HFC-152a is used to negligible extent in this sector.

A study on behalf of the German EPA[222] found that since 2008 all European PU canned foam producers are able to manufacture propellant gas mixtures without HFCs or with reduced quantities of HFCs in preparations of GWP <150.

Under the F-gas Regulation, the use of HFC-134a in preparations with GWP <150 is allowed. Hence the maximum quantity of HFC-134a used in mixtures amounts to ca. 10%.

A time series for the HFC use in PU canned foam is available from Germany, which accounts for about 25% of European OCF applications. The quantity of HFC-134a contained in the cans used annually decreased from 450 t in 2006 to 130 t in 2009.[223]

Compared to the total quantity of propellant gases of 2,500 t, only 5.2% of HFC-134a was used in preparations (130 t / 2,500 t). This indicates high compliance by industry with Article 9 of the F-gas Regulation.

In the medium term, it is estimated that HFC-134a quantities in PU canned foam preparations will continue decreasing. The use of HFC-134a as propellant will be limited to applications where safety concerns apply (e.g. underground coal mining).[224]

With regard to novelty aerosols, the use of HFC-134a for the EU market has decreased significantly since 2005[225] (table 4-28). HFC-152a is of negligible importance in this sector.

Based on the definition of “preparations” set out by the F-gas Regulation which includes mixtures with GWP <150, the use of HFCs in propellant mixtures is allowed as long as the GWP threshold is respected. According to FEA, European aerosol fillers succeeded in recent years to reformulate the propellant gas mixtures. Therefore, since mid-2009 only aerosols containing at maximum 10% of HFC-134a in the propellant gas mixture have been placed on the market in EU-27.

It is estimated that annual HFC use for novelty aerosols will remain at a stable level of 50 t of HFC-134a in the medium term.

With regard to the use of SF_6 in windows for domestic and other use, it is estimated that ca. 29 t were filled into soundproof windows (pane interspace) in 2006 (AnaFgas). About 12 t were used in Germany, which had always been the country with the largest market in EU-27. In 2007, the total quantity in EU-27 decreased slightly to 22 t.

For subsequent years, data from Germany are available from the database of the Board of Statistics. In 2008, SF_6 sales of surveyed gas distributors to manufacturers of soundproof windows amounted to 7 t. In the first full year of the ban in 2009, this quantity decreased to 3.3 t (one German SF_6 supplier). This indicates that full compliance with Article 9 was still

222 Öko-Recherche 2009: HFC-containing Propellants in Canned PU Foam (OCF). Final report on behalf of the German EPA.

223 Öko-Recherche. F-gases 2009. Data on HFCs, PFCs, and SF_6 for the national emissions reporting under the Framework Convention on Climate Change for the reporting year 2009. For the German Umweltbundesamt, December 2010.

224 Öko-Recherche 2009: HFC-containing Propellants in Canned PU Foam (OCF). Final report on behalf of the German EPA.

225 Estimate by FEA (Fédération Européenne des Aerosols), Alain D’Haese, communicated to Öko-Recherche on 12 August 2010.

lacking in 2009 although sales had been reduced by 75% as compared to 2006. Further enforcement of the ban in this subsector seems necessary.

The other sectors subject to Article 9 are of minor importance and are not analyzed in detail. With regard to the use of SF_6 and PFCs in sport shoe soles, production stopped in 2006. Fire protection systems containing PFCs were not sold any more even prior to the F-gas Regulation.

In total, Article 8 and 9 applied successfully and resulted in significant and measureable reductions of F-gas use and hence emissions. SF_6 has been substituted in large magnesium die casting facilities (>850 kg/year). Full compliance with Articles 8 and 9 can be stated for the novelty aerosols and OCF subsectors as HFCs are today only used as components of preparations with GWP <150. Further investigation of the application and potentially enforcement of the bans in soundproof windows and vehicle tyres seems necessary.

It should be noted that Articles 8 and 9 have been applied to a large extent with minor administrative costs since conversion of production in these sectors largely took place, so far, without significant needs for enforcement and control by authorities.

Options for additional bans of the use of F-gases and of the placing on the market of F-gases/ products containing F-gases are discussed in chapter 8.

4.3 Costs of implementation and application of the F-gas Regulation

4.3.1 Costs of the F-gas Regulation

The assessment of the costs of implementation and application of the F-gas Regulation covers additional costs which were caused by provisions of the F-gas Regulation.

Prior to the F-gas Regulation certain measures were in place in some sectors, e.g. leak checks, recovery of F-gases and certification measures in some Member States and sectors. This analysis intends to clarify to what extent additional costs were caused by provisions of the F-gas Regulation.

In the Member States the costs for implementation of the F-gas Regulation differ largely for various reasons not only related to the levels of labour costs and public fees and charges. In some Member States, the infrastructure for application of the provisions including relevant bodies, training programmes, certification requirements etc. has been available prior to the F-gas Regulation, in other Member States this is not the case. Moreover, national regulations can be implemented in addition to the requirements of the F-gas Regulation e.g. with regard to the validity of certificates which might lead to extra costs at national level.

Costs which result from national rules exceeding the minimum requirements of the F-gas Regulation and related Commission Regulations (EC) No 303-307/2008 are not taken into account in this assessment. Examples include costs for company certification in the mobile AC sector as required in Hungary, France and Finland.

The costs of implementation and application of the F-gas Regulation are not separated in this analysis.

The following data are based on surveys among the Member States and relevant industries and industry associations. The different types of cost show a large range within and between Member States and cost data from Member States which have not yet implemented the F-gas Regulation are almost entirely missing. Therefore, it is necessary to make assumptions based on average values.

The types of costs are classified by sectors of application of the F-gas Regulation and are calculated for the entire EU-27.

4.3.2 Most important types of costs

When looking at the costs of implementation of the F-gas Regulation, one-off costs and recurring costs need to be distinguished.

One-off costs result mainly from certification and labelling. They apply to all sectors with regard to certification/attestation (stationary refrigeration, air conditioning and heat pumps; fire protection, high voltage switchgear; solvents; mobile air conditioning sector) and most sectors with regard to labelling (stationary refrigeration, air conditioning and heat pumps; fire protection, high voltage switchgear). Their level differs between sectors as both personnel and companies need to become certified in only two sectors (stationary refrigeration, air conditioning and heat pumps; fire protection).

In the future and after implementation of the F-gas Regulation certification costs for new personnel and companies will occur, too (recurring costs). In addition, it should be noted that in ca. 50% of the Member States national rules limit the validity of certificates and require repeated certification after several years (mostly 5 years) which result in additional costs (cf. table 4-10).

With regard to labelling, one-off costs apply for the development of new labels and change of instruction manuals for all equipment produced and/or placed on the market in EU-27 (equipment, containers).

Recurring costs occur mainly for leak checking/ record keeping and repair in the stationary refrigeration, air conditioning and heat pump sector as well as the fire protection sector (Article 3 costs). Furthermore, recurring costs result from recovery requirements according to Article 4 and from reporting requirements according to Article 6.

In some Member States further national rules exist (e.g. recording requirements in Germany for mobile equipment and disposal companies). Costs resulting from such additional national provisions are excluded from the cost assessment as they are not caused by the F-gas Regulation. On the other hand, administrative costs which occur in public institutions and are not covered by the fees for certification (costs for personnel in authorities, set-up costs, measures to raise awareness, enforcement measures such as inspections etc.) are considered. Such recurring costs for enforcement and control are part of "public set-up costs" (cf. section 4.3.8).

As stated earlier, costs differ largely within and between Member States. Therefore, cost data are averaged. For the sectors with large numbers of personnel to be certified (stationary refrigeration, air conditioning and heat pump sector; mobile air conditioning sector) high differences with regard to training costs and hence total costs for certification between Western Europe (higher price levels) and Eastern/South-Eastern Europe (lower price levels) need to be noted. Average costs for these regions are calculated separately.

As different costs for personnel certification apply in various sectors, the sectors are analyzed individually. Costs for company certification range at rather similar levels and therefore can be considered together.

4.3.3 Costs for certification of personnel and companies

The calculation of certification/ attestation costs according to the requirements set out in (EC) No 303-307/2008 is based on the number of personnel and companies subject to these requirements. Costs occur only once in most cases (one-off costs).

Certification costs generally include the fees which need to be paid for company and personnel certification.

The costs for full certification of personnel include

- Fees for theoretical and practical exams (do not occur for mobile AC sector)
- Fees for training (which is generally necessary)
- Fees for the issuance of the certification documents.

In case personnel certificates can be issued based on existing qualifications (cf. section 4.2.1), costs for trainings and exams do not apply.

As for personnel certification/attestation, costs for the non-productive time, travel costs and other expenses which need to be covered by companies are to be accounted.

The costs for full company certification include

- Costs for the verification of company information by authorities and
- Fees for the issuance of the company certificate.

Stationary refrigeration, air conditioning and heat pumps (personnel certification)

Definitive personnel certification according to (EC) No 303/2008: The total number of personnel subject to certification requirements in this sector amounts to 230,000 (table 4-5). Out of these, about 30,000 personnel can be certified without theoretical and practical exam and do not need training due to their pre-existing qualification.[226]

It is assumed that all other personnel (200,000) need to follow trainings. 85% are required to take certification according to Category (Cat) 1 and about 15% according to Categories 2-4.[227]

Table 4-28: One-off costs of personnel certification according to (EC) No 303/2008 (stationary refrigeration, air conditioning and heat pumps) Cat: Category; Exp.: Expenses

Certification	**Number of personnel in total**	**Costs Western Europe**			**Costs Eastern/South-Eastern Europe**			**Total costs**
		€/ pers.	Number of personnel	M€	€/ pers.	Number of personnel	M€	M€
pers. already qualified	30,000	40	30,000	1.2	40	-	-	1.2
Cat 1	170,000	850	134,300	114.155	300	35,700	10.710	124.865
Cat 2-4	30,000	550	23,700	13.035	200	6,300	1.260	14.295
Exp. Cat 1				171.233			16.065	187.298
Exp. Cat 2-4				13.035			1.260	14.295
Total	230,000		188,000	311.458		42,000	29.295	340.753

Certification costs vary due to the different duration of training programs according to Cat 1 (on average 4 days) and Cat 2-4 (on average 2-3 days). Differences also relate to different price levels in regions and Member States. In Western Europe costs for certification according to Cat 1 amount to about €850 and in Eastern/South-Eastern Europe to about €300. Costs for certification according to Cat 2-4 amount to €550 in Western Europe and to €200 in Southern/Eastern Europe.[228] As outlined earlier, companies also need to account costs for non-productive time, travel and other expenses. For Cat 1 certification in this sector based on

[226] Personnel certification acc. (EC) No 303/2008, Art 5(3): AT (50%), DE (50%), DK (80%), NL (100%).

[227] Estimation based on data from DE, FR, IT, SE, and UK with together 56% of total personnel subject to certification requirements in SRAC.

[228] Certification costs including training differ within and between Member States by a factor of about 10. Western Europe (higher price level): 15 Member States; Eastern/South-Eastern Europe (lower price level): 12 Member States (BG, CY, CZ, EE, EL, HU, LT, LV, PL, RO, SK, and SI). The cost assessment is based on data from 12 Member States (BE, CZ, DE, EE, FR, HU, IT, NL, PL, SE, SK, and UK).

industry information the total costs including expenses are assumed to be 2.5 times the pure personnel certification costs (including training). In this case the factor is 2.5. For Cat 2-4 a factor of 2 is assumed. This leads to total costs including expenses per person of €2,125 (Cat 1) and €1,100 (Cat 2-4) in Western Europe and €750 (Cat 1) or €400 (Cat 2-4) in Eastern/South-Eastern Europe (table 4-28).

The fees for issuance of a certificate are assumed to amount to €40.

Total one-off costs of personnel certification in this sector according to (EC) No 303/2008 amount to approx. €341 million in EU-27. About €140 million (41%) relate to pure certification and training costs while ca. €201 million (59%) are caused by additional costs to be covered by companies.

Recurring costs: Annual costs for new first certification of personnel (beginners) are assumed to range at 5% of the costs calculated above (17 million €/year) based on information from certification bodies.

Fire protection (personnel certification)

Definitive personnel certification according to (EC) No 304/2008: The total number of personnel subject to certification requirements in the Fire protection sector amounts to approx. 4,500 (table 4-6). All personnel need to take training before theoretical and practical tests for certification.

Certification costs for personnel including training (1-2 days) average at approx. €300 in EU-27 (table 4-29). Unlike in the stationary refrigeration, air conditioning and heat pump sector, no clear differences appear between Western and Eastern/South-Eastern Europe.

Total costs including expenses are estimated at €1,000. The share of expenses from the total certification costs is higher in this sector than in the stationary refrigeration, air conditioning and heat pump sector. This is due to the lower training costs compared to the costs for non-productive working time, travel expenses etc.

Table 4-29: One-off costs of personnel certification according to (EC) No 304/2008 (fire protection)

Certification	Number of personnel	Costs/personnel (€)	Total costs (M€)
Incl. training	4,500	300	1.350
Expenses	4,500	700	3.150
Total	4,500	1,000	4.500

The one-off costs of personnel certification in this sector amount to ca. €4.5 million in EU-27. About 30% relate to pure certification and training costs while ca. 70% are caused by additional costs to be covered by companies.

Recurring costs: Annual costs for new first certification of personnel (beginners) are assumed to range at 5% of the costs calculated above (ca. 225,000 €/year) based on information of certification bodies.

High-voltage switchgear (personnel certification)

Personnel certification according to (EC) No 305/2008: The total number of personnel subject to certification requirements in the HVS sector amounts to approx. 3,000 (table 4-7). All personnel need to take training before theoretical and practical tests for certification.

Certification costs for personnel including training (2 days) average at ca. €850 in EU-27[229]. Unlike in the stationary refrigeration, air conditioning and heat pump sector, no significant differences appear between Western and Eastern/South-Eastern Europe.

Total costs (table 4-30) including expenses are estimated at €2,000. (The factor of total certification costs including expenses is 2.4 and thus lower than in the fire protection sector. This is due to the higher costs for training in this sector.)

Table 4-30: One-off costs of personnel certification according to (EC) No 305/2008 (high-voltage switchgear)

Certification	Number of personnel	Costs/personnel (€)	Total costs (M€)
Incl. training	3,000	850	2.550
Expenses	3,000	1,150	3.450
Total	3,000	2,000	6.000

The one-off costs of personnel certification in this sector amount to ca. €6 million in EU-27. About 43% relate to pure certification and training costs while approx. 57% are caused by additional expenses to be covered by companies.

Recurring costs: Annual costs for new first certification of personnel (beginners) are assumed to range at 5% of the costs calculated above (ca. 300,000 €/year).

F-gas based solvents (personnel certification)

Personnel certification according (EC) No 306/2008: The total number of personnel subject to certification requirements in the solvents sector amounts to approx. 170 (table 4-8). All personnel need to take training before theoretical and practical tests for certification.

The costs for certification of personnel including training (0.5-1 day) amount to ca. €230[230]. Total costs including expenses are estimated at €600.

Table 4-31: One-off costs of personnel certification according to (EC) 306/2008 (F-gas based solvents)

Certification	Number of personnel	Costs/personnel (€)	Total costs (M€)
Incl. training	170	230	0.039
Expenses	170	370	0.063
Total	170	600	0.102

The one-off costs of personnel certification in this sector amount to ca. €0.1 million in EU-27. About 38% relate to pure certification and training costs.

Recurring costs: Annual costs for new first certification of personnel (beginners) in this sector are assumed to range at 5% of the costs calculated above (ca. 5,100 €/year).

[229] Basis: Data from 4 Member States (CZ, DE, NL, UK). The lowest and highest data differ by a factor of about 2 (UK: €600; DE: €1150; pure costs of certification).
[230] Basis: Data from UK (sole active certification body).

Recovery of F-gases from AC systems in motor vehicles (personnel attestation)

Personnel attestation according (EC) No 306/2008: The total number of personnel subject to certification requirements in the MAC sector amounts to about 360,000 (table 4-10). All personnel need to take training.

The costs for attestation of personnel, including a 1 day-training course, range between ca. €180 (Western Europe) and €120 (Eastern/South-Eastern Europe).[231]

Table 4-32: One-off costs of personnel attestation according to (EC) No 307/2008 (Recovery of F-gases from AC systems in motor vehicles)

	Number of personnel	Costs Western Europe			Costs Eastern/South-Eastern Europe			Total costs
		€	Number of personnel	M€	€	Number of personnel	M€	M€
Attestation	360,000	180	292,000	52.560	120	68,000	8.160	60.720
Expenses	360,000	320	292,000	93.440	180	68,000	12.240	105.680
Total	360,000	500	292,000	146.000	300	68,000	20.400	166.400

Total attestation costs including expenses are estimated at €500 in Western Europe and €300 in Eastern/South-Eastern Europe (table 4-32).

The one-off costs of personnel attestation in this sector amount to ca. €166 million in EU-27. About €61 million (36%) relate to pure certification and training costs. €105 million (62%) are caused by additional expenses to be covered by companies.

Recurring costs: Annual costs for new first certification of personnel (beginners) in this sector are assumed to range at 5% of the costs calculated above (ca. 8.32 M€/year).

Company certification: Stationary refrigeration, air conditioning and heat pumps/ Fire protection

Company certification is required in the stationary refrigeration, air conditioning and heat pump sector and the fire protection sector according to Regulation (EC) No 842/2006, Art 5(1).

The total number for companies subject to certification requirements is estimated at 65,000 (stationary refrigeration, air conditioning and heat pump sector) and 1,300 (fire protection sector) (table 4-11). The stationary refrigeration, air conditioning and heat pump sector accounts for 98% of all companies.

Additional national requirements in some Member States (company certification also in the mobile AC sector) are not considered in this assessment since additional costs induced by such national further reaching legislation do not relate to the F-gas Regulation.

Information on company certification is available from 15 Member States.[232] Costs for company certification vary largely within and between Member States. According to information of the competent authorities in Slovenia, costs for company certification amount

[231] Basis: Data from 4 Member States (CZ, DE, EE, and UK).
[232] These Member States include BE, CZ, DE, EE, FR, HU, IE, IT, LT, NL, PL, SE. SK, SI, and UK.

to only €20 if the personnel is already certified. In France, company certification includes an audit and costs can amount to up to €2,700. Similar differences of the level of costs for company certification can occur between different regions in Belgium. The range in Germany spans between €75 and €1,500, the average costs amount to €300. The major influencing factor is the size of companies, in different regions and Member States the intensity of the company check and fees of authorities' impact costs.

Large cost differences occur between Western Europe and Eastern/South-Eastern Europe. As for small companies in Western Europe company certification costs range between €100 and €1,200 while costs in Eastern/Southern Europe vary between €20 and €225. As for large companies differences amount to €500-1,300 (Western Europe) and €20-800 (Eastern/Southern Europe).

For Western Europe an average of €400 per company is assumed and in Eastern/South-Eastern Europe an average of €200.

Table 4-33: One-off costs of company certification according to (EC) No 303-304/2008 (Stationary refrigeration, air conditioning and heat pumps/ Fire protection)

	Number of companies	Costs Western Europe			Costs Eastern/South-Eastern Europe			Total costs
		€	Number of companies	M€	€	Number of companies	M€	M€
Total	66,300	400	53,900	21.560	200	12,400	2.480	24.040

The costs for first certification of companies amount to ca. €24 million (table 4-33). 98% relate to the stationary refrigeration, air conditioning and heat pump sector (€23.6 million).

Recurring costs of company certification result from new companies which enter the market and need to become certified. Many small enterprises are active in the stationary refrigeration, air conditioning and heat pump sector. Hence a continuous need for company certification is expected. Assuming that 5% new companies are certified every year, costs for company certification amount to ca. €1.2 million.

Furthermore recurring costs relate to the limited validity of company certificates in about 50% of the Member States (cf. tab. 4-10). It differs between 1 and 5 years and hence requires repeated certification in the respective periods.

These costs are not caused by the F-gas Regulation but by national rules. Costs levels cannot be assessed since the costs for recertification have not been set in most cases.[233]

Costs of certification in total

Total costs of personnel and company certification (one-off costs of first certification) amount to ca. €542 million in EU-27 (table 4-34). About 40% of these costs relate to costs for the required exams, fees and costs of trainings. Around 60% result from non-productive working time of personnel and other expenses.

[233] As first approach: At a five-year-term (running time) of the company certificates in half of the Member States and costs for re-certification as high as for first certification, there is an annual cost burden of around 20 % of first certification costs. For EU- 27 this amounts up to 10% off first certification costs annually, which is € 2.4 million.

The total costs for personnel certification including training amount to ca. € 204 million. Compared to this amount, the costs for company certification (€ 24 million) are in the range of less than 12%. Costs for personnel certification (including expenses) account for >95% of total certification costs.

67% of these total costs occur in the stationary refrigeration, air conditioning and heat pump sector (about €364 million including company certification) and 31% in the mobile AC sector (personnel attestation).

Recurring costs: Assuming that 5% of personnel and companies need to become certified annually (entrants) results in on-going costs for certification of ca. 27.1 M€/year.

Table 4-34: One-off and recurring costs of personnel and company certification/attestation according to the F-gas Regulation

Certification/attestation according to	**Pure costs of certification and training (M€)**	**Costs of certification including training and expenses (M€)**	
	One-off costs		**Recurring costs (per year)**
Personnel certification			
(EC) No 303/2008 (SRAC)	139.160	340.753	17.038
(EC) No 304/2008 (FPS)	1.350	4.500	0.225
(EC) No 305/2008 (HVS)	2.550	6.000	0.300
(EC) No 306/2008 (Solvents)	0.039	0.102	0.005
(EC) No 307/2008 (MAC)	60.720	166.400	8.320
Total personnel certification	203.819	517.755	25.888
Company certification	24.040	24.040	1.202
Total personnel and company certification	227.859	541.795	27.090

In table 4-34 additional costs resulting from time limitation of personnel certificates and necessary re-certification are not taken into account since they are due to Member State specific requirements. The range of these additional costs could be determined in the following way:

As displayed in table 4-10, in 8 of those 20 Member States, which have notified, validation of personnel certificates is time limited to 5 years in almost all cases.

However, this is not the case for all sectors; for example, in a few Member States this only applies to the SRAC sector, which is excluded from this regulation in France at present. To estimate the resulting upper limit of costs, it is assumed that 40% of all certificates have to be renewed every fifth year in EU-27, the annual re-certification rate is 8 %.

There are no general conclusions on the costs for re-certification of the personnel. Training efforts for a re-certification are supposed to be significantly lower because of gained qualifications attested by the first certification. If one takes half of the cost and time efforts of first-certification as a basis for the calculation of recertification costs, annual costs range at 4 % of the costs for first-certification in EU-27 (around 20.7 M€).

The upper limit of annual costs for re-certification of companies is assumed at €2.4 million (see above in the section on company certification).

Recurring costs for re-certification of personnel and companies resulting from national regulations are in the range of € 23.1 million or less than 5% of the total EU-27 costs for first certification. However, in some of the Member States, costs are considerably higher.

4.3.4 Costs of containment provisions (Article 3)

Since 4 July 2007 containment provisions according to Article 3 apply to stationary refrigeration, air conditioning and heat pump equipment, as well as to fire protection installations. Equipment with F-gas charges <3 kg is not subject to these provisions. Standard leakage check requirements are defined in (EC) No 1516/2007 and (EC) No 1497/2007.

Long before entry into force of the F-gas Regulation containment measures (including leak checks and leak detection systems) have been carried out in most F-gas sectors, however to a smaller extent and mostly more reactive than proactive. The application of containment provisions acc to Article 3 involves additional costs for upgrading of systems ≥300 kg with leak detection systems, as well as for leak checking by frequencies defined in Art 3(2) and for repair and record keeping.

Stationary refrigeration, air conditioning and heat pumps (SRAC)

The following table 4-35 shows the approach for the assessment of the additional costs that arise to the operators from application of Art 3, such as costs for regular leak checking, quick repair, and record keeping.

The basis of calculation is the cost of one working hour by certified personnel, which is assumed to amount to € 50 (including travelling) on average in EU-27. In the third column, the percentage of regular checks prior to the F-gas Regulation is displayed, ranging from 10% (roof top air conditioning) to 70% (large industrial refrigeration). The fourth column shows the annual expenses for the measures according to Art 3, ranging from €157 (condensing units) to €1,233 (large industrial refrigeration equipment). The sum is a result of three time units: working time for 1 leak check (5) which is multiplied by its frequency (6), annual hours for repair of detected leaks (7), and time for recording (8). The annual time for leak checking is reduced by the percentage of regular leak checks prior to the F-gas Regulation (3). Equipment charged >300 kg is equipped with a leak detection system, for which the annual cost are shown in column 9. Further explanation of the cost calculation approach is given in annex II.

Table 4-35: Calculation basis for the assessment of additional costs from Art 3 to operators in stationary refrigeration and air conditioning (SRAC sector)

1	2	3	**4**	5	6	7	8	9
Sectors of stationary refrigeration and air conditioning	charge in kg	regular leak check before F-gas Reg	**€/year [€50 one hour]**	1 leak check /hours	frequency /year	repair hours /year	record hours /year	detection system €/year
Commercial condensing unit	8	20%	**157**	3	1	1.6	0.33	
Commercial centralised system	230	50%	**593**	8	2	9.6	0.67	100*
Industrial refrigeration small	650	60%	**1,093**	8	2	6.4	0.67	700
Industrial refrigeration large	4,000	70%	**1,233**	12	2	6.4	0.67	800
Stationary AC Multi split VRF	13.5	15%	**181**	3.5	1	1.28	0.33	
Stationary AC Rooftop	10.5	10%	**162**	3	1	0.8	0.33	
Stationary AC Chillers (displacement)	50	20%	**201**	2	2	0.64	0.67	
Stationary AC Centrifugal chillers	630	35%	**805**	4	2	1.44	0.67	500

* €100 means 10% of systems are > 300 kg, and need a leak detection system of €1,000 per year.

The recurring cost for additional leak checking, repair and recording caused by the F-gas Regulation is estimated under the assumption that the F-gas Regulation has been fully applied in the year 2010.

As stated previously, quantitative data indicating the extent of additional leak checking are not available at industry or service companies. The values in the table are estimates by the sector experts in the project team.

Record keeping (according Art 3(6)) is a new legal requirement and can clearly be attributed to the F-gas Regulation. This also applies to the relevant cost. Although service companies have always kept certain records, e.g. for financial accounting, in the past, it is a new provision that operators have to keep the records.

Additional service costs arise to the operators also from increased labour costs for certified personnel. The increase is estimated +10 % compared to non-certified personnel previously used.

As higher frequency in leak checking implies detection of more leaks, the requirement of Art 3 that leaks shall be repaired “as soon as possible” increases the annual working time for repair compared to the time before full application of the F-gas Regulation. The costs from extra repair of small leaks by certified persons are included in the cost of leak checking. With regard to bigger leaks which lead to system failure it is assumed that such leaks had been repaired also before the F-gas Regulation.

Table 4-36 shows an estimation of the annual costs by the eight sectors of stationary air conditioning and refrigeration and focuses on equipment containing refrigerant charges >3 kg under the assumption of full application of Art 3. Evidently, at a lower level of application, the total costs are lower and achievable emission reduction decrease accordingly.

Table 4-36: Recurring costs for leak checking according to Art 3 (SRAC sector)

Sub sectors with equipment ≥3 kg	**Annual costs/ system (€/year)**	**Number of SRAC-systems (1,000)**		**Annual recurring costs of leak checking (M€)**	
		2010	**2015**	**2010**	**2015**
Commercial condensing unit	157	1,200	1,600	195.8	254.0
Commercial centralised system	593	160	170	92.7	102.7
Industrial refrigeration small	1,093	10.2	14.7	11.2	16.1
Industrial refrigeration large	1,233	5	7.2	6.2	8.8
Stationary AC multisplit-VRF	181	540	980	97.8	178.1
Stationary AC Rooftop	162	470	520	49.9	76.1
Stationary AC Chillers (displ.)	201	760	780	100.0	152.6
Stationary AC Centrif. chillers	805	8.7	10.5	5.3	7.0
Total		**2,722**	**4,011**	**559.0**	**795.7**

Cost calculation according to table 4-35. Number of units from model AnaFgas.

In 2010, a total of ca. 2.7 million SRAC systems were subject to Article 3 of the F-gas Regulation. This number will increase to 4.0 million until 2015. Annual costs that arise to the operators from the measures of Art 3 of the F-gas Regulation are estimated at 559 M€ (2010), and 796 M€ (2015). Full application of Art 3 is assumed. The costs vary by sectors, and are particularly high for condensing units (with charges >3kg) because their number is very large, accounting for 44% of the total number of systems. Annual service cost per condensing unit is estimated at €157, which is approx. three working hours by a certified person.

Fire protection systems (FPS)

Leak checking, record keeping

It is assumed that fire protection systems have already been equipped with appropriate leak detection systems and/or that an existing inspection regime has already been in place to comply with ISO 14520 (Art 3(5)), so that no additional costs for upgrading arise from the F-gas Regulation.

Table 4-37: Recurring costs of additional leak checking and of record keeping according to Art 3 (FPS sector)

	working hours per year	**Number of FPS systems (2010)**		**Annual recurring costs of leak checking and record keeping (M€)**	
		2010	**2015**	**2010**	**2015**
Leak checking	1.00	22,800	24,000	1.1	1.2
Record keeping	0.67	91,000	96,000	3.0	3.2
Total				**4.2**	**4.4**

Number of units from model AnaFgas.

Additional cost, however, arise from extra leak checking. Prior to the F-gas Regulation, we estimate that 25% of the fixed fire protection installations have not been controlled at the same interval as prescribed by Art 3 of the F-gas Regulation. In these cases, additional working time expenditure is estimated at 2x30 minutes per year, related to 25% of the equipment stock. Additional recurring costs arise to all operators for record keeping according to Art 3(6) (0.67 h per year).

Total additional costs for leak checking and record keeping are approx. €4.2 to €4.4 million in 2010/2015 (table 4-37).

4.3.5 Costs of recovery (Article 4)

One of the objectives of the F-gas Regulation is to increase the recovery efficiency through the use of certified personnel. This mainly targets to recovery at end-of-life of stationary equipment. Additional costs to the operators of SRAC systems, resulting from extra recovery activities and from the use of certified personnel, can be attributed to the F-gas Regulation.

No significant additional recovery activities are expected for FPS and HVS installations. In these sectors, only the increase in labour cost (+10%) must be accounted for, which is due to the fact that certified person must be paid more than non-certified personnel. The solvents sector is of negligible size and not considered further, here.

We estimate that the recovery activities in the SRAC sector need to increase significantly for equipment with F-gas charges >3 kg compared to the situation prior the F-gas Regulation (percentage increase similar to leak checking). In the sub sectors of equipment <3 kg the increase in recovery activities must be even very much higher to meet the requirements of Art 4 of the F-gas Regulation, because in many SRAC sub sectors end-of-life was hardly common prior to the F-gas Regulation.

The calculations in table 4-38 refer to SRAC equipment which is decommissioned in 2010/2015 (for further explanation and details of calculation see Annex II.) The basic calculation unit is again €50 for one working hour of a certified person.

The additional recovery cost for Domestic Refrigeration, which shows the highest number of decommissioned units by far, is only €1.50. As recovery at end-of-life is already subject to the WEEE Directive, additional cost arise only from the requirement that recovery must be carried out be certified personnel. The labour costs are estimated €5.00 higher per hour. As there is 0.3 hours time assumed for end-of-life treatment, additional cost from application of Art 4 is €1.50.

The costs for recovery activities which are carried out by certified personnel (calculated to 10% of total annual personnel costs of recovery) amount in the SRAC sector to €100 million (in 2010 and about €222 million in 2015. The additional costs in the fire protection and the high voltage switchgear sector are in the range of €132,000 – €545,000 in 2010/2015.

Table 4-38: Annual costs for recovery according to Art 4 by sectors

Sub sector	Recovery costs/system (€)	charge (kg)	Number of systems at decommissioning		Annual recurring costs of recovery (M€)	
			2010	2015	2010	2015
Stationary refrigeration, air conditioning and heat pump equipment (SRAC)						
Domestic Refrigeration	1,5	0.12	16,600,000	11,200,000	24.950	16.770
Commercial stand-alone	25	0.4	375,000	400,000	9,370	9,990
Stationary AC moveable	25	0.75	316,400	774,600	7.900	19.400
Stationary AC single split	50	1.5	1,133,700	3,250,500	56.700	162.500
Heat pumps	50	2.4	0	27,500	0	1.300
Commercial condensing unit	50	8	1,200	166,200	0.060	8.310
Commercial centralised system	100	230	8,400	8,700	0.839	0.870
Industrial refrigeration small	150	650	0	638	0	0.100
Industrial refrigeration large	300	4,000	0	318	0	0.100
Stationary AC multi split-VRF	50	13.5	0	0	0	0
Stationary AC Rooftop	50	10.5	0	49,000	0	2.500
Stationary AC Chillers (displ.)	50	50	0	0	0	0
Stationary AC Centrif. chillers	75	680	0	0	0	0
SRAC Total			18,470,000	15,860,000	**99.800**	**221.800**
Fire protection systems (FPS)						
Fire protection systems	100	130	0	3,900	**0**	**0.390**
Switchgear (HVS)						
HV switchgear	75	100	1,800	2,000	**0.132**	**0.155**

Explanation of cost calculation in annex II. Number of units from model AnaFgas.

4.3.6 Costs of Reporting (Article 6)

The reporting provisions of Article 6(1) of the F-gas Regulation apply to about 80 companies in EU-27 (importer, exporter and/or producer of >1 tonne of F-gases per annum; see chapter 4.2.7). According to the European Fluorocarbon Technical Committee[234] (EFCTC) the annual reporting costs per company are at maximum ca. €10.000 per year (including personnel costs). With regard to differences between Member States and between large and small companies, we budget €5.000 per year and company.

[234] Communication to Öko-Recherche, 28 March 2011.

Table 4-39: Recurring personnel costs of reporting according to Article 6(1) (importer, exporter and producer of F-gases)

	Annual reporting costs/company (€)	Number of companies (2008/2009)	Annual personnel costs of reporting according to Art 6(1) (M€)
Importer, exporter, producer of >1 tonne F-gases	5,000	80	0.40

The reporting costs according to Article 6(1) total about € 0.4 million per year.

4.3.7 Costs according to Article 7 (labelling, instruction manuals)

Article 7 and (EC) No 1494/2007 set out requirements for labelling of new equipment containing HFCs or PFCs placed on the market after 1 April 2008. The labelling requirements apply to all SRAC/HP systems, to mobile RAC products and equipment installed in rail vehicles, ships and agricultural machines, to FPS systems and fire extinguishers, to HVS equipment and to F-gas containers. Information on F-gases shall be included in the instruction manuals provided for products and equipment covered by Article 7 (chapter 4.2.8).

One-off costs emerge from (re)design of the label and additions in the instruction manuals from companies in the above mentioned sectors. These one-off costs apply to the original equipment manufacturers (OEM) and to the contractors which are assembling customized components on site, and to fillers of F-gas containers.

Table 4-40 contains information on costs related to Article 7.

The information is based on estimations of the number of affected companies in each sector and the average costs for redesign of labels and additional text in instruction manuals.[235]

The number of affected companies in the stationary refrigeration, air conditioning and heat pump sector is the most important factor in this calculation since ca 50.000 OEM manufacturers and contractors assembling on site components are affected in EU-27 (industry estimate).

Table 4-40: One-off costs of labelling according to Article 7

Sector	Companies/model series concerned (number)	Costs per company/model series (€)	Total costs (M€)
SRAC/HP	50,000*	1,000	50.00
FPS	30	2,000	0.06
HVS	115**	2,300	0.265
F-gas supplier	70	1,000	0.07
Total			50.39

* OEM and contractors; ** model series, all manufacturers

[235] Calculation based on data input from EFCTC, EPEE, EUROFEU, and T&D Europe.

4.3.8 Public set-up costs

Public set-up costs include public expenses which are not covered by certification fees or other fee, for designation/set-up of certification systems, and related central data systems, for public awareness rising and other information activities as well as for enforcement, control and inspections. Public costs can be partly considered one-off costs but partly occur regularly and hence relate to recurring costs (e.g. control and inspections).

On the basis of information from 6 Member States[236] average public set-up costs are estimated at ca. €50,000 per 1 million inhabitants (table 4-41)[237]. These 6 Member States include countries which had to set-up completely the initial infrastructure (e.g. Hungary, Estonia, Malta) and others which could at least partially rely on existing information systems (e.g. Poland).

This is well in line with the governmental set up costs for the Dutch STEK system. The costs for the Dutch STEK system were estimated at €750,000 by the Dutch Environment Ministry VROM, which corresponds to €46,000 per million inhabitants[238].

Recurring costs for registration systems, for public control and inspection measures and other administrative activities in the 6 Member States amount to ca. €23,000 per 1 million inhabitants.

By extrapolation to EU-27, the sample estimate adds up to ca. €25.0 million of one-off costs and ca. €11.4 million of recurring costs (table 4-41).

Table 4-41: Public set-up costs from implementation and application of (EC) 842/2006

	One-off costs	Annual recurring costs
€/million inhabitants	50,000	23,000
Total EU-27 (M€)	25.0	11.4

4.3.9 Summary: Total costs acc. to Articles 3-7 of the F-gas Regulation

The table 4-42 summarizes the total costs of the F-gas regulation for both one-off costs and recurring costs in 2010 and 2015.

One-off costs, which are related to implementation and application of the F-gas Regulation, are in the range of €617 million. Almost 90% thereof result from costs for certification of the personnel and companies. Costs for Article 7 (labelling) and other public set-up costs are comparatively low. Two thirds (66%) of the certification costs arise in the sectors stationary refrigeration, air conditioning and heat pumps.

Recurring annual costs of the F-gas Regulation are higher than the one-off costs.

In 2010 recurring costs are estimated at about €890 million for EU-27, in 2015 at €1,250 million. They account for the major costs of the F-gas Regulation. The highest costs by far

[236] The Member States include Estonia, Finland, Hungary, Malta, the Netherlands, and Poland. In case of the Netherlands the government set up costs for the STEK system have to be taken into account.

[237] Enviros 2002: Assessment of the Costs & Impact on Emissions of Potential Regulatory Frameworks for Reducing Emissions of HFCs, PFCs & SF_6.

[238] Cited in: Enviros 2002: Assessment of the Costs & Impact on Emissions of Potential Regulatory Frameworks for Reducing Emissions of HFCs, PFCs & SF_6.

arise to the operators in the SRAC sectors for regular leak checking, repair and record keeping. These expenses account for approx. 85% of the recurring costs of the F-gas Regulation.

Table 4-42: Total costs of implementation and application of the F-gas Regulation by Articles 3 to 7

Type of costs	Sectors	One-off costs (M€)	Recurring costs (M€)		
			2010	2015	2030
Art 5 Certification	SRAC, FPS, HVS, Solvents, MAC	541.8	27.1	27.1	27.1
Art 3 Containment	SRAC, FPS		563.2	800.0	967.6
Art 4 Recovery*	SRAC, FPS, HVS		99.9	222.4	544.4
Art 6 Reporting	Fluid suppliers		0.4	0.4	0.4
Art 7 Labelling	SRAC, FPS, HVS, Fluid suppliers	50.4			
Other (public set-up costs)		25.0	11.4	11.4	11.4
Total		617.2	702.0	1,061.3	1,550.9

* Recovery costs mostly from small air conditioners.

Recurring costs in 2030 are estimated at €1,550 million. Both containment and recovery costs are increasing from 2015 to 2030. The doubling of recovery costs is caused by the growing number of systems in use and from which F-gas has to be recovered eventually.

5. Impact and cost-effectiveness of the current EU F-gas policy framework

5.1 Concept of the current EU F-gas policy framework

The approach in the current F-gas Regulation distinguishes between F-gas emissions released from

- closed applications such as stationary refrigeration, air conditioning and heat pump equipment, stationary fire protection systems, switchgear equipment

and

- open applications of F-gases such as the use of HFCs in one-component foam and novelty aerosols, or of SF_6 in car tyres, SF_6 in magnesium casting, etc.

For closed applications, the Regulation establishes containment and recovery measures, while restrictions for use or placing on the market were established for specific open applications where alternatives were already technically feasible and cost-effective. Emissions from mobile air conditioning equipment contained in passenger cars are addressed by the MAC Directive, which requires gradual phase-out of F-gases with GWP >150 in new systems in the period 2011-2017 in EU-27.

Certain sources of F-gas emissions in EU-27 are today addressed by neither the F-gas Regulation nor the MAC Directive. Chapter 5.3 lists and describes these emissions and their sources.

The impact of the F-gas Regulation relies primarily on the extent to which HFC refrigerant emissions from stationary equipment for refrigeration, air conditioning and heat pumps can be reduced, since equipment from these sectors accounts for most emissions, after those from mobile air conditioning, whereas open applications covered by restrictions account for a minor share of emissions. Containment and recovery measures aim at reduction of emissions from operation in the use phase and at decommissioning at end of life of equipment. Use-phase emissions are indicated by the use-phase emission factor, end-of-life emissions are indicated by the disposal emission factor.

It has not been possible to substantiate empirically disposal emission factors in detail as no reliable measurement approach exists for this type of emissions. Existing monitoring systems, including the Dutch STEK system, refer to use-phase emissions only and disregard from disposal emissions. Statistics on recovered F-gas quantities for recycling, reclamation and destruction (RRRD) are only partially helpful, because they do not indicate quantities recycled onsite and quantities released to the atmosphere during recovery. End-of-life or disposal emission factors used in the model AnaFgas are based on expert assumptions as outlined in chapter 2 on methodology.

Before adoption of the F-gas Regulation, many experts expected a significant decrease in use-phase emissions within a short time after entry into force. This expectation was based on experience from the Dutch STEK system regulating ODS and HFCs, which is the model for containment provisions of the F-gas Regulation. Reduction of the overall use-phase emission factor in stationary refrigeration and air conditioning by 50% was considered to be likely within five years, because the STEK system was reported to have cut of the annual leakage rate in the Netherlands from more than 11% to less than 5%[239], within the same timeframe[240].

Empirically verified data on use-phase emission factors are available to very limited extent only. It is not possible to simply extrapolate available data to all sectors and EU-27. Therefore, assumptions on use-phase emission factors were made as described and listed in chapter 2 on methodology. Emission reductions caused by bans set out in the F-gas Regulation (Articles 8 and 9) are reflected in the model AnaFgas from 2008 onwards.

5.2 Current and projected impact of the F-gas Regulation and its cost-effectiveness

5.2.1 Model output: Emission scenarios in EU-27

The impact of the F-gas Regulation is illustrated by a comparison of the counter-factual WOM scenario and the WM scenario calculated by the model AnaFgas.

- **Without measures (WOM):** An emission scenario for the EU-27 and each MS reflecting the situation that would likely have occurred since 1995 (baseline year for F-gases under the Kyoto Protocol) without the 2006 EU policy intervention (F-gas Regulation, MAC Directive). The projected emissions until 2050 are based on sub sector specific growth assumptions, which in most cases do not include technology changes or introduction of alternative fluids ("frozen technology"). Often the F-gas bank of the last year, or the trend over the last years before enforcement of F-gas legislation is extrapolated to the future in order to estimate emissions. Details are given in the model description in annex III.
- **With measures (WM):** A scenario of actual or baseline emission trends for the period 1995-2050 taking into account the existing policies and measures to reduce F-gas emissions in EU-27 and each Member State. The WM scenario is based on the same underlying growth trends as the WOM scenario, but varies those parameters that are influenced by the European legislation (F-gas Regulation, MAC Directive) for the period when the respective policies and measures are expected to be effective. These parameters include leakage rates, recovery efficiency and the substitution of certain gases which would not have occurred without regulatory action.

Both the WOM and the WM scenario include not only F-gas emissions but also the underlying demand for F-gases. In chapter 8, a further scenario with additional measures (WAM) is presented. It shall help determine the emission and demand reductions which could be achieved by additional policies and measures which are discussed in that chapter.

F-gas emissions and the differences between the two scenarios are summarized in table 5-1 for selected years. Figure 5-1 shows F-gas emissions in EU-27 in the period 1995-2050. All data in this chapter are calculated with GWP values from the 4th IPCC Assessment Report.

239 The basis for these assumption was the 2003 report "Assessment of the costs and implication on emissions of potential regulatory frameworks for reducing emissions of HFCs, PFCs and SF_6" by the consultancy Enviros. In this study the timescale for emissions reduction is the Kyoto timeframe of 2008 to 2012, consistent with the ECCP analysis.

240 Dan de Bruyckere, current manager of STEK, pers. comm. 27 August 2010.

Table 5-1: F-gas emissions in EU-27 in the WOM and WM scenarios in 2000-2050 (kt CO_2 eq) and differences between the scenarios (kt CO_2 eq; %)

	2000	2006	2008	2010	2015	2020	2030	2050
WOM	84,929	92,162	104,013	116,114	144,580	164,561	183,928	204,162
WM	84,929	92,162	103,104	113,253	113,666	118,489	103,657	110,824
Diff in kt CO_2	0	0	909	2,861	30,914	46,072	80,271	93,338
Diff. In %	0	0	0.9%	2.5%	21.4%	28.0%	43.6%	45.7%

Table 5-1 shows that without policy measures, the emissions of fluorinated greenhouse gases in EU-27 would increase from 92 Mt CO_2 eq in 2006 to more than 204,000 kt CO_2 eq until 2050. In case of full application of EU F-gas legislation, F-gas emissions can be reduced substantially as compared with the WOM scenario. Relative emission reductions can amount to 2,900 kt CO_2 eq (2.5%) in 2010, 31,000 kt CO_2 eq (21%) in 2015, ca. 80,000 kt CO_2 eq (44%) in 2030 and 93,000 kt CO_2 eq (46%) by 2050.

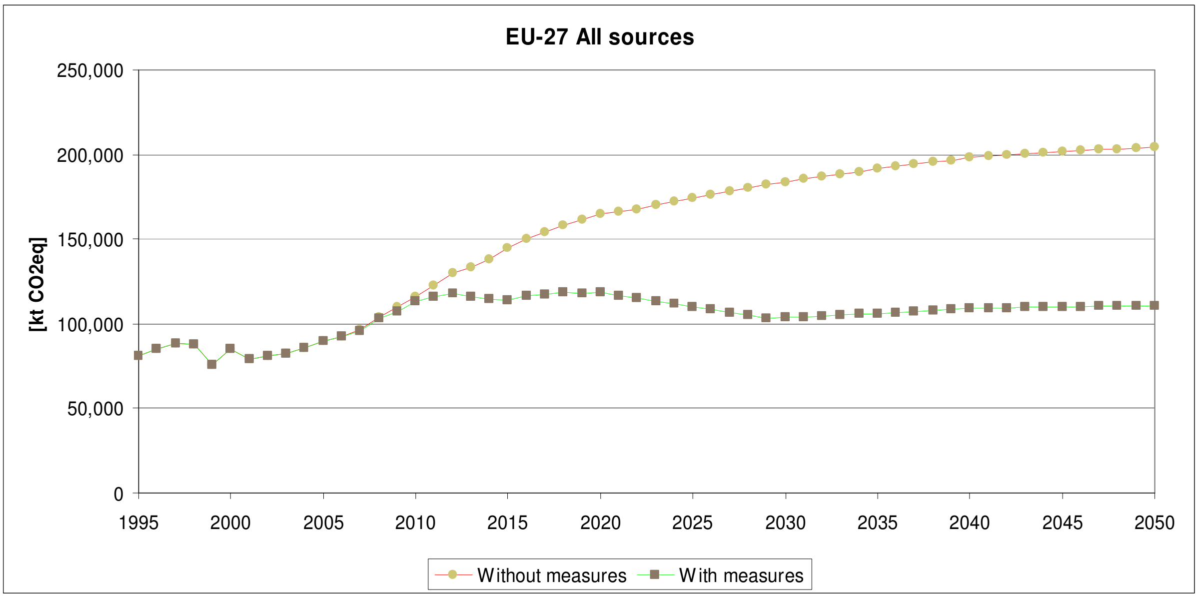

Figure 5-1: F-gas emissions in 1995-2050 in a scenario without measures (WOM) and a scenario with measures (WM) of EU F-gas legislation. The shape of the emission curves indicates the emission reduction potential for F-gas emissions. From 2008/2010 onwards the two curves distinctly split up. In the WM scenario, emissions will remain at a stable level from 2010 until 2050, while in the WOM scenario emissions continue to increase up to almost the double. It should be noted that even in the WM scenario absolute emissions in 2050 will be higher than in the WOM scenario in 2008 (by 6,800 kt CO_2 eq).

Scenario without measures (WOM)

Without EU policies addressing F-gas emissions, total emissions would rise by 122% in the period 2006-2050. In 2006, the year of entry into force of the F-gas Regulation and the MAC Directive, F-gas emissions in EU-27 amounted to ca. 92 million t CO_2 eq. They would increase to 204 million tons by 2050. A particular steep rise would take place until 2030 and F-gas emissions would reach 184 million t CO_2 eq then (table 5-1).

Table 5-2 reveals that under WOM, the refrigeration sectors (including commercial, industrial, and transport refrigeration) and mobile air conditioning would contribute 25%-30% each to total F-gas emissions in 2030 and 2050. Stationary air conditioning would become the largest sector, accounting for 29% in 2050. HFC refrigerants cause most of the F-gas emissions in EU-27.

Table 5-2: Historical and projected F-gas emissions (kt CO_2 eq) in EU-27 by sectors in the WOM and WM scenarios in 2000-2050, GWP values according to the 4^{th} IPCC AR

	2000	2006	2008	2010	2015	2020	2030	2050
WOM								
Total by Sector	**84,929**	**92,162**	**104,013**	**116,114**	**144,580**	**164,561**	**183,928**	**204,162**
Refrigeration	13,471	28,530	34,478	39,347	49,295	52,884	54,833	56,862
Stationary A/C & HP	2,110	8,693	11,750	15,058	26,761	38,195	52,113	59,091
Mobile A/C	10,679	25,172	30,625	34,525	40,026	43,254	49,391	58,652
Foams	8,304	4,954	4,721	4,906	5,408	5,938	7,034	8,680
Other HFCs	7,223	9,651	9,423	9,491	10,083	10,500	10,748	11,181
SF_6 users*	9,610	5,919	5,887	6,370	7,399	8,808	4,824	4,711
PFC and Haloprod	33,532	9,242	7,129	6,417	5,607	4,982	4,986	4,985
WM								
Total by Sector	**84,929**	**92,162**	**103,104**	**113,253**	**113,666**	**118,489**	**103,657**	**110,824**
Refrigeration	13,471	28,530	34,478	39,347	32,093	34,363	35,556	37,277
Stationary A/C & HP	2,110	8,693	11,750	15,058	20,641	28,206	36,992	40,971
Mobile A/C	10,679	25,172	30,625	34,525	36,608	30,105	8,426	8,736
Foams	8,304	4,954	4,480	3,299	3,631	3,974	4,634	5,746
Other HFCs	7,223	9,651	9,423	9,155	9,503	9,893	10,143	10,576
SF_6 users*	9,610	5,919	5,220	5,452	5,583	6,966	2,921	2,533
PFC and Haloprod	33,532	9,242	7,129	6,417	5,607	4,982	4,986	4,985

*This sector includes the following sub sectors: electrical switchgear, magnesium and secondary aluminium industry, soundproof glazing, car tires, and footwear.

The other sectors including aerosols, solvents and fire extinguishers („other HFCs") and foam blowing agents, which caused almost two-thirds of global warming emissions of fluorinated gases (CFCs, HCFCs) 20 years ago, currently play a minor role compared to HFC refrigerants. Even in the WOM scenario, emissions of "other HFCs" would rise only slowly in the future.

This also applies to emissions of SF_6, and to PFCs released during semiconductor and aluminium manufacture as well as to emissions from the production of halocarbons. Halocarbon production causes amongst others by-product emissions of HFC-23 which accounted for 25% of the total F-gas emissions still in 2000 (50% in 1995). Due to abatement technologies and as a result of the HCFC phase out, HFC-23 emissions have decreased in recent years. Further information on HFC-23 by-product emissions are laid down in chapter 5.3. As mentioned earlier, PFC emissions and emissions from halocarbon production are not affected by any provisions of the F-gas Regulation[241].

[241] Annex II of the F-gas Regulation prohibits placing on the market of PFCs in fire protection systems and fire extinguishers, in addition to F-gases in footwear. The last year in which PFC (C_3F_8) containing sport shoe soles were sold to the EU market was 2006, and PFCs (C_4F_{10}) have not been used for new fire protection equipment since 2005. A specific reduction of emissions from the F-gas Regulation cannot be identified.

With-measures (WM) scenario

The WM scenario is used to calculate emission reductions until 2050 as compared to the WOM scenario, which result from EU F-gas legislation including the current F-gas Regulation and the current MAC Directive.

Tables 5-1 and 5-2 show significantly lower emissions in the WM scenario than in the WOM scenario from 2010 onwards. The difference to the emissions in the WOM scenario amounts to 46% in 2050.

Calibration of the model output: Comparison with CRF reports

Sectoral data of the model AnaFgas are only partly based on emission data reported by the Member States to the UNFCCC in form of CRF tables although CRF data represent the best available empiric information source on F-gas activity data and emissions in Member States. Sectors largely relying on CRF data include fire protection, solvents, semiconductor manufacture, primary aluminium production, production of halocarbons, and XPS foam (see description of model AnaFgas in annex III).

As CRF data are often too general, incomplete, and not sufficiently transparent and of varying quality, most sectoral data were compiled in a different manner, as described in annex III.

A comparison of the F-gas emissions reported by CRF and F-gas emissions calculated by the model AnaFgas has been undertaken for validation. This comparison refers to historic data until 2009 and does not look at projected emission data.

Table 5-3 summarizes the total EU F-gas emissions for the years 2000-2009. In the first line emissions from the recent CRF submission (EU CRF table 10s4.2) in 2011 are listed. The second line contains total F-gas emissions from the model AnaFgas. The GWP values are in both time series from the 2nd IPCC AR, because they are used in CRF reporting.

Table 5-3: Comparison of CRF reported EU F-gas emissions with the model output, for the time series 2000-2008, in kt CO_2 eq. GWP values according to 2nd IPCC AR[242]

kt CO_2 eq	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
CRF	66,205	63,833	66,949	69,303	70,113	73,485	74,657	78,551	80,950	81,352
Model	74,023	69,197	70,722	71,701	74,285	77,694	79,887	83,077	89,210	92,707
Diff in %	12%	8%	6%	3%	6%	6%	7%	6%	10%	14%

[242] Note that reporting to the UNFCCC, which includes CRF data, needs to be based on GWP values according to the 2nd IPCC AR. For comparison, the model data given in this table are also calculated by using these GWP metrics while most other data in this report are based on GWP values from the 4th IPCC Assessment Report.

Figure 5-2 illustrates the comparison of the model output and CRF data.

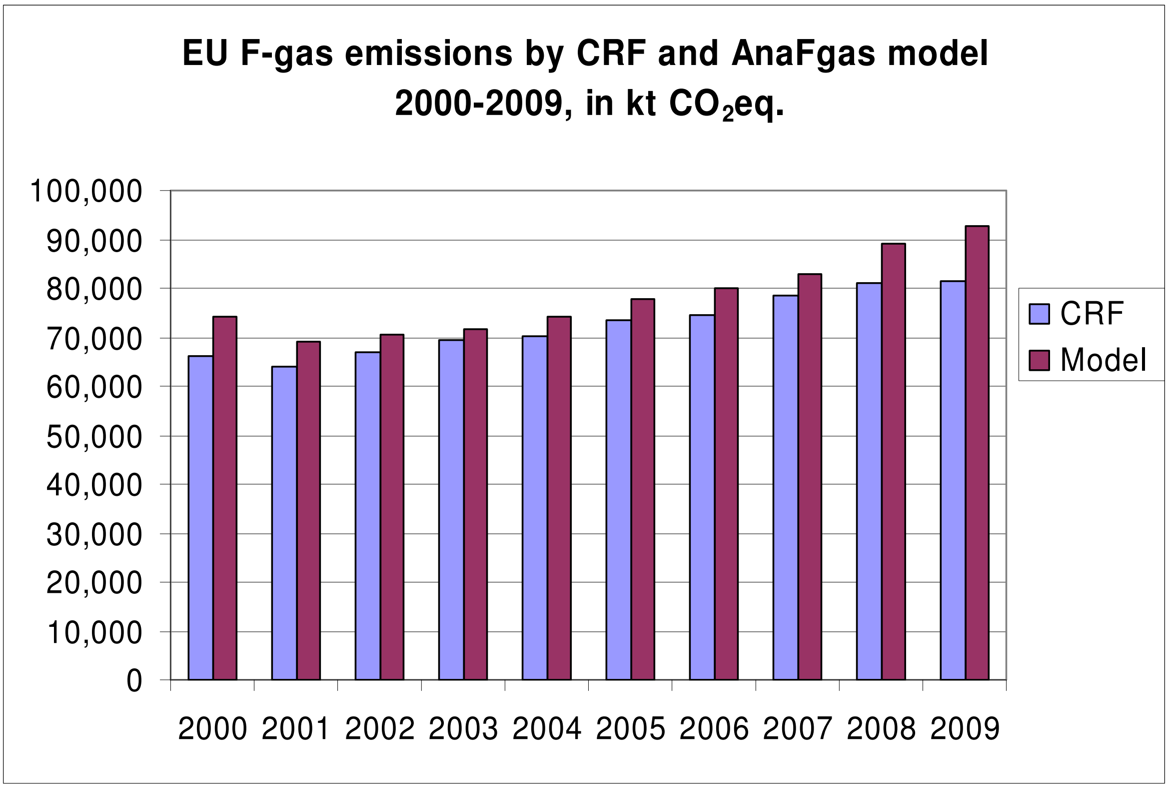

Figure 5-2: Comparison of CRF reported F-gas emissions for the EU (left bars) with the model output of the EU F-gas emissions (right bars). The deviation between the annual data ranges in the order of magnitude, which is considered acceptable.

From the comparison it can be seen:

1. CRF reports and model output feature the same upward trend from 2001 to 2009.
2. The deviation between the annual emission data ranges between 2% and 14%.
3. The model emissions are always higher than the national reports.

The third point is not surprising because the model sets the same completeness standards to all Member State reports and frequently adds data where MS do not provide any information[243]. The result of the comparison is considered an indication of the quality of the model output.

[243] For instance, one country has never reported HFC-23 by-product emissions although there is an HCFC-22 plant with estimated emissions of at least 0.4 million t CO_2 eq.

5.2.2 Emission Reduction Potential of current EU F-gas legislation

Emission reduction potential by types of measures

While empirical data and time series on emission reductions caused by measures of the F-gas Regulation are currently lacking, it can be expected that once the F-gas Regulation is fully implemented and applied in EU-27, F-gas emissions can be substantially reduced already within the next few years (2011 - 2015).

Data on results of containment measures

Reliable data on a broad basis to assess the quantitative effects of containment measures of the F-gas Regulation is not yet available. As outlined in chapter 2 on the measurability of emission reductions, evidence for quantitative effects requires evaluation of appropriate records and compilation of data in appropriate databases.

Significant evaluation and compilation of data in databases have not been undertaken so far, because implementation of certain key provisions of the F-gas Regulation in the Member States either occurred just recently or is still ongoing. New monitoring systems which are intended or currently being established in some Member States are promising. Time series sufficiently long for determination of leakage rate trends are not expected before the next couple of years.

Stakeholders from industry are aware of this problem. Whilst some experts state that a substantial reduction of leakage rates has been already achieved by the F-gas Regulation[244] no comprehensive information to verify this assumption by reliable large scale empirical data is currently available. As outlined, few data available from the commercial refrigeration sector (table 2-5) already indicate an effect of containment measures: For the time period 2004-2009 a reduction of the emission rate from 18 – 15% for a large population of supermarkets can be seen. In other cases (industrial refrigeration) a trend could not yet be verified.

The association of F-gas manufacturers, EFCTC, underlines that no databases exist with quantitative indicators on the development and occurrence of leakage rates. “Furthermore, even if emissions were estimated, the length of the EFCTC database, at two years since the implementation of the regulation, is too short to give a statistically significant trend”. EFCTC refers to the analysis of reported data[245] on consumption and emissions from EU Member States submitted to UNFCCC, which show “continuing trends in improvement in containment that predates the implementation of the F-gas Regulation”. Apart from methodological problems, these studies are not of relevance for the analysis because they do not relate to the period after introduction of F-gas Regulation and cannot be used as indicator of the effectiveness of the containment measures of this Regulation.

[244] Statement by AREA: “Experience from countries that either implemented the Regulation in time or had leakage check requirements in place beforehand, however, shows a substantial decrease in leakage rates, which is now well under 10%.”

[245] A. McCulloch, Evidence for improvements in containment of fluorinated hydrocarbons during use: an analysis of reported European emissions. Environmental Science & Policy 12, 2009, 149-156.

The fire protection industry could not provide data on current trends of leakage rates in the context of the application of the F-gas Regulation either.[246]

Emission reduction potentials in 2015-2050

Due to the described lack of empirical time series, model data had to be based on assumptions concerning emission factors (see chapter 2 on methodology).

Emission reduction potentials refer to the potential effect of current measures on emission reductions and can be calculated by comparing projected emissions of the WOM scenario and the WM scenario.

Particular large emission reduction potential emerges through containment and recovery measures as set out by Articles 3 and 4 of the F-gas Regulation, which address emissions from the sector of stationary refrigeration and the sector of stationary air conditioning including heat pumps. In the WOM scenario the emissions from these sectors are projected to rise from 2010 to 2015 by 10 million t CO_2 eq (table 5-2), each. In the WM scenario the aggregated emissions from the two sectors decrease by 1.7 million t CO_2 eq in the same time periods. Emissions from refrigeration[247] even decrease within the 5 years, by 7 million t CO_2 eq compared to the WOM scenario. By 2050, emission reductions in those sectors will have increased to 38 million t CO_2 eq compared to WOM due to measures of containment and end-of-life recovery set out by the F-gas Regulation.

As for the fire protection sector and the high voltage switchgear sector, potential emission reductions resulting from containment and recovery measures will amount to 1 million t CO_2 eq by 2015 (table 5-7). This emission reduction potential will remain stable until 2050.

Bans according to Articles 8 and 9 of the F-gas Regulation will lead to emissions reductions (relative to WOM scenario) in the foam sectors, other HFC sectors and all applications of SF_6 in the range of 3 million t CO_2 eq by 2015 (table 5-8). Emission reduction potentials of these sectors are expected to increase to 4.6 million t CO_2 eq by 2050.

As for mobile air conditioning, emission reductions resulting from measures of the MAC Directive will begin in 2011 (assumed start of the phase-out of HFC-134a) and take several years to reach their full potential. In the model, HFC emissions from AC systems contained in passenger cars will be almost completely cut by 2029 (figure 5-3), which leads to emission reductions of 50 million t CO_2 eq by 2050, compared to the WOM scenario. Remaining F-gas emissions will be released from mobile air conditioning systems contained in other sub-sectors such as trucks, buses, ships, and railcars, which are not effectively addressed by current measures[248].

[246] In its response to the Öko-Recherche questionnaire on Fire Protection Systems (May 2010), the association ASSURE refers to a recent report from the US-HFC Emissions Estimating Program (HEEP) which indicates a 2008/2009 decline in USA. ASSURE concludes: “The reduction in emissions in 2008 and 2009 is likely the result of an overall decline in economic activity rather than a large decrease in emission rates.” Specific data on Europe are not provided by this association.

[247] Refrigeration includes also mobile systems in trucks or fishing vessels. The indicated emission reductions from the F-gas Regulation (WM scenario) occur only in the stationary subsectors.

[248] In the model, the general provision of Art 4(3) for recovery by “appropriately qualified personnel” is not considered to impact quantitatively the disposal emission factor in mobile air conditioning of cars, trucks, buses and other vehicles.

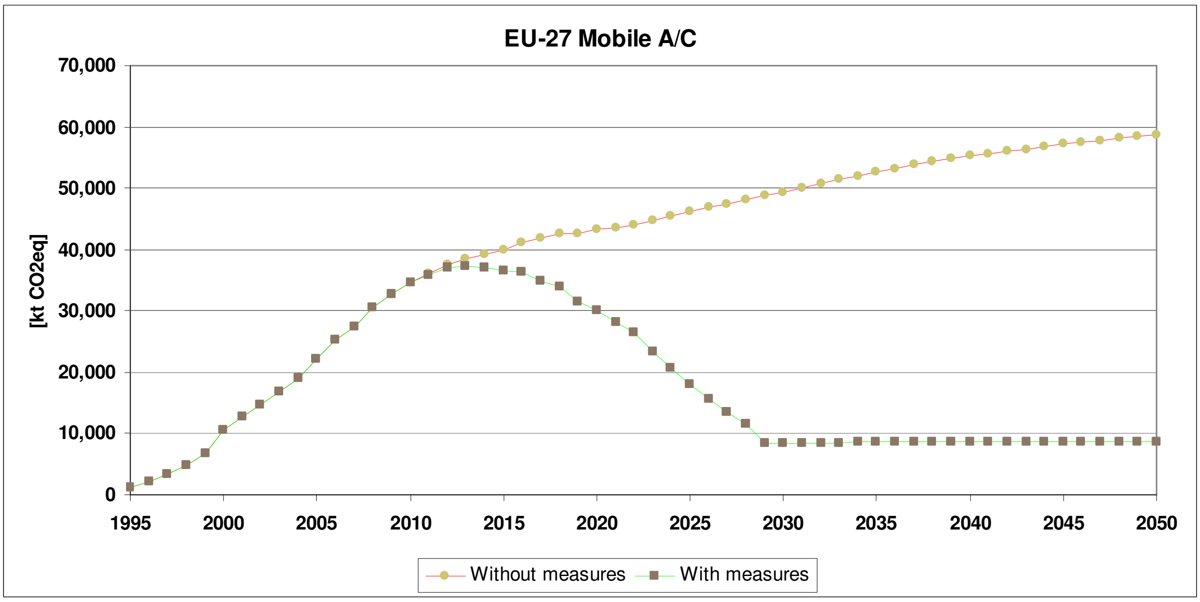

Figure 5-3: EU-27 emissions from mobile air conditioning in the WOM and WM scenarios. The effect of the MAC Directive for passenger cars can clearly be seen in the curve split from 2011 onwards. From 2030 HFC emissions are released from MAC systems in trucks, buses, ships and railcars only.

Table 5-4 and figure 5-4 show emission reduction potentials of containment measures according to Article 3, recovery measures according to Article 4, prohibition measures of Articles 8 and Art 9 set out by the F-gas Regulation, and the emission reduction potential of the prohibition of HFC-134a (substances with GWP >150) according to the MAC Directive.

Table 5-4: Emission reduction potentials (kt CO_2 eq) of measures set out by EU legislation on F-gases (including F-gas Regulation and the MAC Directive) in 2008-2050 (WOM-WM)

		2008	2009	2010	2015	2020	2030	2050
MAC Directive		0	0	0	3,419	13,150	40,965	49,916
F-Gas Regulation	Art 3 and Art 4	0	0	0	24,357	29,478	35,609	38,815
	Art 8 and Art 9	909	2,687	2,861	3,012	3,223	3,750	4,616
Total		**909**	**2,687**	**2,861**	**30,787**	**45,850**	**80,325**	**93,347**

Emission reduction from prohibition measures is visible with measurable effect already in 2008 and 2009. The sectors concerned are one-component-foam (OCF), novelty aerosols, SF_6 for magnesium die casting, and SF_6 for car tyres.

From 2015, the year for which full application of the F-gas Regulation is assumed and Articles 3 and 4 take effect, emission reduction in stationary refrigeration and air conditioning equipment determines the overall picture, with the tenfold emission reduction potential of Articles 8 and 9.

From 2030 onwards, the MAC Directive contributes the largest emission reductions of all measures of almost 50 million t CO_2 eq by 2050.

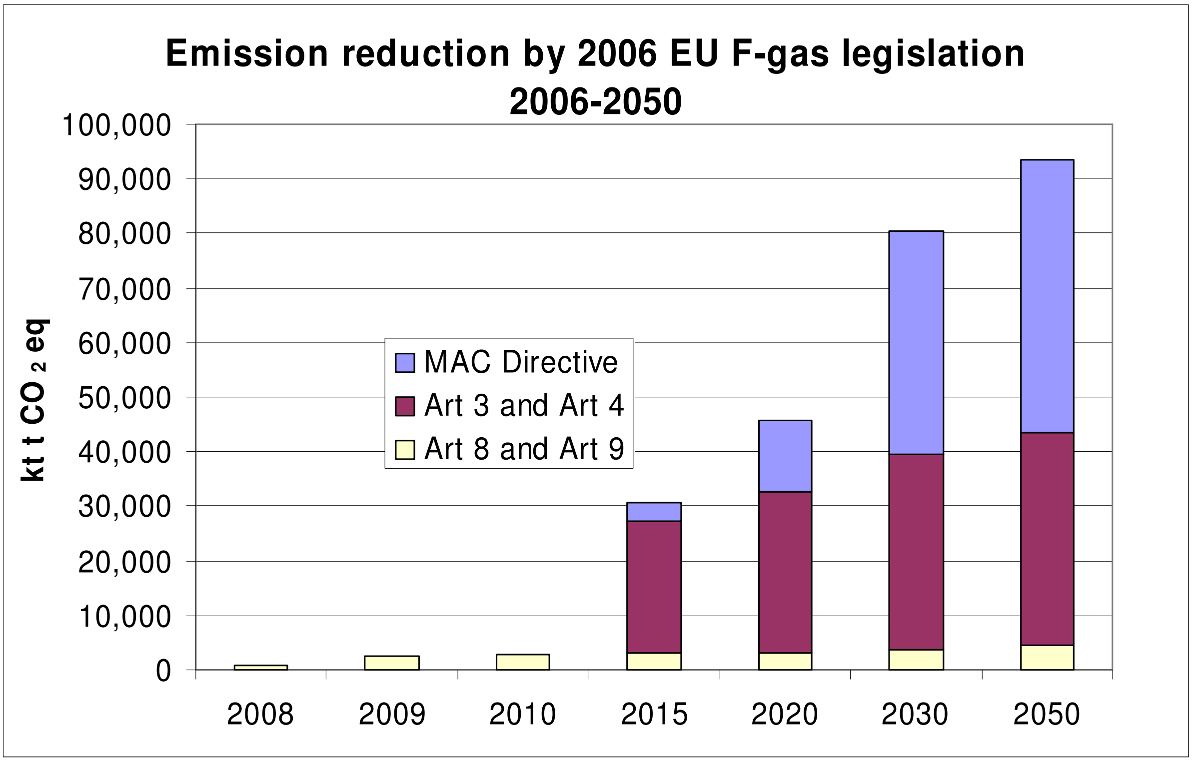

Figure 5-4: Emission reduction potential of the EU F-gas legislation by containment/recovery measures according to Art 3 and 4 of the F-gas Regulation, prohibition measures of Art 8 and 9, and by the MAC Directive in EU-27 in selected years. In 2015 and 2020 containment and recovery measures show strongest effect. The MAC Directive contributes large emission reductions in 2015. Prohibition measures show measurable effects in 2008 already.

Emission reduction potentials by sectors

Detailed information on emission reduction potentials of each sector subject to current EU F-gas legislation helps to determine the effectiveness of different types of policy measures.

- **Stationary refrigeration, air conditioning and heat pumps & mobile refrigeration**

The emission reduction potential widely differs by sub sectors of the refrigeration and air conditioning sector (table 5-5).

Table 5-5: F-gas emission reduction potential (kt CO_2 eq) in refrigeration and air conditioning by sub sectors until 2050 (WOM-WM)

Sub sector	2010	2015	2020	2030	2050
Domestic Refrigeration	0	190	130	3	3
Commercial Refrigeration	0	11,800	13,000	13,600	13,900
Industrial Refrigeration	0	5,200	5,445	5,670	5,670
Transport Refrigeration (road)	0	0	0	0	0
Transport Refrigeration (fishing)	0	0	0	0	0
Subtotal Refrigeration	***0***	**17,190**	**18,575**	**19,273**	**19,573**
Moveable & Single split	0	3,800	6,500	10,600	12,500
Multi split & Rooftop	0	930	1,400	1,900	2,000
Chillers incl. centrifugal	0	1,300	1,800	1,900	1,900
Heat Pumps	0	50	180	900	1,800
Subtotal Stat. AC & heat pumps	**0**	**6,080**	**9,880**	**15,300**	**18,200**
Total	***0***	**23,270**	**28,455**	**34,573**	**37,773**

Table 5-5 highlights the following aspects:

- Not surprisingly, commercial refrigeration, where large centralised systems with comparably high use-phase-emission factors prevail, shows the highest reduction potential in all years, ranging from 11.8 (2015) to 13.9 million t CO_2 eq (2050).
- The sub sector of small room air conditioners (moveables and single split) with refrigerant charges <3 kg is not subject to containment measures of Art 3 but only to recovery measures of Art 4. Nevertheless, the emission reduction potential is almost as high as that of commercial refrigeration, by 2050 (12,500 kt CO_2 eq). The high reduction potential is a result of the high market growth of room air conditioning systems of the single-split type, which is forecast until 2030. The emission reduction potential results only from an increase in recovery efficiency at end-of-life, with a reduction of the disposal emission factor from 70% to 35%.
- In 2030, emission reduction potential of 5,670 kt CO_2 eq in the industrial refrigeration sub sector is reached. This potential is mostly based on containment measures.
- Emissions from chillers, multi-split & rooftop air conditioners, and heat pumps show reduction potentials by 2030 of 2,000 kt CO_2 eq each. While chillers and multi-split air conditioners are subject to both Art 3 and Art 4, most domestic heat pumps have charges <3kg and are only subject to recovery by certified personnel.
- Emission reduction potential in domestic refrigeration from application of Article 4 (recovery at end-of-life) is low not only because the absolute amount of emissions is

small but also because the end-of-life treatment is already covered by the WEEE Directive and is reflected in the WOM scenario.

- **Mobile air conditioning**

Currently only mobile air conditioning systems contained in passenger cars are subject to EU legislation addressing F-gas emissions, i.e. the MAC Directive. The general provision of Art 4(3) for recovery by "appropriately qualified personnel" is not considered to impact quantitatively the disposal emissions in mobile air conditioning. The high emission reduction potential in the sub sector of passenger car air conditioning in 2050 is caused by two aspects: Firstly, the refrigerant bank is by far the largest F-gas emission source in Europe. Secondly, emissions will be cut to a very low level as the MAC Directive establishes a full phase-out of refrigerants with GWP >150 in this sector.

Table 5-6: F-gas emission reduction potential (kt CO_2 eq) in the sub sector of passenger car air conditioning until 2050

	2010	2015	2020	2030	2050
MAC in passenger cars	-	3,419	13,150	40,965	49,916

- **Fire protection and electrical switchgear**

The emission reduction potential in this sector amounts to 250-300 kt CO_2 eq during the period 2015-2050. It is comparably low although both containment and recovery measures must be applied in the sector (Articles 3 and 4 of the F-gas Regulation). The reason is that independent from the F-gas Regulation in this sector regular inspection is quasi standard in order to meet the particularly high reliability requirements of fire suppression equipment. This is an important difference to the sectors and sub sectors of stationary refrigeration and air conditioning where the application of Art 3 of the F-gas Regulation will significantly increase the current level of leak control activities, with differences between individual sub sectors.

We estimate that in the fire protection sector only in a minority of cases the containment provisions of the Regulation cause higher frequency of control measures by qualified personnel, compared to the current situation. Therefore the emission factor of 2.5% is considered to experience only a small further reduction to 2.3%, from application of Art 3. As disposal emissions on-site are negligible because most end-of-life emissions arise in off-site reclamation facilities which are not subject to the F-gas Regulation, further significant disposal emission reduction is not assumed (disposal emission factor decreases from 10% to 9%).

The emission reduction potential of the switchgear sector is based on recovery measures only (Article 4) which lead to some decrease in disposal emissions of SF_6.

Table 5-7: F-gas emission reduction potentials (kt CO_2 eq) in the fire protection and switch gear sectors until 2050

	2010	2015	2020	2030	2050
Fire protection	0	245	272	270	270
Electrical switchgear	0	830	805	763	760
Total	**0**	**1,075**	**1,077**	**1,033**	**1,030**

- **Other sectors**

Article 8 of the F-gas Regulation includes prohibitions of the use of SF_6 in large magnesium die casting plants and for filling of vehicle tyres. Article 9 includes prohibition of placing F-gases on the market, in particular for soundproof windows (SF_6), one-component foam (HFCs), and novelty aerosols (HFCs). Emission reduction potentials for these subsectors are listed in table 5-8.

The last full years before these prohibition measures are mostly 2006 or 2007, for novelty aerosols it is the year 2008. Emission reduction effects can hence already empirically be identified in 2008 for some SF_6 sub sectors and OCF foam. In the model AnaFgas the 2008 emission reduction (WM vs. WOM) is in the case of the affected SF_6 applications 0.68 million t CO_2 eq and 0.24 million t CO_2 eq in the foam sector (OCF). The highest emission reduction potential based on prohibition measures (Articles 8 and 9) is achievable in the OCF sub sector, increasing from 2009 to 1.8 million t CO_2 eq by 2015, and to almost 3 million t CO_2 eq by 2050.

From 2009 onwards, car tyres, and novelty aerosols also cause significantly lower emissions and show certain emission reduction potentials. The use of SF_6 for soundproof glazing and emissions during manufacture started decreasing in 2009. However, end-of-life emissions of SF_6 from this application are expected to peak in 2020.

Table 5-8: F-gas emission reduction potential (kt CO_2 eq) of sub sectors covered by prohibition measures (Articles 8 and 9 of the F-gas Regulation)

	2008	2009	2010	2015	2020	2030	2050
OCF	242	1,607	1,607	1,777	1,965	2,400	2,934
Novelty aerosols	0	264	335	335	335	335	335
Mg die casting	668	647	653	600	609	672	739
Soundproof windows	0	169	172	188	203	231	497
Car tyres	0	0	93	112	112	112	112
Total	**909**	**2,687**	**2,861**	**3,012**	**3,223**	**3,750**	**4,616**

5.2.3 Impact of the EU F-gas policy framework

In 2003, the European Commission's proposal for a Regulation to reduce emissions of fluorinated greenhouse gases[249] was expected to reduce the F-gas emissions by ca. 23 million t CO_2 eq by 2010 (EU-15), which were projected to increase to 98 million t CO_2 eq until 2010 in a business as usual projection[250].

This implied the target of not exceeding 75 million t CO_2 eq by 2010 (GWP values of the 2nd IPCC AR). The WM scenario of the model AnaFgas projects F-gas emissions in EU-15 (not including the 12 new Member States) to range at about 82.4 million t CO_2 eq in 2010. This value is ca. 7 million t CO_2 eq above the emission abatement target of 75 million t calculated in 2003, but it is to considerable extent below the amount of 98 million t CO_2 eq in the mentioned business-as-usual projection.

It must be pointed out that the comparably slow emission increase until 2010 is only to a small part caused by the F-gas Regulation. Empirically verified impacts of the F-gas Regulation today only refer to the sub sectors covered by prohibition measures (Articles 8 and 9) and amount only to 2.4 million t CO_2 eq (table 5-4, recalculated GWP values). As outlined in chapter 4, implementation and application of the provisions of the F-gas Regulation in EU-27 are progressing slowly and are hardly monitored on large scale.

However, in anticipation of the F-gas Regulation, numerous actors have made important efforts to reduce use-phase emissions or replace F-gases by other substances and technologies. This increase of awareness has certainly contributed to prevent an increase of the F-gas emissions to the projected amount of 98 million t CO_2 eq in 2010.

From the model AnaFgas, which was developed in the course of this project, it can be concluded: Without policy mitigation measures, the emissions of fluorinated greenhouse gases in the EU-27 would increase from today (2009/2010) ca. 110,000 kt CO_2 eq to more than 204,000 kt CO_2 eq (GWP 4th AR) until 2050. The F-gas legislation which includes the F-gas Regulation and the MAC Directive opens up the opportunity to significantly slow down the increase of future emissions. The emission reduction potential relative to the "without-measures-scenario" scenario totals 31,000 kt CO_2 eq in the short-term (by 2015) and even 93,000 kt CO_2 eq in the long-term (by 2050).

While the MAC Directive is considered to substantially cut HFC-134a emissions in the mobile air conditioning sector, the F-gas Regulation will leave large quantities of F-gas emissions continue rising. This is not only due to the fact that certain emission sources are not addressed by containment and/or recovery measures, such as mobile refrigeration equipment, the sectors of XPS or PU rigid foam, or the semiconductor industry. Even after full implementation and application of the F-gas Regulation large quantities of F-gas emissions will arise in the sectors which are already subject to containment measures.

Figure 5-5 shows a comparison of F-gas emissions in the WOM and WM scenarios by those individual sectors which are already subject to the F-gas Regulation. The reference year is 2030.

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[249] This proposal was a key element of the first phase of the European Climate Change Programme (ECCP), which was established in June 2000 to identify cost-effective reduction measures.

[250] European Commission: Climate Change: Commission tackles fluorinated gases. Press Release from 12.08.2003, IP/03/1155.

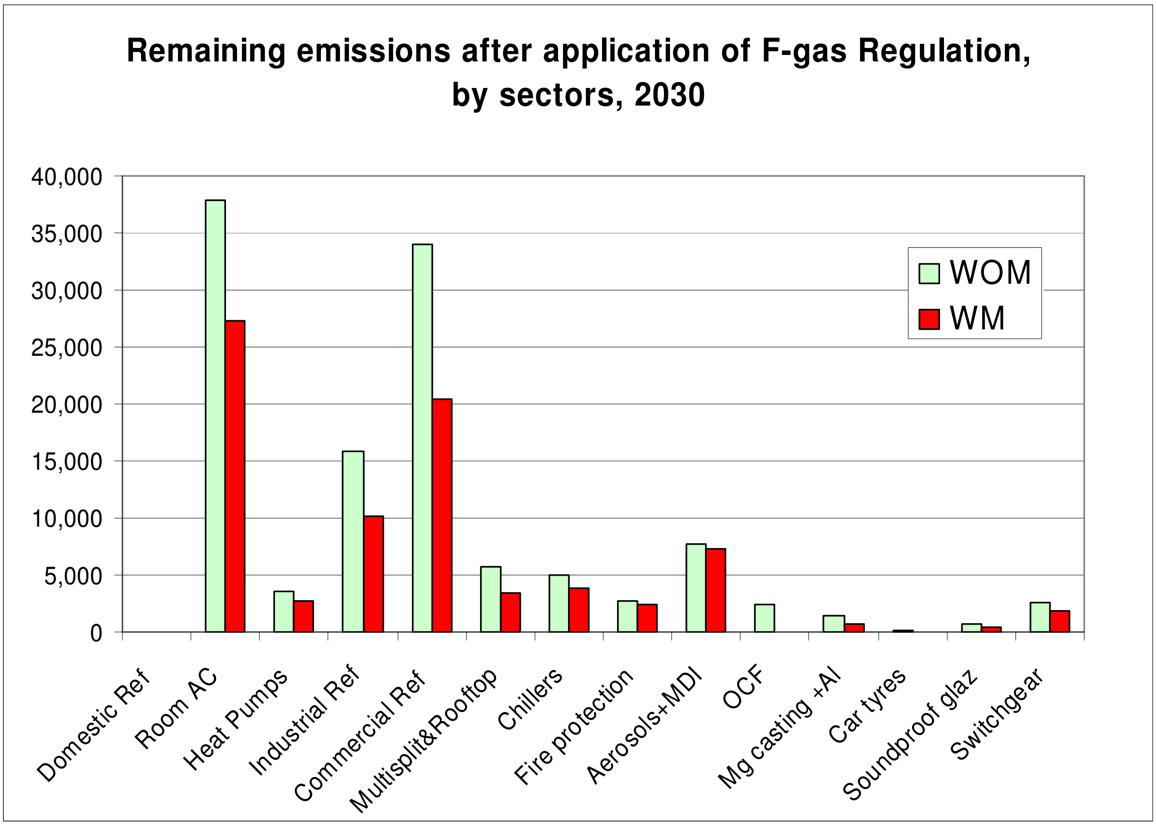

Figure 5-5: Comparison of F-gas emissions (kt CO_2 eq) in 2030 as projected in the WOM and WM scenarios by sectors covered by measures of the F-gas Regulation.

In 2030, from those sectors that are covered by the F-gas Regulation emissions of 120,000 kt CO_2 eq would arise in the WOM scenario. In the same year and the same sectors, the emissions will be reduced by 39,000 kt CO_2 eq from application of containment and recovery provisions. However, emissions of 81,000 kt CO_2 eq are still left unabated.

Although already covered by containment and recovery provisions the following sectors will account most of the remaining F-gas emissions in 2030:

- Room air conditioning (27,300 kt CO_2 eq)
- Commercial refrigeration (20,400 kt CO_2 eq)
- Industrial refrigeration (10,100 kt CO_2 eq)

Options for further EU action addressing F-gas emissions are assessed in chapter 8 of this report.

5.3 Cost-effectiveness of the EU F-gas Regulation

Effectiveness is a key criterion for the quality assessment of any environmental law. Evidently, the effect of the F-gas Regulation refers to the reduction of emissions of fluorinated greenhouse gases in EU-27. We estimate that as a result of full implementation and application of the F-gas Regulation, the F-gas emissions can be reduced by ca. 27.5 Mt CO_2 eq until 2015 compared to a projection without policy measures (WOM scenario without passenger cars minus WM scenario minus passenger cars). The emissions reduction as a result of the F-gas Regulation would increase to 39.3 Mt CO_2 eq by 2030.

The second key criterion for the F-gas Regulation is its cost effectiveness which can be expressed in quantitative terms by the relationship between annual cost and annual emissions reductions.

In chapter 4.3, the total cost was estimated that arises to industry, operators, and authorities for and from implementation and application of the F-gas Regulation. One-off cost and recurring cost was distinguished. The one-off costs which are for the most part caused by personnel and company certification according to Art 5 of the Regulation amount to €617 million. Recurring costs are estimated at €1,061 million in 2015 and €1,551 million in 2030. Additional leak checking, repair and recording according to Art 3 of the Regulation in the sectors of stationary refrigeration and air conditioning account for two thirds of the annual costs.

In order to estimate the cost effectiveness for a particular year, the one-off cost must be annualised. We assume that the one-off measures for the implementation of the Regulation will be valid at least for ten years[251]. Under these conditions the annualised cost for certification (and labelling) amount to approx. €60 million (no discounting).

In the year 2015, for which we assume full application and full effect of the measures of the F-gas Regulation, the total annual costs are €1,121 million (table 5-9). The efficiency of the Regulation can be expressed by a single coefficient, such as the relationship between the annual cost in 2015 and the projected emission reduction of 27.5 Mt CO_2 eq in this year.

The 2015 efficiency coefficient is hence €1,121 million annual costs divided by 27.5 Mt CO_2 eq of emission reduction in this year, and amounts to €40.8 /t CO_2 eq. By 2030, the specific abatement cost by the F-gas Regulation would be in the same order, with €41.0 /t CO_2 eq because both the cost and the emission reduction will increase to the same extent.

Table 5-9: Estimate of cost effectiveness of the F-gas Regulation in 2015 and 2030

	Article 5 annualised cost	**Art 3-6 costs per year**	**Total annual cost**	**Emission reduction**	**Cost effectiveness**
	million Euro	million Euro	million Euro	Mt CO_2 eq	€ /t CO_2 eq
2015	60	1,061	1,121	27.5	40.8
2030	60	1,551	1,611	39.3	41.0

[251] 50% of certifications are valid for 5 years; the other 50% are not limited in time. As an average, we assume ten years before re-certification.

5.4 Emissions not addressed by the EU F-gas policy framework

Certain F-gas emissions are not currently addressed effectively by the EU F-gas policy framework. These include

- HFC emissions from mobile air conditioning systems contained in vehicles other than motor vehicles: Ship AC, Rail AC.
- HFC emissions from mobile refrigeration systems like refrigerated trucks, refrigerated containers or fishing vessels.
- HFC emissions from foams other than OCF.
- HFC emissions from halocarbon production.
- HFC-23 by-product emissions.
- PFC emissions (e.g. from primary aluminium production, or from the semiconductor industry).
- SF_6 emissions from certain applications such as photovoltaic manufacture, particle accelerators, air borne military radar systems, etc.
- F-gas emissions from Organic Rankine Cycles (ORC; i.e. generation of power from heat recovery).
- Emissions of other F-gases not currently included in the scope of the F-Gas Regulation: NF_3 emissions, SO_2F_2 emissions, unsaturated HFCs.

In chapter 8, options for further EU action addressing the following sectors are discussed: HFC emissions from mobile AC in ships and rail vehicles, HFC emissions from mobile refrigeration, HFC emissions from foams, HFC emissions from halocarbon production, HFC-23 by-product emissions, PFC emissions, SF_6 emissions and NF_3 emissions from photovoltaics industry.

This section includes background information on some of these sectors while others are discussed extensively in chapter 6.

F-gas emissions from ORC

Organic Rankine Cycles (ORC) are used for the generation of power from heat recovery, e.g. heat recovery from geothermal sources or waste heat recovery from industrial processes. Several tons of HFCs or PFCs (e.g. HFC-245fa, HFC-365mfc, HFC-134a, PFC-4-1-12) are contained in each system. So far, little information on the current extent and future potential of ORC application in Europe is available and emissions remain to be investigated.

In this context AnaFgas does not model this sector in WM/WOM scenarios and no measures addressing F-gas emissions from ORC systems are discussed. However, this application of F-gases should not be overlooked in future analyses and monitoring efforts.

HFC-23 by-product emissions

HFC-23 (CHF_3) is a fluorinated greenhouse gas with particularly high GWP (14,800). HFC-23 emissions arise as unintentional by-products from manufacture of HCFC-22 and HFC-32.

If not emitted, HFC-23 is recovered and used

- as refrigerant in low temperature refrigeration systems,
- as fire extinguishing agent,
- as etch gas in the semiconductor industry.

The market for these products is of limited size. Before the mid 1990s HFC-23 was used in much larger amounts as intermediate for Halon-1301.

The HFC-23/HCFC-22 ratio in the manufacture of HCFC-22 is typically in the range between 1.5% and 4%, depending on how the process is operated. Process optimization can decrease the generation of HFC-23 below 2%. However, substantial reduction in by-product emissions relies on capture and destruction. Mostly used destruction method is incineration of the captured gas at >1,200 °C in a thermal oxidation chamber. In Europe, reactor cracking in a hydrogen flame at 2,000 °C also plays a role. This abatement technology relies on the existence of a hydrogen-source (from chlorine-alkali electrolysis), and cannot be universalized.

Current best practice technology comprising capture and thermal oxidation of the vent gases can achieve a destruction efficiency of up to >99%. However, the impact of “down-time” of thermal oxidation units, which is estimated at 5%-10% of the operating time of the HCFC-22 plant[252], needs to be taken into account since HFC-23 is released to the atmosphere during this time period[253]. HFC-23 emissions from HCFC-22 plant with an incineration system amount to 0.1 to 0.2% of the HCFC-production.

Before the mid-1990s, 10 HCFC-22 plants were operated in Europe. 4 of them produced HCFC-22 as feedstock, 6 produced for end-use applications, mostly refrigerants. To most part HFC-23 by-products were captured and processed to Halon-1301.

When the production of Halon-1301 discontinued, surplus HFC-23, which could not be marketed as refrigerant or fire extinguishing agent, was vented to the atmosphere. By 1995, 2 plants had installed thermal oxidisers, in 1996 another 2 plants started destruction of HFC-23. The abatement installations could not prevent an increase of HFC-23 emissions because the production of HCFC-22, which was used as replacement for CFCs, grew at even faster pace. In 1997, European HFC-23 by-product emissions amounted to 3,000 t and accounted for large shares of European GHG emissions (figure 5-6). In 1999 another 2 plants installed thermal oxidation systems so that HFC-23 emissions in 2000 ranged at only half of the 1997 level (1,500 t). Nevertheless, emissions of HFC-23 contributed with 25% to the total European F-gas emissions in 2000 (see table 5-10). By 2003 only 2 plants without abatement systems were in operation, one of them closed in 2006. In 2008-2010, the closure of 4 further plants reduced HFC-23 by-product emissions to their present level of 100 t (2011).

[252] IPCC/TEAP SROC, 2005, p. TS 81.
[253] In some European plants operation-time >95% has been reported.

Table 5-10: Quantities and share of HFC-23 by-product emissions (MT CO_2 eq; %) in total EU F-gas emissions (MT CO_2 eq), 1995-2010 (source AnaFgas; GWP according to 4^{th} AR)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total F-gas emiss	80.9	84.8	88.3	87.1	75.0	84.2	78.2	79.9	81.1	84.2	88.0	90.2	94.2	102	107	114
HFC-23 emiss.	39.6	43.0	44.7	42.2	27.6	21.6	13.4	10.9	9.7	6.5	5.8	3.0	2.2	2.5	2.4	1.7
Share (%)	49%	51%	51%	48%	37%	26%	17%	14%	12%	8%	7%	3.3%	2.4%	2.5%	2.3%	1.5%

At the end of 2010, 5 chemical plants with HFC-23 emissions were operated in Europe (in France, Germany, Netherlands, Spain, and Italy[254]). Four of them produce HCFC-22 as feedstock for fluoropolymers (PTFE); one plant has been retrofitted for the production of the HFC refrigerant blend component HFC-32 in 2002.

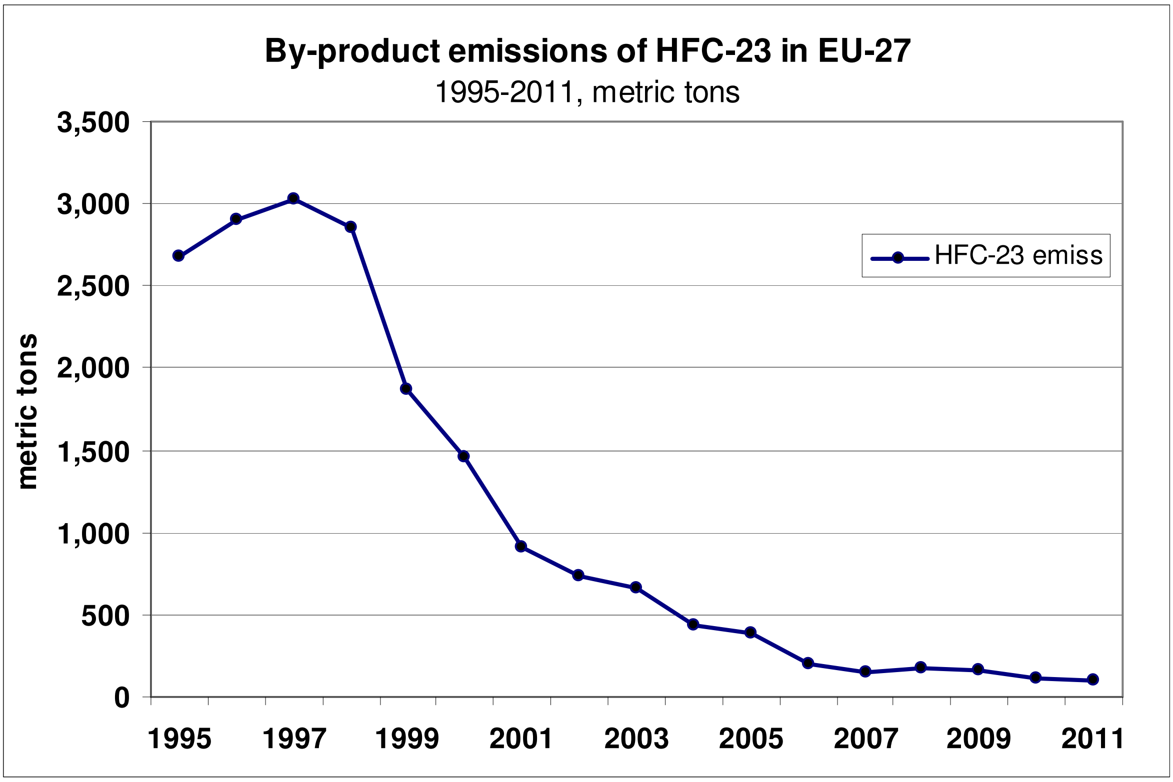

Figure 5-6: HFC-23 by-product emissions in EU-27. The drop from 3,000 t to 100 t in 1997-2006 results mainly from installation of abatement equipment in the HCFC-22 plants.

[254] In measurements of the atmospheric concentration of HFC-23 at the Swiss station "Jungfraujoch", important HFC-23 emission sources were located and identified in four of these countries (Italy, The Netherlands, France and Germany) in addition to UK. The conclusion is that the national inventories under-report the emissions by 60-140%. The largest discrepancy was found for Italy. The measurements were finished in 2010, before the closure of 1 of the 2 German HCFC-22 facilities and of the last UK HCFC-22 facility. Source: Christoph A. Keller et al.: Evidence for under-reported western European emissions of the potent greenhouse gas HFC-23, in Geophysical Research Letters, VOL. 38, L15808, doi: 10.1029/2011GL047976, 2011.

Three of these five plants (A, B, and C) are equipped with thermal oxidation systems. In 2008, plant A reported by CRF 26 t emissions, plant B reported 18 t, C does not report, and is estimated here at 30 t emissions[255].

The fourth plant (D) is directly connected to the adjacent crack reactor, and reports 0 t emissions.

The fifth plant (E) is not equipped with an abatement system, and reported 26 t emissions.

Taking account of estimated emissions from plant C, HFC-23 emissions amount to 100 t in 2011, when the last production plant for HCFC-22 end-use had closed. These 100 t emissions from the remaining five plants A, B, C, D, E is estimated the magnitude for future HFC-23 by-product emissions in the WOM/WM scenario in the model AnaFgas.

HFC-23 emissions are in scope of the UNFCCC and its Kyoto Protocol. Thus, they are subject to emission reduction obligations by Annex I countries and can be treated by CDM projects for HFC-23 mitigation/capture in developing countries.

The amendment proposals to the Montreal Protocol currently discussed at international level both include strict emission limits for HFC-23 by-product emissions and make its destruction mandatory. Details of the two proposals with regard to HFC-23 are summarized in table 5-11.

Table 5-11: Elements of the Montreal Protocol amendment proposals with regard to HFC-23 emissions

<table>
<tr><th>Proposal resubmitted by the Federates States of Micronesia (FSM) in 2011</th><th>Proposal resubmitted by North American countries (NA) in 2011</th></tr>
<tr><td>Entry into force on 1 January 2014</td><td>Entry into force on 1 January 2015</td></tr>
<tr><td colspan="2">Prohibits production and introduces a regulatory limit on emissions (from condenser vent and additional sources) to 0.1% (mass based) of HCFC-22 production (including feedstock uses), i.e. mandates destruction of HFC-23 by technologies to be approved.</td></tr>
<tr><td>This rule does not apply to plants approved by CDM projects before 1 January 2010 (provided that HFC-23 is indeed being destroyed).
HFC-23 destruction is subject to financial assistance under the Multilateral Funds (excluding costs covered by other financial mechanisms).</td><td>This rule applies universally.
HFC-23 destruction is subject to financial assistance under the Montreal Protocol (excluding costs covered by other financial mechanisms and excluding plants and production lines which are being covered by ongoing CDM projects).</td></tr>
</table>

In Europe, there is no law that limits the by-product emissions of HFC-23 or obliges the plant operators to install abatement equipment. So far, all abatement systems have been installed voluntarily by the chemical companies which resulted in emission reductions by 97% during the period 1995-2010. However, further emission reduction potential exists as long as

- 1 of the 5 remaining HCFC-22 facilities operates without abatement technology for HFC-23 emissions. The operator has indicated his intention to apply incineration equipment but to date this has not happened yet;
- the abatement technology installed does not perform HFC-23 destruction to the extent technically possible.

[255] Although the relevant National Inventory Report and CRF claim explicitly that no emissions from this plant occur since 1995, we cannot accept this statement, given that the abatement equipment is a common thermal oxidiser with usual technical parameters.

In addition, it should be noted that HFC-23 emissions also occur from production of other halocarbons such as HFC-32 (one production facility in Spain).

For estimates of HFC-23 emissions and related measures for abatement the quantity of halocarbons produced in Europe should be used for determining the type of abatement technology, and not the quantity of halocarbons placed on EU markets. HFC-23 emissions contribute to climate change no matter whether in Europe or elsewhere.

Chapter 8 on further EU policy action contains suggestions on how to address HFC-23 emissions from halocarbon production.

PFC emissions

PFC emissions are in the scope of the F-gas Regulation and must be reported according to Article 6. However, semiconductor manufacture and aluminium production, from where most PFC emissions arise, is not included in any provisions of the Regulation.

Another measure targets PFC emissions from aluminium industry: As laid down in the revised EU-ETS Directive (Directive 2009/29/EC), PFC emissions from the aluminium industry will be included in emissions trading from 2013 onward. As outlined in chapter 3.3, this interaction is assumed to support the introduction of technological improvements aiming at emission reductions. The estimated decrease of PFC emissions ranges at ca. 1.3 million t CO_2 eq in EU 27 by 2020.

PFC emissions from semiconductor manufacture have so far been addressed by a global voluntary agreement by industry with specific emission reduction targets for European manufacturers (see chapter 3.2). An extension/ update of a voluntary agreement is suggested in chapter 8.

SF_6 emissions

SF_6 emissions from electrical switchgear are addressed by measures set out by the F-gas Regulation. Furthermore, prohibition measures have limited the use and related emissions of SF_6 in some applications such as vehicle tyres, footwear, soundproof windows and large magnesium die casting facilities.

Nevertheless, the use and related emissions of SF_6 in other applications are not in the scope of the F-gas Regulation so far. These applications include small magnesium die casting and the sand casting facilities, photovoltaics and semiconductor industries, secondary aluminium production, particle accelerators and AWACS radar systems. Data on these emission sources are included in the model AnaFgas.

Policy options (chapter 8) suggest addressing the use of SF_6 in small magnesium die casting facilities and recycling of magnesium alloys.

Other F-gas emissions

Some other F-gases are currently neither included in the scope of the F-gas Regulation nor the basket of fluorinated greenhouse gases covered by the Kyoto Protocol which both consider HFCs, PFCs and SF_6. Two gases from other substance groups used increasingly in Europe include NF_3 and SO_2F_2.

Use and emissions of NF_3

Like several other fluorinated compounds, NF_3 is used in electronics industry for cleaning of chemical vapour deposition (CVD) tool chamber-walls from residual silicon film. The gas has been used since the mid1990s in semiconductor manufacturing, it was introduced before 2000 to the production of thin-film-transistor flat panel displays (LCDs), and it is in use from 2004/2005 onwards in the production of photovoltaic cells of the silicon-based thin-film type.

For a long time the global warming potential of NF_3 had been considered tolerable compared to that of SF_6 which is also widely used for CVD chamber cleaning in the manufacture of LCD and photovoltaic cells[256]. Although the 2nd IPCC AR (1995) had not specified the GWP value of NF_3, it had been estimated in the 1990s between 8,000 and 10,000[257]. The 3rd IPCC AR (2001) defined the GWP for the first time, with 10,200; the 4th IPCC AR (2007) however, increased the GWP to 17,200. Thereby the GWP of NF_3 comes close to that of SF_6 (22,200), so that the gas shows the second highest GWP value of all known greenhouse gases.

In 2008, NF_3 was criticized in the media since high atmospheric concentrations had been measured and indicated annual global emissions of more than 600 t[258] which were estimated 16% of the annual production quantity[259].

In the 1990s, the semiconductor industry was the only user of NF_3. After introduction of NF_3 into the production of flat panel displays (TFT-LCD) and the rapid expansion of the sector after 2000 in Korea, Japan, and Taiwan, the demand for NF_3 rapidly increased and caused quadrupling of the production capacities for NF_3 in the USA and East Asia. The gas replaced step by step SF_6 which had initially been used as main cleaning agent in this sector. NF_3 emissions from the East Asian LCD production were considered the main cause of the steep increase in measured atmospheric concentrations[260].

The advantage of NF_3 compared to PFCs like CF_4 or C_2F_6 is its high "conversion efficiency" (utilisation rate) in the low-pressure plasma chamber. This means that in comparison to most PFCs, NF_3 fed into the deposition chamber provides significantly more elemental fluorine to remove the residue silicon from chamber walls and product carriers. Thereby the cleaning time shortens up to 60% compared to the CF_4 or C_2F_6 process, and the throughput of the targeted substrates (wafers, photovoltaic cells, displays) increases by up to 20%. The higher

[256] In the semiconductor industry SF_6 is hardly used for chamber cleaning but for the etch process. The common chamber cleaning gases are C_2F_6, CF_4 (also used for etching), and in minor quantities C_3F_8 and c-C_4F_8. In 2007 (only then) in Austria hexafluorobutadiene (C_4F_6), which is not listed in Annex I, had been used in a quantity of 30 kg. This gas is not considered further here. This also applies to C_4F_8O (octafluorotetrahydrofuran) which had been discussed as CVD cleaning gas in 2003 in the Netherlands (Philips), but for which no consumption could be found in the course of this study.

[257] The 1999 IPCC Good Practice Guidelines note: "Molina et al. have estimated a GWP-100 of 8,000 and an atmospheric lifetime of 740 years (Molina 1995)." In 1996, McClear/Taylor from the company Praxair estimated the GWP at 9,720. McClear, M./Taylor, A., PFC Recycling, in: European Semiconductor, July/August 1996, pp. 41-44.

[258] Weiss, R. F., J. Mühle, P. K. Salameh, and C. M. Harth 2008: Nitrogen trifluoride in the global atmosphere, Geophys. Res. Lett., 35, L20821, doi:10.1029/2008GL035913.
Prather, M. J. and J. Hsu 2008: NF_3, the greenhouse gas missing from Kyoto, Geophys. Res. Lett., 35, L12810, doi:10.1029/2008GL034542.

[259] Weiss et al 2008 (see above): "This rise rate corresponds to about 620 metric tons of current NF_3 emissions globally per year, or about 16% of the poorly-constrained global NF_3 production estimate of 4,000 tons yr^{-1}."

[260] NF_3 production is estimated to range around at least 6,000 t/y. Almost 5,000 t are used in LCD manufacturing in Korea, Taiwan and Japan.

productivity from the application of NF_3 offsets the higher cost[261] of this gas and of its feeding equipment[262].

Quantities of NF_3 used in Europe

Although the application of NF_3 in the European **semiconductor industry** is growing, the companies in the sector rarely discontinue employing existing fluorinated cleaning gases in a facility once the application has been technically optimized to the chamber cleaning process by pressure, time, temperature, plasma power, flow rate, gas ratios and many further parameters. Therefore, PFCs (C_2F_6, CF_4) are still the most important fluorinated compounds for CVD chamber cleaning in Europe. According to estimates by the European Semiconductor Industry Association EECA-ESIA, and by experts from European gas distributors, in 2007 approximately 450 t of these PFCs were used in the semiconductor industry, while the sales of NF_3 to the sector amounted to 300 t[263].

The main user countries of NF_3 in Europe, according to our own estimate, are Germany (35%), Ireland (28%), France (14%), Italy (11%), and Austria (7%). Minor quantities are used in the Netherlands, Great Britain, Finland, and the Czech Republic.

In European **photovoltaic industry**, LCD production does not take place. The only application outside the semiconductor industry is manufacturing of thin film silicon solar cells. This technology represents globally ca. 5% of the overall production of photovoltaic cells, 80% of which is of the crystalline type to which SF_6 or NF_3 are not applied. After 2004, NF_3 was introduced to new production lines of silicon-based thin-film solar cells in Germany where large-sized tool chambers, similar to those in LCD manufacture, are used for deposition and removal of silicon film[264]. SF_6 which is still applied to existing facilities is no longer used for new production lines.

In Germany, thin film silicon photovoltaic cells have been manufactured on small scale from the mid1990s. From 2003 onwards, the German production of silicon-based thin-film solar cells significantly increased and caused a steep rise in the use of SF_6 from 3 t to >50 t in 2008, and in the use of NF_3 from 3 t in 2006 to >30 t in 2008[265].

In 2008 the production of silicon-based thin-film solar cells, using NF_3 as chamber cleaning gas, also started in Spain. In 2009, the sales of NF_3 to the 2 Spanish plants are estimated at 10 t[266].

NF_3 use and emissions from electronics industry in Europe

The present overall use of NF_3 in the European electronics industry is estimated at 340 t, including 300 t in the semiconductor industry and 40 t in the photovoltaic industry. In terms of global warming, the annual use amounts to 5.8 million t CO_2 eq.

[261] At the end of 2009, in the European photovoltaic industry the price of SF_6 was €20 per kg while the cost of 1 kg NF_3 was ca €40.

[262] There are two types of NF_3 based cleaning processes: (1) in-situ plasma cleaning and (2) remote plasma cleaning. In the latter, NF_3 is already dissociated (by microwaves) in a remote plasma source (RPS) upstream of the chamber, thus providing higher efficiency for etching of residual silicon films.

[263] Shane Harte from EECA-ESIA: Communication to Öko-Recherche, 25 November 2010.

[264] While in semiconductor manufacture, the wafers in the CVD chamber are sized 300 mm, thin film silicon solar cells have the size of up to 5.6 square metres.

[265] Öko-Recherche 2009: SF_6 and NF_3 in the German Photovoltaic Industry, study for the German EPA (in German).

[266] Estimate by Kai Schwarz, Air Products GmbH Germany, 15 Oct 2010.

The emissions of NF_3, like those of PFCs or SF_6, are lower than the purchased quantities which are fed into the CVD chamber for cleaning. Effective emissions mainly depend on two factors:

- the fraction of gas destroyed in the cleaning process (process tool emission factor);
- the fraction of gas destroyed by the emission control technology (emission control factor).

The semiconductor industry is not of the opinion that emissions monitoring via continuous measurements of the waste gas is technically or economically viable. Under the 1999 Voluntary Agreement of the World Semiconductor Council (WSC), which is represented in Europe by the European Semiconductor Industry Association EECA-ESIA, emissions from semiconductor manufacturing are calculated based on the methodology suggested in the 1999 IPCC Guidelines for National Greenhouse Gas Inventories. The emissions reporting of the EU Member States under the UNFCCC, provided in CRF tables, follows the same methodology. The equation used for the calculation is that of the Tier 2c approach as described in the Guidelines. The equation uses industry-wide generic default values, the most important of which are the average emission factor of a gas and the average destruction efficiency of the abatement tool.

The operating conditions of F-gases in semiconductor manufacturing vary widely, not only by companies but also by fabrication plants and production lines, and are not constant over time. This does not only apply to existence or absence of abatement tools for the waste gas from the process chamber, but also to the degree of dissociation of the F-gas in the process chamber itself (process tool emission factor). This should be kept in mind when using default emission values for any fluorinated compound including NF_3.

The 1999 IPCC-Guidelines present for NF_3 emissions from semiconductor manufacturing a default factor of 0.2 (Table 3.15). The 2006 update of the Guidelines confirms this value for in-situ cleans in semiconductor manufacturing and additionally presents a default value for photovoltaic manufacturing of 0.3[267]. A default emission factor of 0.02 is given for “remote” application of NF_3, which, however, has not been used yet for emissions monitoring. Compared to SF_6, CF_4 and C_2F_6, the NF_3 emission factors are low. This means for the 1999 default factor that only 20% (30% in case of photovoltaic manufacturing) of the gas fed to the cleaning process are released unchanged from the process chamber.

The 1999 IPCC-Guidelines present for Tier 2c an identical default parameter for the efficiency of emission reduction technologies of 0.9 for seven fluorinated compounds including NF_3. The 2006 values, which include also LCD and photovoltaic cell manufacturing,[268] do not differ from the 1999 values with the exception for NF_3. The destruction removal efficiency for NF_3 is estimated not only 0.9 but 0.95. This means, only 5% of the NF_3 gas fed to the abatement system is released unchanged to the atmosphere

The combination of default process emission factor and default abatement tool efficiency factor, results in an overall default ratio emissions/use for the semiconductor industry of 2% (0.2 x 0.1 = 0.02) in the equation of the 1999 Guidelines and of 1% (0.2 x 0.05 = 0.01) in the

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[267] 2006 IPCC Guidelines, volume 3: Industrial Processes and Product Use, Chapter 6: Electronics Industry Emissions, Tables 6.3 and 6.5.

[268] 2006 IPCC Guidelines, volume 3, chapter 6, Table 6.6: Default Efficiency Parameters for Electronics Industry FC Emission Reduction Technologies.

equation of the 2006 Guidelines. In the photovoltaic industry, for which only the 2006 Guidelines provide default values, the ratio emissions/use is 1.5% (0.3 x 0.05 = 0.015). It must be emphasized that these default emission parameters can only be applied to production lines which are actually equipped with properly working exhaust gas treatment systems, either for application at the point-of-use or at the end-of-pipe.

Ratio emissions/use in photovoltaic and electronics

It can be expected that modern production lines for photovoltaic cells established after 2006 do not run without waste gas control[269]. Strict emission standards are mandatory for this sector. All sector experts from solar cell manufacturing, gas distribution, and waste gas management interviewed in the context of another study[270], confirmed that the 6 plants using NF_3 for CVD chamber cleans have been equipped with exhaust gas abatement tools (thermal decomposition) from the very beginning. Therefore, the 1.5% NF_3 emissions value is considered plausible and is used in this study.

However, in the semiconductor industry, where CVD chamber cleaning with NF_3 has been introduced in the 1990s, waste gas abatement systems are not installed everywhere. Real NF_3 emission factors in the semiconductor industry differ from plant to plant, and from country to country depending on the actual prevalence of emission control systems. Thus, the ratio emissions/use ranges between maximum 0.2 (default process emission factor without abatement system) and minimum 0.02 (default process emission factor plus abatement factor).

Estimates of NF_3 emissions

Although NF_3 is included in the voluntary agreement of the EU semiconductor industry to reduce the 2010 emissions of fluorinated compounds below the 1995 level, and the industry collects emission data on NF_3, so far, the EU Member States that report F-gas emissions from their semiconductor industry do not include NF_3 emissions in the CRF tables. This is because the gas is not subject to the reporting obligations under UNFCCC. Five of the eight Member States with domestic semiconductor industry represent more than 95% of this industry in EU and report emissions of other fluorinated compounds. Some Member States are already collecting NF_3 data for their internal F-gas inventory. So far, annual data of use and emissions of NF_3 are available from Germany and Austria only. Industries located in these countries are estimated to account for one third of the EU use.

For the entire EU, the availability of data on NF_3 has significantly improved when EECA-ESIA presented combined data on use and emissions for the period 1995-2007 (table 5-12; some

[269] The above mentioned study for the German UBA reports statements of operators of new-erected German facilities for thin film silicon cells who claim even efficiencies of >99.96% for their emission control systems, referring to real measurements (NF_3 input to chamber 5,040 g/h, NF_3 mass flow after waste gas treatment 2.1 g/h). However, one has to distinguish between real operation and optimal operation. The 2006 IPCC Guidelines warn against identity of technical top results with real emissions: "An emission control device that can destroy 99 percent of an FC when it is optimised to destroy that FC on a certain tool may destroy less than 95 percent of that FC when it is optimised to destroy something else or when it is used on a tool for which it was not designed, or if the FC or total exhaust flow exceeds a certain limit." 2006 IPCC Guidelines, volume 3: Industrial Processes and Product Use, Chapter 6: Electronics Industry Emissions, 6.21.

[270] Öko-Recherche 2009: SF_6 and NF_3 in the German Photovoltaic Industry, study for the German EPA (in German).

years are omitted, for lucidity). The time series shows a steady growth in use until 2007, and a steady growth in emissions until 2006. The global warming potential of the 2007 emissions is ca. 97 kt CO_2 eq. The emission factor has significantly decreased from 17% to 2% over the same period of time, and is now at the level of the default ratio emissions to input (use) of the 1999 IPCC Guidelines.

Table 5-12: NF_3 use and emissions of the European semiconductor industry in 1995-2007*

	1995	1997	1999	2001	2003	2005	2006	2007
NF_3 (purchase -kg)	9,705	15,730	24,899	76,592	147,622	193,392	223,343	299,791
NF_3 (emissions-kg)	1,700	1,700	3,000	2,700	5,900	6,500	8,100	5,600
Implied Emission factor	17%	11%	12%	4%	4%	3%	4%	2%

Source: EECA-ESIA, Brussels, 2010 (recalculated from MTCE units)

By application of an default NF_3 emission factor of 1.5% to the photovoltaic industry and of 2% to the semiconductor industry to the annual use of the gas in the two sectors, emissions can be estimated for 2008/2009 (table 5-13) (from 2007 to 2009 no growth in use and emissions in the semiconductor industry is assumed).

Table 5-13: Emissions of NF_3 (metric tonnes; kt CO_2 eq) from the EU semiconductor and photovoltaic industry in 2008 (preliminary estimates; GWP: 17,200)

	Semiconductor industry	**Photovoltaic industry**
Input (use) in metric t	300	40
Input (use) in kt CO_2 eq	5,160	688
Emission factor	2%	1.5%
Emissions in metric t	6	0.6
Emissions in kt CO_2 eq	103.2	10.3

The emissions of NF_3 from the EU electronics and photovoltaic industry are estimated at 115 kt CO_2 eq in 2008. The share of NF_3 emissions in total 2008 F-gas emissions (92,200 kt CO_2 eq in AnaFgas) amounts to 0.12%. The share of NF_3 in the 2008 EU F-gas use, i.e. before decomposition in the process is considerably higher, with 3% (total 2008 F-gas use 200,000 kt CO_2 eq in AnaFgas).

F-gas emissions from **semiconductor manufacturing** constantly decreased in the period 1999-2008[271] reflecting both, the commitment to the voluntary agreement on PFC emission reductions via continuous process optimization and improved abatement technologies. New manufacturing facilities have rarely been established in Europe in the last decade in contrast to East Asia where the production has expanded. Growth of EU semiconductor production is not expected in the medium and long term. This implies that overall F-gas use and emissions will remain rather stable.

Under the voluntary agreement of the EU semiconductor industry to reduce the 2010 emissions of fluorinated compounds below the 1995 level, the reduction is caused by the predominant gases SF_6, CF_4, C_2F_6 and CHF_3. NF_3 which primarily replaces C_2F_6 is the gas with the highest growth rates.

[271] In its Intermediate Status Report of the Progress towards the Reduction of Perfluoro-compound (PFC) Emissions from European Semiconductor Manufacturing, EECA-ESIA shows graphically a decrease of the emissions of C_2F_6, CF_4, CHF_3, NF_3, SF_6, C_3F_8, and C_4F_8 from 0.7 MMTCE (1999) to 0.46 MMTCE (2005). The data for following years are included in AnaFgas.

The shift of substances used for chamber cleaning from C_2F_6 to NF_3 is likely to continue, thus increasing use and emissions of NF_3. If the trends of 2003-2008 continue, the use of NF_3 in the European semiconductor industry might double until 2030 to 600 t per year, while C_2F_6 use will decrease to the same extent.

Emission projections from the highly dynamic **photovoltaic industry** are very difficult and uncertain. This is even more difficult with respect to the thin film silicon cell technology which is only one of several low-cost alternatives to crystalline cells. Crystalline cells, however, are more efficient and more expensive. As mentioned earlier, silicon-based thin film technology represents only 5% of the total worldwide and EU-wide production of solar cells (expressed in MW). Assuming that this share of 5% will be kept in the long-run and that grows rates of the overall solar cell production of the last decade remain stable during the next 20 years, the annual use of NF_3 for chamber cleaning will probably increase to 300-400 t/y or even more. Like the used quantities, emissions could also increase tenfold by 2030, from today 10 kt CO_2 eq to 100 kt CO_2 eq.

There is, however, another important uncertainty to be taken into account. Since 2009, in 1 of the 6 German production plants for thin film silicon solar cells, NF_3 has already been replaced by elemental fluorine. The highly reactive fluorine gas is produced on-site by electrolysis of hydrogen fluoride (HF) stored in tanks. The inventor of the cleaning system, which is already in use in a Korean LCD plant, claims elemental fluorine to be not only a climate-neutral but also a cost-effective solution in all solar cell plants of the common size (capacity >100 MW per year)[272]. The first plant for thin film silicon solar cells in Italy (which started the production in 2010) uses elemental fluorine for chamber cleaning from the very beginning. If elemental fluorine proves to be a technically feasible, cost effective and climate friendly solution, projected use and emissions of NF_3 would need to be revised.

The introduction of reporting requirements for NF_3 under the F-gas Regulation is discussed in chapter 8.

Use and emissions of SO_2F_2 (sulfuryl fluoride)

SO_2F_2 is mainly used as structural fumigant in cereal grain mills and food processing facilities. Furthermore, it has been used for fumigation of timber, building and construction materials for quarantine pre-shipment purposes for several decades. The use of SO_2F_2 has gained importance in recent years since it is a substitute for methyl bromide in structural fumigations and in containers but not in soil fumigation. Methyl bromide is subject to phase-out under the Montreal Protocol[273].

[272] For details see the mentioned Öko-Recherche study for the German UBA. In addition:
Pro: S. Petri, P. Stockman, J.-C. Cigal, P. Szych, W. Beyer, Application of molecular fluorine to chamber cleaing for thin film silicon solar cell fabrication, 24th European Photovoltaic Solar Energy Conference, 21-25 September 2009, Hamburg, Germany.
Schottler, Martin, Mariska de Wild-Scholten, Carbon footprint of PECVD chamber cleaning. *Photovoltaics International* journal's second edition in November 2008.
Contra: Safety and Environmental Considerations of NF_3 and F_2 Chamber Cleans for Thin Film Silicon Solar Cells. White Paper from Air Products and Chemicals, Inc., 2009.

[273] Concerning methyl bromide, the EU went beyond the requirements of the Montreal Protocol and established a full use ban since March 2010, except in an emergency to prevent the spread of pests or disease (the maximum period of use in such case is 120 days, the maximum quantity is 20 metric tonnes) (Commission Regulation (EC) No 1005/2009, Article 12). The use of methyl bromide as a

In Europe, sulfuryl fluoride is sold under the trademarks of Vikane and Profume. The fumigation process usually takes several hours. The total quantities of sulfuryl fluoride used in EU-27 in recent years[274] are displayed in table 5-14:

Table 5-14: European use of SO_2F_2 (metric tonnes) 2006-2010

Year	2006	2007	2008	2009	2010
Quantity (t)	132	222	282	232	209

The decrease of quantities used after 2008 in EU-27 is estimated to be related to a change of behaviour and the search for other chemical and non-chemical alternatives to methyl bromide such as heat treatment and strict hygiene measures. While methyl bromide fumigation was done according to schedule, fumigation with SO_2F_2 is today carried out only when pest infestations have increase to specified levels. Furthermore, the application of SO_2F_2 is more restricted in terms of surveillance, monitoring, sealing and education of personnel. However, the impact of the methyl bromide phase out under the Montreal Protocol on the use of SO_2F_2 after 2010 remains to be investigated.

The producer of SO_2F_2 has established a mandatory product stewardship programme for all users, which is based on a contract with the authorized fumigator. This programme includes trainings to promote safe use of the products and self-inspections.[275]

Measurements of atmospheric concentrations in Europe indicated seasonal use of SO_2F_2 in Southern France, Germany, and Spain in summer in 2008, 2009 and 2010.[276] This partly relates to the Member States which have authorized the use of Vikane and Profume: Austria, Belgium, France, Germany, Italy, Netherlands, Spain, Sweden, and United Kingdom. A mandatory monitoring programme of sulfuryl fluoride concentrations in the troposphere has been initiated (Commission Directive 2009/84/EC).

Calculations of global warming emissions of SO_2F_2 are not possible at the moment since the GWP value is preliminary and emission factors are unknown. While the 4th IPCC Assessment Report does not indicate any GWP value for SO_2F_2, recent research calculated a direct GWP of 4,780 (Vassileios et al. 2008)[277] but indicated high uncertainty of the atmospheric lifetime of SO_2F_2 of 36 +/- 11 years. Atmospheric loss processes of this gas are known and have been included in the calculations. Mühle et al (2009)[278] estimate that about two thirds of the quantity of sulfuryl fluoride used reached the atmosphere and about one third was destroyed or removed possibly during the fumigation process.

The Pesticides Directive (Commission Directive 2010/38/EC) requires the Member States to ensure that the producer of sulfuryl fluoride provides additional information on the

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biocide is banned in EU-27 since 1 September 2006 and the use as a plant protection product as well as for quarantine and pre-shipment applications is banned since 18 March 2010.

[274] Information provided by Dow Agro Sciences, February 2011.

[275] Information provided by Dow Agro Sciences, February 2011.

[276] EMPA Material Science and Technology 2010: Kontinuierliche Messung von halogenierten Treibhausgasen auf dem Jungfraujoch (HALCLIM-4); project with funding from the Swiss EPA (BAFU), pp.21; 38. First progress report, October 2010.

[277] Vassileios et al. 2008: Experimental and theoretical study of the atmospheric chemistry and global warming potential of SO_2F_2. Journal of Physical Chemistry 2008, 112, pp. 12657 – 12666.

[278] Mühle, J. et al. 2009: Sulfuryl fluoride in the global atmosphere. Journal of Geophysical Research, 2009, p. 114.

atmospheric lifetime and the GWP to be submitted to the Commission by 31 August 2012. However, it should be noted that this directive does not refer to biocide uses of SO_2F_2.

In view of the measures in place and ongoing research, it can be concluded that

- SO_2F_2 is currently covered by monitoring requirements under Directives 98/8/EC and 2010/38/EC, which does not refer to biocide use.
- Quantities of SO_2F_2 used in EU-27 are likely to remain stable,
- Personnel applying SO_2F_2 is required to attend regular training.
- The global warming potential of SO_2F_2 is not included in any IPCC report yet and loss processes have not been fully understood yet, which does not allow substantiated calculation of emissions.

The potential inclusion of SO_2F_2 in the scope of the F-gas Regulation is considered in chapter 8.

Unsaturated HFCs

Development of unsaturated HFCs (partially fluorinated olefins) started some years ago when the climate impact of HFCs came into focus of the UNFCCC and its Kyoto Protocol. The best known unsaturated HFC is the hydrofluoroolefin 2,3,3,3,-tetrafluoroprop-1-ene (HFC-1234yf) which has been developed and proposed for use in mobile air conditioning in passenger cars as replacement for HFC-134a.

Like all other HFCs, unsaturated HFCs are synthetic gases constituted of hydrogen, fluorine and carbon. However, they are part of a group that has carbon molecules linked with a double bond, which makes them olefins. The "o" for "olefins[279]" is used by the producers to distinguish this group from other HFCs. Two substances are increasingly discussed as alternatives to the previous generation of HFCs: HFC-1234yf (refrigerant) and HFC-1234ze (foam blowing agent, aerosol propellant, and refrigerant)[280]. Due to their low GWPs of 4 in the case of HFC-1234yf[281] and 6 in the case of HFC-1234ze, significant emission reductions could be achieved through application of unsaturated HFCs in certain sectors as discussed in chapter 6. The GWPs of unsaturated HFCs are currently not included in IPCC reports.

This new group of fluorinated refrigerants started to be commercialized in 2010. It should be noted that blends of saturated and unsaturated HFCs being developed for refrigeration and air conditioning applications are "preparations" in the sense of the F-gas Regulation and hence already considered within the scope of current provisions unless their GWP is <150. Furthermore, HFC-1234yf and HFC-1234ze are included in the scope of the two amendment proposals to the Montreal Protocol, the North American proposal and the proposal by the Federated States of Micronesia (chapter 7). The introduction of reporting requirements for these substances, in view of the international discussion related to the use of unsaturated HFCs is considered in chapter 8.

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[279] "Olefin" is another, old term for unsaturated hydrocarbons.

[280] In addition to HFC-1234ze [HBA-2], further unsaturated HFCs with GWP <15 are discussed by industry experts mostly for use as blowing agents (e. g HFC-1336mzz [FEA 1100], AFA L1).

[281] Nielsen, O.J. et al 2007: Atmospheric Chemistry of $CF_3CF{=}CH_2$: Kinetics and mechanisms of gas-phase reactions with Cl atoms, OH radicals and O_3.Chemical Physics Letters 439, pp 18-22.

Another class of fluorinated compounds that replace HFCs are fluorinated ketones. The most important species is FK-5-1-12 (3M Novec 1230) which has already been widely used as fire extinguishing agent in Europe and elsewhere. In addition, FK-5-1-12 is in use as a cover gas for magnesium casting as a replacement of SF_6 outside of Europe. The application of this fluoro-ketone in the EU magnesium industry is a possible technical option for the coming years to substitute SF_6 in sand casting and recycling of sand casting alloys, where the application temperature is higher than in common die casting. The GWP of FK-5-1-12 is not listed in the 4th IPCC Assessment Report but it is estimated at 1.

6. State and potential of technology in the different sectors

This chapter describes the technical feasibility and cost-effectiveness of the replacement of F-gases in sectors currently relying on HFCs and other F-gases. Differences between Europe and other parts of the world concerning the feasibility of particular replacement options are indicated for each sector. It should be noted that this analysis focuses on HFCs, which are the most important group of F-gases and where most of the replacement potential can be found.

An introduction into underlying assumptions of the models used, differences between the models, and the methodology of these calculations are given in chapter 2. A description of the EU model AnaFgas is attached in annex III.

Detailed information on the state and potential of technology for each sector included in this analysis is outlined in annex VI. All sector assumptions and calculations for the EU-27 under the WM scenario are included in the EU sector sheets in annex V. Assumptions for the global consumption scenarios are summarized in the data input sheet (DIS) for each sector in annex IV.

This assessment of state and technology in each sector relying on F-gases provides important input for the development of policy options at international level to reduce F-gas emissions (chapter 7) and for further EU action to reduce F-gas emissions (chapter 8).

6.1 State of technology and HFC use and emission trends

6.1.1 Common technology by sectors

Common technology used in the different sectors and subsectors is listed in an overview table (table 6-1) and includes conventional F-gas technology and established alternative (halogen-free) technology. For detailed information on each sector please refer to annex VI.

HCFC technology listed is today used for new products and equipment in developing countries and servicing of existing systems in developed countries. By quantity, the most important HCFC used today is HCFC-22 (GWP 1,810; ODP 0.05). HCFC technology still represents the state of technology of new and existing products and equipment in developing countries. In the USA, new HCFC equipment was sold widely until the end of 2010. In Europe, HCFC equipment is becoming more and more outdated technology but still exists to some extent. Only reclaimed HCFCs may be used for servicing needs of existing equipment and new virgin HCFCs must not be placed on the market any more (Regulation (EC) No 1005/2009).

HFC technology is widely applied in all refrigeration, air conditioning, foam, aerosol and fire protection sub sectors and can be considered state of technology in Europe and other developed countries. The most important HFCs used today include HFC-134a (GWP 1,430) and the blends R404A (GWP 3,922) and R410A (GWP 2,088).[282]

Technologies not relying on HFCs, PFCs, or SF_6 but on alternative substances with low GWP (thus called alternative technologies or low-GWP technologies here) are also common and widely used in some sectors and sub sectors such as domestic refrigeration, industrial refrigeration, certain sub sectors of commercial refrigeration and stationary air conditioning, foams, aerosols, solvents as well as the fire protection sector.

SF_6 (GWP 22,800) is used, amongst others, in electrical switchgear and non-ferrous metal industry. SF_6-free alternatives are used to some extent for medium voltage switchgear. In the non-ferrous metal industry, which refers to the magnesium industry in EU-27, the use of SF_6 has been banned in large die casting facilities (annual SF_6 quantities used >850 kg) by the F-gas Regulation (Article 8). Small die casting facilities (annual SF_6 quantities used <850 kg) today partly rely on SF_6 but also introduced other technologies, such as the use of HFC-134a (GWP 1,430, which is considerably lower compared to the GWP of SF_6) or SO_2.

[282] If not otherwise stated, the GWP values in this report are from the 4th IPCC Assessment Report (2007).

Table 6-1: State of technology in sectors relying on F-gases (excl. unsaturated HFCs)

Sector	Conventional F-gas technology	Established alternative technology
Domestic refrigeration	- HFC-134a	- HC-600a
Commercial refrigeration		
Centralized systems	- HCFC-22 - R404A, R407C - HFC-134a	- R744 in LT-cascade systems - R744 for MT and LT - R290, R1270 or R717 with secondary loop systems, sometimes R744 LT-cascade systems
Condensing units	- HCFC-22 - R404A, R410A - HFC-134a	
Stand alone units	- CFC-12 - HFC-134a - R404A	- R744 for a ice cream freezers and beverage vending machines - HC (hydrocarbon, mainly R290, sometimes R600a) for bottle coolers and LT cabinets, etc.
Industrial refrigeration	- HCFC-22 - R404A, R407C	- ammonia (R717) - ammonia and CO_2 cascade
Transport refrigeration		
Reefer containers	- HFC-134a - R404A	
Road refrigerated transport	- HFC-134a - R404A, R410A, R407C	
Fishing vessels	- HCFC-22 - R404A	- ammonia (R717) - ammonia and CO_2 cascade
Stationary AC	- HCFC-22 - R410A, R407C - HFC-134a (chillers) - R404A (chillers)	- R290 (room AC, chillers, heat pumps) - R717 (large chillers) - R744 (heat pumps)
Mobile AC		
Road vehicles	- HFC-134a - CFC-12	- hydrocarbons (service only) (R744 in prototypes)
Ships and rail	- HFC-134a	
Foam	- HFC-152a, HFC-134a - HFC-245fa - HFC-365mfc/227ea - HCFC-141b, HCFC-142b - HCFC-22	- hydrocarbons (pentanes) - organic solvents/CO_2 - water-CO_2
Fire protection	- HFC-227ea - HFC-236fa - HFC-23 - HFC-125	- water, water mist, dry chemical, foam aerosols; - CO_2 - inert gases
Aerosols; OCF (excl. MDI)	- HFC-152a - HFC-134a	- hydrocarbons - dimethylether
Medium voltage secondary switchgear	- SF_6	- solid insulation
Non-ferrous metal industry (Mg industry)	- SF_6 - (HFC-134a)	- SO_2 - HFC-134a

LT = Low Temperature; MT = Medium Temperature.

6.1.2 Global BAU trend of HFC use until 2030 by sectors

Many sectors relying on HFC technology are likely to grow in the near future and hence consumption[283] of HFCs is expected to increase.

A business-as-usual (BAU) projection of global HFC consumption by sectors for the period 2010-2030 has been calculated for both developed (A2) and developing countries (A5)[284]. Europe forms part of the group of developed countries. This scenario is based on current industry trends and considers the accelerated HCFC phase out under the Montreal Protocol in developing countries. It also integrates alternative technologies to the extent they likely replace conventional HFCs without additional policy measures[285].

Annual HFC consumption comprises HFC quantities used for the first fill of new equipment in the particular year and HFC quantities for servicing needs of existing equipment. Servicing quantities relate to use-phase emissions, which is losses through leakage and accidents (included in leakage rates).

Table 6-2: HFC consumption (Mt CO_2 eq) by sectors in A2 countries in the period until 2030 in a BAU scenario

A2 countries (Mt CO_2 eq)	2010	2015	2020	2030
Domestic refrigeration	6	7	8	10
Commercial refrigeration	108	121	125	110
Industrial refrigeration	25	31	39	58
Transport refrigeration	29	32	33	33
Stationary AC	315	417	519	620
Mobile AC	81	87	92	103
Foam	37	48	56	75
Aerosols	16	16	16	16
Fire extinguishing	15	21	22	22
Total	633	779	909	1,047

[283] Under the Montreal Protocol "consumption" means production plus import minus export, minus destruction and minus feedstock of controlled substances. It represents the total annual supply of bulk substances for emissive uses in a country or world region (see chapter 2.2.4). In this chapter "consumption" means the annual F-gas flow into the particular application sectors A5 or A2 countries including EU-27. In quantitative terms, the consumption considered herein is considered equal to the demand (D) of these sectors for first fill and refill, not accounting for recycling or reclamation of used HFCs for re-use in new or existing equipment. For the EU-27, the term “demand” is used in its second extension (Demand $_{ext2}$) which includes the F-gas quantities in imported pre-filled equipment which are refilled domestically, and the first fill into systems manufactured for export to third countries, which are not re-filled domestically. According to chapter 2.2.4, the equation for the 2nd extension of demand for HFCs is: Demand $_{ext2}$ = $F_{irst\ fill}$ of systems for domestic use + $F_{irst\ fill}$ of systems imported in the EU + $F_{irst\ fill}$ of systems pre-charged for export from the EU + R_{efill} of systems for domestic use + R_{efill} of imported pre-charged systems. In EU-27, first fill of HFCs in systems for export takes place in mobile air conditioning of motor vehicles, in addition to OCF cans and medical aerosols, the latter not being refilled.

[284] Developed countries are called A2 countries in this report based on the terminology of the Montreal Protocol. Developing countries are called A5 countries accordingly. For more details about the definitions see chapter 2.2.3 (FN 9).

[285] The EU MAC Directive, which leads to alternatives to conventional HFCs, is an existing political measure and therefore included in the BAU scenario for the A2 countries.

The assumptions made for each sector concerning leakage rates, sectoral growth rates and replacement patterns during HCFC phase-out are described in detail in annex VI as well as annex IV (DIS).

HFC consumption trends in each sector are shown separately for A2 countries and A5 countries (tables 6-2 and 6-3). Since this chapter focuses on HFCs, HCFC use trends are not shown in the tables but are included in the graphs 6-1 and 6-2.

In developed countries (A2) HFC consumption is projected to increase to nearly 1.1 GT CO_2 eq in total in 2030 in this BAU scenario. HFC demand by the stationary AC sector is growing at high rates and is projected to almost double (from 315 MT CO_2 eq in 2010 to 620 MT CO_2 eq in 2030).

In developing countries (A5) HFC consumption is projected to reach 2.6 GT CO_2 eq in 2030. Largest quantities are used in the stationary AC sector, industrial refrigeration, transport refrigeration as well as the mobile AC sector.

Table 6-3: HFC consumption (Mt CO_2 eq) by sectors in A5 countries until 2030 (BAU scenario)

A5 countries (Mt CO_2 eq)	**2010**	**2015**	**2020**	**2030**
Domestic refrigeration	12	14	18	24
Commercial refrigeration	8	34	78	171
Industrial refrigeration	12	90	226	529
Transport refrigeration	28	66	127	270
Stationary AC	30	203	510	1,190
Mobile AC	62	86	118	224
Foam	1	19	87	142
Aerosols	7	7	8	9
Fire extinguishing	3	5	7	12
Total	163	524	1,179	2,570

Sectors for which particularly strong increase of HFC consumption is projected include the stationary AC and heat pump sector (51% of HFC demand in A5 countries and 59% in A2 countries in 2030; figure 6-1) and the industrial refrigeration sector (23% of HFC demand in A5 countries and 5.5% in A2 countries in 2030; figure 6-2).

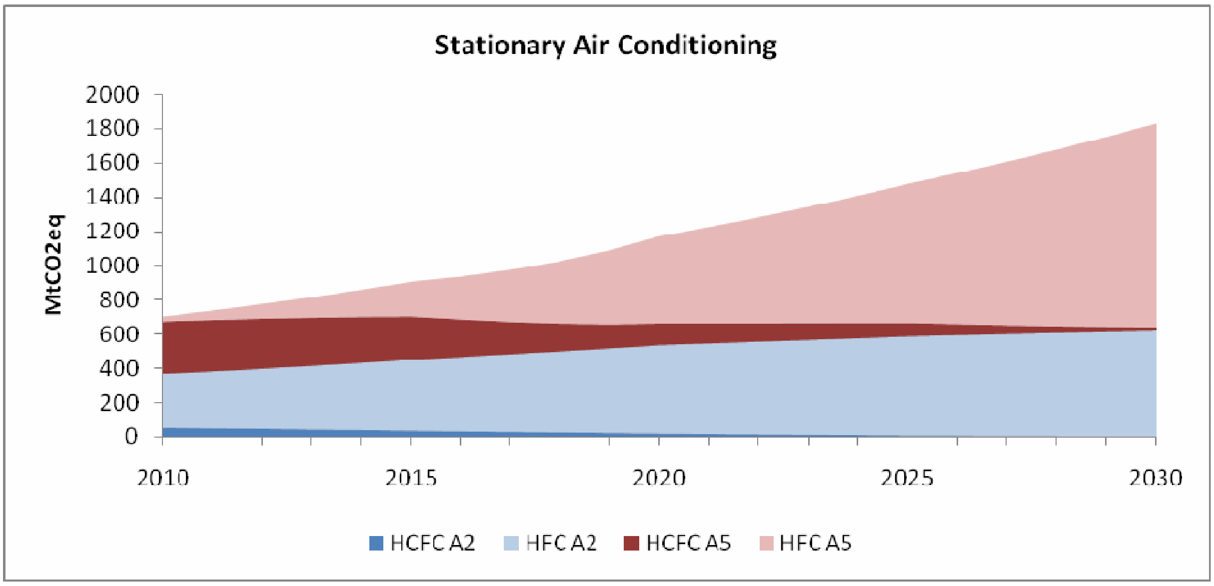

Figure 6-1: HFC and HCFC consumption in the stationary AC sector in A2 and A5 countries in the period until 2030.

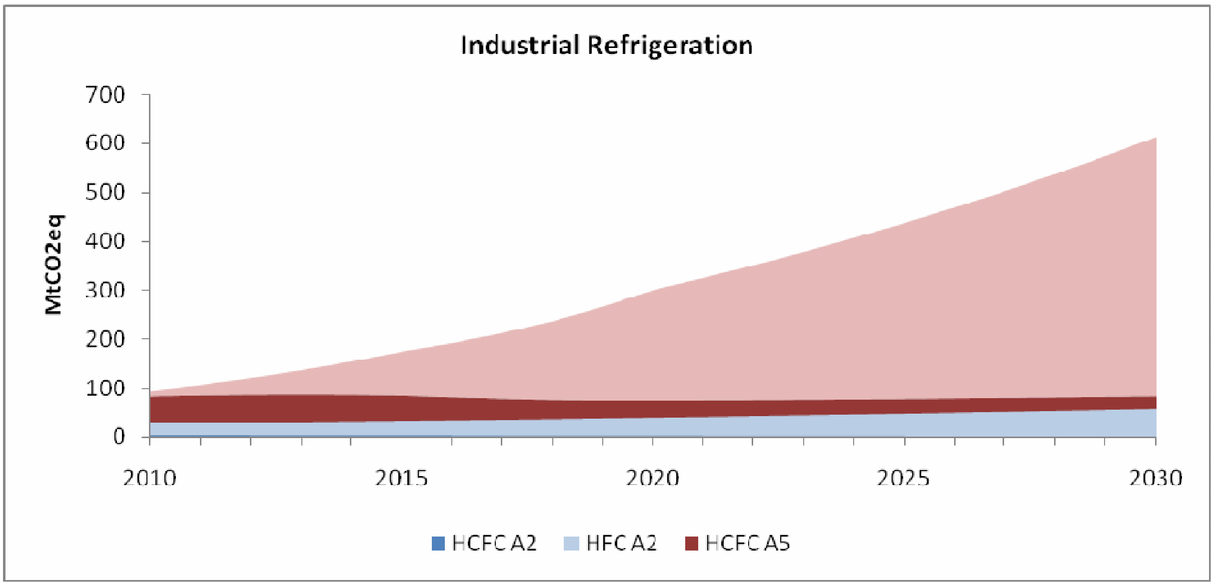

Figure 6-2: HFC and HCFC consumption in the industrial refrigeration sector in A2 and A5 countries in the period until 2030.

6.1.3 HFC demand and emissions in EU-27 until 2050 (WM scenario)

Projected F-gas emissions in EU-27 in a WM scenario including the measures set out by the F-gas Regulation and the MAC Directive are presented in chapter 5. The main results about emissions are repeated here in tabular and graphical form. Data on underlying demand are added.

F-gas demand and emissions in EU-27 are projected to remain at stable levels from about 2010 onwards (tables 6-4 and 6-5, bottom line "Total"). As already mentioned the term "demand" is used in its second extension which includes quantities in imported pre-filled equipment and quantities first filled into equipment manufactured for export[286]. It should be noted that, although the demand considered here includes first fill in exported pre-charged equipment, the calculation of emissions does not include exported pre-charged equipment because pre-charged F-gases emit outside the EU.

Table 6-4: F-gas demand by sectors in EU-27 as projected in the WM scenario (AnaFgas), including imported pre-filled equipment and pre-filled systems for export (demand $_{ext2}$)

F-gas demand (kt CO_2 eq)	2010	2015	2020	2030	2050
Refrigeration	60,557	49,748	51,919	55,265	57,264
Stationary AC	40,665	52,485	61,373	72,710	74,243
Mobile AC motor veh.	39,287	31,705	20,373	10,117	10,130
Mobile AC ships+rail	2,266	1,888	1,934	1,942	1,987
Foam	10,935	10,810	10,781	10,810	10,828
Other	18,684	19,433	21,205	19,545	20,035
- thereof MDI	*7,670*	*8,167*	*8,225*	*8,471*	*8,961*
Total HFCs	172,395	166,070	167,586	170,389	174,444
Total HFCs w/o mobile AC motor vehicles	133,108	134,365	147,213	160,272	164,314
SF_6	48,209	47,698	46,322	46,298	46,358
PFCs	1,844	1,844	1,844	1,844	1,844
Total	**222,449**	**215,612**	**215,751**	**218,529**	**222,690**

F-gas demand is projected to stabilise around 220 Mt CO_2 eq in the 2010–2050 period. The constancy is the result of an absolute decrease in HFC demand caused by the MAC Directive by 29 Mt CO_2 eq in 2010 to 10 Mt CO_2 eq in 2050 (row "Mobile AC motor vehicles) HFCs") and by reduced demand per systems in sectors addressed by the containment measures of the F-gas Regulation . The reduction in HFC demand is counterbalanced from 2015 onwards by the increase of HFC demand by 30 Mt CO_2 eq in sectors other than motor vehicles, due to growing use ("Total HFCs w/o mobile AC motor vehicles"), in particular in stationary air conditioning which also includes imported pre-charged equipment like moveable and split systems.

Table 6-5 shows, over the 2010-2050 time period emissions follow the same trend as the demand. In spite of the containment measures of the existing F-gas Regulation (see chapter 5.2) emissions from stationary air conditioning strongly increase by 25 Mt CO_2 eq until 2050.

[286] Demand $_{ext2}$ = $F_{irst\ fill}$ of systems for domestic use + $F_{irst\ fill}$ of systems imported in the EU + $F_{irst\ fill}$ of systems pre-charged for export from the EU + R_{efill} of systems for domestic use + R_{efill} of imported pre-charged systems.

In addition, from 2015 to 2050 emissions from the refrigeration sector increase by 5 Mt CO_2 eq. As a result, the reduction in emissions from air conditioning of motor vehicles by almost 30 Mt CO_2 eq. is offset by 2050.

Table 6-5: F-gas emissions by sectors in EU-27 as projected in the WM scenario (AnaFgas)

F-gas emissions (kt CO_2 eq)	**2010**	**2015**	**2020**	**2030**	**2050**
Refrigeration	39,347	32,093	34,363	35,556	37,277
Stationary AC	15,058	20,641	28,206	36,992	40,971
Mobile AC motor veh.	32,526	34,819	28,293	6,604	6,889
Mobile AC ships+rail	1,999	1,789	1,812	1,822	1,846
Foam	3,299	3,631	3,974	4,634	5,746
Other	9,155	9,503	9,893	10,143	10,576
- thereof MDI	*2,921*	*3,065*	*3,202*	*3,453*	*3,886*
Total HFC	101,384	102,476	106,541	95,750	103,306
Total HFCs w/o mobile AC motor vehicles	68,858	67,657	78,248	89,146	101,460
SF_6	5,452	5,583	6,966	2,921	2,533
PFCs and haloproduction	6,417	5,607	4,982	4,986	4,985
Total	**113,253**	**113,666**	**118,489**	**103,657**	**110,824**

The effect of containment and recovery measures set out by the F-gas Regulation is expected to occur in the period until 2015 if the provisions will be fully implemented and applied.

The sector, where the effects of containment and recovery measures are more significant is commercial refrigeration (figure 6-3).

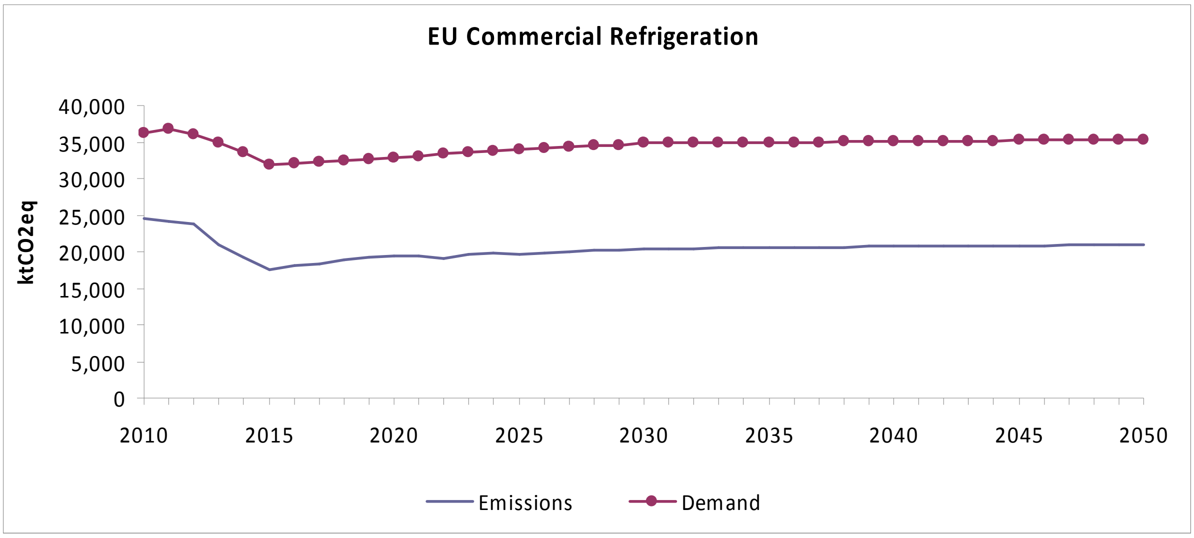

Figure 6-3: Projected HFC emissions and demand (kt CO_2 eq) in commercial refrigeration (2010-2050), for EU-27 under WM scenario. After reductions in 2010-2015 due to F-gas Regulation, constant long term levels for emissions and demand are projected.

In the stationary AC and heat pump sector, where containment provisions apply to certain equipment with charges >3 kg, the effects of these measures are offset by the growth of the sub sectors with equipment of charges <3 kg and which are not subject to Article 3 (figure 6-4).

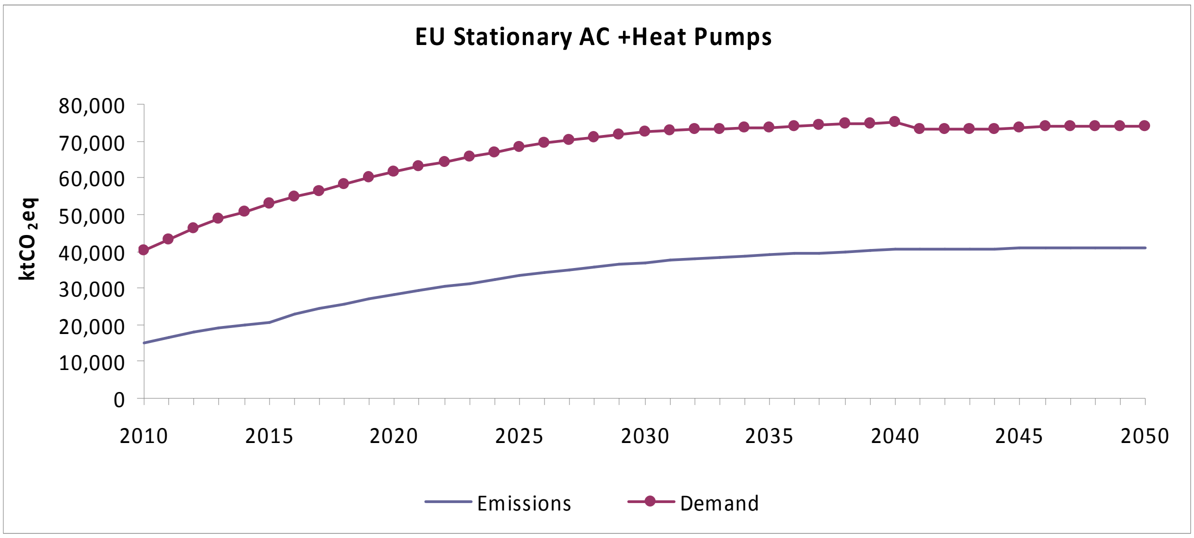

Figure 6-4: Trend of HFC demand and emissions under the European WM scenario in stationary air conditioning and heat pumps. Before in 2035 the market is saturated, considerable growth is expected, which makes stationary air conditioning the largest individual HFC sector in Europe. In this graph, demand includes imported HFCs in pre-filled systems.

6.2 The market potential of abatement technology

6.2.1 Selection of sector abatement options

For each sector today relying on HFCs or HCFCs (in A5 countries), cost-effective and technically feasible abatement solutions were identified and qualitatively and quantitatively compared to the sector-typical conventional HFC technology as reference.

This comparative analysis was guided by the following main criteria:

- Safety
- Energy consumption.
- Maximum reduction potential of CO_2-weighted HFC use and emissions.
- Cost effectiveness (expressed in abatement cost of €/t CO_2 eq).

Energy consumption is an essential selection criterion. After the preliminary identification of alternative options only those options that show at least equivalent energy performance as the reference HFC technology are considered further. This criterion is important because additional energy consumption would negatively impact the total climate performance of a system (TEWI) up to the point where reductions of direct F-gas emissions by replacement of HFCs could be offset by additional CO_2 emissions from energy production (indirect emissions).

In several cases a standard abatement solution might not be able to achieve the same or better energy performance as the reference option in any climatic region due to low thermodynamic performance. This applies e.g. to indirect refrigeration or air conditioning systems even if they use efficient refrigerants such as propane (R-290) or unsaturated HFCs (HFC-1234yf). In some of those cases, the energy consumption of direct HFC systems can be matched with the indirect use of gases if additional technical measures (e.g. larger heat exchanger surface) are implemented. Such technical optimisation increases, however, the investment cost of the abatement option. In the foam sector poorer insulation performance of alternative blowing agents must be compensated by increased foam thickness, which likewise raises the cost compared to HFC based technology. In those cases an abatement option is considered in the analysis but with the additional investment costs accounted.

Therefore, the comparative analyses include only abatement options when these can, with or without technical optimisation, require equal or less energy for operation.

6.2.2 The concept of penetration rates

Existing and future market penetration is a key parameter for the calculation of the consumption and emission reduction potential of any technical alternative to current HFC technology.

Penetration rates

The penetration rate is defined as the maximum market potential of a technical choice (i.e. abatement option) to replace new products or equipment relying upon HFCs in a particular sector. Penetration rates are given for each abatement option based on technical feasibility to replace existing HFC technology by a specific alternative technology. A penetration rate of

30% in 2015 means that 30% of the new HFC units installed in 2015 could potentially be replaced by units of this particular abatement option.

However, any abatement option is rarely universally applicable to a sector. Thus, maximum market penetration for replacement of current HFC technology in a specific sector in 2015, 2020, 2025 or 2030 can only be met by aggregation of two or more abatement options.

Constraints to market penetration

Limitations of each abatement option are due to safety, cost and/or efficiency implications, and further parameters. It is therefore necessary to consider the use of each relevant abatement option for a specific sector within the context of the various limiting factors.

- Safety constraints

The application of refrigerants[287] is generally controlled by national regulations, such as those dealing with the use of hazardous substances, buildings and so on. Generally such regulations are non-specific in terms of how refrigerants can be applied and aim at towards “safe use”. However, in many countries, safety standards and codes of practice are available which are more specific in the manner by which refrigerants are applied; noting also that such standards and codes are not normally legally mandatory but are considered as “best practice”.

Many of the currently used F-Gas refrigerants have a safety classification of lower-toxicity/no flame propagation (i.e., class “A1”). This means that they can be applied within most situations without consideration of quantity limitations. However, many abatement solutions are flammable or have higher toxicity or both (typically “A2”, “A3” and “B2” classifications), which results in limitations in terms of the quantity of refrigerant permitted within different locations. As such, where standards specifically limit certain technical abatement options in particular locations, this can impact on the penetration rate.

As an example, R717 (class B2) is not permitted to be used in direct systems, so the maximum penetration for room air conditioners would be 0%, whilst R290 (class A3) can be used in direct systems provided the charge size is below a certain quantity. Thus, the penetration would be more than 0% but less than 100% because it would not ordinarily be possible to use R290 in systems that require a large charge.

Whilst safety standards may partially or wholly restrict certain abatement options from being used in certain locations, it is possible to redesign systems in order to ensure the refrigerant is kept within an alternative location or reduce the quantity of refrigerant in a system. This may be applicable where two refrigerant circuits are used instead of one, or an indirect system is employed instead of a direct system.

- Efficiency constraints

As mentioned previously, it is a basic principle in this study that any abatement option considered does not risk offsetting refrigerant-related emissions reduction by consuming more energy. Furthermore, this principle is in line with the fact that in many countries, there are – or will be – minimum efficiency standards for e.g. room air conditioning systems.

[287] Penetration rates are assessed not only for refrigerant using systems but also for fire protection equipment, foams, and aerosols. Refrigerants, however, are by far the largest application of HFCs.

Therefore abatement options can only be considered where systems would achieve at least the same level of efficiency. In general, most of the abatement options under consideration can already provide at least the same level of efficiency as the existing refrigerants.

In cases, where abatement options have a poorer efficiency than the existing HFC technology when used in comparable systems, additional materials and components may be required to bring the efficiency up to the required level, and these may incur costs. In particular, where indirect systems are used instead of direct systems and the construction is such that efficiency may be lost, increases in exchanger surface areas, for example, may be necessary to achieve the target level.

However, in some cases abatement options may not be able to achieve the required efficiency level (even with optimization), in which case the penetration rate would be limited.

As an example, the abatement option transcritical use of CO_2 (which is more energy efficient than most HFC systems in geographical zones with moderate climate could be used in air conditioning systems within temperate climates. The penetration could reach 100% there, but in hot climates the ideal cycle efficiency of CO_2 (R744) would still be below the minimum efficiency of such air conditioners and therefore the penetration would be 0%. In our analysis the penetration rate would be reduced according to share of moderate and hot climates. As an example, for Europe the penetration rate would be halved compared to the technical maximum because CO_2 systems are energetically superior north of the Alps but inferior south of the Alps.

- Cost constraints

In principle any technically feasible abatement option can be used for any application, provided unlimited funds are available to implement it. However, the market may not accept products at considerably higher cost (price) than existing products. The cost implication of using different abatement options which may be affected by several different parameters, including safety requirements, desired efficiency, system complexity and special materials. Therefore it is important to establish situations where abatement options may result in excessively high cost such that the penetration potential of that abatement options would be limited.

- Availability of materials and components

Some parts are specific to certain refrigerants, e.g. compressors. Whilst it is feasible to use, e.g. R744/CO_2 in rooftop air conditioners, no suitable compressors are currently available. Reciprocating compressors normally used for commercial refrigeration could be applied but the efficiency would be much lower than the equivalent (scroll) compressors that an R22 system may use. Another example is electrical components for flammable refrigerant systems. HC chillers need to use “protected” electrical devices to avoid ignition of a leak but certain components e.g. low flow switches are not available, except for maybe oil rig applications which would lead to overly high costs for use in refrigeration and AC applications. Today not every system could be build with each of the abatement options using “off the shelf” parts and the systems would need to be improvised, which could lead to high costs and/or low efficiency.

- Availability of refrigerants and blowing agents

Whilst hydrocarbons, CO_2, ammonia or water are available in sufficient quantities, new developed unsaturated HFCs are not yet commercially available of the necessary scale today. However, these gases show promising prospects for replacement of conventional HFCs and hence unsaturated HFCs are included in the comparative analyses in this study wherever possible.

This applies particularly to HFC-1234yf (refrigerant) and, to minor extent, HFC-1234ze[288] (foam blowing agent, aerosol propellant, refrigerant). The penetration rates of HFC-1234yf will still be low by 2015, which is the first year for which production at large scale is announced. As the market availability can be assumed to develop over time, the accurate quantitative assessment of the penetration rates is key condition for the estimation of the HFC reduction potential in the period until 2030.

- System complexity and design know-how

Systems running on ODS, HFCs and HFC blends are of similar complexity and design. In contrast, design and construction of a refrigeration or air conditioning system running on flammable refrigerants or transcritical CO_2 systems require additional knowledge and training. Therefore, design engineers and technicians need to acquire additional know-how in order to install abatement technology properly.

6.2.3 Determination of penetration rates

In estimating the maximum potential penetration rate, several factors are considered. For each of the constraints considered above, the proportion (χ) for each constraint (i) – in terms of refrigerant quantity, not necessarily number of systems – of the sector that could not accommodate the specific abatement option due to each is estimated.

These factors are estimated for the year 2030, which should therefore account for both (i) anticipated technical developments and (ii) market maturity. For example, where charge size limits are a limiting factor, it can be assumed that research and development efforts over the next 20 years will reduce specific charge sizes (kg/kW) to below today's lowest values, or that system components for certain abatement options are widely available such that the product development and small production scale costs have been eliminated from the purchase price.

Thus, the overall maximum penetration rate is estimated from $1 - \max\{\chi_i\}$.

i.e., the maximum possible penetration under business-as-usual should be based on the maximum proportion of a sector unable to accommodate the abatement option for any of the given constraints. For each abatement option the proportions (χ) are based on expert knowledge of the characteristics of the systems and equipment, system design characteristics, requirements of safety standards, technology requirements, etc. and coupling these with characteristics of the refrigerants under consideration.

288 Honeywell, the manufacturer of HFC-1234ze, stated that in 2011 HFC-1234ze was “commercially available”. It should be noted that by May 2011 this unsaturated HFC was produced at a “small-scale production facility”. In May 2011 the company announced to triple the capacities (Honeywell News Release, May 12, 2011).

Whilst the constraints detailed above are mechanistic, another constraint may be included to account for the “willingness” of the market to adopt a given abatement option, which may be a function of the additional considerations necessary to suitably apply a particular abatement option. These considerations may include having to get special training for technicians, interpretation of complicated standards and so on. Using this approach the maximum penetration rate could be scaled down.

Whilst the maximum penetration rate detailed above represents the best estimate for 2030, the penetration rates for the intermediate dates – 2015, 2020 and 2025 – are obtained from interpolation between the current status (i.e., penetration of each abatement option in 2010) and the 2030 penetration, but also accounting for the typical lifetime of the equipment within the sub sector.

It must be noted here that there is no generally accepted methodology for the determination of penetration rates, and that the rates are subjective and with uncertainties. Evidently, nobody can exactly forecast and quantify the technical development in the coming 20 years. The penetration rates for the numerous individual technical solutions rely on the best knowledge of the project experts. The assessment is inter alia a result of detailed literature study, and of intensive discussion with the industries concerned[289].

6.2.4 Combination of penetration rates (“penetration mix”)

It should be pointed out that in reality a sector may comprise a number of different abatement options. However, the mix of different technical solutions cannot necessarily be represented by the maximum penetration values for each abatement option since the same constraints that apply to one abatement option may apply to another (for example, flammability, etc).

Therefore the maximum penetration rate of each abatement option for any one sector is the maximum penetration rate of any one of the abatement option within each of the groups listed in table 6-6 (refrigerants only). The groups represent the abatement option that are dominated by the same constraints and which are hence mutually exclusive.

For example, the penetration rates of two flammable refrigerant abatement options in direct systems cannot be added since flammability is the same limiting factor. However, the penetration rates for Group 1/2 and Group 4 can be added since Group 4 abatement option could be applied where it would be impossible to use Group 1 or 2.

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[289] For example see “Remark on the replacement potential of hydrocarbon refrigerants in split room air conditioners” following the Data Input Sheet “Stationary air conditioning – single split type” in annex IV which explains in detail the penetration rate assessment for room air conditioners with R-290. Room air conditioners with R-290 are the abatement technology with the highest individual HFC reduction potential in the study. It should be noted that the assumptions for the relevant variables of R-290 room air conditioners are in line with the draft Commission Regulation implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans.

Table 6-6: Classification of abatement options by limiting factors

Group 1 **Highly flammable**	R600a R290/R1270
Group 2 **Flammable**	Unsaturated HFC R717
Group 3 **Moderate ambient only**	R744
Group 4 **Indirect operation** **Highly efficient**	R290/R1270 + R744 cascade R717 + R744 cascade HC + evaporation secondary (e.g. R744) Unsaturated HFC+ evaporation secondary (e.g. R744)
Group 5 **Indirect operation** **Normal efficiency**	HC + liquid secondary R717 + liquid secondary Unsaturated HFC+ liquid secondary
Group 6 **Poor performance, high cost**	Air cycle Liquid absorption Solid adsorption

In the survey of closed and open applications of HFCs underlying the following section on key abatement options, the penetration rates estimated for each individual replacement solution for 2015, 2020 and 2030 are presented. The aggregation of these individual penetration rates to complementary sector penetration rates follows the least-cost principle, which means that in case of equal reduction potential the most cost-effective abatement option comes first, the second after, and so on, until the technical maximum for the sector is reached.

The cost of an abatement option is considered as the cost difference between the sector-typical HFC reference system, which is quantified and put in relation to the avoided HFC quantity of emissions or demand of this system. The result of the calculation is the specific annual abatement cost in €/t CO_2 eq of an alternative option, as measure of its cost effectiveness. The calculation is shown for each abatement option in the Global Data Input sheets (annex IV) and, for Europe, in the EU sector sheets in annex V.

The 2030 penetration mix for each application sector is shown in percentages, in tables at the end of each chapter, for A2 and A5 countries. For the EU the same penetrations mix as for the A2 countries is assumed, if not otherwise stated. Corresponding to the percentage of the individual abatement options in the 2030 penetration mix, the individual abatement cost are aggregated to average sector abatement cost, in €/t CO_2 eq.

The first objective for each sector is identification of those technically feasible alternative technologies that provide highest possible emission or demand reduction potential. The cost of these technologies is not the primary but the secondary selection criterion, which determines the order of different alternative options in the mix. From this it follows that abatement options relying upon low or no GWP technologies are preferred choice. However, solutions with GWP which are lower than the ones used today, such as blends of HFCs with unsaturated HFCs (GWP ~700) or substances like HFC-32 (GWP 675) are also considered for the assumed penetration mix, if such solutions, in a given year, are either the only alternative to high-GWP HFCs, or can further increase the reduction potential of low-GWP options. According to our analysis, only in few sectors (passenger ship air conditioning, room air conditioners <12 kW, and heat pumps[290]) inclusion of such solutions could increase the reduction potential of the low-GWP options to achieve highest possible reduction effect until 2030. In all other sectors, the combination of low-GWP solutions alone represented the highest possible reduction potential.

6.2.5 Difference between A2 countries and Europe

Although the abatement options, their individual penetration rates, and sector penetration mix are the same for A2 countries and Europe (EU-27), which is part of the industrialized world, the marginal abatement cost per t CO_2 eq differ mostly in the following sector presentations. This applies to all sectors with closed stationary systems like refrigeration, air conditioning, and fire protection.

The main reason for the deviation is the different nature of the underlying baseline scenarios (see chapter 2) for A2 and Europe in this study. For A2 countries reference for the abatement option is the conventional HFC technology under business-as-usual, while for Europe the reference system is (in most cases) subject to the F-gas Regulation, which means a system "with measures" (WM). This system has higher service cost due to application of Articles 3 and/or 4 and has at the same time lower emissions as a result of the measures of Articles 3 and/or 4. Both cost difference and emissions difference to the reference systems are lower in Europe than in A2 countries.

In some cases, the global warming emissions of the HFC reference systems in A2 countries differ from those of the EU reference systems. This is because in the global model for A2 countries often a mix of HFCs with different GWP values is applied (e.g. R407C/410A) in order to account for the variety of similar refrigerants in the same application in different A2 countries. In contrast, in the EU calculation model (see EU sector sheets in annex IV) mostly one HFC species (e.g. R410A), namely the "typical one", forms the reference for abatement options, even though in reality further HFC species with different GWP are in use.

[290] In the sub sectors of room air conditioners <12 kW (movable and single split systems) the additional reduction effect from inclusion of HFC-32 lasts only until 2029 because in 2020 the penetration mix of low-GWP technologies has reached 100% (lifetime 10 years).

6.2.6 Key abatement options by sectors

For each sector today relying on HFCs or HCFCs (in A5 countries), cost-effective and technically feasible abatement technology has been identified and compared to the sector-typical conventional HFC technology as reference (see chapter 6.1.1). Detailed information on each sector is given in annex VI.

The different types of abatement technologies are partly based on alternative technology already common today (chapter 6.1.1) and partly on technology at least in prototype state, which is expected to be available at large scale in the near future.

An aggregated market penetration potential, which includes for a sector the most effective abatement options which complement each other, with priority on more cost effective solutions in case of equal abatement potential, has been determined for A2 and A5 countries and is shown for 2030 in the following tables by sectors ("penetration mix").

Refrigeration and air conditioning sub sectors

In most refrigeration sub sectors (table 6-7) the penetration mix of abatement options can reach 100% in or before 2030. Exemptions include the industrial refrigeration sector and refrigeration in fishing vessels.

Table 6-7: Key abatement options in the refrigeration sectors and their aggregated market penetration potential in 2030 in A2 and A5 countries

Refrigeration and air conditioning	**Key abatement options**	**Market penetration of abatement options (penetration mix) in 2030 (%)**	
		A2	**A5**
Domestic refrigeration	R600a CO_2 (R744) R1234yf	95 (100*) 5 0	95 5 0
Commercial refrigeration			
Centralized systems	R290 indirect + CO_2 cascade R290 + CO_2 + CO_2 cascade CO_2	90 10 0	80 15 5
Condensing units	R290 direct R290 indirect CO_2	40 30 30	60 30 10
Stand-alone units	R290 direct CO_2	85 15	85 15
Industrial refrigeration			
Small equipment	NH_3	95	80
Large equipment	NH_3	95	80
Transport refrigeration			
Refrigerated trucks	R290 direct CO_2	80 20	80 20
Refrigerated vans	CO_2 HFC-1234yf	50 50	50 50
Reefer containers	CO_2	100	100
Fishing vessels	NH_3 + CO_2 cascade	95	95

* For Europe 100% market potential of hydrocarbon refrigerant (R-600a) is assumed already for 2015.

In many air conditioning sub sectors, the penetration mix of abatement options can reach 100% in or before 2030 (table 6-8).

Table 6-8: Key abatement options in the stationary and mobile air conditioning sectors and their combined market penetration potential in 2030 in A2 and A5 countries

Air conditioning	Key abatement options	Market penetration of abatement options (penetration mix) in 2030 (%)	
		A2	**A5**
Stationary AC			
Moveable AC	R290 direct	40	50
	CO_2	20	20
	HFC-1234yf	40	30
Single split AC	R290 direct	40	50
	CO_2	15	10
	HFC-1234yf	45	40
Multi split AC	R290 indirect	70	70
	CO_2	30	20
	HFC-1234yf	0	10
Rooftop AC	R290 indirect	65	80
	CO_2	35	10
	R290 + evaporating secondary (CO_2)	0	10
Small chillers	R290 direct	60	60
	CO_2	20	20
	NH_3	20	20
Large chillers	R290 direct	15	15
	CO_2	0	10
	NH_3	60	60
	R718	25	25
Centrifugal chillers	R290	20	20
	HFC-1234ze	50	50
	R718	30	30
Heat pumps	R290 direct	60	60
	CO_2	20	20
	HFC-1234yf	20	20
Mobile AC – road vehicles			
Passenger cars (incl. trucks)	HFC-1234yf	(100)	(60)
	R744	(100)	(60)
	HC indirect	0	40
Buses	HFC-1234yf	100	35
	R744	0	15
	HC indirect	0	50
Mobile AC – ships and rail vehicles[291]			
Passenger ships	Blends w unsat HFCs	90	Not assessed
Cargo ships	NH_3-brine	90	
	Blends w unsat HFCs	10	
Rail vehicles	R744	60	

[291] Abatement options for ships and rail vehicles have been assessed for Europe only but not for the remaining A2 countries and for A5 countries, due to very limited data availability.

Foam sub sectors

In all foam subsectors (table 6-9), current HFC blowing agents could be substituted by abatement options in or before 2030.

Table 6-9: Key abatement options in the foam subsectors and their combined market penetration potential in 2030 in A2 and A5 countries

Foam blowing agents	Key abatement options	Market penetration of abatement options (penetration mix) in 2030 (%)	
		A2	A5
Insulation foams of PU and XPS for the construction sector			
Sandwich panels with metal facings, continuous (CME)	HC Unsaturated HFC	90 10	90 10
Sandwich panels with metal facings, discontinuous (DIP)	HC Unsaturated HFC	90 10	90 10
Sandwich panels with flexible facings, boardstock (CFF)	HC Unsaturated HFC	90 10	
Spray foam (SPR)	Unsaturated HFC H_2O-CO_2	50 50	50 50
XPS Foam Boards (XPS)	HC incl. organic solvent+CO_2 Unsaturated HFC	85 15	85 15
PU Foam for refrigeration applications and integral skin			
Domestic refrigeration (DOR)	HC	100	100
Commercial refrigeration (COR)	HC Unsaturated HFC	50 50	100 0
Refrigerated trucks, reefer containers (RTRU)	HC Unsaturated HFC	90 10	90 10
Integral foams (INT)	H_2O Unsaturated HFC	50 50	100 0

Fire protection and technical aerosols

Table 6-10 includes technical aerosols[292] (excluding MDI[293]) and the fire protection sector. In fire protection, the key abatement option could fully substitute the use of HFC-23 (GWP 14,800) as fire extinguishing agent in or before 2030. The use of HFC-227ea, in contrast, can be replaced in most but not all applications.

[292] There is currently no definition of technical aerosols in the legal text. FEA (Fédération Européenne des Aerosols) suggests the following definition: Technical aerosols are aerosol dispensers used in maintenance, repair, cleaning, testing, disinsecting, manufacturing, installation and other applications where a non-flammable formulation is required for safety reasons. (Communication to Öko-Recherche, 15 May, 2011). This definition also separates novelty aerosols from “technical” aerosols.

[293] HFCs are used in Metered-Dose Inhalers for the treatment of asthma and other respiratory diseases. Health aspects related to the application of MDIs as compared to potential abatement technology need specific investigation.

With regard to technical aerosols, it is estimated that the market penetration potential of unsaturated HFCs will cover 85%/95% of the applications.

Table 6-10: Key abatement options in the aerosol and fire protection sectors and their market penetration potential in 2030 in A2 and A5 countries

Fire protection Technical aerosols	**Key abatement options**	**Market penetration of abatement options (penetration mix) in 2030 (%)**	
		A2	**A5**
Fire protection			
Equipment with HFC-227ea	FK 5-1-12	90	80
Equipment with HFC-23	FK 5-1-12	100	100
Technical aerosols	Unsaturated HFCs	95	85

Electrical switchgear and magnesium die casting

For both sectors, the assessment of abatement options for the use of SF_6 focused on Europe. Analyzes do not refer to A2 and A5 countries and the global situation.

Table 6-11: Key abatement options in the electrical medium voltage secondary switchgear and magnesium casting sectors and their market penetration potential in EU-27 in 2030

Other sectors	**Key abatement options**	**Market penetration of abatement options (penetration mix) in 2030 (%)**
Medium voltage secondary switchgear	Solid insulation	40
Magnesium die casting and recycling	HFC-134a, SO_2	100

Since in magnesium die casting large facilities (SF_6 use >850 kg/y) already were required to substitute the use of SF_6, alternative options for small facilities are readily available and could reach full market penetration earlier than 2030. In the switchgear sector SF_6 is currently the only technical solution for voltage >52 kV. Below 52 kV, in so called medium voltage, SF_6 or air is used at the interface between high and medium voltage (primary level); at the interface between medium and low voltage (secondary level) SF_6 clearly dominates the market (ca. 98%) but solid insulation is technically possible today.

6.3 Abatement costs and global HFC consumption reduction

In the previous section, technically feasible replacements of conventional HFC technologies were presented for each sector and the optimum penetration mix for each sector was shown. In this section, the consumption reduction potential for 2030 (kt CO_2 eq) and the abatement cost for 2030 (€/t CO_2 eq) for each sector are summarized for both developed (A2) and developing countries (A5). This section only refers to HFCs. All sector specific abatement costs are based on the penetration rate mix in 2030, which aggregates abatement costs of individual options to sector values.

6.3.1 Developed countries (A2)

Table 6-12: Consumption reduction potential (kt CO_2 eq) per sector in developed (A2) countries in 2030 and abatement costs (€/t CO_2 eq)*

Sector	Sub sector	Consumption Abatement Cost (€/t CO_2 eq)	Pot. consumption Reduction 2030 (kt CO_2 eq)
Domestic Refrigeration	Refrigerators + Freezers	18.1	11,200
Commercial Refrigeration	Centralized systems	-12.9	35,300
	Condensing units	1.4	71,400
	Stand-alone equipment	-16.9	4,000
Industrial Refrigeration	Small industrial refrigeration	2.0	4,000
	Large industrial refrigeration	-6.0	73,800
Transport Refrigeration	Trucks and trailers	-6.6	25,100
	Ships (Containers)	9.0	4,600
Stationary A/C	Moveable type	8.4	13,200
	Split type	17.5	209,900
	Multi-spilt	46.3	149,200
	Ducted rooftop	47.7	50,400
	Chillers small	22.9	13,800
	Chillers large	-42.0	64,400
	Centrifugal Chillers	16.2	9,300
	Heat pumps (heating only)	64.2	17,800
Mobile A/C**	Passenger cars	-3.0	73,200
	Buses	29.0	2,300
Foam	XPS	1.3	42,000
	Spray Foam	9.3	18,700
	Sandwich panels disc (DIP)	7.0	11,000
	Sandw. panels metal (CME)	4.9	6,500
	Sandw. flexible, boardstock (CFF)	1.4	1,300
	Domestic Ref.	8.0	10,800
	Commercial Ref.	17	4,400
	Refrigerated Trucks	5.9	1,700
	Integral Foam	10.5	3,600
Fire Protection	Fire protection	3.8	21,900
Aerosols	Aerosols	9.5	16,300
Total			**1,016,200**

* Figures of A2 include Europe, but are not specific European values, see table 6-14.

** Maritime and rail sectors are listed only for Europe and not for A2 and A5, due to lack of global data.

In the business-as-usual scenario, the total HFC consumption in developed countries is projected to reach 1,395 Mt by 2030 (without MDIs). At this time, technically feasible abatement options can cover 1,016 Mt CO_2 eq (= 73%). This is called the reduction potential (Table 6-12).

Stationary air conditioning is the sector with the highest reduction potential. Single and multi-split air conditioners account for 24% and multi-split systems for 19% of the total. Other large sub sectors are passenger cars (9%), commercial condensing units (7%), and chillers (6%).

75% of the overall reduction potential can be reached at abatement costs below €20. Some important sectors feature negative cost, amongst them chillers, refrigerated trucks, large industrial refrigeration plants, and passenger car air conditioning.

There are 4 sub sectors with abatement cost >20 €/t CO_2 eq including buses, multi split systems, ducted air conditioners, and heat pumps.

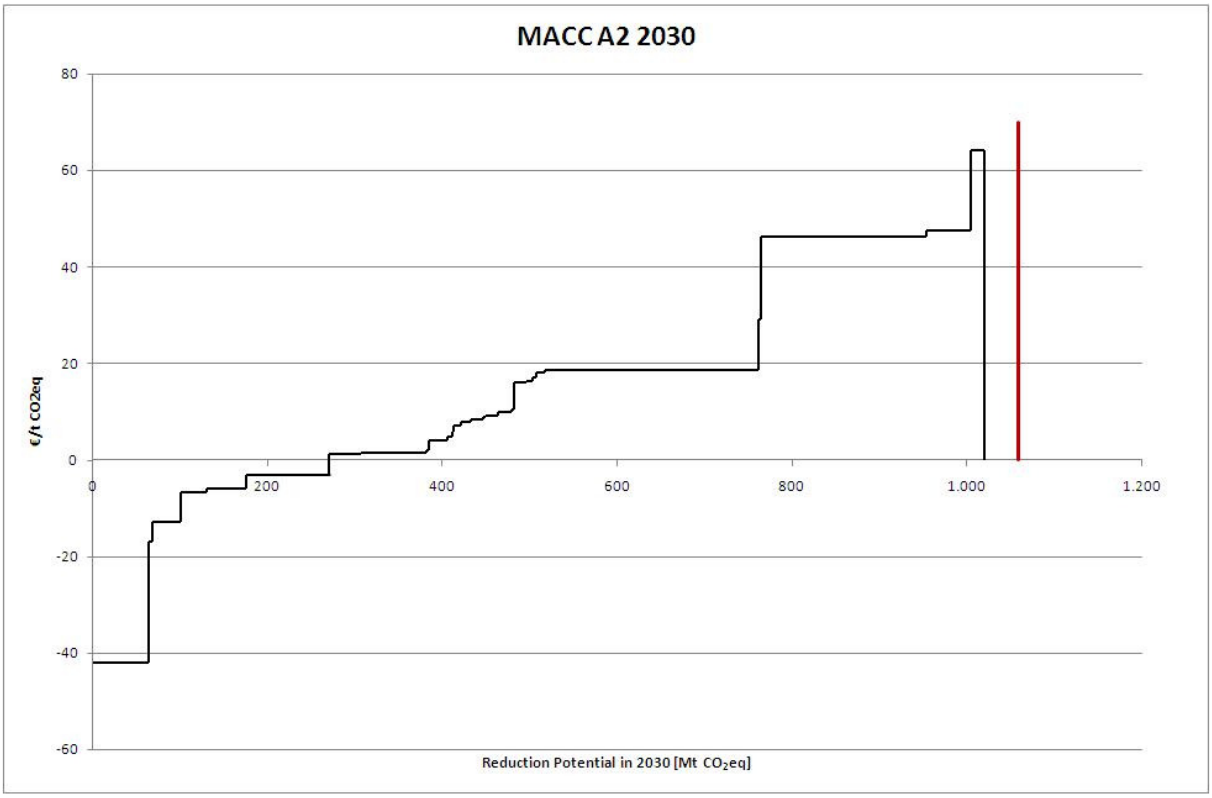

Figure 6-5: Marginal Abatement Cost Curve for A2 countries in 2030. The red line on the right indicates total HFC consumption in A2 countries in 2030.

Figure 6-5 illustrates that an HFC consumption reduction of approx. 760 Mt CO_2 eq can be abated at costs <20 €/t CO_2 eq.

6.3.2 Developing countries (A5)

In the business-as-usual scenario, the total HFC consumption in developing countries is projected to reach 2,650 Mt by 2030 (without MDIs). At this time, the technically feasible reduction potential amounts to 2,490 Mt CO_2 eq. (= 94%) (Table 6-13).

Table 6-13: consumption reduction potential (kt CO_2 eq) per sector in developing (A5) countries in 2030 and abatement costs (€/t CO_2 eq)

Sector	Sub sector	Consumption Abatement Cost (€/t CO_2 eq)	Potential consumption reduction 2030 (kt CO_2 eq)
Domestic Refrigeration	Refrigerators + Freezers	8.7	26,500
Commercial Refrigeration	Centralized systems	-7.1	92,400
	Stand-alone equipment	-40.8	25,500
	Condensing units	-4.9	109,600
Industrial Refrigeration	Small industrial refrigeration	1.6	41,200
	Large industrial refrigeration	-4.0	781,700
Transport Refrigeration	Trucks and trailers	-39.1	310,000
Stationary A/C	Moveable type	7.3	15,300
	Split type	9.3	657,900
	Multi-split	34.4	648,200
	Ducted rooftop	28.1	26,400
	Chillers small	-2.0	18,300
	Chillers large	-47.9	104,700
	Centrifugal Chillers	11.7	16,300
	Heat pumps (heating only)	45.8	23,400
Mobile A/C*	Passenger cars	4.2	233,800
	Buses	27.6	12,500
Foam	XPS	8.1	16,800
	Spray Foam	5.0	48,500
	Sandw panels metal (DIP)	3.0	29,900
	Sandwich panels with metal facings, continuous (CME)	2.2	9,500
	Domestic Ref.	4.0	53,300
	Commercial Ref.	13.0	10,800
	Refrigerated Trucks	6.4	6,400
	Integral Foam	10.0	6,300
Fire Protection	Fire protection	3.8	12,900
Aerosols	Aerosols	8.5	8,000
Total			**2,490,500**

* The maritime and rail sectors are analysed only for Europe and not for all A2 and for A5, due to lack of global data.

Stationary air conditioning is also in developing countries the sector with the highest reduction potential. Single and multi-split air conditioners account for 22% and multi-split systems for 19% of the total. Other large sub sectors are large industrial refrigeration plants (18%), refrigerated trucks (11%), and passenger cars (7%).

78% of the overall reduction potential can be reached at abatement costs <€20. Some important sectors like chillers, refrigerated trucks, or industrial refrigeration plans feature negative cost.

The sub sectors with abatement cost >20 €/t CO_2 eq are the same sectors as in A2 countries including buses, multi-split systems, ducted air conditioners, and heat pumps.

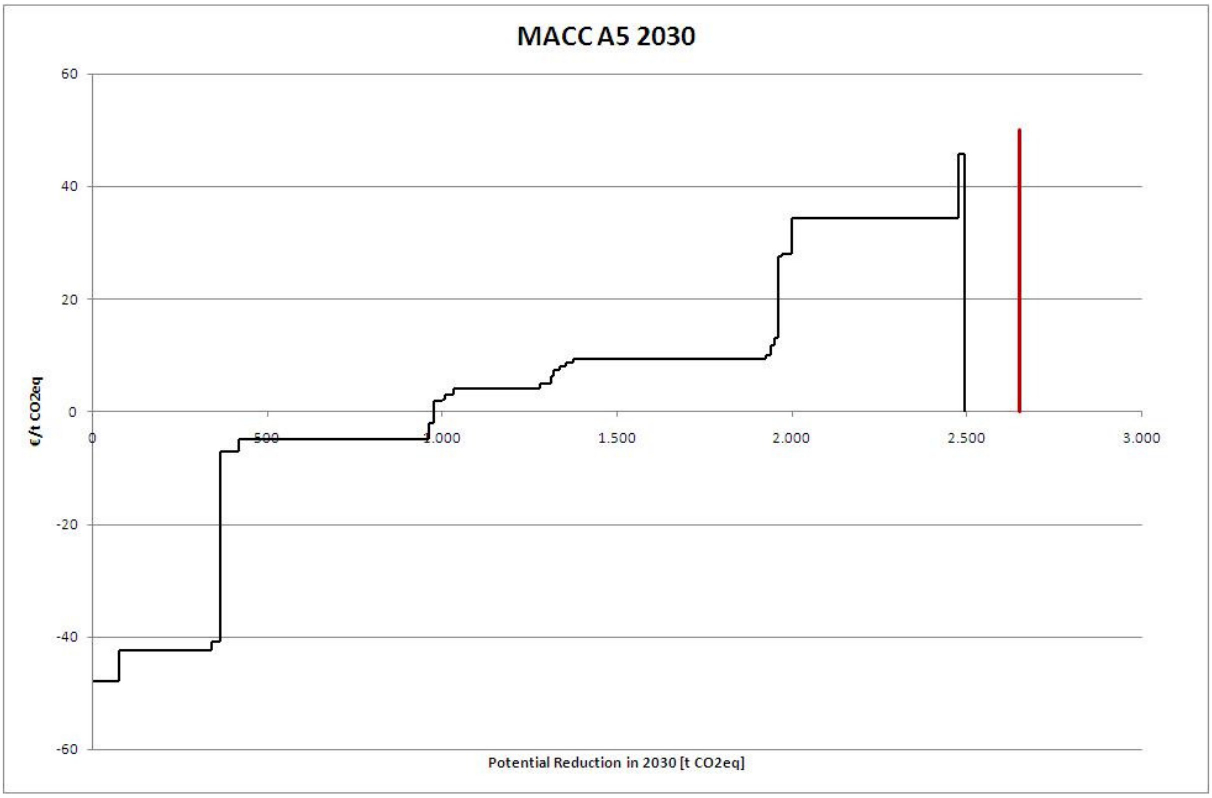

Figure 6-6: Marginal Abatement Cost Curve for A5 countries in 2030. The red line on the right indicates total HFC consumption in A5 countries in 2030.

Figure 6-6 illustrates that an HFC consumption reduction of almost 2,000 Mt CO_2 eq can be abated at costs <20 €/t CO_2 eq.

6.4 Abatement cost, emission and demand reductions in EU-27

In chapter 6.2, technically feasible and cost effective replacements of conventional HFC technologies were presented for each sector. In this section on abatement options in Europe, both demand[294] reduction potential and emission[295] reduction potentials for 2030 (kt CO_2 eq) as well as the abatement cost for 2030 (€/t CO_2 eq) for each sector are summarized.

6.4.1 Demand reductions in EU-27 by 2030

It is important to know that in the given context demand in its 1st and 2nd extension includes not only those F-gas (HFC) quantities that are filled into new or existing equipment in one of the 27 Member States but also F-gas quantities that are imported in pre-filled equipment to one of the 27 Member States. Pre-filled equipment, in particular stationary split air conditioners contribute to EU emissions once they have been installed within the territory of the European Union. Therefore, demand for F-gases in the EU is bigger than sales of F-gases in bulk quantities to the EU market (chapter 2.2.4).

In the WM scenario, the total HFC demand of the relevant sectors in Europe is projected to range at 160.3 Mt CO_2 eq in 2030 (see table 6-4, HFCs without MAC of motor vehicles). By then, technically feasible abatement options for HFCs can cover 141.9 Mt CO_2 eq (table 6-14, HFCs total w/o motor vehicles). This is a reduction potential of 88.5%.

By inclusion of mobile air conditioning of trucks and buses the 2030 demand for HFCs can be reduced by additional 5.7 Mt CO_2 eq (table 6-14, MAC trucks and buses).

In addition, SF_6 demand of 3.3 Mt can be abated (table 6-14, SF_6 application).

The total F-gas demand reduction potential amounts to 150.9 Mt CO_2 eq.

Stationary air conditioning is the sector with the highest HFC reduction potential by far (72.1 Mt CO_2 eq; almost 50% of the 141.2 kt CO_2 eq HFC demand reduction potential w/o motor vehicles, followed by commercial refrigeration (34.4 Mt CO_2 eq; 24%). Single split systems represent the sub sector with the highest reduction potential in stationary air conditioning, and centralised supermarket systems show the highest reduction potential in commercial refrigeration. The abatement cost in the two large sectors are of similar size, with €10.9 in commercial refrigeration and 8.7 €/t CO_2 eq in stationary air conditioning (if heat pumps are excluded).

95% of the overall demand reduction potential of HFCs (without motor vehicles) can be reached at abatement cost <20 €/t CO_2 eq, and 95.5% at abatement cost <50 €/t CO_2 eq. Four sectors feature negative costs, amongst them the large sector of industrial refrigeration.

There are four HFC sub sectors with abatement cost >16 €/t CO_2 eq including passenger ships, refrigerated vans, heat pumps, and rail vehicles, in addition to the MAC sub sectors of buses and trucks, and the SF_6 sub sector of MV secondary switch gear.

[294] Demand includes first fill in imported pre-charged systems and first fill in domestically manufactured systems for export to third countries (2nd extension of the term demand, see chapter 2.2.4).

[295] Emissions are those which take place in the EU. i.e. although demand includes pre-charged exported equipment, emissions of those are not counted as EU emissions.

Table 6-14: Demand abatement cost and reduction potential by alternative options in sectors and sub sectors relying on F-gases in EU-27 in 2030

Sector	**Sub sector**	**Abatement Cost (€/t CO_2 eq)**	**Potential Demand Reduction 2030 (kt CO_2 eq)**
Domestic Refrigeration	Refrigerators/Freezers	-	0
Commercial Refrigeration	Stand-alone systems	-0.3	219
	Condensing units	0.7	8,949
	Centralized systems	14.6	25,214
Industrial Refrigeration	Small Industrial equipment	-0.6	2,186
	Large Industrial equipment	-15.5	6,557
Transport Refrigeration	Refrigerated Vans	37.2	516
	Refrigerated Trucks	2.0	4,325
	Fishing vessels	3.2	539
Mobile Air Conditioning*	Rail vehicle AC	414.2	129
	Cargo ship AC	15.8	353
	Passenger ship AC	33.1	160
Stationary Air Conditioning	Moveable systems	4.4	5,369
	Split systems	10.8	45,428
	Multi-split/VRF systems	7.0	6,426
	Rooftop systems	3.1	1,489
	Chillers (displacement)	2.2	6,851
	Centrifugal chillers	5.5	460
	Heat Pumps	74.7	6,147
Fire protection	Fire protection 227ea	7.4	2,578
	Fire protection 23	1.0	2,946
Aerosols	Non-medical aerosols	10.0	3,637
Foam	XPS-152a	-1.6	460
	XPS-134a	0.3	4,092
	PU-Spray	10.0	4,801
	PU other	0.2	2,058
HFCs total w/o motor vehicles		average 10.7	***141,888***
Mobile Air Conditioning trucks and buses*	Trucks	37.2	4,017
	Buses	42.7	1,694
MAC trucks and buses		average 38.8	***5,711***
Total HFC sectors		average 11.7	***147,599***
Selected SF_6 application sectors	Magnesium casting	0.4	250
	MV secondary switchgear	33.9	3,103
SF_6 application		average 31.4	***3,353***
Total		average 12.2	***150,952***

* Passenger cars are not included in the table because the abatement technology is already part of the WM scenario (MAC Directive).

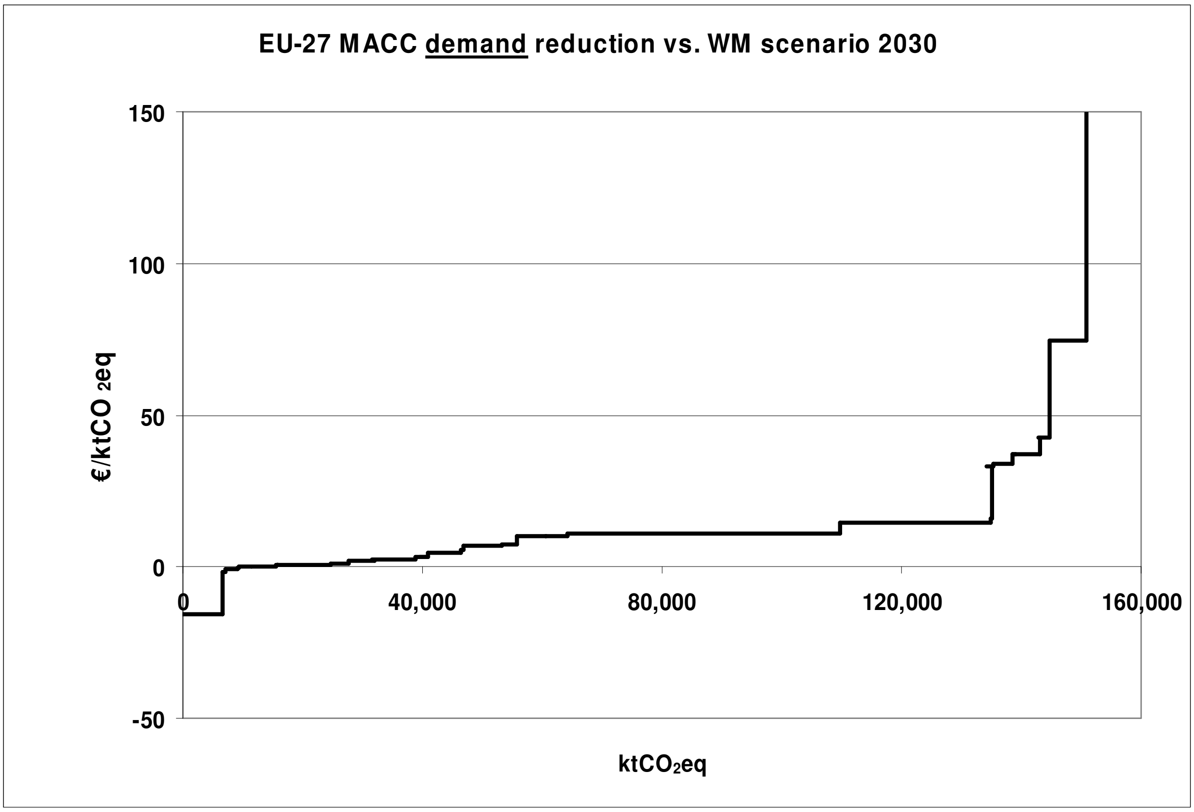

Figure 6-7: Marginal Abatement Cost Curve for F-gas demand reductions in EU-27 in 2030 in 28 HFC sectors and two SF_6 sub sectors. The HFC quantities include pre-filled imported equipment.

Figure 6-7 illustrates that F-gas demand reductions of 135 Mt CO_2 eq can be abated at costs <20 €/t CO_2 eq in 23 of the analysed 28 HFC sub sectors (including trucks and buses) and 2 SF_6 using sub sectors in EU-27.

6.4.2 Emission reductions in EU-27 by 2030

As stated, demand for F-gases includes new equipment, no matter if it is first filled within or outside the EU, plus refill in existing equipment within the EU to account for losses during use-phase. Emissions likewise include leakage in the use-phase, but do not account for first fill. Instead, emissions include emissions on disposal when old equipment is decommissioned. Values of emissions are lower than values of demand because end-of-life emissions from equipment are not as high as the first fill into the equipment, once there is some recovery. In addition, first fill exceeds the quantity for disposal as long as there is growth in the F-gas bank in the equipment stock.

In the WM scenario, total F-gas emissions of the 26 analysed HFC sub sectors (without motor vehicles) in Europe are projected to range at 89.1 Mt by 2030 (table 6-5, total HFCs without motor vehicles). By then, technically feasible HFC abatement options can cover 69.6 Mt CO_2 eq or 78% (table 6-15).

If mobile air conditioning of trucks and buses is included, the 2030 emissions of HFCs can be reduced by additional 5.8 Mt CO_2 eq. (table 6-15, MAC trucks and buses)

In addition, SF_6 emissions of 0.3 Mt can be abated (table 6-15, SF_6 application).

The total F-gas emission reduction potential amounts to 75.8 Mt CO_2 eq. by 2030.

Stationary air conditioning (excluding heat pumps) is the sector with the highest reduction potential (32.1 Mt CO_2 eq; 46%), followed by commercial refrigeration (18.8 Mt CO_2 eq; 27%). Single split systems represent the sub sector with the highest reduction potential in stationary AC, and centralised supermarket systems show the highest reduction potential in commercial refrigeration. The abatement costs in the two large sectors are in the same range, with €16.2 (stationary air conditioning w/o heat pumps) and 18.8 €/t CO_2 eq (commercial refrigeration).

Table 6-15: Emission abatement cost and reduction potential by alternative options in F-gas applying sectors and sub sectors of EU-27 in 2030

Sector	Sub sector	Abatement Cost (€/t CO_2 eq)	Potential Emission Reduction 2030 (kt CO_2 eq)
Domestic Refrigeration	Refrigerators/Freezers	1.0	12
Commercial Refrigeration	Stand-alone systems	-0.8	149
	Condensing units	1.2	3,927
	Centralized systems	23.7	14,471
Industrial Refrigeration	Small Industrial equipment	-0.9	871
	Large Industrial equipment	-21.6	2,612
Transport Refrigeration	Refrigerated Vans	45.1	421
	Refrigerated Trucks	2.6	2,990
	Fishing vessels	3.4	405
Mobile Air Conditioning*	Rail vehicle AC	555.6	26
	Cargo ship AC	16.7	320
	Passenger ship AC	35.0	125
Stat Air Conditioning	Moveable systems	8.9	2,781
	Split systems	19.0	22,970
	Multi-split/VRF systems	13.1	2.827
	Rooftop systems	8.2	573
	Chillers (displacement)	5.9	2,512
	Centrifugal chillers	11.1	82
	Heat Pumps	130.2	2,282
Fire protection	Fire protection 227ea	22.3	440
	Fire protection 23	3.1	961
Aerosols	Aerosols	10.0	3,637
Foam	XPS-152a	-1.6	460
	XPS-134a	1.0	1,553
	PU-Spray	61.6	1,369
	PU other	3.5	587
HFCs total w/o motor vehicles		average 18.7	***69,633***
Mobile Air Conditioning trucks and buses*	Trucks	43.1	4,170
	Buses	48.5	1,616
MAC trucks and buses		average 44.6	***5,785***
Selected SF_6 application sectors	Magnesium casting	0.4	250
	MV secondary switchgear	347.3	97
SF_6 application		average 97.2	***347***
Total		average 21.0	***75,765***

* Passenger cars are not included in the table because the abatement technology is already part of the WM scenario (MAC Directive).

94% of the overall emission reduction potential of 69.6 Mt CO_2 eq of HFCs without motor vehicles can be reached at abatement costs <25 €/t CO_2 eq. Some important sectors feature negative cost, e.g. the industrial refrigeration sector.

There are five HFC sub sectors with abatement cost >25 €/t CO_2 eq: passenger ships, refrigerated vans, PU spray foam, heat pumps, and rail vehicles, in addition to the MAC sub sectors of buses and trucks, and the SF_6 sub sector of MV secondary switch gear. The emission abatement cost for rail vehicles and MV switchgear are higher than 300 €/t CO_2 eq.

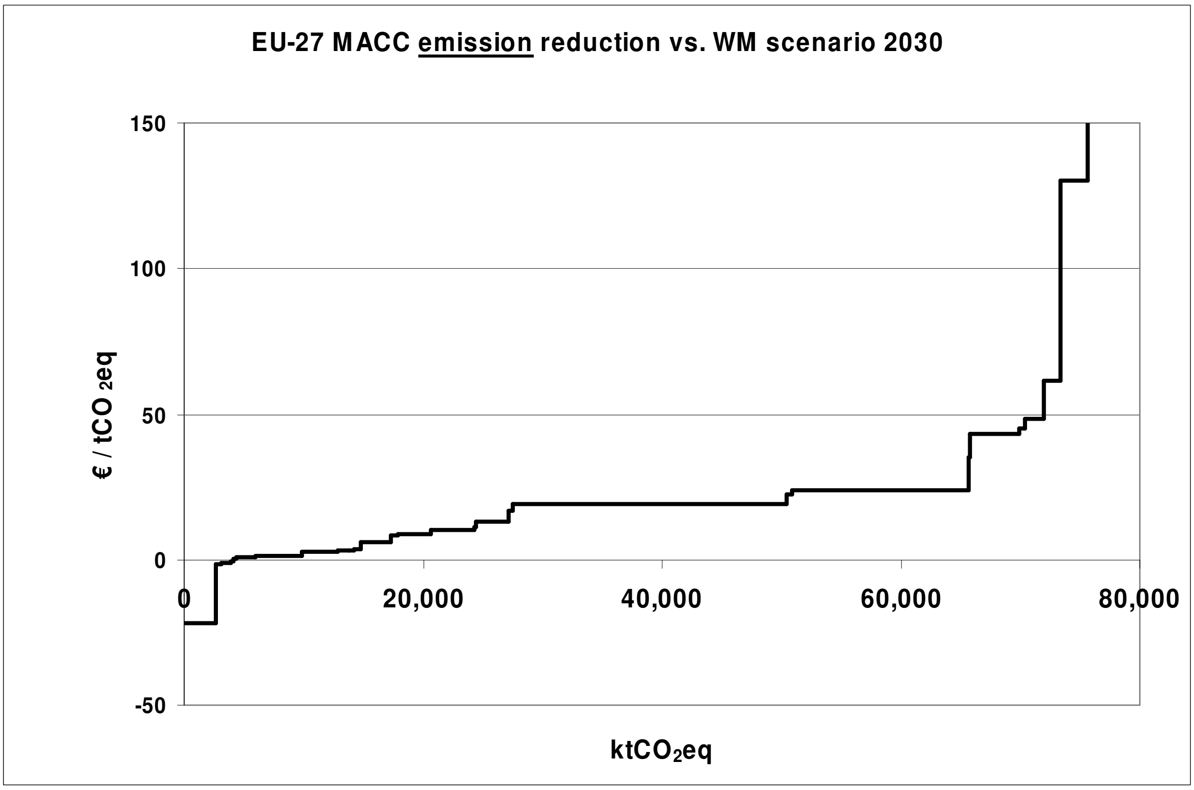

Figure 6-8: Marginal Abatement Cost Curve for emission reductions in EU-27 in 2030 in 28 HFC sectors and two SF_6 sub sectors.

Figure 6-8 illustrates that HFC emission reduction of 65.7 Mt CO_2 eq can be abated at costs <25 €/t CO_2 eq in 22 of the analysed 28 HFC sub sectors and 2 SF_6 using sub sectors in EU-27.

7. Options for further international action to reduce F-gas emissions

7.1 Projection of global HFC consumption and the need for international action

Growing consumption of HFCs and hence emissions are mainly driven by the phase out of ODS under the Montreal Protocol (chapter 3.1). The Montreal Protocol regime controls production and consumption of ODS but the choice of alternatives to ODS technology is not regulated. HFCs were developed as ozone-friendly substitutes for ODS in the early 1990s and their use has increased largely since. However, their significant global warming potential and related climate impact has caused global concerns.

Figure 7-1 and table 7-1 show projections of global HCFC and HFC consumption in a business as usual scenario (BAU) in the period until 2030, as calculated by the global AnaFgas model on HFC consumption developed within this project (see chapter 2). In this chapter, the term consumption is used in its definition under the Montreal Protocol which follows the equation Consumption = Production + Imports – Exports – Destruction – Feedstock. It should, however, be kept in mind that the annual flow of substances in A2 and A5 countries has been calculated in this study on the basis of the demand for first and refill of substances in the individual application sectors (see chapter 2.2.4).

As outlined earlier, developed countries are referred to as A2 countries based on the terminology of the Montreal Protocol. Developing countries are referred to as A5 countries accordingly.[296] For simplification, it is assumed that the classification of countries into one group or the other remains constant over time although this might not reflect future reality.

HFC consumption in A5 countries is projected to increase drastically in the next decades while HCFC consumption will decrease due to ODS phase out under the Montreal Protocol. HFC consumption in A2 countries is likely to reach stable levels around 2030.

As highlighted in other reports, under a restricted Kyoto scenario with future control caps on total CO_2 emissions in Non-Annex I countries, a partially uncontrolled consumption of HFCs[297] and related emissions may lead to a significant share of HFC emissions. In unconstrained BAU scenarios, the share of HFCs of total GHG emissions ranges around 6% in certain projections (Gschrey et al. 2011[298]) and even at 9-19% in extreme projections (Velders et al 2009[299]). The share would be substantially higher in scenarios where CO_2 emissions were restricted, but not the consumption of HFCs.

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[296] Under the Montreal Protocol, the decision whether a particular country is considered A5 or Non-A5 country depends on the annual per capita consumption of ODS. For details see footnote 10, chapter 2.

[297] HFCs are controlled substances under the national emission targets in Annex I countries. Therefore, they are limited by national preferences of Annex I in their efforts to constrain their overall greenhouse gas emissions. In Non-Annex I HFC could potentially grow unconstrained. Therefore, it is not correct to consider growth in Annex I as “uncontrolled”, even though tighter mechanisms to maintain and reduce HFCs will be economically essential to achieve national emission targets in most of the Annex I countries.

[298] Gschrey, B.; Schwarz, W.; Elsner, C.; Engelhardt, R. 2011: High increase of global F-gas emissions until 2050. Greenhouse Gas Measurement and Management 1, p.85-92.

[299] PNAS 2009, Schellnhuber, Velders, Molina et al.: Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO2 emissions, p. 1-6.

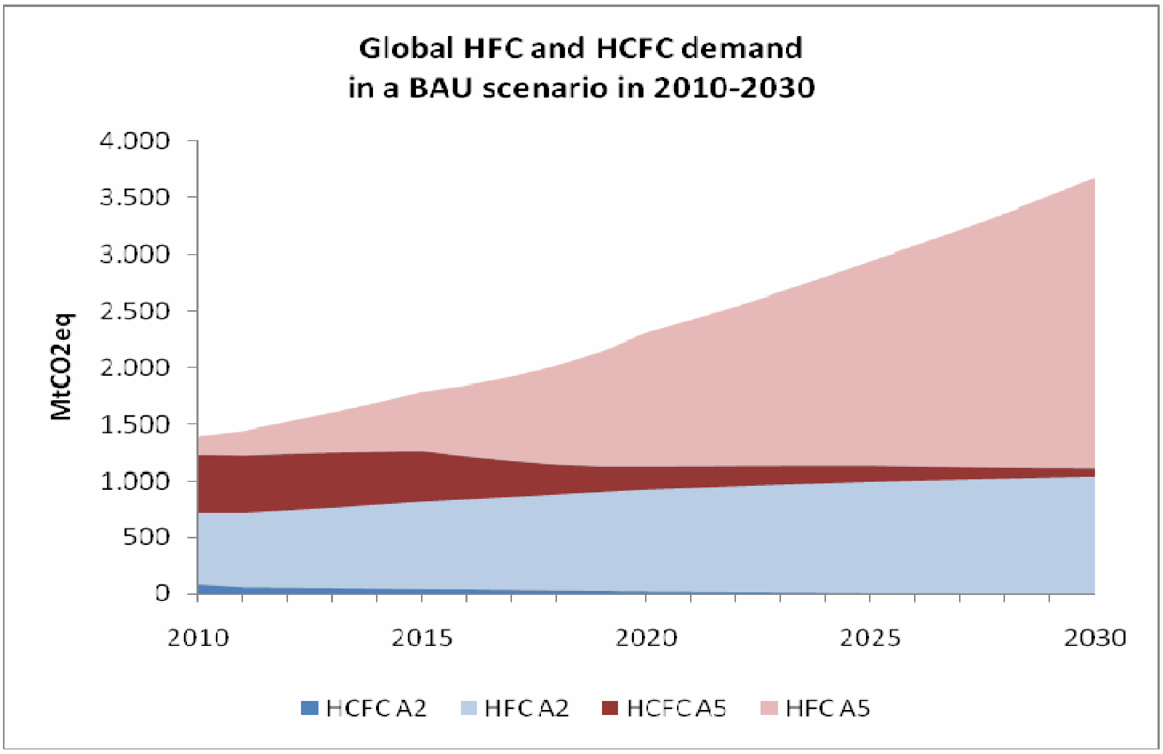

Figure 7-1 Consumption (demand) of HCFCs and HFCs in A2 and A5 countries projected in a business as usual scenario (BAU) in the period 2010-2030.

Table 7-1: Consumption of HCFCs and HFCs in A2 and A5 countries projected in a business as usual scenario (BAU) in the period 2010-2030, in Mt CO_2 eq

Consumption	**A2 countries**		**A5 countries**		**World**	
Mt CO_2 eq	**HFC**	**HCFC**	**HFC**	**HCFC**	**HFC**	**HCFC**
2010	**633**	**88**	**163**	**513**	**796**	**601**
2011	659	59	217	508	876	567
2012	687	55	279	499	966	554
2013	716	51	351	485	1,067	536
2014	747	47	432	467	1,179	514
2015	779	43	524	443	1,304	486
2016	804	39	628	374	1,432	413
2017	830	34	743	312	1,573	346
2018	856	30	873	259	1,729	289
2019	882	26	1,018	219	1,900	245
2020	**909**	**22**	**1,179**	**197**	**2,089**	**219**
2021	927	19	1,292	184	2,219	203
2022	944	16	1,410	171	2,355	187
2023	962	13	1,536	159	2,497	172
2024	977	10	1,668	146	2,646	156
2025	993	7	1,808	134	2,801	141
2026	1,005	6	1,948	117	2,953	123
2027	1,016	5	2,094	102	3,110	106
2028	1,026	4	2,246	87	3,273	91
2029	1,037	3	2,405	74	3,441	76
2030	**1,047**	**1**	**2,570**	**62**	**3,616**	**63**

As outlined in chapter 3.1, F-gas markets are global markets. This means that HFC production often takes place in one country while HFC consumption and related emissions during and at the end of product life may take place in other countries. Local or regional policy action can hence only address the contribution of HFCs to global warming to minor extent, while international action can result in emission reductions at large scale.

Current policy discussions at international level treat the question on how to link the work on F-gases, in particular HFCs, done under the climate regime (UNFCCC) and further phase out of ODS under the Montreal Protocol more closely.

Activities under the UNFCCC and the Kyoto Protocol addressing HFC emissions have been described in chapter 3.2 and include monitoring and reporting requirements, reduction targets for emissions from all GHG and projects under the CDM and JI mechanisms (see chapter 3). So far, action under the climate regime has resulted in certain, but comparably small reductions of F-gas emissions. For example, cumulated emission reductions being achieved through CDM projects on F-gases in developing countries in the first commitment period (2008-2012) amount to <5 Gt CO_2 eq in total, largely (>90%) resulting from HFC-23 destruction projects. JI projects yield emission reductions of ca 12 Mt CO_2 eq during the same period which are also caused by HFC-23 destruction to large extent.

The Montreal Protocol holds a special role as it addresses most industries and sectors which rely on F-gases while not addressing these gases. It could be possible to abate HFC emissions at a global level in a similar way as ODS by applying the approach of the Montreal Protocol.

Key advantages of the Montreal Protocol to control production and consumption of HFCs include the following aspects:

- Reductions in the production and consumption of similar chemicals in developed and developing countries were achieved.
- Experiences of funding the incremental cost of phasing out similar chemicals through the Multilateral Fund (MLF) for the implementation of the Montreal Protocol are available.
- The technical bodies of the Montreal Protocol hold expertise on all sectors related to HFCs.

This way forward is exactly suggested by two proposals for an amendment of the Montreal Protocol with regard to HFCs submitted in 2009-2010 and updated in 2011, one by the Federated States of Micronesia (FSM) and one by Northern American (NA) countries including the USA, Canada and Mexico. Both proposals suggest control of production and consumption of HFCs and are currently being discussed at international level. Detailed descriptions of the FSM and NA amendment proposals will be outlined in chapter 7.3.

The next sections include general considerations for a framework on HFCs (chapter 7.2). Scenarios for the control of HFC production and consumption in line with the approach of the Montreal Protocol are presented and compared in chapter 7.3. The scenarios referred to in this comparison include scenarios according to the FSM and NA amendment proposals as well as two scenarios on global HFC consumption (see chapter 2.2) based on the assessment of HFC abatement technology by sectors (see chapter 6) undertaken within this project.

7.2 Scenarios for the control of consumption and production of HFCs

7.2.1 Presentation of the scenarios

The scenarios based on the amendment proposals to the Montreal Protocol (FSM, NA) suggest control steps for production and consumption of HFCs in both developed and developing countries. The phase down schedules applied in the FSM and NA proposals differ with regard to the control levels in developed and developing countries. The FSM scenario is more ambitious than the NA scenario with regard to A2 countries, while the NA scenario is stricter concerning phase down in A5 countries.

The other two scenarios included in the comparison are based on the work undertaken within this project in terms of technical feasibility of HFC abatement technology (chapter 6). Replacement of current HFC technology in a particular sector by the abatement options assessed to the extent considered possible (indicated as penetration mix) results in reductions of HFC consumption in this sector. A combined analysis of potential reductions of HFC consumption in all sectors has lead to 2 scenarios:

- A reduction scenario (RED) is based on all technically feasible abatement options identified for each sector at the maximum penetration rates in a particular year.
- A reduction scenario which considers cost aspects (RED10) is based on technically feasible abatement options at abatement costs <10 €/t CO_2 eq identified for each sector at the maximum penetration rates in a particular year.

Figure 7-2 shows a comparison of the RED, RED 10 and the business as usual (BAU) scenario derived from the model on global HFC consumption developed within this project. In 2030, global HFC consumption as compared to the BAU scenario (3,705 Mt CO_2 eq) can be reduced by -3,523 Mt CO_2 eq in the RED scenario and by -2,652 Mt CO_2 eq in the RED10 scenario.

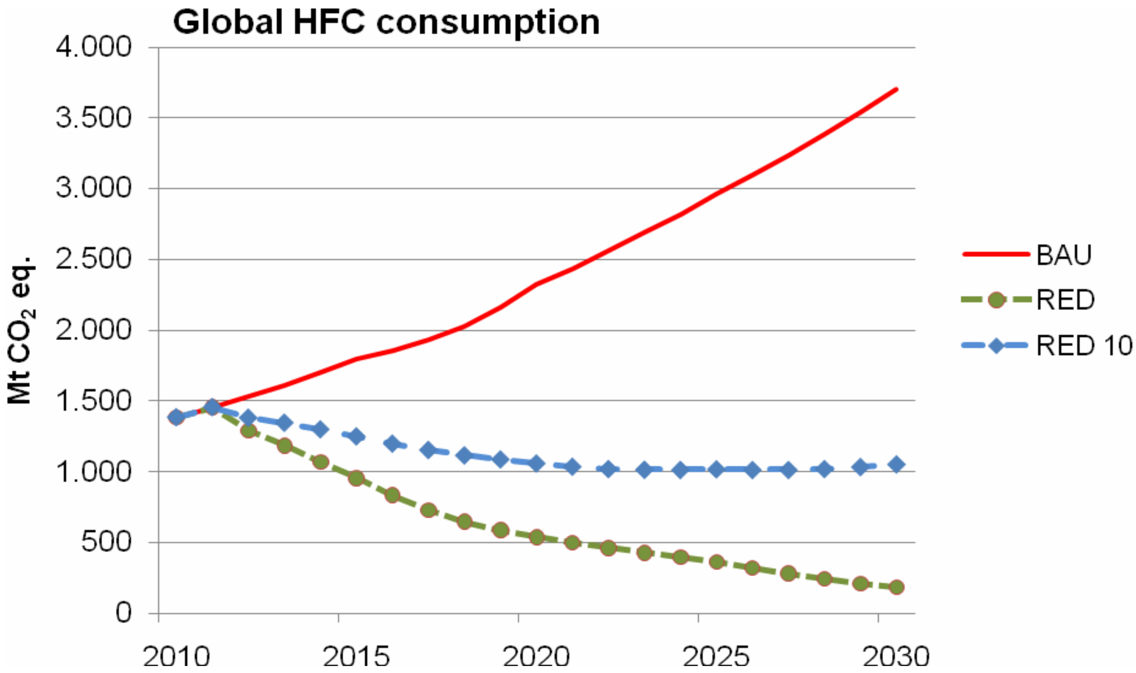

Figure 7-2: Scenarios calculated by the model on global HFC consumption include the business as usual (BAU) scenario, a reduction scenario (RED) taking into assuming application of all technically feasible abatement technology as assessed in chapter 6 and a reduction scenario (RED10) which only considers technically feasible abatement technology at costs of <10 €/t CO_2 eq.

The implementation of each HFC consumption reduction scenario (FSM, NA, RED, RED10) would lead to different implications for A2 and A5 countries, which are compared in the following sections. Since the end of the BAU projections (2030) lies right in the middle of the proposed phase-down scenarios, the BAU projections are extrapolated until 2050. For A2, the growth rates from 2020-2030 are further applied until 2050. This is justified because the consumption trend of A2 countries stabilizes at low growth rates between 2020 and 2030. In A5 countries, half of the growth rates from 2020-2030 are assumed for the period of 2030-2050, because market saturation is approached but not yet reached. The further the projections reach into the future, the higher the associated uncertainties.

7.2.2 Comparison of scenarios for A2 countries

A comparison of the four scenarios for A2 countries by technical elements is summarized in table 7-2. Baseline and reduction steps of the RED and RED10 scenario are adjusted to the calculated trends for introduction of abatement technology in these scenarios.

The baseline ranges between 697 Mt CO_2 eq (RED) and 732 Mt CO_2 eq (NA), freeze levels start in 2014 or 2015 with a step between 85% and 90%. The intermediate control steps are adapted to the calculated regression of the scenarios.

Final consumption tails range from 10% to 15% in the scenarios. The comparably late control steps of the RED10 scenario illustrate the increasing market penetration of alternative technologies at abatement costs below 10 €/t CO_2 eq over time (as presented in chapter 6).

Table 7-2: Comparison of the scenarios: Technical elements for A2 countries

Summary A2 countries	**NA**		**FSM**		**RED**		**RED10**	
Proposed Baseline	85% of HCFC plus HFC consumption		Combined HCFC and HFC consumption		25% of HCFC baseline plus HFC consumption		25% of HCFC baseline plus HFC consumption	
Baseline years	2005-2008		2004-2006		2004-2006		2004-2006	
Year of first control level	2015		2014		2014		2014	
Proposed first control level (freeze level)	90%		85%		85%		85%	
Final phase down level	15%		10%		10%		10%	
Year of final step down	2033		2031		2028		2046	
Total baseline (Mt CO_2 eq)	732		724		697		697	
Control schedule	2015	90%	2014	85%	2014	85%	2014	85%
	2017	80%	2017	70%	2016	70%	2018	70%
	2020	70%	2020	55%	2019	50%	2022	60%
	2025	50%	2023	45%	2022	30%	2026	50%
	2029	30%	2026	30%	2025	15%	2031	40%
	2033	15%	2029	15%	2028	10%	2036	30%
			2031	10%			2041	20%
							2046	10%

Figure 7-3 compares the regression trends of the individual phase-down scenarios for A2 countries in the period until 2050 in order to better illustrate the differences. In 2030, the RED10 scenario still includes relatively high HFC consumption of around 300 Mt CO_2 eq while the RED and FSM scenarios already (almost) reached their final control steps.

In 2050, the highest tail consumption of >100 Mt CO_2 eq is scheduled in the NA scenario. The FSM, RED and RED10 scenarios end at tail consumptions of around 80 Mt CO_2 eq.

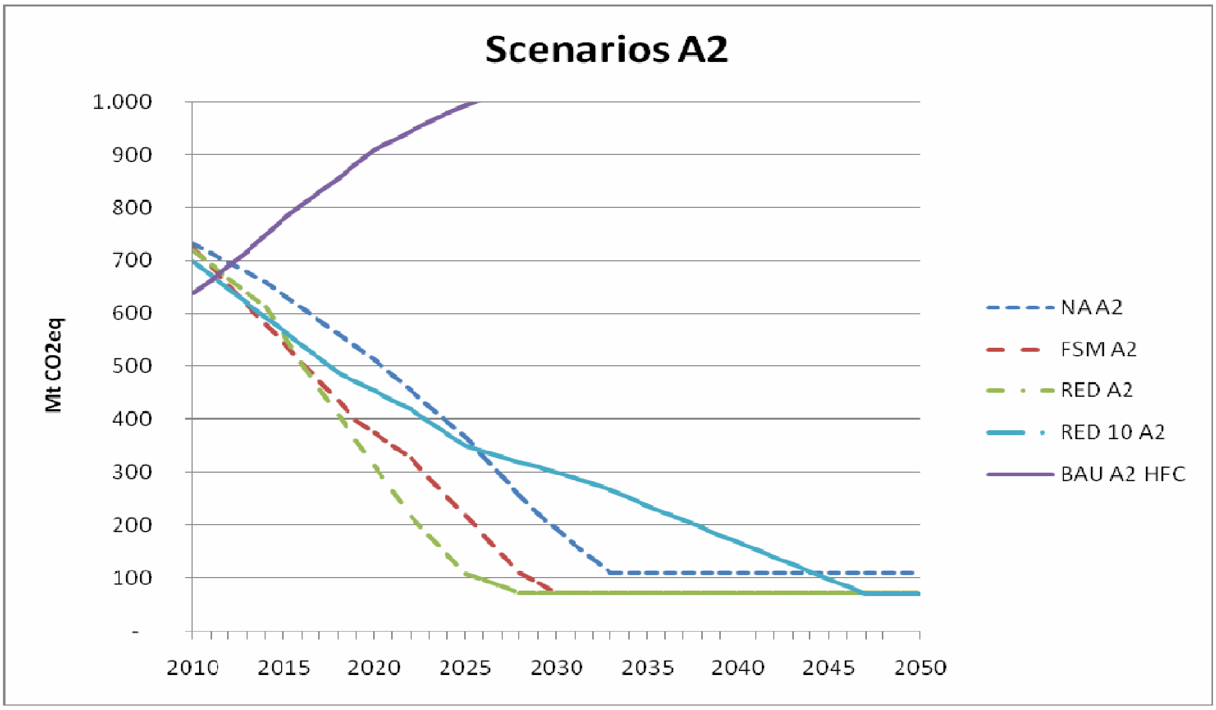

Figure 7-3: Comparison of different HFC trend scenarios in A2 countries based on the analyzed scenarios.

Figure 7-4 compares the phase-down steps for A2 countries in the different scenarios. In the early stages of phase down, FSM and RED scenario follow the same sequencing of steps.

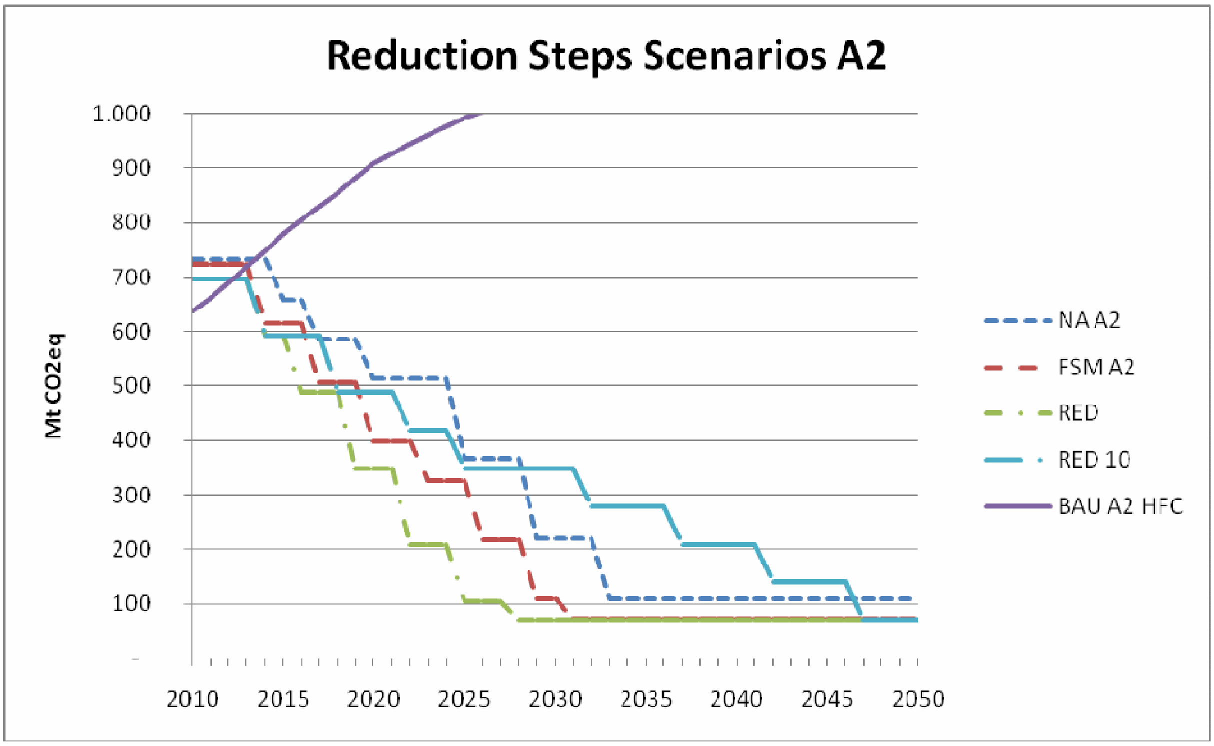

Figure 7-4: Comparison of phase down steps in A2 countries according to the compared scenarios.

Figure 7-5 illustrates the relative differences of the scenarios for A2 countries regarding their aggregate reduction potential. The scenario with the lowest consumption reduction until 2030, the RED10 scenario, was chosen as reference. The cummulated reduction is highly influenced by the early reduction steps. This is the main reason why NA shows a lower reduction potential than the other scenarios. As outlined above, the 2050 projections are to be considered highly uncertain.

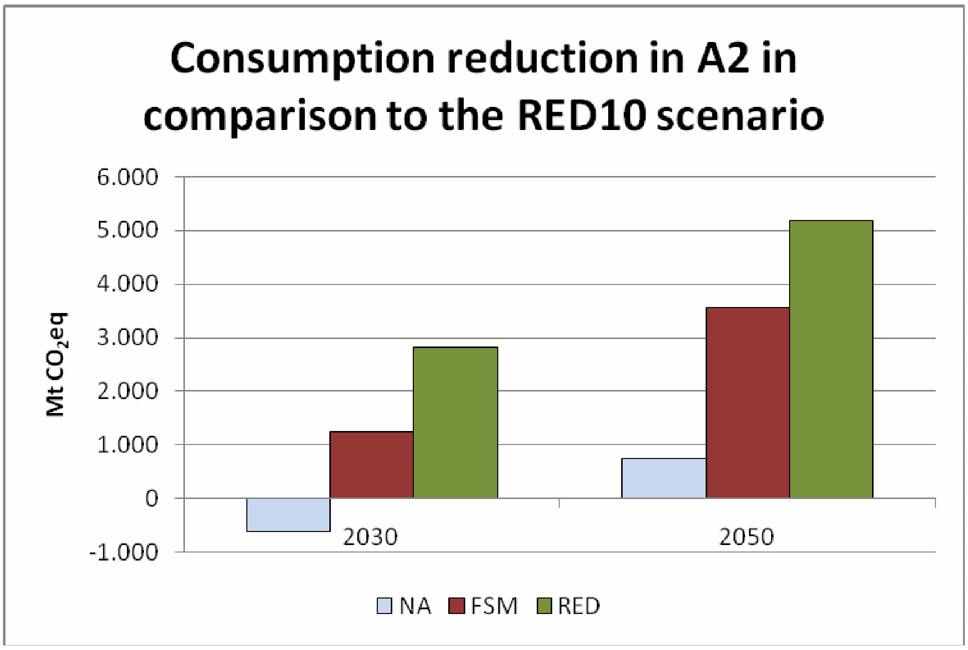

Figure 7-5: Accummulated consumption reductions (Mt CO_2 eq) in A2 countries achieved in the NA, FSM and RED scenarios relative to the RED10 scenario.

7.2.3 Comparison of scenarios for A5 countries

The comparison of the four scenarios for A5 countries is summarized in table 7-3. Baseline and reduction steps of the RED and RED10 scenario are adjusted to the calculated trends for introduction of abatement technologies (chapter 6). The definition of the RED 10 scenario, allowing only abatement options at or below 10 €/t CO_2eq, results in only one reduction step to 85% of the baseline. Compared to the soaring BAU consumption, reductions are still significant, even though they will never reach the potential of any other scenario.

The NA scenario includes a combined HCFC and HFC baseline, while an HCFC baseline is applied in the FSM, RED and RED10 scenarios. Freeze dates range between 2015 and 2019. Early freeze dates will avoid uncontrolled growth of HFC consumption between 2010 and the freeze. While freeze dates in the NA, FSM and RED10 scenario are set in 2017-2019, an earlier control is established in the RED scenario.

Finally, the consumption tail ranges from 10% (RED, FSM) to 15% (NA) and 85% (RED10). The intermediate control steps in RED allow A5 countries a longer period for the phase down. Final consumption tails range from 10% to 15% in the scenarios. The comparably late control steps of the RED10 scenario illustrate the increasing market penetration of alternative technologies at abatement costs <10 €/t CO_2 eq over time (as presented in chapter 6). Abatement technologies at costs <10 €/t CO_2 eq are available for most sectors except for e.g. refrigerated containers, air conditioning in buses, centralized commercial systems.

Table 7-3: Summary of scenarios for A5 countries

Summary A5 countries	**NA**		**FSM**		**RED**		**RED 10**	
Proposed Baseline	HCFC consumption		HCFC consumption		HCFC consumption		HCFC consumption	
Baseline years	2005-2008		2007-2009		2005-2007		2007-2009	
Year of first control level	2017		2020		2015		2019	
Proposed First Control level (Freeze level)	100%		85%		100%		100%	
Final phase down level	15%		10%		10%		85%	
Year of final step down	2043		2036		2040		2019	
Total baseline (Mt CO_2 eq)	563		654		543		654	
Control schedule	2017	100%	2020	85%	2019	85%	2019	85%
	2021	80%	2023	70%	2022	72%		85%
	2025	70%	2026	55%	2025	60%		85%
	2029	50%	2029	45%	2028	50%		85%
	2035	30%	2032	30%	2031	40%		85%
	2043	15%	2035	15%	2034	30%		85%
			2037	10%	2037	20%		85%
					2040	10%	2050	85%

Figure 7-6 compares the regression trends of the individual phase-down scenarios for A5 countries in the period until 2050. All scenarios appear to be quite close in early stages of the phase down schedules. Tail consumption in both 2030 and 2050 varies largely between the RED10 scenario and the group of NA, FSM and RED scenarios since the last control step of the RED10 scenario is reached at 560 Mt CO_2 eq in 2019 already.

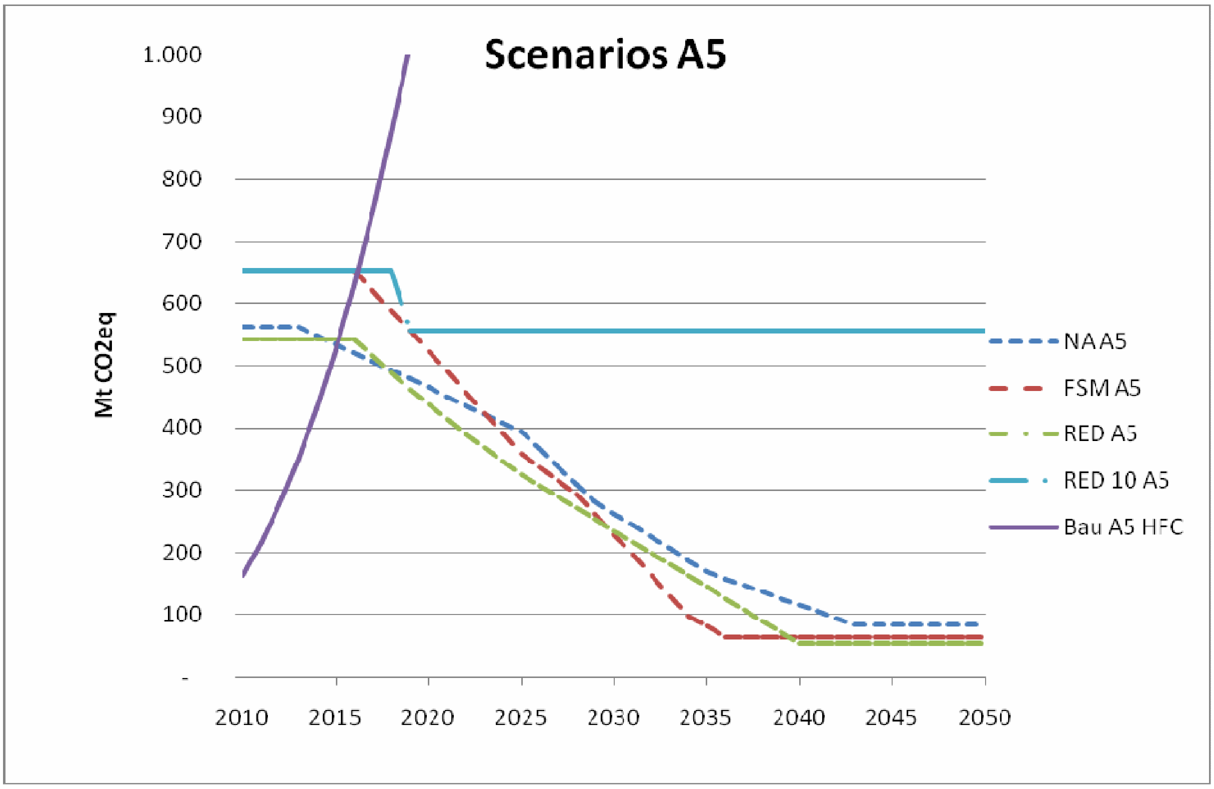

Figure 7-6: Comparison of the A5 countries trend scenarios of proposed and alternative schedule.

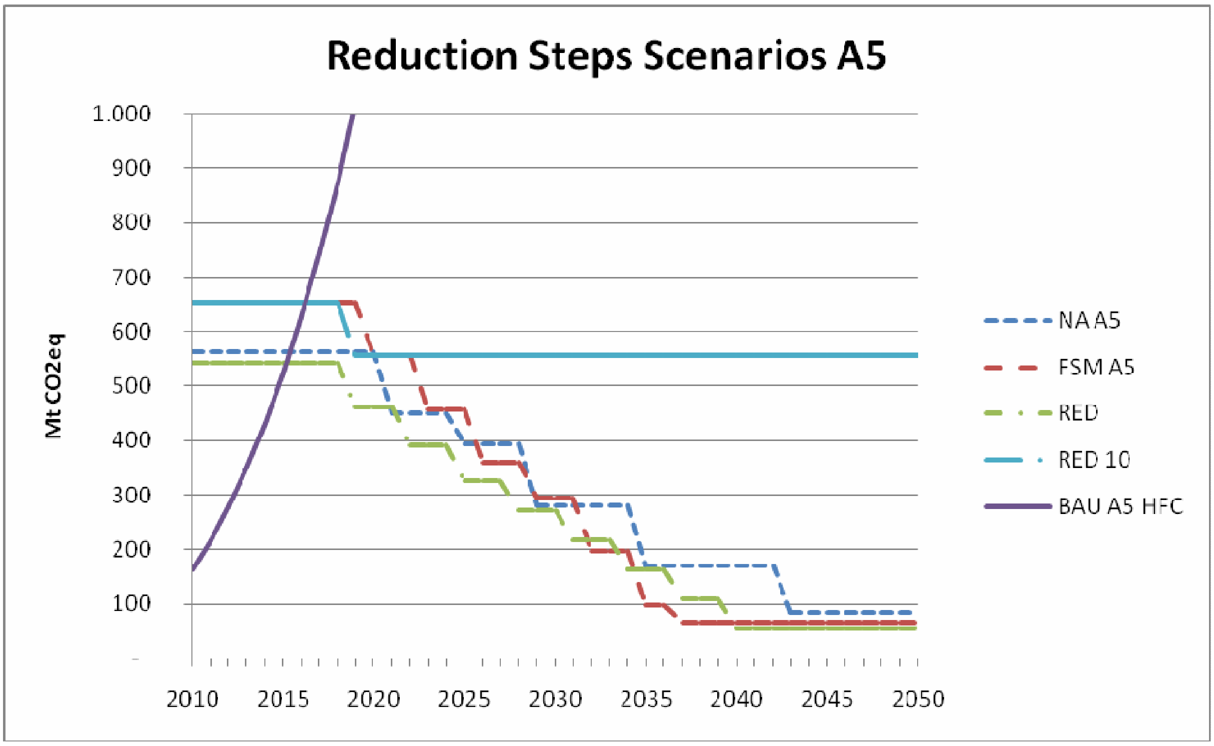

Figure 7-7: Comparison of A5 countries phase-down steps for NA, FSM and RED scenario.

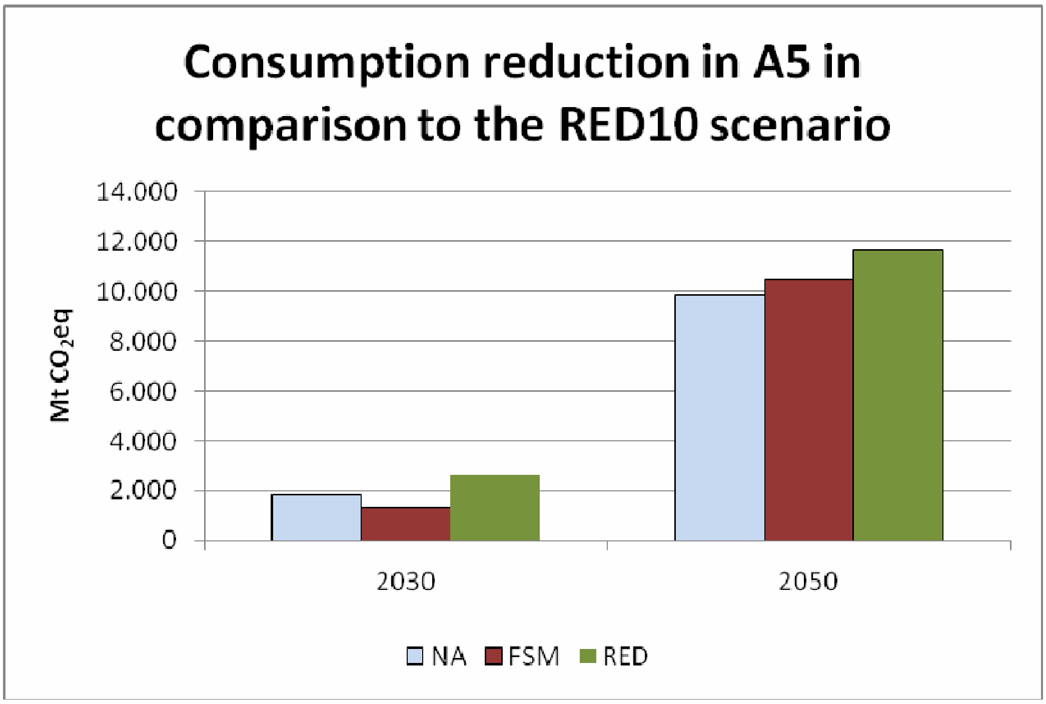

Figure 7-8: Accummulated consumption reductions (Mt CO_2 eq) in A5 countries achieved in the NA, FSM and RED scenarios relative to the RED10 scenario.

Figure 7-8 illustrates the relative differences of the scenarios for A5 countries regarding their reduction potential. The scenario with the lowest consumption reduction in 2030, the RED10 scenario, was chosen as reference. As outlined above, the 2050 projections are to be considered highly uncertain.

7.2.4 Comparison of HFC consumption reductions in the scenarios

The total accumulating consumption reduction versus the BAU scenario are compared for the RED10, NA, FSM, RED scenarios in table 7-4.

The FSM scenario results in significantly higher consumption reductions in A2 countries than the NA proposal. RED has significant higher consumption reductions in the period until 2030 in A2 countries as the other scenarios. Global emission reductions would be 24% higher in the RED scenario compared to RED10.

In the time frame until 2030, cumulative consumption reductions range between 22.9 and 28.3 Gt CO_2 eq. The difference of the regressions of each of the scenarios in comparison to the unconstrained BAU scenario appears almost insignificant. However, the BAU scenario for the year 2030 is the worst case scenario, assuming that almost no transition to HFC-free technologies has taken place.

The relative difference between the most and the least environmentally ambitious scenarios amounts to 5.4 Gt CO_2 eq of additional accumulated consumption reductions in 2030, which might be a better indicator for the evaluation of differences between the scenarios (table 7-4; figure 7-9).

Given the high uncertainties of projections until 2050, the following reduction potentials are to be treated as trend only. Accumulated reduction potentials until 2050 range at108 Gt CO_2 eq (RED10) and 125 Gt CO_2 eq (RED).

Table 7-4: Overview of accumulated HFC consumption reductions (Gt CO_2 eq) from freeze to 2030 achieved under the various scenarios and compared to the RED10 scenario (%)

Region	**Scenario**	**Consumption reduction until 2030 (Gt CO_2 eq)**	**Consumption reduction in comparison to the RED 10 scenario**
World			
	RED 10	22.9	100%
	RED	28.3	124%
	FSM	25.5	111%
	NA	24.1	105%
A2 countries			
	RED 10	8.1	100%
	RED	10.9	135%
	FSM	9.3	115%
	NA	7.5	92%
A5 countries			
	RED 10	14.8	100%
	RED	17.4	118%
	FSM	16.1	109%
	NA	16.7	112%

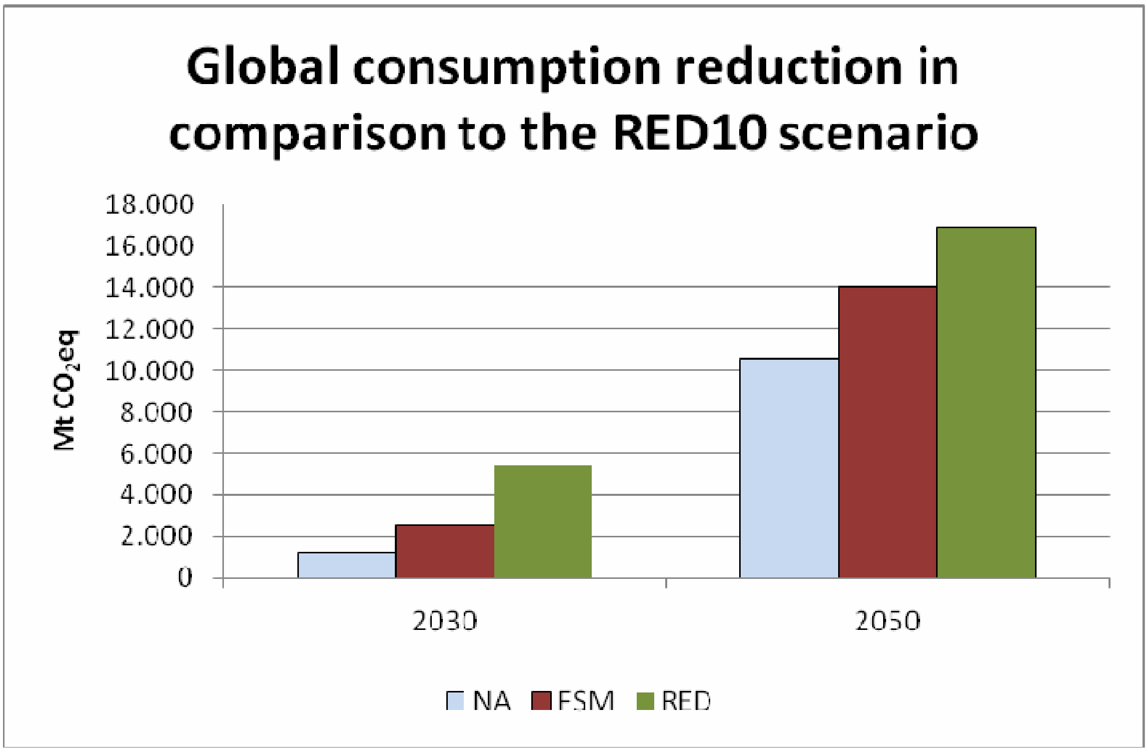

Figure 7-9: Comparison of lowest vs. highest scenario reductions (World)

8. Options for further EU action to reduce F-gas emissions

8.1 Options for the review of the F-gas Regulation

Technically feasible and effective policy options for further EU action should aim at a cost-effective contribution to the EU's emission reduction commitments, in particular the emission reductions agreed for the non-ETS sectors under Decision 406/2009/EC (Effort Sharing Decision)[300] for 2020 and longer-term emissions reductions as outlined in the Commission's "Roadmap for moving to a competitive low carbon economy in 2050" (COM(2011)112).

The identification of policy options for further EU action addressing emissions of fluorinated greenhouse gases is based on the projected impact of the current Regulation, takes into account emission sources not yet covered (chapter 5) and includes the options listed in Article 10 of the Regulation.

The initial starting point for identifying policy options is the WM scenario (chapter 5). This scenario is used as reference scenario.

Option A Business-as-usual (do nothing).

Option B reflects the development of F-gas emissions if current provisions would be suspended.

Option C takes non-regulatory approaches into account.

Option D describes further regulatory action and includes several sub-options addressing particular sectors, types of measures and/or types of F-gas emissions.

Option E includes market-based approaches such as activities under the EU-ETS, tax schemes as well as deposit-refund schemes.

Policy options for further action describe different ways forward and in most cases are mutually exclusive. Therefore, the underlying approaches vary significantly although certain sub-options might complement each other.

[300] OJ L 140, 5.6.2009, p. 136.

8.1.1 Option A: No policy change

This option represents the current situation and assumes full implementation and application of the provisions of the F-gas Regulation in all Member States and sectors.

The assessment of the emissions is illustrated by the WM scenario of the model AnaFgas (chapter 5). F-gas emissions are projected to remain at stable levels from 2015 onwards.

8.1.2 Option B: Discontinue existing provisions

Option B assumes that current provisions of the F-Gas Regulation are suspended. The development of emissions will gradually align with the scenario prior to the measures set out by the F-gas Regulation (WOM scenario in the model AnaFgas) except for the sector of mobile air conditioning of passenger cars which is covered by the MAC Directive and included in the WM scenario.

As outlined in chapter 4, existing provisions have not been fully implemented and applied in all Member States yet. Delay and problems of implementation vary between sectors and Member States.

It should be noted that general suspension of existing provisions would disadvantage Member States and industry compliant with current legislation. Such measure would also not be in line with the climate and energy package and the 2050 roadmap, that require contributions from all sectors to the EU emission reduction targets in 2020 and beyond until 2050.

This option would not be consistent with EU emission reduction targets since long-term emissions would grow.

Option B that the current provisions of the F-gas regulation would be suspended was discarded from further analysis because such approach would not be in line with the EU's climate and energy package and with the EU's overall objective that all relevant sectors should contribute to the mitigation of greenhouse gas emissions in the future.

8.1.3 Option C: Non-regulatory approaches at EU level

Some specific measures for the abatement of F-gas emissions could be implemented via voluntary agreements or via regulatory approaches. These are addressed under option C and option D respectively and an assessment of pros and cons for the respective option is provided.

Option C includes non-regulatory approaches which comprise voluntary agreements, open methods of coordination and the provision of information and guidelines.

Sub-option C-1: Environmental agreements and self-regulation

In chapter 3 on F-gas policies, the report describes in which areas voluntary agreements related to fluorinated gases already exist at international, European or Member State level. This section explores additional areas for voluntary agreements with industry.

Environmental agreements are a form of self-regulation as they are not binding at Community level. However, the Commission can encourage them, recognize them or propose that the legislature makes use of them (co-regulation). While self-regulation does not involve the adoption of a legislative instrument, the Commission can nevertheless decide to introduce a monitoring and evaluation system. Such environmental agreements can generally be recognized at Community level:

- by a recommendation from the Commission accompanied by adoption of the agreement or by an exchange of letters between the Commission and representatives of the sector, recognizing the agreement;
- by a recommendation from the Commission accompanied by a Council and European Parliament decision setting up a monitoring and reporting system.

Co-regulation concerns agreements concluded in the framework of a Community legislative instrument laying down the objectives to be achieved, the timetable to be met, monitoring methods and penalties to be imposed for non-compliance. Details for implementation are set out in the agreements. In general, it is the Commission that takes the initiative for such agreements.

According to the communication on environmental agreements at Community level[301], the criteria that should also be taken into account in the establishment and assessment of environmental agreements are the following:

- **Representativeness**: signatories to environmental agreements should represent the majority of the economic sector concerned and should be responsible and organised;
- **Quantified and staged objectives**: the objectives of the agreements must be clearly stated. If the agreement covers a long period, intermediate objectives must likewise be specified. There must be reliable indicators to measure the extent to which objectives have been achieved;

[301] European Commission 2002: Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions - Environmental Agreements at Community Level Within the Framework of the Action Plan on the Simplification and Improvement of the Regulatory Environment, COM(2002) 412 final of 17.7.2002.

- **Monitoring and reporting**: Environmental agreements should include a monitoring and reporting system for achieving the objectives;
- **Cost-effectiveness of administration**: Administrative costs should not be higher than those of other available instruments;
- **Involvement of civil society**: Agreements should be accessible to the public on the internet, and the same applies to the relevant reports and accounts. Interested parties should be able to express their opinions.

If the voluntary agreement does not produce the results envisaged, the Commission could still propose binding regulatory legislation; however emission reductions would then be considerably delayed. Past experiences with voluntary agreements at EU and Member States level have not always been successful, and for any new voluntary agreements it would be essential that staged targets are agreed and that an appropriate monitoring and reporting system is established that provides early signals whether the objectives of the agreement is met to allow for appropriate measures by the Commission in case of non-compliance with the agreement.

In the following section a number of new or enhanced voluntary agreements are considered as a way to achieve further F-gas emission reductions. For the assessment of the proposed specific options the criteria provided by the Commission's communication were used (with the exception of the involvement of civil society which would be an issue for the further implementation of such agreements). Voluntary agreements seem to be a promising option for sectors where few actors are involved as this would allow simple follow-up.

It is generally considered that particular applications of HFCs for which negative abatement costs have been estimated in the cost assessment (see annex V and VI), would be interesting options for voluntary agreements.

Option C-1 a: Voluntary agreements with industry to phase-out HFCs in commercial refrigeration

The Paris-based Consumer Goods Forum (CGF), which includes more than 400 of the world's largest consumer goods manufacturers and retailers[302], announced on 29 November 2010 at COP 16 in Cancún a commitment to start phasing out the use of HFCs in refrigeration equipment as of 2015. HFCs shall be replaced with non-HFC refrigerants (natural refrigerant alternatives) where these are legally allowed and available for new purchases of point-of-sale units and large refrigeration installations.[303] As part of this voluntary commitment the company Coca-Cola announced that its vending machines should be HFC-free by 2015.

The Forum also recognized that barriers exist to wide scale adoption of more climate-friendly refrigeration, namely legislative restrictions in some markets, availability, cost, safety, maintenance and servicing and committed to work to overcome those barriers by strengthening existing collaborative platforms and initiatives and to use its collective influence to encourage our supply base to develop natural refrigerant technologies that meet business demand under commercially viable conditions.

[302] The Consumer Goods Forum includes well-known brands such as Carrefour, Coca-Cola, Johnson & Johnson, Kellogg, Kraft, L'Oréal, Nestlé, Procter & Gamble, Tesco, Unilever, and Wal-Mart.
[303] The Consumer Goods Forum (2010): TCGF Board Resolution on Sustainable Refrigeration. Published at http://www.ciesnet.com/pfiles/publications/copenhagenpaper.pdf

This initiative could be used as a starting point for a more formal voluntary agreement with industry for the phase-out/phase-down of HFCs. The specific applications addressed are stand-alone hermetic refrigeration systems which use HFC-134a or R-404A, condensing units in small commercial refrigeration and centralized systems in supermarkets.

Representativeness

The Consumer Goods Forum as initiator comprises a large number of important international retailers and includes a majority of the sector concerned. It already took responsibility and announced a voluntary agreement at COP 16 in Cancún. The Consumer Goods Forum is a global, parity-based industry network, driven by its members. It brings together the CEOs and senior management of over 650 retailers, manufacturers, service providers and other stakeholders across 70 countries. The Forum provides a global platform for knowledge exchange and initiatives around five strategic priorities – Emerging Trends, Sustainability, Safety & Health, Operational Excellence and Knowledge Sharing & People Development. Thus the forum is representative and through the membership of CEOs and senior managers it includes the key responsibles that are able to implement adopted strategies in the companies.

Quantified and staged objectives

The objectives of the voluntary agreements stated in Cancún and available from the Consumer Goods Forum webpage are not clearly stated. This refers to the starting point, to a target year and to the quantification of the share of HFC refrigerants that should be replaced until the target year. Thus, the targets and the period needs to be further specified.

Monitoring and reporting

The proposed voluntary action by the Consumer Goods Forum does not mention any monitoring and reporting system for achieving the objectives. Such system would need to be established and would need to monitor and report

- the existing amount of HFC refrigerants covered by the participating companies;
- the replacement of HFC refrigerant by natural refrigerant alternatives;
- any effects of potential accompanying measures to reduce leakage from appliances with HFCs;
- recycling and re-use of HFCs.

The Forum could provide guidance and assistance to the individual companies related to collecting of data, the monitoring and reporting.

Potential emission reductions

The potential additional emission reduction that can be achieved with the phase-down of HFCs in centralized systems, commercial hermetic systems and condensing units is estimated at 18,818 kt CO_2 eq in 2030, thus the sector offers a rather high emission reduction potential.

Cost-effectiveness

Emission reduction costs for a phase-down of HFCs in closed stationary centralized systems, commercial hermetic systems and condensing units are rather low and vary from -0.8 €/t CO_2 eq for commercial hermetic systems to 23.7 €/t CO_2 eq for centralized systems.

Option C-1b: Voluntary agreement with refrigerated transport industries to phase down HFCs in transport refrigeration

A VA on phase down of HFCs in transport refrigeration equipment has been suggested by industry as in this sector only a relatively small number of manufacturers[304] place equipment on EU markets and could hence contribute to a phase down of HFCs in transport refrigeration. However, the operators of equipment ultimately decide for the type of equipment and would need to be involved to large extent in order to successfully establish such VA. The number of operators of transport refrigeration equipment in EU-27 is unclear and no large end-user association for this sector is known to be able to implement, monitor and control such VA. Therefore, this option for a VA is not followed further in this work.

Nevertheless, attempts of the transport refrigeration industry to address F-gas emissions from their sector on a voluntary basis could complement other action.

Option C-1c: Voluntary agreements with photovoltaics industry to replace NF_3

As explained in chapter 5, NF_3 was introduced to new production lines of silicon-based thin-film solar cells in Germany and Spain after 2004 where large-sized tool chambers, similar to those in LCD manufacture, are used for removal of silicon from tools after deposition. The quantity of NF_3 used by the solar industry is still very small with about 40 tons of NF_3 in 2008/ 2009. The photovoltaic plants that use NF_3 for CVD chamber cleaning have been equipped with exhaust gas abatement tools (thermal decomposition) from the very beginning.

The solar industry is very interested to keep a positive climate-friendly image, therefore it is considered possible that thin film silicon solar cell plants would be interested to replace NF_3 by e.g. elemental fluorine.

Thin silicon-film producers in Europe that would need to be included in a voluntary agreement are the producers Inventux, Sunfilm, Malibu, Masdar, Signet Solar, Inventux, Gadir Solar, and T-Solar (state 2010). The objective that needs to be agreed would be a replacement of NF_3. For replacement of SF_6 further companies should be addressed, e.g. Schott and Bosch. As few companies are involved, specific timelines would need to be agreed. Monitoring would be rather simple as few companies are concerned for which the phase out of NF_3 use would need to be monitored.

In this study, emissions for 2008/2009 are estimated at 10.3 kt CO_2 eq and are projected to increase to about 100 kt CO_2 eq. by 2030. According to suppliers of abatement equipment no additional costs would arise to operators.

Option C-1d: Voluntary agreement to replace HFC-134a in XPS foam

In chapter 6 it was explained that the replacement of HFC-134a by low GWP alternative blowing agent for XPS foams corresponds to abatement costs of as low as 1.0 €/t CO_2 eq[305]. Due to the low costs, this application seems to offer a potential to achieve a voluntary agreement with industry who at the same time can significantly improve the environmental image of their product.

[304] As outlined by the industry association Transfrigoroute, only two companies account for ca. 85% of the equipment placed on the market in EU, another 7-10 manufacturers contribute the remaining 15%.
[305] The industry association EXIBA disagrees with the estimated level of abatement costs.

XPS foam industry to be included in a voluntary agreement is represented at European level by the industry association EXIBA, which, however, does not represent all manufacturers. However EXIBA has expressed the view that “a voluntary agreement as proposed could not occur for the following reasons: i) Replacement of HFCs has already occurred for a majority of XPS products with CO_2 based blowing agents, ii) the technically feasible alternative using unsaturated HFCs is currently not possible since these substances are hardly available yet and not in large commercial quantities, iii) EXIBA might not represent all EU XPS manufacturers using HFC-134a.”

The objective that needs to be agreed would be a timeline for the replacement of HFC-134a by alternative blowing agents. As very few companies are involved, specific timelines could be agreed. Monitoring would need to monitor the point in time and quantities of HFC-134a that individual companies would replace by low GWP blowing agents.

Emissions reductions that can be achieved with the replacement of HFC-134a in XPS foams are estimated to be 1,553 kt CO_2 eq by 2030.

Option C-1e: Renewed voluntary agreement for reducing F-gas emissions in the semiconductor industry

As described in chapter 3, the semiconductor industry (including all the countries where production is located) had committed to a voluntary agreement to reduce F-gas emissions of HFC-23, PFCs, SF_6 and NF_3[306] by 10% until 2010 (baseline 1995). This target has been reached and a new voluntary agreement for the post-2010 period could be prepared and agreed with the semiconductor industry.

Global representativeness as for the first voluntary agreement should again be the objective. At EU level the representative organisation is the European Semiconductor Industry Association (EECA-ESIA). At global level, it is the World Semiconductor Council. A voluntary agreement should target NF_3, HFC-23, PFCs and SF_6 emissions from semiconductor industry just as the previous agreement[307]. The emission reduction potential of such agreement is not estimated in this work as plant-specific circumstances would need to be taken into account.

Option C-1f: Voluntary agreement for phasing out HFC-134a in domestic refrigeration

Domestic refrigeration has been identified as another sector with rather low mitigation costs of 1.0 €/t CO_2 eq by 2030 if HFC-134a would be completely phased out. However, the achievable emission reduction is only about 12 kt CO_2 eq until 2030 because remaining HFCs are already being phased-out in Europe, and will be of negligible size by 2030. The domestic refrigeration sector has in the past served as “lighthouse sector” for sustainability in the context of ODS phase out, but today only very few units containing F-gases are imported to Europe. Such voluntary agreement is thus excluded in the screening process for policy options (chapter 8.2).

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[306] In the semiconductor industry the term “PFC” means “perfluorocompounds”, not perfluorocarbons, and is used also for SF_6 and NF_3. In addition it includes HFC-23 although it is not fully but only partly fluorinated (containing hydrogen). In the IPCC GL the term “fluorinated compounds (FC)” is used.

[307] The World Semiconductor Council (WSC) stated on their 15th Meeting (May 26, 2011) in Fukuoka (Japan) to intend “a new voluntary agreement for the next 10 years”. It shall target at a reduction in Normalized Emission Rate (NER) in 2020 to 0.22 kgCO2e/cm^2, which is equivalent to a 30% NER reduction from 2010 aggregated baseline. It should be noted that such a reduction per cm^2 substrate is a relative reduction which does not necessarily imply reduction in absolute emissions.

Option C-1g: Voluntary agreement to replace HFC-23 in fire protection

In the EU, Spain is the main user of HFC-23 as fire extinguishing agent (with a very high GWP of 14,800) with more than 93% of the total European use (2008).[308] Six further Member States apply HFC-23 in comparably small quantities[309]. As described in chapter 6, the fluoroketone FK 5-1-12 is available as abatement option. Due to the limited regional use of HFC-23, a voluntary agreement to replace HFC-23 can be considered.

An objective of full replacement of HFC-23 until 2015 could be set. The emission reduction that can be achieved until 2030 is estimated at 961 kt CO_2 eq. The estimated mitigation costs are low with 3.1 €/t CO_2 eq in 2030. Yet, it should be noted that phase out of HFC-23 in fire protection is likely to result to large extent in replacement by HFC-227ea, which would limit the emission reduction potential, unless restrictions for the use of this substance also apply.

The total number of EU based original equipment manufacturers and fillers of fire suppression systems is rather high (estimated at 30), with 3 companies accounting for ca. 60% of the total market of all kind of fire protection systems (Tyco, UTC, and Minimax).

In Spain several local companies are also important suppliers of HFC-23 installations. In Central Europe an Austrian company sells such systems. However, there is no EU wide association which represents the majority of fillers, thus making an agreement difficult. The organization EUROFEU underlined an interest to work with the Commission in the development of a voluntary agreement concerning the use of HFC-23 in fire protection.

Option C-1h: Voluntary agreement for destruction of HFC-23 emissions from halocarbon production

F-gas emissions from sectors addressed by current measures of the F-gas Regulation do not include fugitive and by-product emissions in the halocarbon production (chapter 5). So far, one of the five operators of halocarbon plants which cause HFC-23 by-product emissions does not operate an abatement system for by-product emissions (chapter 5). Installation of such system is said to be "in preparation". The other four manufacturers have each installed abatement systems on a voluntary basis. Due to the limited regional scope, a voluntary agreement should be considered, in particular as the producers already announced its intention to install an abatement system.

The emission reduction that can be achieved until 2030 is estimated at 370 kt CO_2 eq. The estimated mitigation costs are low with 2 €/t CO_2 eq in 2030. Monitoring would be relatively easy as few Member States and companies are concerned. The industry association that could be involved in such agreement is EFCTC (association of fluorocarbon producers).

This option is particularly relevant for consistency with a potential international HFC agreement and would be in line with European climate policies which support HFC-23 destruction in developing countries through the CDM.

[308] The industry association ASSURE states that „the Spanish market for HFC-23 is more a reflection of the relatively low cost of the product in the country and historical preference for HFC-23 systems rather than a result of its specific technical properties".

[309] Amongst them, only Portugal, France and Austria used up to 5 metric t, each in 2008. Spain used 255 t. Data from AnaFgas.

Sub-option C-2: Improved co-ordination

Improve compliance with existing legislation

Low compliance with provisions of the F-gas Regulation has been identified for several sectors in different Member States (chapter 4). Although rules and penalties on infringements of the provisions have been established at national level, industry experts pointed out that lacking compliance was also due to the low level of control and enforcement by authorities. Authorities confirmed that inspections were rarely carried out and were mostly restricted to reported data.

This finding implies that encouraging co-operation between Member States on ways to improve compliance, the exchange of best practice in the implementation and agreement of additional guidelines for the enforcement authorities could be added value at Community level. Areas that should be specifically tackled by such measures of coordination are

- Additional guidance for environmental inspectors could contribute to raise awareness about the areas of use and the emissions of F-gases. Synergies with the ODS Regulation should be underlined in order to minimize administrative efforts and related costs.
- Exchange of best practices about mechanisms for a more efficient control by authorities.
- Exchange of best practices for leakage control.
- Integration of relevant certification systems under the Pressure Equipment Directive, the Energy Performance of Buildings Directive and the Renewable Energy Directive at Member State level in order to facilitate compliance with these requirements and to enhance cost-effectiveness of certification.

Industry has started an initiative for improved co-ordination by implementing the homepage www.figaroo.org, a webpage dedicated as a pan-European resource for users of HFCs, designed to share information and best practice, to make a success of the F-Gas Regulation. The UK set up the initiative REAL Zero 'Refrigerants emissions and leakage zero' (http://www.realzero.org.uk/) to help achieve significant reductions in carbon emissions due to refrigerant leakage from installed systems. REAL Zero is a project carried out by the Institute of Refrigeration, with the support of the Carbon Trust and the objective is building a better understanding of where and why leakage occurs and how to prevent it. The initiative offers training, additional practical guidance, toolkits, guidance notes and conducts case studies.

Improved co-ordination at EU level for the implementation and application of the F-gas Regulation could take up these initiatives and promote additional guidance and best practices across Member States. This could be implemented by conferences at EU level inviting Member States with related initiatives as well as business and industry that are involved in effective implementation initiatives.

For the implementation of the EU-ETS two 'ETS compliance conferences' have been held so far with the aim to improve compliance across Member State and to open a communication channel with the policy-making process at Member State level. The focus is on implementation of the ETS monitoring and verification provisions at regional and, possibly, local levels, and the facilitation of the participation of Competent Authorities in the exchange of experiences. The work of the compliance forum is supported by additional research projects in Member States on the status and ways of implementation of monitoring and verification under the ETS.

A similar approach could be implemented for the F-gas Regulation to address the important area of compliance with the existing regulation at Member State level and further promote the best practice examples and initiatives from Member States and businesses.

Calculations of F-gas emissions in the WM scenario of this study are based on the assumption that the F-gas Regulation is fully applied. This sub-option summarizes ideas to improve compliance with existing legislation but will not lead to additional emission reductions beyond the level of the WM scenario. It is thus not analyzed further in the course of this chapter.

Sub-option C-3: Enhanced technical standards

Article 10(2d) requires an assessment of the need for Community standards relating to the control of emissions of F-gases from products and equipment, in particular as regards foam, including technical requirements with respect to the design of products and equipment.

A standard is a technical document designed to be used as a rule, guideline or definition, and standardization is the voluntary process of developing technical specifications based on consensus among all interested parties (industry including Small and Medium-sized Enterprises, consumers, trade unions, NGOs, authorities, etc).[310]

The standardization process is carried out by independent standards bodies, acting at national, European and international level. The three European Standardization Organizations (ESOs) include CEN – Committee for European Standardization (Comité Européen de Normalisation, Europäisches Komitee für Normung), CENELEC – European Committee for Electrotechnical Standardization, and ETSI – European Telecommunications Standards Institute. They are recognized as competent in the area of voluntary technical standardization and listed in Annex I of European Directive 98/34/EC.

The CEN is the relevant standards body for the most relevant equipment containing F-gases. All CEN activities are undertaken by a group of stakeholders, manufacturers, users, research organizations, government departments and consumers.

Standardization supports market-based competition, so as to achieve objectives such as the interoperability of complementary products and services, or to provide agreed test methods and requirements for health, safety, organizational and environmental performance. Through the development of European standards and the withdrawal of conflicting national standards, standardization has played a leading role in the achievement of a Single Market for goods.

Most standards are prepared at the request of industry. The European Commission can also request the relevant standards bodies to prepare standards in order to implement European legislation. This type of standardization activity is 'mandated' by the European Commission. In most cases, such initiatives are supported by the EFTA Secretariat. Draft mandates are drawn up by the Commission services through a process of consultation with a wide group of

[310] European Commission: European standardization policy, 2010; http://ec.europa.eu/enterprise/policies/european-standards/standardisation-policy/index_en.htm

stakeholders. Before being formally addressed to the ESOs, they are submitted for opinion to the Member States in the Standing Committee of the 98/34/EC Directive.

The ESOs, which are independent organisations, have the right to refuse a mandate if they do not think that standards can be produced in the area being covered. In practice this refusal happens rarely due to the informal consultation mentioned above.

Three types of mandates could be considered:

- study mandates to check the feasibility of standardization;
- mandates requesting the elaboration of a standardization programme;
- mandates for the development and adoption of European standards (reference Art 10).

The target of ESOs is to develop standards in 3 to 4 years depending on the complexity of the issue and the consensus building between various stakeholders. If standards are developed based on mandates given by the European Commission, the time needed to draft a mandate and the time given to the standardization organisations for response need to be added. The drafting will take ca. 6-18 months and response from standardization bodies is usually given within 6 months.[311]

European Standards are a key component of the Single European Market and are highly important for manufacturers inside and outside Europe as they increase product safety and quality and lower transaction costs and prices. A standard codifies best practice and is usually state of the art relating to products, services or systems. A European Standard automatically becomes a national standard in all Member States, but remains voluntary to use.

Existing standards and reductions of F-gas emissions: Products and equipment relying on F-gases are addressed by various international, European and national standards, which set out specifications, performance requirements, and safety measures (see chapter 3 on existing standards).

Standards can support reductions of F-gas emissions by transferring best practices to markets and thereby replacing previous technologies and methods. Regulatory mechanisms often refer to existing standards, which anticipated legislation, e.g. Article 3(5) of the F-Gas Regulation refers to the ISO 14520 standard.

In the context of the overall policy target of GHG emission reductions, it should be noted that

- standards are voluntary to use. Monitoring of technical parameters, reporting to databases/institutions and evaluation is not included;
- the impacts of standards on emission reductions within a particular time frame are almost impossible to quantify as they depend on market uptake of standardized products and equipment or on the number of personnel and companies applying the standards.

Standards cannot be considered as an effective tool to achieve significant emission reductions within a particular time but are likely to contribute to long-term emission reductions through the consensus-based introduction of best practices.

[311] Written communication from Aare Viljanen, European Commission, DG Enterprise and industry, Standardisation; 28.10.2010.

As standards contain technical specifications for products and equipment, F-gas emissions from various sectors cannot be covered under one standard only, but would have to be controlled through standards specific to each application. Therefore, covering large shares of F-gas emissions would require several standardization procedures to get started.

Since the effects of such voluntary measures on F-gas emissions cannot be determined in the short and medium term, this option is not considered further in the screening of options. Nevertheless, industry should be encouraged to continue the exchange of best practices in the various sectors.

8.1.4 Option D: Regulatory approaches

Sub-option D-1: Include F-gases currently not included in Annex I of the F-gas Regulation

Article 10(2)b of the F-gas Regulation requires the Commission to publish a report which shall, in the light of future assessment reports of the IPCC, assess whether additional fluorinated greenhouse gases should be added to Annex I. This annex lists 17 HFC substances, 7 PFC substances and with their GWP values as presented in the 3rd IPCC assessment report from 2001.

Certain fluorinated greenhouse gases currently not addressed by the F-gas Regulation including NF_3, SO_2F_2 (sulfuryl fluoride) and unsaturated HFCs have been screened for their quantitative significance to the EU F-gas inventory (chapter 5).

As for NF_3, it is suggested to include this substance in reporting provisions as well as those PFCs and HFCs for which a GWP was listed in the IPCC's 4th Assessment Report and which have not been included in the reporting guidelines (HFC-152, HFC-161, c-C_3F_6 and PFC 9-1-18).

Based on the findings on SO_2F_2 stated in chapter 5.3, no additional benefit would result from including this gas in Annex I of the F-gas Regulation.

In case an international HFC agreement will include unsaturated HFCs, it will be necessary to establish monitoring and reporting requirements for these substances. However, in the absence of such agreement, unsaturated HFCs should not be included in the scope of the F-gas Regulation as their projected emissions are very low. Other abatement options with similar emissions will not be reported either.

Sub-option D-2: Enhance application and monitoring of the Regulation

Sub-option D-2a: Enhance labelling requirements

Labelling requirements currently apply to refrigeration products and equipment containing PFCs, refrigeration and AC products and equipment (other than those contained in motor vehicles), heat pumps, fire protection systems and fire extinguishers, if they contain HFCs or preparations containing HFCs, switchgear containing SF_6 or preparations containing SF_6, and all F-gas containers. The label must include the chemical name of the F-gas contained by using the accepted industry nomenclature and the quantity of F-gas.

Provisions on labelling allow responsible installation, servicing, maintenance, and end-of-life treatment of equipment and products containing F-gases. Therefore, labelling requirements could help to communicate relevant information on types and quantities of F-gases contained in products and equipment currently not covered by relevant provisions and raise awareness of operators of equipment and users of products.

With regard to end-of life, F-gas banks contained in foams seem to be particularly important to be treated properly particularly in the future due to their long lifetime. High disposal emissions could be avoided by providing information on the F-gas banked in particular foam products.

It is estimated that labelling requirements could be extended through the review of the F-gas Regulation to all types of foams containing F-gases[312] and all mobile AC equipment containing F-gases. Based on information on labelling costs of products and equipment already covered by provisions, costs for extended labelling requirements are assumed to be rather low. Yet, the emission reduction potential of this option can hardly be determined.

This option should be considered rather an additional step for improved management of F-gas banks than a measure resulting in significant emission reductions on its own.

Sub-option D-2b: Improve definitions and clarify provisions under the F-gas Regulation

Certain needs for clarification of provisions in the F-gas Regulation have been identified by experts and stakeholders in the course of the project. In particular, it was suggested to streamline definitions and provisions with other European legislation, e.g. the ODS Regulation (EC) No 1005/2009. Usually the same operators of equipment, service companies, industry associations and authorities deal with both ODS and F-gases.

Examples for terms and definitions, which could benefit from further clarification, include:

- "as soon as possible repair detected leakage"

The time period for repair of leakage could be specified. Article 3(1b) could be revised e.g. according to the wording of the ODS Regulation and then read "as soon as possible repair detected leakage and in any event within 14 days".

- "operator"

The term "operator" is defined as follows (Article 2(6)): "*the natural or legal person exercising actual power over the technical functioning of the equipment and systems covered by this Regulation: a Member State may, in defined, specific situations, designate the owner as being responsible for the operator's obligations*". This definition is interpreted differently in national legislation in the Member States, e.g. in France it always refers to the owner of equipment.

Article 2(6) clarifies that ownership is not a decisive criterion to be used to identify the operator. However, it suggests that Member States may designate the owner as being responsible for the operator's obligations even though the owner does not have actual power over the technical functioning of the system or equipment.

Guidance of the European Commission underlines that Member States who want to refer to that clause should make sure that legislative, regulatory or administrative provisions clearly identify the defined and specific situations in which the owner is responsible for the operator's obligations. It might hence be useful to clarify the definition in this respect.

- "hermetically sealed system"

The term "hermetically sealed system" is defined as follows (Article 2(11)): *"a system in which all refrigerant containing parts are made tight by welding, brazing or a similar*

[312] The industry association EXIBA stated concerns with regard to the long product life of insulation foams of several decades and that no marking or labelling would last sufficiently long. – Further input to this matter is expected from a study on behalf of the EU Commission assessing policy options for the management of ODS and F-gas banks in the EU with a particular focus on foams.

permanent connection which may include capped valves and capped service ports that allow proper repair or disposal and which have a tested leakage rate of less than 3 grams per year under a pressure of at least a quarter of the maximum allowable pressure".

This definition seems to have created confusion among stakeholders concerning the scope of the provisions of the F-gas Regulation. It could be revised and changed to e.g. "factory sealed systems".

- "preparation"

Preparations are defined (Art 2(5)) "*for the purposes of the obligations in this Regulations, excluding destruction, a mixture composed of two or more substances at least one of which is a fluorinated greenhouse gas, except where the total global warming potential is less than 150. The total global warming potential of the preparation shall be determined in accordance with Part 2 of Annex I*".

It should be noted that certain F-gases are in the scope of the provisions if used as pure substances (e.g. HFC-152a which has a GWP of 120; HFC-41 which has a GWP of 97) but out of the scope if contained in a blend with GWP <150. This seems to counteract the objective of the Regulation which is to contain, prevent and thereby reduce F-gas emissions[313].

- Containment and recovery provisions

Article 3 of the F-gas Regulation sets out provisions on HFC containment and applies to stationary refrigeration, air conditioning and heat pump equipment and fire protection systems but excludes mobile applications such as transport refrigeration and mobile AC (which is partly covered by the MAC Directive). Article 3(1) requires operators to use "all measures which are technically feasible and do not entail disproportionate cost" to carry out containment measures.

Article 4 of the F-gas Regulation states provisions on recovery. Article 4(1) covers stationary equipment and requires operators to put "in place arrangements for the proper recovery [of HFCs] … to ensure their recycling, reclamation, and destruction." This means that HFCs banked in stationary equipment are subject to mandatory recovery for recycling, reclamation and destruction. Provisions for mobile equipment, in contrast, are less stringent and apply "to the extent that it is technically feasible and does not entail disproportionate costs… to ensure their recycling, reclamation, and destruction" (Article 4(3)).

Both containment and recovery provisions remain unclear about technically feasible measures and the actual cost thresholds for these measures, which creates uncertainty among operators of equipment. In order to provide further guidance, sector specific requirements for cost-effective containment and recovery may be laid down.

- Certification and liability

According to Article 5(3), operators are required to ensure that personnel are holding the necessary certifications and are hence liable to check the certification status. However, personnel and companies involved in installation, maintenance or servicing of the equipment and systems covered by Article 3(1) as well as for the personnel involved in the activities

[313] In contrast, the industry association FEA states that this definition has fostered innovation for F-gases and products reducing F-gas emissions significantly.

provided for in Articles 3 and 4 are not liable at all. Therefore, penalties apply only to operators of equipment and not to non-certified personnel and companies which may undertake the relevant activities.

Further improvement of the provisions should take this aspect into account and consider assigning liability also to personnel and companies subject to certification provisions.

- Streamlining with other pieces of EU legislation

Terms and definitions set out by ongoing reviews of other pieces of European legislation should be checked for complementarities/overlaps in order to further streamline EU legislation and avoid confusion. This would apply, for example, to the requirements for certification of personnel set out by the Pressure Equipment Directive, the Energy Performance of Buildings Directive, the Renewable Energy Directive and the F-gas Regulation. Potentials for the combination of trainings and/or certificates could be explored.

The emission reduction potential of this option cannot be calculated and the costs for improving definitions and providing further guidance are estimated to be rather low. This option should be considered rather an additional step for improvement of the existing legislation and its application than a measure resulting in significant emission reductions on its own.

Sub-option D-2c: Improve reporting system for fluorinated gases

Article 10(2)(f) requires the Commission to consider the modification of the reporting requirements in Article 6(1), in particular the one tonne quantitative limit, and for the competent authorities to report periodically to the Commission estimated emissions based on representative samples to improve the practical application of those reporting requirements.

Current reporting provisions require producers, importers and exporters of F-gas quantities of >1 tonne per year to communicate the following information to the European Commission:

- Total production of each F-gas;
- Total imported quantities of each F-gas in the Community;
- Total exported quantities of each F-gas from the Community;
- Total quantity of each F-gas placed on EU market and their intended applications;
- Any quantities of each F-gas recycled, reclaimed or destroyed, imported or exported for recycling, reclamation or for destruction.

The format for reporting by producers, importers and exporters of F-gases is set out by Commission Regulation (EC) No 1493/2007.

Quantities of F-gases contained in imported or exported pre-charged equipment are presently not subject to reporting provisions.

Several sub-options for enhancing the reporting obligations are to be considered:

- **Extending the company reporting requirements to quantities contained in imported or exported pre-charged products and equipment**

Within an analysis of existing F-gas policies, data on quantities of F-gases contained in pre-charged equipment and currently not covered by reporting requirements have been collected (cf. chapter 4.2.7). Pre-charged equipment in large numbers is imported to or exported from EU-27 in several sectors including

- Mobile air conditioning (import and export of motor vehicles)
- Stationary air conditioning (import of factory-made devices)
- One component foam (export of cans)
- High-voltage switchgear (export of systems containing SF_6)
- Metered Dose Inhalers (export of aerosol cans).

Imported and exported quantities of F-gases contained in pre-charged equipment have been estimated (table 4-25).

As outlined in chapter 4.2.7, exports of F-gas contained in pre-charged equipment amounted in 2008 to ca. 8,000 tonnes and imports of F-gas contained in pre-charged equipment are about 8,700 tonnes. Imported quantities of F-gases contained in pre-charged equipment represent almost 13% of the total import of bulk F-gases covered under reporting obligations. Export of F-gases contained in pre-charged equipment represents ca. 42% of the exported quantities reported under Article 6(1).

While imports and exports of quantities contained in pre-charged equipment balance each other almost out in absolute quantities, when taking into account the composition of imported and exported quantities by individual F-gas types, an additional layer of information becomes evident: Due to the high GWP of SF_6, the emission potential from F-gases contained in exported pre-charged equipment is higher than the emission potential of imported equipment. For the future, however, F-gases in imported pre-filled air conditioning systems will significantly grow in quantities[314].

Reported data on F-gas quantities produced, imported and exported according to Article 6 currently do not allow calculation of banks. Hence future potential emission might be underestimated and could lead to decisions based on incomplete information.

If F-gas quantities contained in imported and exported pre-charged equipment would be included in reporting obligations, a more detailed overview of F-gas banks could be possible.

- **Review of the one-tonne threshold**

The reporting obligation under Art 6(1) covers only entities which produce and/or import and/or export more than one metric tonne per year of F-gases or preparations containing F-gases. This one tonne limit hardly distorts the total data outcome as discussed in chapter 4.2.7.

- **Introducing reporting obligations for reclamation and destruction of F-gases by specialized facilities**

Under Art 6, producers, importers and exporters are required to report quantities of F-gases recycled, reclaimed or destroyed. However, data on the actual extent of destruction of recovered F-gases in the Member States are available to very limited extent only since the largest share of destruction is undertaken by entities which do not produce or import or export, at specialised destruction facilities.

[314] For conceptual clarification of F-gases in imported and exported pre-filled equipment see 2.2.4.

Reporting obligations for F-gases could be extended to F-gas quantities destroyed by destruction facilities and reclaimed by specialized entities in destruction or reclamation facilities in order to complete the data on F-gas banks and stocks in EU-27. In some Member States, reclaimed and destroyed quantities of F-gases are already subject to reporting and monitoring (cf. chapter 4.2.6) and help to control these waste streams.

Reporting obligations for destruction facilities would be in line with provisions of the ODS Regulation (EC) No 1005/2009 (Art 27(5)). Since usually the same facilities are dealing with both ODS and F-gases it is assumed that established reporting schemes within destruction companies could be used at low additional cost. Costs for reporting by reclamation facilities will be higher since they are presently not subject to reporting provisions.

- **Specifying further the reporting systems which Member States need to establish under Art 6(4) with a view to evaluate long-term trend in leakage rates from certain applications**

Article 6(4) requires Member States to establish reporting systems for the relevant sectors with the objective of acquiring, to the extent possible, emission data. This provision remained unclear for some experts from authorities and industry, while others elaborated and established reporting systems allowing calculation of emissions in certain Member States.

Within the assessment of the status of implementation and application of the F-gas Regulation (chapter 4.2.7), it has been considered that the provisions do not require the set-up of new monitoring and reporting systems in addition to existing national systems for CRF reporting under the UNFCCC. Additional systems or tools were considered useful only if they allow verification of emission trends and emission factors over time.

Examples for such systems are being planned or set-up in Hungary, Bulgaria, Lithuania, Estonia and Poland. Key component of these systems is a central database of all stationary refrigeration and air conditioning equipment with charges >3 kg. In this way, it is possible to determine the refrigerant bank in the country. Reporting obligations arise for operators of equipment, service companies, as well as reclamation and destruction facilities. It should be underlined that the establishment of such equipment inventories is rather costly and requires certain administrative efforts and time. As outlined, today only one Member State uses at least partially such a system for estimation of emissions (Hungary).

In order to evaluate long-term trends of emission rates, in particular leakage rates of certain applications, another approach could provide useful information: The underlying assumption is that complete inventories of equipment and F-gas banks require comparably high effort to be established and maintained.

At present, it can be assumed that data on banks and emissions exist at the level of individual installations only as recording provisions apply. The records (logbooks), in particular if kept electronically, could hence be used as basis for emission monitoring and calculation of emission factors. Instead of assessing the records of the entire equipment stock in a particular Member State, monitoring of banks and emissions could be based on a statistical sample survey over several years based on records of a certain number of selected installations. In this way, a reliable overview of the quantitative development of F-gas emissions and emission rates in the most important applications could be gained.

It is estimated that such approach of a monitoring system based on statistical sample surveys would also fulfil the requirements of Article 6(4) at lower cost than the establishment and maintenance of a full equipment inventory in most cases.

Article 6(4) could benefit from further specifications of such reporting systems which also take into account current experiences and knowledge gained in the countries where such databases have been developed. However, new and creative approaches should be possible, too.

- **Including additional gases in reporting provisions in the light of new gases being included in Annex I of the Regulation**

If additional gases are included in Annex I of the Regulation (see sub-option D-1), reporting requirements will need to be adjusted in order to take into account such change and to complement current provisions.

HFCs (such as HFC-161 and HFC-152) and PFCs (PFC 9-1-18, c-C_3F_6) listed in the 4th IPCC AR, although not commonly used today, should be considered for inclusion in Annex I.

SO_2F_2 (sulfuryl fluoride) was found to be covered by extensive monitoring and reporting requirements already.

The use of HFC-1234yf and other unsaturated HFCs is presently not required to be reported since unsaturated HFCs are not listed in Annex I of the F-gas Regulation. It should be noted that GWP values for these substances have been published in peer reviewed scientific publications but were not included in any IPCC report yet (chapter 5). Unsaturated HFCs are being commercialized on a mass-produced basis, are likely to be used in mobile air conditioning systems of passenger cars this year (2011) and in other applications in the near future. As outlined in option D-1, in case an international HFC agreement will include unsaturated HFCs, monitoring and reporting of these substances will be required. However, as long as no such agreement exists, reporting of unsaturated HFCs is not suggested as projected emissions are rather low.

The inclusion of NF_3 in the reporting under the F gas regulation would also ensure a coherent approach across different legal instruments in the EU. As part of the proposal for the revision of Decision No 280/2004/EC concerning a mechanism for monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol on the monitoring (Monitoring Mechanism Decision)[315], the Commission considers including NF_3 in Member States reporting requirements for national greenhouse gas inventories.

The EU also proposed to include a mandatory reporting requirement for NF_3 and additional fluorinated gases for which the IPCC proposed GWPs in its 4th Assessment Report in the revision of the reporting guidelines for Annex I GHG inventories under the UNFCCC.[316]

It will be possible to integrate additional reporting requirements into existing national and European data collection and reporting schemes at comparably low cost in most cases. Whether additional undertakings would be subject to reporting obligations will depend on the decision which additional gases to include in Annex I.

[315] OJ L 49, 19.2.2004, p. 1.

[316] UNFCCC 2010: Views on the revision of the UNFCCC Annex I reporting guidelines – submissions from Parties. FCCC/SBSTA/2010/MISC.7.

- **Update GWPs according to the latest Assessment Report by the IPCC**

Article 10(2)(k) requires the Commission to consider the amendment of the global warming potential of fluorinated greenhouse gases, taking into account technological and scientific developments and the need to respect industrial product planning schedules.

The development of emissions in the scenario with measures in the period 1995-2050 have been recalculated by using different global warming potentials as listed by three IPCC Assessment Reports for each substance emitted (figure 8-1).

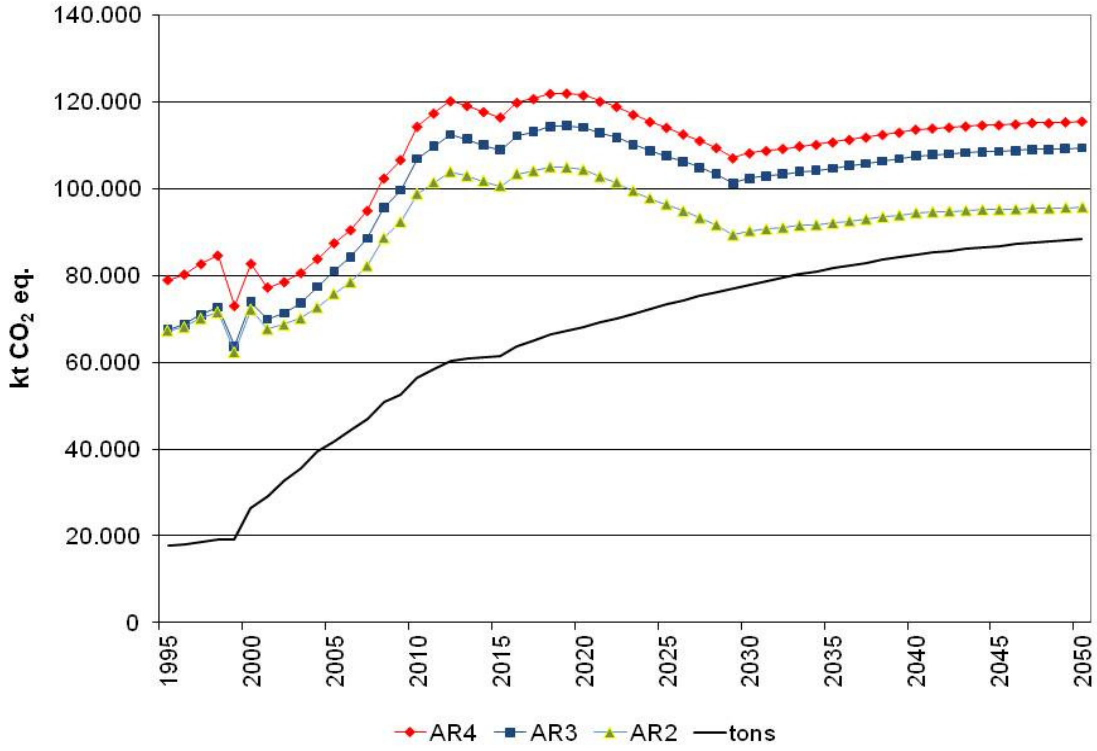

Figure 8-1: Development of emissions in the WM scenario in 1995-2020 based on the same tonnage of F-gas emissions (black line) but calculated by using different values for the global warming potential according to the 2nd, 3rd and 4th IPCC Assessment Reports for each F-gas emitted. The F-gas Regulation refers to the values of the 3rd Assessment Report, while reporting under the UNFCCC and the Kyoto Protocol is currently based on values from the 2nd Assessment Report.

F-gas emissions are ca. 10% higher when calculated by referring to the values for global warming potentials from the latest IPCC Assessment Report (4th AR, 2007, top curve) than according to the current way of calculating by using values from the 3rd AR (2001, middle curve).

An overview of changes of GWP values for common F-gases is provided in table 8-1. The global warming potentials of almost all types of F-gases have been increased in the 4th Assessment Report.

Table 8-1: Global warming potentials (GWP100) of common types of F-gases according to the 3rd and 4th IPCC Assessment Reports

Fluorinated greenhouse gas	GWP100 from 3rd AR	GWP100 from 4th AR
HFC-23	12,000	14,800
HFC-32	550	675
HFC-43-10-mee	1,500	1,640
HFC-125	3,400	3,500
HFC-134a	1,300	1,430
HFC-152a	120	124
HFC-143a	4,300	4,470
HFC-227ea	3,500	3,220
HFC-236fa	9,400	9,810
HFC-245fa	950	1,030
HFC-365mfc	890	794
PFC-14 (CF_4)	5,700	7,390
PFC-116 (C_2F_6)	11,900	12,200
PFC-218 (C_3F_8)	8,600	8,830
PFC-3-1-10 (C_4F_{10})	8,600	8,860
PFC-4-1-12 (C_5F_{12})	8,900	9,160
PFC-5-1-14 (C_6F_{14})	9,000	9,300
PFC-318 (c-C_4F_8)	10,000	10,300
SF_6	22,200	22,800

The changes of global warming potentials are based on recent scientific findings on the contribution of each substance to atmospheric global warming, compared to CO_2.

Certain impacts of this option are to be noted:

Blends with GWP just below 150 are currently being used for use in PU canned foams and novelty aerosols. By updating the GWP values referred to in the F-gas Regulation, these preparations could exceed the GWP 150 threshold and therefore fall within the scope of the relevant prohibition.

Decision 2007/742/EC for the award of eco label to heat pumps relies on the GWP values used in the F-gas Regulation through a reference. It also foresees that the refrigerant contained in heat pumps should have a GWP <2,000 which allows the use of R-410A which was considered energy efficient. By updating the GWP values of the F-gas Regulation, R-410A would have a GWP of 2,082. Consequently, heat pumps running on R-410A would not be eligible for the eco label any more. If appropriate, eco label criteria could be revised based on the TEWI principle and in line with ecodesign criteria.

Sub-option D-3: Improve containment and recovery in certain sectors

Existing containment measures such as regular leakage control by certified personnel, maintenance of records and installation of leakage detection systems apply to stationary refrigeration, air conditioning and heat pump equipment and fire protection systems (table 8-2). Sectors subject to these provisions include commercial refrigeration, industrial refrigeration, stationary air conditioning, heat pumps and fire protection.

Table 8-2: Overview of requirements for regular leakage control

Frequency of leak checks of stat. equipment and systems	System charge Normal	System charge Hermetically sealed
None	<3 kg	<6 kg
Annually	3 kg – 30 kg; 30 kg – 300 kg if automatic leak detection system in place	6 kg – 30 kg; 30 kg – 300 kg if automatic leak detection system in place
6 monthly	30 kg – 300 kg; >300 kg if automatic leak detection system in place	30 kg – 300 kg; >300 kg if automatic leak detection system in place
3 monthly	>300 kg	>300 kg

Equipment containing charges <3 kg of F-gases are exempt from these measures under existing provisions. With regard to the sectors identified to cause high F-gas emissions in future decades according to the model AnaFgas, this charge-based exemption is de-facto relevant for room air conditioning equipment (average charge of movables: 0.75 kg; average charge of single split systems: 1.5 kg), for domestic heat pumps (average charge: 2.6 kg), and for a large number of commercial condensing units.

With regard to recovery, the scope of current provisions does not refer to minimum charges and the requirements apply generally for stationary equipment listed in Article 4(1) as well as products and equipment, including mobile equipment unless it is serving military operations, to the extent that is technically feasible and does not entail disproportionate cost (Article 4(3)).

Certain sectors are also covered by recovery provisions set out by other pieces of European legislation (table 8-3).

Table 8-3: Overview of EU legislation with regard to RRRD for sectors relying on F-gases

Legislative act	Sectors/applications covered by provisions on RRRD
WEEE Directive	Treatment before disposal of - waste household appliances and small commercial refrigeration equipment containing ODS or gases with a GWP >15; - separate collection and treatment of ODS in accordance with Regulation 1005/2009; - refrigerants and foam contained in appliances.
ELV Directive	Before further treatment of end-of life vehicles, removal of - CFCs and HFCs contained in air conditioning systems.
Waste Directive 2008/98/EC	Recovered F-gases are considered hazardous waste, which is addressed by certain waste management measures. Collection, transportation, treatment and disposal must be carried out in a way that protects human health and the environment. Hazardous waste must not be mixed with other wastes. At least 70% of construction and demolition waste (by weight) will be recovered by 2020. - Implications for construction foams containing ODS and HFCs.

As pointed out earlier (chapter 2; chapter 4.2.6), data on recovered quantities of F-gases and their mass flow are also rare: Quantities recovered on-site and used for recycling are not registered in any statistics but should be recorded in the logbooks specific to each system. Little statistical information is available on F-gas quantities reclaimed or destroyed as reporting provisions do not apply to specialized reclamation and destruction facilities that would be able to provide this kind of information.

Little evidence for any current effectiveness of containment and recovery measures since 2006 has been found and quantitative data are widely lacking (chapter 4.2.6). Furthermore, the wording of both containment and recovery provisions remains vague about measures considered "technically feasible and do not entail disproportionate cost" and should be supported by additional guidance on these aspects.

Therefore, several sub-options to improve containment and recovery have been identified:

D-3.a) Extending the scope of Articles 3 and/or 4 to transport modes;

D-3.b) Lowering the applicable F-Gas charge threshold of certain equipment already covered by Article 3;

D-3.c) Extending the training and certification requirements to personnel undertaking activities not currently covered by Article 5;

D-3.d) Introducing maximum leakage rates in certain applications;

D-3.e) Introducing obligation for producers and suppliers of F-gases to take back recovered F-gases for reclamation and destruction.

a) Extending the scope of Articles 3 and/or 4 to transport modes

Article 10(1) requires the Commission to consider the extension of the provisions of Article 3 to air conditioning systems, other than those fitted to motor vehicles referred to in Directive 70/156/EEC, and refrigeration systems contained in modes of transport.

A recent study[317] investigated whether the provisions of Article 3 and/or Article 4(1) of the F-gas Regulation should be extended to the following sectors:

- Refrigerated road transport: vans (<3.5 t), trucks (>3.5 t), trailers (classification according to Directive 70/156/EEC);
- Rail transport: trains (railway vehicles, metro, trams);
- Maritime and inland waterway transport: sea-going merchant ships, ships for refrigerated cargo, fishing vessels, inland navigation vessels.

In a business as usual scenario, emissions of F-gases from these sectors in 2020 were estimated. Emission reduction potentials and costs of the measures of Art 3 and 4 were calculated and compared for each sector.

Calculations based on data of the model AnaFgas were undertaken in order to reconsider the assessment of the 2008 study for the European Commission.

The sector specific costs for containment and recovery measures according to Articles 3 and 4(1) were taken from the service cost table in annex II and were used for a detailed

[317] BIPRO 2008: Study on the potential application of Art 3 and 4(1) of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases to air conditioning and refrigeration systems contained in different transport modes. Final report, prepared for the European Commission, DG Environment.

comparative analysis of sector-typical systems not subject to measures (reference) and the same systems in the sub sectors concerned when the measures of Articles 3 and 4(1) are applied[318]. In the sub sector of refrigerated vans (av. charge 1.5 kg), only the application of Art 4(1) is considered. The calculations are shown in sector sheets 7-9, and 17-19 (in annex V). Based on these datasets, potential emission reductions and abatement costs for these sectors currently not covered by certain containment provisions were calculated. The classification of sub sectors is more detailed in AnaFgas which distinguishes the road vehicles into vans and trucks & trailers[319], but the following table 8-4 groups the sub sectors into the structure applied in the BIPRO assessment in order to facilitate reading.

Inland waterway vessels are not considered because emissions are negligible.

Table 8-4: Emissions from the relevant sectors in the WM scenario (identical with WOM scenario), emission reduction potentials of the application of Articles 3 and 4(1) to these sectors (kt CO_2 eq) (option D-3a) and abatement costs (€/t CO_2 eq) in 2030

Sector	Sub sector	WM Emissions 2030 (kt CO_2 eq)	Option D-3a Reduction potential (kt CO_2 eq)	Marginal Abatement costs (€/t CO_2 eq)	*Marginal Abatement costs according to BIPRO study* (€/t CO_2 eq)
Refrigerated road transport	Vans	421	11	291	*119*
	Trucks and trailers	3,646	1,430	46	
Rail transport		122	16	340	*1,413*
Maritime transport	Cargo ship AC	684	273	10.5	*22*
	Passenger ship AC	1,015	405	8.5	
	Fishing vessel refrigeration	906	360	0.5	
Total		**6,795**	**2,494**	**-**	**-**

GWP values of IPCC 4th AR. Option D-3a includes the first time application of Articles 3+4(1) to sectors for which the F-gas Regulation (WM) does not apply yet. In the sub sector of refrigerated vans (av. charge 1.5 kg), only application of Art 4(1) is assumed (not Art 3).

Estimated annual emissions, emission reductions and cost data differ from the 2008 calculations of the BIPRO assessment[320], but are of the same order of magnitude and confirm in principle the BIPRO findings:

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[318] It should be mentioned that the cost of Art 3 include only those leakage checks that are carried out in addition to the state without F-gas Regulation. The estimated percentage of existing leak checking compared to requirements by Article 3 is listed in the cost table in annex II.

[319] Assumptions in AnaFgas on average charges of refrigerated vans are 1.5 kg and 6.5 kg of refrigerated trucks and trailers.

[320] This is due to several methodological aspects:

- The annual containment & recovery costs are lower in AnaFgas.
- BIPRO does not distinguish refrigerated road vehicles into vans and trucks &trailers.
- In emission calculations, the GWP values according to IPCC 4th AR were applied.
- Calculations of emissions and emission reduction potentials refer to the year 2030.
- In the WOM scenario certain parameters such as charges and leakage rates remain unchanged while BIPRO assume gradual decrease of charges and leakage rates.

- Marginal abatement costs for containment and recovery measures in the maritime transport sector (AC systems in cargo ships and passenger ships, refrigeration systems in fishing vessels) are comparably low.
- Marginal abatement costs for containment and recovery measures in the rail sector are comparably high.
- Marginal abatement costs for refrigerated road transport vary depending on the charge size of the system. In the sub sector of refrigerated trucks & trailers the cost per t CO_2 eq are €46. In the sub sector of refrigerated vans, where Art 3 does not apply (charge <3 kg) the application of Article 4(1) causes small emission reductions, resulting in high marginal abatement cost of € 291/tCO_2 eq. As a consequence, we do not consider refrigerated vans in further assessment.

The calculations based on the model AnaFgas and the assumptions made within this project largely confirm the findings of the BIPRO assessment undertaken earlier on behalf of the European Commission. Under Option D-3a, application of Art 3 and 4 to mobile equipment including refrigerated road vehicles, fishing vessels, and air conditioning of railcars and sea-going ships could reduce projected emissions of 6,785 kt CO_2 eq in 2030 (WM scenario) by 2,494 kt CO_2 eq (36%) to 4,301 kt CO_2 eq[321].

b) ***Lowering the applicable F-gas charge threshold of certain equipment already covered by Article 4(1)***

The scope of containment provisions could potentially be extended to applications containing charges <3 kg. Some Member States have introduced minimum charges <3 kg nationally, such as France (2 kg), Denmark (1.5 kg). In this way, additional equipment could be subject to containment measures which currently apply to equipment containing charges ≥3 kg of F-gases (≥6 kg for hermetically sealed systems).

In the model AnaFgas, there are five stationary F-gas application sectors with average system charges <3 kg: domestic refrigerators, hermetic commercial refrigeration equipment, moveable air conditioners, single split air conditioners, and domestic heat pumps. Refrigerators, commercial hermetics and moveable air conditioners are factory sealed ("hermetically sealed") which implies that threshold charge size for these systems is 6 kg.

All systems, whatever the threshold, are subject to Article 4(1) which makes recovery by certified personnel mandatory. Accounting for this, the model AnaFgas assumes for the WM scenario a considerable reduction in disposal emission factors for the five sectors which takes place gradually in the period 2010-2015.

Table 8-5 shows for these sectors average charges and projected emissions in 2030 in the WOM and WM scenarios (Article 4(1)), annualised recovery cost (end-of-life[322]), the specific

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[321] The emissions reduction is slightly lower if rail vehicles will be subject only to Art 4(1) as BIPRO suggested.

[322] In this study, recovery generally means recovery at end-of-life. The term recovery is broader in the F-gas Regulation (see definition in Art 2 and chapter 4.2.6) and includes all removal from equipment, even in the use-phase, e.g. on service. So far, no method exists for a clear distinction of removal emissions in the use-phase from the total of use-phase emissions. In the model AnaFgas all emissions in the lifetime are considered use-phase emissions. This approach is deemed justified the more so as the containment measures of Art 3 of the F-gas Regulation by certified personnel imply

emission abatement cost in €/t CO_2 eq, and the total cost arising to the operators in the sectors from application of Article 4(1).

Emissions and charges are taken from the model AnaFgas. The annualised costs of the one-off recovery measure are divided by the lifetime resulting in cost of service in €/year (4th column), for detailed calculation see service cost table in annex II. Based on a hourly working rate for recovery of €50, the annualised cost for split air conditioners is €5.0, for heat pumps is € 3.33, for hermetic commercial refrigerators and moveable air conditioners is €2.50. One-off recovery costs for the domestic refrigerators are estimated very low, at €1.50 which is €0.10 per year (lifetime is 15 years). This assumption is related to the provisions of the WEEE Directive (collection systems) (see table 8-3 on European legislation).

The marginal abatement costs per t CO_2 eq are estimated based on the detailed comparative analyses of sector-typical systems, which are displayed in the EU sector sheets 1, 2, 10, 11, 16 in annex V to this report.

The calculation of the WM sector cost, i.e. the cost arising to the operators of the systems in 2030, follows a different approach. AnaFgas includes the annual number of units for decommissioning in each sector. Multiplication of these numbers of units with their one-off recovery cost (not the cost in column 4 which represent the one-off recovery cost already divided by the lifetime years) results in the sector cost in the last column to the right (col. 6).

Table 8-5: WM scenario: Emissions reduction potential and costs of application of Art 4(1) to the five sectors with average charges <3 kg/6 kg (reference year 2030) – according to AnaFgas

Sector	1. average charge (kg)	2. 2030 WOM emiss. (kt CO_2 eq)	3. 2030 WM emiss. (kt CO_2 eq)	4. WM Art 4(1) service (€/year)	5. WM Marginal abatement cost (€/t CO_2 eq)	6. WM sector costs (M€/year)
Domestic refrigeration	0.12	15	12	0.10	87	2.7
Commercial hermetics	0.40	266	149	2.50	125	5.7
Moveable AC	0.75	4,366	2,781	2.50	46	34.3
Split AC	1.5	33,569	22,970	5.00	46	96.7
Heat pumps (ground source)	2.4	3,577	2,713	3.33	29	9.7
Total		**41,793**	**28,625**			**149.2**

The total emissions under the WM scenario are 28,625 kt CO_2 eq which is a reduction relative to the WOM scenario by 13,168 kt CO_2 eq. The specific abatement costs €/t CO_2 eq are moderate for heat pumps and moveable and split air conditioners, with €29 and €46 (2x), respectively.

It should, however, be noted that the marginal abatement cost for commercial hermetics and domestic refrigerators are higher and amount to 125 €/t CO_2 eq and 87 €/t CO_2 eq.

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diligent handling of refrigerants and thus prevention of release to the atmosphere to the extent possible.

The total costs of the application of Art 4(1) that arise in the year 2030 to the operators/end-users in the five sectors amount to €150 million, on condition that the recovery scheme has completely been established. These costs do not account for the fact that recovery had been carried out to some extent prior to the F-gas Regulation[323]. Therefore, the additional cost to the operators is lower than €150 million. It should be noted that in the large sector of split room air conditioners appropriate end-of-life treatment had not been well-developed before 2006 (it virtually did not exist). Another uncertainty refers to the state of application of Article 4(1) to such small systems in EU-27.

Additional application of Article 3 (Option D-3b) to the five sectors would significantly increase the expenditure on working time and, consequently, the costs to the sector operators, while savings in refrigerant refill which arise from reduction in use-phase emissions are not very high. Anyway, domestic and commercial refrigerators, and factory sealed (moveable) air conditioners are not refilled in the use-phase. The extremely high cost increase can be seen in table 8-6.

The 1st data column is the same as in the previous table. However, the 2nd column shows the emissions that would arise if additionally the measures of Art 3 (regular leak checks, recording) apply. The new emissions total 21,171 kt CO_2 eq in 2030 which is 7,455 kt CO_2 eq less than in the WM scenario (table 8-5, col. 3).

In column 3 and 4 of table 8-6, for the five sectors the annualised service costs for application of Article 4(1) and for application of Art 3 alone are shown in € per year (data are taken from the cost list in annex II). Column 5 reveals the marginal abatement cost of the additional application of Article 3 (regular leak checks) to the systems with charges <3 kg. In the last column to the right the additional costs to the operators in the five sectors are listed, in million € per year.

Table 8-6: Application of Art 4(1) <u>and</u> Art 3 to the five sectors with average system charges <3 kg/6 kg (reference year 2030) in a WAM scenario – according to model AnaFgas

Sector	1. average charge (kg)	2. WAM em (Art 3+4(1)) in 2030 (kt CO_2 eq)	3. WM Art 4 service (€/year)	4. Option D-3b Art 3 service (€/year)	5. Art 3 add. abatement cost (€/t CO_2 eq)	6. Option D-2b add. cost (M€/yr)
Domestic refrigeration	0.12	11	0.10	67	324,722	186.4
Commercial hermetics	0.40	136	2,50	70	29,575	402.6
Moveable AC	0.75	2,137	2.50	72	3,707	2,474.1
Split AC	1.5	16,913	5.00	132	2,015	12,731.8
Heat pumps (ground source)	2.4	1,974	3.33	127	2,204	1,237.2
Total		**21,171**	1.67			**17,032**

The additional decrease in emissions from 28,625 (WM) to 21,171 (WAM), by 7,455 kt CO_2 eq, from additional application of Art 3 to the five sectors is very expensive. The total costs to

[323] This is different for domestic refrigerators, where the assessment of the costs of Art 4(1) accounts for the fact that the equipment has already been subject to the WEEE Directive.

the operators would rise from €150 million per year (Art 4(1) only) to €17.0 billion (17,032 million). This is a result of the quite high abatement cost per t CO_2 eq which range from €2,015 (split air conditioners) to an extremely high value of €324,722 for domestic refrigerators. The high calculated marginal abatement costs are a consequence of the low absolute emissions which arise from low-charged systems, and the low absolute emission reduction which can be achieved by annual leak checking.

The relation of additional cost to additional emission savings, i.e. WAM vs. WM scenario, is somewhat improved if the minimum charge for the application of Article 3 would not completely be omitted but lowered from 3 kg/6 kg to 1 kg in order to include only heat pumps and split air conditioners. In that case the emission reduction would be 6,796 kt CO_2 eq (WAM vs. WM) and the specific abatement cost would be lowered to values between € 2,000 and € 3,700/t CO_2 eq.

Alternatively, a minimum charge of 2 kg which would de-facto limit the extension of provisions in Article 3 to heat pumps would not lead to significantly higher emission reduction vs. the WM scenario. The emission reduction potential would be 740 kt CO_2 eq.

In conclusion, the extension of Article 3 of the F-gas Regulation to systems with HFC charges <3 kg could decrease the 2030 emissions from the affected sectors by up to 7,455 kt CO_2 eq, compared to the WM scenario. However abatement costs would be extremely high.

c) Extending the training and certification requirements to personnel undertaking activities not currently covered by Article 5

The requirements for certification of personnel and companies according to Art 5 are established by several Commission Regulations setting out minimum requirements and the conditions for mutual recognition of certificates by Member States[324].

Certification of personnel is a prerequisite for careful execution of containment measures (Article 3) such as regular leakage checks, and recovery (Article 4). Member States must ensure that the companies involved in carrying out these activities only take delivery of F-gases if the relevant personnel hold the personnel certificates.

Based on examples from different Member States and suggestions from experts and stakeholders, the extension of the training and certification requirements set out by Article 5 to personnel undertaking certain activities not presently covered by the provisions, is considered.

Examples from Member States refer mostly to mobile F-gas applications:

- Personnel recovering F-gases from all types of mobile refrigeration and mobile air conditioning equipment containing charges >3 kg of F-gases (Sweden).
- Personnel undertaking installation, maintenance, servicing and any other activities related to refrigerants contained in AC systems in motor vehicles (Hungary; Sweden).

[324] Certification requirements (cf. chapter 4.2.2) apply in the stationary refrigeration, air conditioning and heat pump sector (303/2008), the fire protection sector (including fire extinguishers for recovery only) (304/2008), the high-voltage switchgear sector (305/2008), the sector of F-gas based solvents (306/2008) and the MAC sector (307/2008). Member States are required to establish training and certification programmes for the sectors listed above and to notify these schemes to the Commission (308/2008).

- Attestation could be changed to certification based on an exam according to Commission Regulation (EC) No 307/2008 (Germany, Netherlands, Spain) in order to streamline the provisions for the MAC sector with those for other sectors.

Furthermore, existing exemptions from certification requirements e.g. for personnel undertaking brazing, soldering or welding in the stationary refrigeration, air conditioning and heat pump equipment (Regulation (EC) No 303/2008, Article 4(3b)), could be potentially revised in order to improve leak-tightness of permanent joints. However, the F-gas Regulation is at different stages of implementation and application in the Member States (chapter 4), where conditions for professional education and qualification vary largely. It is hence considered that additional certification requirements can be established at national level in order to account for national circumstances.

d) Introducing maximum leakage rates in certain applications

Article 10(2e) requires an assessment whether maximum leakage rates for installations could be established. Full implementation, application and control of existing containment measures according to Article 3 are considered prerequisites for this measure. The control of leakage rates would need to rely on the information gathered in the records required by Art 3(6) since they are specific for each system.

From a legal point of view, the establishment of maximum leakage rates would lead to clear identification of leaks and hence provide an additional tool for control and enforcement of containment measures resulting in F-gas emission reductions.

Maximum leakage rates have been set through international and European standards in the fire protection sector (ISO 14520[325], adopted as EN 15004[326]) and the high voltage switchgear sector (IEC TR 62271-303[327]), and anticipated the measures introduced by the F-gas Regulation.

In the refrigeration and air conditioning sector, a number of standards also relate to leakage of stationary refrigeration and AC systems: For example, EN 378 provides minimum tightness of systems and frequencies for maintenance and EN 16084 refers to tightness of components and joints. The number of personnel and companies applying these standards is unknown although it is likely that most large companies do follow them. Nevertheless, the impacts of these standards on reductions of emissions from stationary refrigeration and air conditioning systems have not been evaluated yet and hence cannot be quantified reliably.

As outlined in chapter 4.2.5, compliance with the containment measures of the F-gas Regulation varies largely in the refrigeration and air conditioning sector and is relatively low in small companies. It is hence likely that small companies operating refrigeration and air conditioning equipment would be less compliant with maximum leakage rates than large companies, no matter whether these were established through a regulation or a standard.

The identification of national policies in the Member States stricter than provisions of the F-gas Regulation has shown that currently 3 Member States implemented maximum leakage rates for stationary refrigeration and air conditioning equipment containing F-gases: Germany, Belgium, and Luxembourg.

[325] ISO 14520: Gaseous fire-extinguishing systems – physical properties and system design.
[326] EN 15004: Fire extinguishing systems – Components for gas extinguishing systems.
[327] IEC TR 62271 High voltage switchgear and control gear – Part 303: Use and handling of sulphur hexafluoride (SF_6) (2008) defines tightness classes of equipment and sets maximum leakage rates.

Belgium and Luxembourg have established maximum leakage rates of generally 5% in order to establish the basis for a definition of leakage. An evaluation of these rates and related compliance is not available.

Maximum leakage rates for stationary refrigeration and air conditioning equipment containing F-gases in Germany are based on a national standard agreed by industry and were established in August 2008 (table 8-7).

Table 8-7: Maximum leakage rates for stationary refrigeration and AC equipment in Germany

Charge	Date of manufacture of equipment		
	Before 30/06/2005	01/07/2005 - 30/06/2008	After 01/07/2008
<10 kg	8%	6%	3%
10-100 kg	6%	4%	2%
>100 kg	4%	2%	1%

Certain disadvantages of the German standard on maximum leakage rates have been identified:

- Maximum leakage rates apply during normal operation of equipment and do not include losses of refrigerant during accidents and other damage. Hence regular leakage could be excluded from the calculation of the leakage rates by declaring the quantities emitted during equipment damage in the records.
- Technical problems in accurately determining low leakage rates by common leak detection systems and devices. Currently no standards are known allowing the calibration of leak detectors and demonstrating compliance of the detector with the provisions of Regulation (EC) No 1516/2007 (Article 6). Most of the current standards are vacuum standards which cannot be considered appropriate under other circumstances.
- Compliance with the rates set out by legislation in Germany was reported by certain industry experts to be not possible on a large scale, even if all available measures to improve containment were taken because the rates were unrealistically low in practice.
- Maximum leakage rates do not relate to the refrigerant used and its GWP although high losses of a substance with high GWP causes higher global warming emissions than leakage of a refrigerant with low GWP.
- The maximum leakage rates do not encourage the use of equipment with low charges of F-gases. Hence the establishment of large F-gas banks is still supported.

No analysis of the status of implementation and compliance of industry with the maximum rates set out in Germany has been undertaken so far.

It should be noted that maximum leakage rates for certain applications could help to define leakage as compared to bad service practices. However, the choice of maximum leakage rates would need to be supported by experiences on best practices and determination of such rates. No information on the actual impact of maximum leakage rates on F-gas emissions has been available to this point which does not allow considering this measure as an effective instrument to reduce F-gas emissions. Therefore, this sub-option is not followed further in the screening and comparison of options in this work.

e) ***Introducing producer responsibility schemes for reclamation and destruction of F-gases***

A recent study[328] recommends producer responsibility schemes to promote recovery and appropriate treatment of used F-gases. It is suggested that HFC producers could offer take-back programs for unwanted chemicals for the purpose of reclamation or destruction to allow users to return unwanted F-gases at low or no cost to producers via distributors. It is also outlined that chemical producers would be able to reclaim the used F-gases more cost-effectively than they could produce virgin chemicals, which could then be sold within the EU or abroad. This finding, however, has not been confirmed by industry experts contacted within the current project who pointed out that reclamation of used F-gases was rarely possible for technical reasons and linked to high costs of the reclamation process. Reclaimed gases are usually added to virgin chemicals of the same type and are not placed on the market separately[329].

The introduction of obligations for producers and suppliers of F-gases to take back used F-gases for reclamation and destruction would be in line with EU waste legislation which supports producer responsibility schemes in order to promote life-cycle thinking and the integration of environmental costs into the price of products (e.g. WEEE Directive).

Germany has introduced an obligation for producers and suppliers of F-gases to take back recovered F-gases for reclamation and destruction in national legislation in 2009 in order to set out clear responsibilities for users of F-gases. It is estimated that returned quantities of F-gases have not significantly increased yet due to the short time since entry into force of the legislation. Quantitative data are available to very limited extent at present. It should be noted that service companies returning F-gases to distributors or producers have to pay fees of ca. €4/kg depending on the quantities and levels of purity of the gases. Distributors and producers subsequently decide whether the returned gases can be reclaimed by the company itself, or need to be destroyed in specialized destruction facilities. It is considered likely that the fee to be paid by service companies limits their efforts to return recovered F-gases for reclamation. Costs also apply when recovered F-gases are delivered directly to destruction facilities: Destruction facilities charge fees of around €2/kg of F-gases returned.

In other countries, no-cost schemes for recovered refrigerants are established and funded e.g. via taxes on import and production of F-gases as well as products and equipment containing F-gases or deposit-refund schemes apply (see options E-2 and E-3).

Due to the variety of existing approaches and the differences of market structures between Member States, it is considered that producer responsibility schemes may be appropriate if implemented at national level. When introducing such schemes, experiences from existing schemes in other Member States should be taken into account, in particular with regard to mechanisms to minimize costs for service companies to return used gases in order to effectively promote recovery for reclamation and destruction and overcome costs passed to consumers.

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[328] ICF International: Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-gases) Banked in Products and Equipment; Final Report prepared for the European Commission, May 2010; p. 58.

[329] Communication via telephone and email with Westfalen AG and TEGA, Germany.

Sub-option D-4: Ban the use and/or the placing on the market of open F-gas applications

Article 10(2)(j) requires the Commission to consider the inclusion of further products and equipment containing fluorinated greenhouse gases in Annex II to the Regulation, taking account of energy-efficiency.

Current measures for the control of use (Art 8) refer to SF_6 and preparations thereof in magnesium die casting relying on quantities of SF_6 >850 kg/year and in the filling of vehicle tyres. Bans of placing on the market (Article 9) apply to products and equipment containing F-gases as listed in Annex II: Non-refillable containers, non-confined direct evaporation systems containing refrigerants, fire protection systems and fire extinguishers containing PFCs, windows, footwear, tyres, one-component foams (except when required to meet national safety standards) and novelty aerosols.

These bans have already effectively reduced emissions from these sectors and applications (see chapter 5.2.2) and are included in the WM scenario of the model AnaFgas. Additional bans could potentially address additional open applications of F-gases in order to achieve further emission limitations.

a) Use of SF_6 in magnesium casting

The use control of SF_6 for die casting in plants with annual SF_6 use >850 kg leads to reduction in emissions from the magnesium casting sector of 1,452 kt CO_2 eq by 2030 (calculation AnaFgas). Remaining emissions from the sector are projected to range at 625 kt CO_2 eq in 2030.

In this context, Article 10 requires an assessment whether the substitution of SF_6 is technically feasible and cost-effective in the entire sector which includes not only die casting in plants with SF_6 use <850 kg/year but also sand casting and the recycling of die casting and sand casting alloys. A study of this matter was undertaken in 2009[330] and resulted in the following findings:

- Technical options to reduce SF_6 emissions by containment, recovery, or substitution are not currently feasible in two sub sectors of the magnesium industry in Europe including magnesium sand casting and recycling of special magnesium alloys, which are used in sand casting.
- For magnesium die casting a full ban of the use of SF_6 was recommended.
- For recycling of magnesium die casting alloys a ban of the use of SF_6 was recommended.

Abatement costs and reductions of F-gas emissions in magnesium die casting (<850 kg/year) were found to vary according to the substitute chosen, either HFC-134a or SO_2. In recycling of magnesium die casting alloys, only one alternative is the likely technical alternative choice: SO_2. Abatement costs and emission reductions of recommended options are summarized below (table 8-8).

[330] Öko-Recherche 2009: Service contract to assess the feasibility of options to reduce emissions of SF_6 from the EU non-ferrous metal industry and analyse their potential impacts; Final Report, prepared for the European Commission.

Table 8-8: Abatement costs and emission reductions resulting from a use ban of SF_6 in magnesium die casting (<850 kg/year) and recycling of magnesium die casting alloys (GWP from 4th IPCC AR), updated to reference year 2030

		Mg die casting		**Recycling of Mg die casting alloys**
Alternative		**SO_2**	**HFC-134a**	**SO_2**
SF_6 emission reduction	kt CO_2 eq	171	160	85
Net costs	k€	50	146	-19
Abatement costs	€/t CO_2 eq	0.29	0.91	-0.22

All operators of die casting and recycling plants are facing costs for new equipment. The annual savings from the application of the new cover gas, however, are in the same range. Therefore, on an annual basis the additional costs that arise to the operators are low, in the recycling of die casting alloys even negative. Emission reductions in magnesium die casting are lower in case of conversion to HFC-134a due to the global warming potential of HFC-134a, which negatively impacts total emission reductions (difference of 11 kt CO_2 eq).

Ban and substitution of SF_6 in magnesium die casting and recycling of die casting alloys results in maximum emission reductions from the magnesium sector by 256 kt CO_2 eq in 2030, below the 625 kt CO_2 eq emissions from the total sector in the WM scenario.

b) Open applications of HFCs

In the following sections, potential bans to the placing on the market non-medical aerosols as well as XPS and PU foam products are considered.

Another open application of F-gases is metered dose inhalers (MDI) for the treatment of asthma and further respiratory diseases. The emissions in 2030 are projected at 3,450 kt CO_2 eq (AnaFgas). Replacement of HFCs in this sector is excluded from subsequent assessment because this form of aerosols represents a use which requires special investigation by experts from the medical and pharmaceutical industry.

The key abatement options with alternatives to HFCs in the European aerosol and foam sectors have been discussed in annex IV, V and VI and are presented in chapter 6 of this report. The analyses resulted in sector-specific emission abatement cost per t CO_2 eq. This information, together with the reduction potential for the year 2030, is repeated here in tabular form (table 8-9).

Table 8-9: Emission abatement potential and cost of switching to alternative options in 5 sectors of open HFC-application 2030

EU-27 – emissions abatement vs. WOM/WM scenario in foam and aerosols 2030						
Sub sectors		**XPS with 134a**	**XPS with 152a**	**Spray foam**	**Other PU**	**Non-medical Aerosols**
emission abatement cost	€/tCO_2 eq	1.0	-1.6	61.6	3.5	10.0
emission reduction	ktCO_2 eq	1,553	460	1,369	587	3,637

Source: chapter 6.4 of this report, annex VI, and EU sector sheets 22-26 in annex V.

The assessment of open F-gas applications (except for MDIs) which are not yet subject to the F-gas Regulation shows varying results. In technical aerosols, XPS foam and “other” PU foam applications specific abatement cost of 10 €/t CO_2 eq or less could be achieved if available low-GWP alternatives to HFCs are introduced.

The calculated abatement costs per t CO_2 eq amount to €10.0 for technical aerosols, to €1.0 for XPS with HFC-134a and negative costs for HFC-152a (€-1.6), and €3.5 for PU applications other than spray foam. PU spray foam is the largest PU sector using HFCs, but so far replacement of HFCs cannot be carried out with abatement cost below 50 €/t CO_2 eq. In this sector social impacts must also be duly considered (prevalence of small enterprises).

The maximum emission reduction potential amounts to 7,606 kt CO_2 eq in 2030, if bans on HFCs are introduced in 2015 in all sectors. Without the PU spray foam application, the emission reduction potential in 2030 is reduced to 6,237 kt CO_2 eq.

As shown in annex V, EU sector sheets 22-26, 100% sector penetration rate of abatement options can be achieved by 2015 in all sectors except for the non-medical aerosol sector. Here, only 95% of HFC applications can be replaced by alternative propellant gases. A ban on HFCs as of 2020 is feasible if the remaining 5% can clearly be identified as exemptions.

Sub-option D-5: Ban the placing on the market of certain closed applications containing F-gases where energy efficient and safe alternatives are available

In chapter 6 alternative technologies to conventional HFC technology for the abatement of emissions are presented. Detailed data on the comparative calculations of sector typical HFC reference cases of the WM scenario and several replacement solutions are shown in the EU sector sheets in annex V to this report.

The results include

- HFC emissions in the WM scenario in 2030.
- The individual penetration rates of alternative options in the years 2015, 2020, and 2030 and the sector penetration mix of the alternative options in the same years, which provide important information for the feasibility of bans in these years.
- The aggregated emission reduction potential in 2030, vs. WM emissions (kt CO_2 eq).
- The marginal abatement cost of the emission reduction by the aggregated alternative solutions (€/t CO_2 eq).

Table 8-10: Emission abatement cost and technically feasible reduction potential of switching to alternative options in closed systems of F-gas sectors and sub sectors of EU-27 (2030)

Sector	Sub sector	Marginal emission abatement cost €/t CO_2 eq	Potential emission reduction 2030 kt CO_2 eq
Domestic Refrigeration	Refrigerators/Freezers	1.0	12
Commercial Refrigeration	Stand-alone systems	-0.8	149
	Condensing units	1.2	3,927
	Centralized systems	23.7	14,741
Industrial Refrigeration	Small Industrial equipment	-0.9	871
	Large Industrial equipment	-21.6	2,612
Transport Refrigeration	Refrigerated Vans	45.1	421
	Refrigerated Trucks	2.6	2,990
	Fishing vessels	3.4	425
Mobile Air Conditioning	Rail vehicle AC	556.6	26
	Cargo ship AC	16.7	320
	Passenger ship AC	35.0	125
Stat Air Conditioning	Moveable systems	8.9	2,781
	Split systems	19.0	22,970
	Multi split/VRF systems	13.1	2,827
	Rooftop systems	8.2	573
	Chillers (displacement)	5.9	2,512
	Centrifugal chillers	11.1	82
	Heat Pumps	130.2	2,282
Fire protection	Fire protection HFC-227ea	22.3	440
	Fire protection HFC-23	3.1	961
Electrical equipment	MV secondary switchgear SF_6	347.3	97
Total		**19.5**	**62,125**

At the end of chapter 6, the sector-specific abatement costs and the emission reduction potential for the year 2030 have been summarized in a Marginal Abatement Cost Curve (MACC). Certain sectors are repeated here (table 8-10), notably closed systems containing refrigerants and fire extinguishing agents, in order to discuss sub-option D-5.

The total emission reduction potential by 2030 amounts to 62,125 kt CO_2 eq. Reductions in individual sectors range from 12 kt CO_2 eq (domestic refrigerators) to 22,970 kt CO_2 eq (split room air conditioners). Abatement cost average €19.4, ranging from €-21.6 (large industrial refrigeration) to €347.3 (MV secondary switchgear) and €556.6 (rail vehicle air conditioning).

The emission reduction potential which is shown in table 8-10 represents the technically feasible maximum by 2030. It arises under the condition that in every year since 2015 the market potential of alternative technical solutions is completely been utilised for new equipment. The market potential of most abatement technologies (their penetration rates) is considered to grow over time, but in many cases even their combination will not reach 100% before 2025-2030. Placing on the market bans, however, cannot follow gradually the growth trend of replacement solutions; they cannot be established before the penetration mix of alternative technologies has reached 100% or, if less, if the difference from 100% can clearly be defined for exemptions.

In order to quantify the 2030 emission reduction specifically attributable to placing on the market bans, those sectors where the penetration mix is still below 100% in 2030 are excluded. In the remaining sectors a placing on the market ban is considered to be feasible in the year in which the penetration mix reaches 100% (or 95% with clearly definable exemptions).

It must be noted that full replacement of F-gases in new equipment does not result in the immediate termination of emissions from the existing stock. Depending on the lifetime, use-phase emissions and disposal emissions from closed systems continue arising for many years. The shorter the time from a ban year to the year 2030, the lower the specific emission reduction potential from the prohibition measure in 2030.

Table 8-11 reveals that the emission reduction potential from feasible placing on the market bans is significantly lower than the technically feasible emission reduction potential shown in the preceding table 8-10.

Table 8-11: Sub option D-5. F-gas emission reduction potential by 2030, resulting from placing on the market bans on closed systems, and first year of 100% market penetration of alternative technologies

Sector	**Sub sector**	**Potential emission reduction 2030 kt CO_2 eq**	**Penetration rate mix 100%**
Domestic Refrigeration	Refrigerators/Freezers	12	2015
Commercial Refrigeration	Stand-alone systems	147	2020
	Condensing units	2,849	2020
	Centralized systems	12,055	2020
Industrial Refrigeration	Small Industrial equipment	67	2030 (95%)
	Large Industrial equipment	202	2030 (95%)
Transport Refrigeration	Refrigerated vans	421	2020
	Refrigerated trucks/trailers	322	2030
	Fishing vessels		Not 100%
Mobile Air Conditioning	Rail vehicle AC		Not 100%
	Cargo ship AC	232	2020
	Passenger ship AC		Not 100%
Stat Air Conditioning	Moveable systems	2,781	2020
	Split systems	22,970	2020
	Multi split/VRF systems	2,172	2020
	Rooftop systems	573	2020
	Chillers (displacement)	1,989	2020
	Centrifugal chillers	9	2030
	Heat Pumps	1,356	2020
Fire protection	Fire protection HFC-227ea		Not 100%
	Fire protection HFC-23	961	2015
Electrical equipment	MV secondary switchgear SF_6		Not 100%
Total		**49,119**	

The 2030 emission reduction potential of placing on the market bans amounts to 49.1 Mt CO_2 eq, which is 78.5% of the maximum technically feasible potential of 62.1 Mt CO_2 eq. for closed applications.

In five sectors 100% penetration rate mix is not achieved by 2030. In four sectors, amongst them small and large industrial refrigeration, the first year of a full penetration mix[331] is 2030. As a result, the emission reduction in 2030 is still low for those sectors. In the sectors of stationary air conditioning, 2020 is mostly the year when the aggregated penetration rates can reach 100%. Because of 10 years lifetime, the emission reduction potential is fully utilised by 2030, which explains the high reduction potential of this sector. Split air conditioners alone account for 47% of the overall emission reduction potential by 2030 of this option.

[331] In industrial refrigeration a 95% penetration rate is forecast for 2030; the remaining 5% represent exemptions that can be defined.

Sub-option D-6: Set quantitative limits for placing F-gases on the market in the EU-27

In the previous section, bans of the placing on the market of F-gases in several open applications of HFCs and a large number of closed applications in refrigeration, air conditioning, and fire protection have been analyzed. The general question was: What is the emission reduction potential from not allowing the placing on the market a certain F-Gas containing application?

Sub-option D-6 considers the establishment of quantitative limits for the supply of certain F-gases (HFCs). Demand is assumed to adjust to reduced supply to reach balance, thereby reducing emissions.

The term supply which is used in sub-option D-6 includes not only bulk quantities to serve the demand for first fill on domestic manufacturing plus refill into domestically manufactured and imported equipment in the use-phase, but also the import of F-gases in pre-charged imported systems[332]. It must be noted that this supply also accounts the quantity of F-gases used as first fill in pre-charged systems for export from the EU, although emissions from these systems do not take place in the EU (and therefore are not accounted as EU emission reductions). The "supply" considered in this option is the second extension ($supply_{ext2}$), which includes Production + Import – Export of bulk substances plus Import in pre-charged equipment[333]. Therefore, supply includes the sales of F-gases to the EU market both in bulk quantities and in imported equipment which is pre-charged in a third country. Demand of F-gases (HFCs) for first fill which is served by the supply includes

(1) products manufactured in the EU for domestic use,

(2) products manufactured and filled in the EU for export from the EU, and

(3) products manufactured and filled in third countries and subsequently imported into the EU.

Although the option for quantitative limits for the supply of HFCs to the market in the EU ultimately relies upon the transition of the different F-gas using subsectors to alternative technologies like the ban options discussed above (sub options D-4b and D-5), the specific characteristics of sub-option D-6 is that it gives more room for manoeuvre to the actors involved. Under this option, maximum gradually declining ceilings for the total supply of HFCs to the EU market in bulk quantities as well as in products and equipment would be established until a final plateau (tail end) is reached. This option could be implemented by

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332 A possible exclusion of imported pre-filled equipment or products from sub-option D-6 would reduce the effectiveness of the option, especially in stationary air conditioning, which is the sector with the largest emissions from 2030 onwards, under the WM scenario. Split and multi split air conditioners and small moveable systems are imported with shares of 75%-90% from outside the EU, in particular from Asia. Domestic first fill is only carried out for the remaining 10%-25% of systems which are domestically manufactured. In 2015, the “first fill” for new installations which include all systems sold to the European market, including imported pre-filled equipment will exceed the first fill for domestic production and domestic on-site topping-up, by 19,200 kt CO_2 eq (see table 8-13). The surplus will grow to even 27,200 kt CO_2 eq until 2030, if the present ratio between importation and domestic production remains the same (data from model AnaFgas).

333 In full, the equation for the second extension of the term supply is: $Supply_{ext2} = P_{roduction} + I_{mports}$ (bulk) – E_{xports} (bulk) – $F_{eedstock}$ – $D_{estruction}$.+ I_{mports} (pre-charged). See chapter 2.2.4.

the establishment of a system for allowances to place HFCs on the EU market. This option would require to:

- establish a system that allocates such allowances to the relevant undertakings. This system could either be a “grandfathering” system which applies to new equipment only, based on the amounts of HFCs that undertakings placed on the market in a recent historic year or during several years, or an auctioning system that annually auctions at EU level allowances to all undertakings that intend to place HFCs (including in products and equipment) on the market.
- The design of a monitoring and verification system at EU level that monitors the amounts of HFCs placed on the market by undertakings in the EU.
- The design of a compliance system that requires undertakings to submit allowances equivalent to their total annual placing on the market for the past year to the Commission where it is checked whether the submitted allowances cover the amounts placed on the market. The compliance system would include fines and consequences in case of non-compliance with the requirement to submit allowances for the amounts placed on the market.

Use-phase emissions are part of the total emissions but are also covered by supply (sales) data since the use-emissions need to be replaced by refill quantities in most cases[334]. Therefore, measures reducing use-phase emissions limit directly the demand and at the same time indirectly the supply, and vice versa.

Regulatory measures according to Articles 3 and 4 as well as 8 and 9 substantially differ in the quantitative effect on demand and supply reduction. While Article 4 provisions largely aim at minimizing disposal emissions at end-of-life of equipment, which do not affect the F-gas demand or supply at all, containment measures of Article 3 can reduce refill quantities and hence demand and supply, but not first fill quantities which are independent from leakage rates.

Prohibition measures to closed F-gas applications according to Articles 8 and 9 can stop demand and supply for (domestic) first fill of equipment, but do not immediately stop the demand and supply for refill because servicing quantities are needed for existing equipment containing HFCs. However, the quantity for refills would constantly decrease over time until end-of-life of the equipment. Prohibition measures can hence be more effective than containment/recovery measures alone since they also avoid first fill and increase of banks.

It should be noted that prohibition on the placing on the EU market of closed applications does not reduce the first fill for products which are manufactured for export to third countries. For instance, the ban of HFC-134a in mobile air conditioning of passenger cars applies to use within the EU only but not to production for third countries. In this report, it is not assumed that the use of HFC-134a is banned outside of the EU so that ca. 25% of the annual demand for first fill (current export quota) continues until 2030 and after. The same export quota applies to domestic first fill of mobile air conditioning systems of buses and trucks, for which we assume in this chapter a phase-out of HFC-134a from 2015 onwards, according to the EU sector sheets 28 and 29 in annex V. Such transition was not considered

[334] In model AnaFgas, factory-sealed systems containing small charges such as domestic refrigerators, commercial stand-alone equipment and factory-sealed air conditioners are not assumed to be refilled for their (small) leakage.

as a sub-option in option D-5 since it could be implemented in the context of a revision of the MAC Directive. However, in this option, which includes all applications of HFCs regardless, the calculation of the HFC reduction potential of mobile air conditioning of trucks and buses becomes important and is therefore included.

In this context, the quantification of possible supply limits relies on the analysis of the extent to which technically possible transitions away from current HFC technology, as described in annex VI and presented in chapter 6, could contribute to lower HFC demand and supply in EU-27. We ask:

- In which subsectors transitions to low-GWP technologies can be achieved?
- On that basis, to which levels can HFC supply be reduced?
- On that basis, to which extent the direct reduction in HFC supply contributes to indirect reduction in emissions?

The target year in this sub-option D-6 is again 2030, and 2015 has been chosen the first year for gradual introduction of available replacement solutions (technically feasible, cost-effective, and energetically equivalent). F-gases other than HFCs are not considered in this option[335]. All stationary air conditioning equipment is considered wherever it is filled first. The mobile air conditioning sector includes in this option not only rail and ship AC systems but also AC systems contained in motor vehicles under the MAC Directive (passenger cars) and AC systems of buses and trucks which are currently not covered by the MAC Directive.

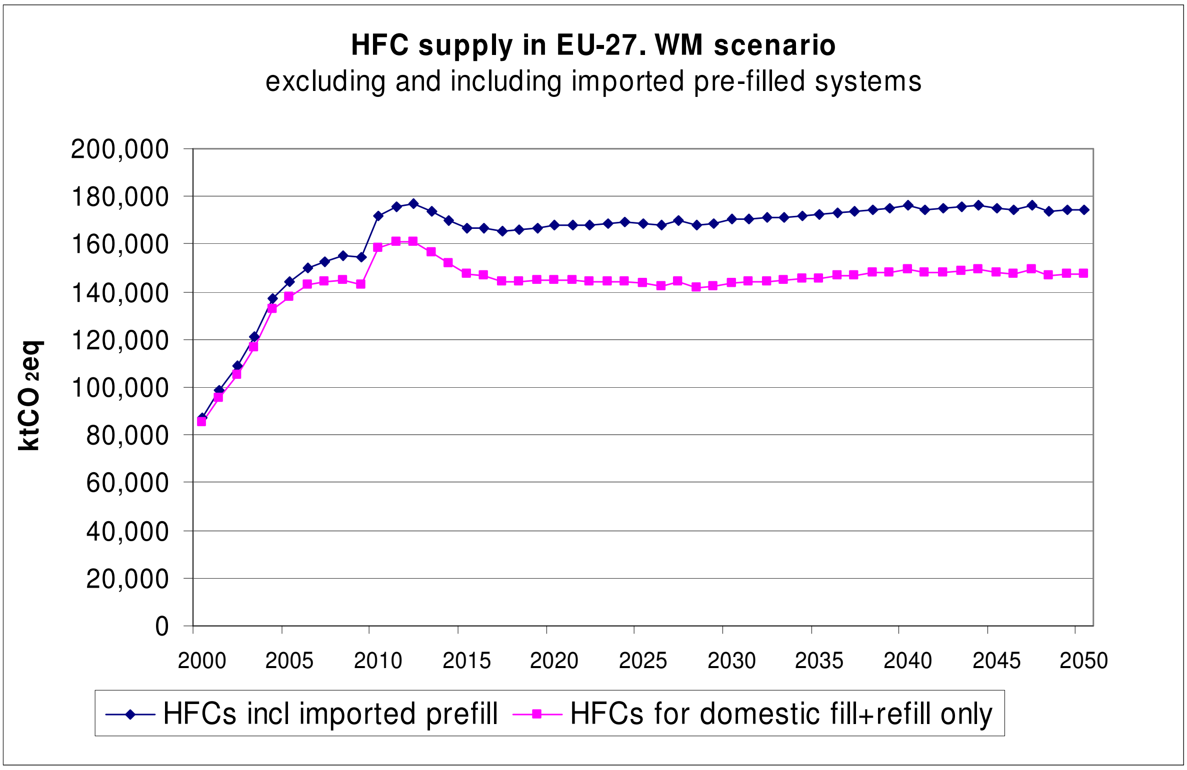

Figure 8-2: Supply of HFCs to EU-27 (kt CO_2 eq) in the WM scenario (including application of F-gas Regulation and MAC Directive) in the period 2000-2050. The steep increase in 2010 results from the accelerated R-22 phase-out which is assumed to be implemented according to the Regulation (EC) No 1005/2009. The upper curve includes HFCs in pre-filled equipment from imports (supply $_{ext2}$); the lower curve displays only supply of F-gases in containers, etc. for the European market (supply). Source: AnaFgas.

[335] The SF_6 application sectors of magnesium casting and MV secondary distribution switchgear are not included in the discussion of sub-option D-6.

Figure 8-2 and table 8-12 show the HFC supply from 1995 to 2050, according to AnaFgas, under the WM scenario. The WM scenario includes all provisions of the F-gas Regulation and the MAC Directive (phase-out of HFC-134a in AC systems in passenger cars). The quantitative difference between supply with and without HFCs in pre-filled imported equipment is shown in the table and is graphically displayed in the diagram.

Table 8-12: Supply of HFCs in EU-27 (kt CO_2 eq) in the WM scenario (F-gas Regulation and MAC Directive) in the period 2010-2050 – with and without pre-filled systems

Year	**2010**	**2015**	**2020**	**2030**	**2050**
Supply for domestic fill/refill (supply)	159,143	146,870	144,766	143,735	147,218
Supply for HFCs in imported pre-filled systems	13,252	19,200	22,820	26,654	27,226
Total demand incl. pre-filled imported systems (supply $_{ext2}$)	172,395	166,070	167,586	170,389	174,444

Source: AnaFgas

The supply of HFCs (which follows the demand) steeply rises from 2000 to 2012 driven by HCFC substitution. Afterwards containment and recovery provisions of the F-gas Regulation (Articles 3 and 4) start showing effects. The HFC supply (demand) would nevertheless considerably increase after 2012 without the MAC Directive, but the HFC-134a phase-out from passenger cars completely compensates the increase in the other sectors, in particular in stationary air conditioning. It must, however, be emphasized that between 2010 and 2050, there is no absolute reduction in HFC demand and supply of the EU-27.

In the WM scenario, HFC demand $_{ext2}$ totals ca. 170,400 kt CO_2 eq in 2030. It can be related to eight sectors relying on HFCs:

a. Closed stationary air conditioning (incl. import): 72,700 kt CO_2 eq
b. Closed stationary refrigeration 49,400 kt CO_2 eq
c. Fire protection 6,600 kt CO_2 eq
d. Open applications (aerosols, foam, solvents): 15,000 kt CO_2 eq
e. Mobile air conditioning of ships and rail vehicles and mobile refrigeration on ships and road vehicles 8,300 kt CO_2 eq
f. Mobile air conditioning of passenger cars (first fill for export only) 3,500 kt CO_2 eq
g. Mobile air conditioning of trucks and buses 6,500 kt CO_2 eq
h. Metered dose inhalers (incl. for export): 8,500 kt CO_2 eq

In the assessment of the emission reduction potential under sub-option D-4 and D-5, a ban in a sector was assumed feasible as of the year that the penetration mix of alternative technologies reached 100%. In contrast, under sub-option D-6 the assumed replacement of HFCs follows the gradual growth in the market potential of alternative technical solutions. As a consequence, the emission reduction potential by 2030 is higher than under sub-options D-4 and D-5 and could potentially match the reduction potential shown in table 8-10 (maximum technically feasible reduction potential).

However, a possible technology transition may not include sectors with extraordinary high abatement cost in €/t CO_2 eq. As an upper limit for the inclusion in option D-6, a maximum threshold of emission abatement cost of €50 is considered. From table 8-10 it emerges that two sectors of closed systems with HFCs, rail air conditioning and heat pumps, feature abatement cost of €556.6 and €130.2, respectively. According to table 8-9, in one sector of open application, PU spray foam, the abatement cost per t CO_2 eq is €61.5. Both the reduction potential for demand and for emissions of these three sectors is excluded from the analysis underlying sub-option D-6. Therefore this limit leads to the exclusion of three HFC sectors with a combined technically possible 2030 emission reduction potential of 3,677 kt CO_2 eq (demand reduction potential 11,077 kt CO_2 eq). The reduction potential for HFC demand and emissions by abatement options compared to the WM scenario in 2030 is shown in table 8-13.

Table 8-13: Potential for reduction of HFC demand in sectors and sub sectors in 2030 at maximum costs of emission abatement at €50/t CO_2 eq and resulting emission reductions.

Sector	Sub sector	Demand reduction 2030 kt CO_2 eq	Emission reduction 2030 kt CO_2 eq
Domestic Refrigeration	Refrigerators/Freezers	0	12
Commercial Refrigeration	Stand-alone systems	219	149
	Condensing units	8,949	3,927
	Centralized systems	25,214	14,741
Industrial Refrigeration	Small Industrial equipment	2,186	871
	Large Industrial equipment	6,557	2,612
Transport Refrigeration	Refrigerated Vans	516	421
	Refrigerated Trucks	4,325	2,990
	Fishing vessels	539	405
Mobile Air Conditioning	Cargo ship AC	353	320
	Passenger ship AC	160	125
	Bus AC	*1,694*[336]	*1,616*
	Truck AC	*4,017*	*4,170*
	Rail AC	No reduction considered (>€50/t CO_2 eq)	
Stat Air Conditioning	Moveable systems	5,369	2,781
	Split systems	45,428	22,970
	Multi split/VRF systems	6.426	2,827
	Rooftop systems	1,489	573
	Chillers (displacement)	6,851	2,512
	Centrifugal chillers	460	82
	Heat pumps	No reduction considered (>€50/t CO_2 eq)	
Fire protection	Fire protection 227ea	2,578	440
	Fire protection 23	2,946	961
Aerosols	Technical aerosols	3,637	3,637
	Medical aerosols	No reduction considered: technical constraints	
Foam	XPS-152a	460	460
	XPS-134a	4,092	1,553
	PU other	2,058	587
	PU spray foam	No reduction considered (>€50/t CO_2 eq)	
Total		***136,522***	***71,742***

336 * After full replacement of HFCs for new truck and bus MAC systems (assumed for 2030) domestic first fill in new systems for export to third countries continues with a 25% of the WOM/WM first fill. The remaining demand in 2030 amounts to 112 kt CO_2 eq for buses and 388 kt CO_2 eq for trucks.

Table 8-13 shows a reduction potential for HFC demand and emissions in 25 sub sectors. The technical basis of the 2030 reduction potential for demand and emissions of sub-option D-6 is the same as under the preceding sub-options: the growth in the market penetration rates of replacement technologies in 2015-2030.

Under the WAM scenario, the maximum reduction potential for the HFC demand which can potentially emerge from 25 sectors of closed stationary and mobile applications and open applications in 2030 is 136,500 kt CO_2 eq. The corresponding emission reduction potential amounts to ca. 71,740 kt CO_2 eq.

This reduction could be achieved if the technically feasible replacement potential at emission abatement cost below €50 per t CO_2 eq would be followed. Related HFC emissions in EU-27 would be reduced by 71,740 kt CO_2 eq as compared to the WM scenario by 2030. This equals almost 70% compared to the EU F-gas emissions in the WM scenario of 103,657 kt CO_2 eq (see table 6-5).

Under the assumed transitions, the remaining 2030 HFC demand for deliberate use (from a total of 170,400 kt CO_2 eq under the WM scenario) is 33,900 kt CO_2 eq. It is distributed over five different demand quantities:

(1) Unabated HFCs in the 25 reduction sectors (10,600 kt CO_2 eq).

(2) HFCs in the three sectors (heat pumps, spray foam, rail vehicle air conditioning) excluded from sub-option D-6 (10,800 kt CO_2 eq).

(3) HFC-134a and -227ea for filling of metered dose inhalers for domestic use and exports (8,500 kt CO_2 eq).

(4) First fill of HFC-134a in passenger car MAC systems for export to third countries (3,500 kt CO_2 eq).[337]

(5) Other HFCs in small quantities like solvents, HFCs in OCF and novelty propellant gas mixtures with GWP < 150, and HFC-236fa for fire extinguishing in military vehicles (600 kt CO_2 eq).

The residual F-gas demand after the HFC demand reduction driven by the application of sub option D-6 for the years 2015, 2020, 2030, and 2050 can be seen in table 8-14. Please note that HFC emissions from halocarbon production, e.g. HFC-23 by-product emissions, are not included in the table because the do not represent deliberate demand/supply. Figure 8-3 graphically illustrates the reduction potential of HFC supply until 2050.

Table 8-14: Reduction potential of HFC supply in 2015-2050 (WAM) and remaining supply of F-gases under WM in sub-option D-6 (limits for placing on the market of F-gases) by sectors*

	2015	**2020**	**2030**	**2050**
Total HFC Demand WM	**166,100**	**167,600**	**170,400**	**174,500**
WAM reduction in 25 HFC sectors	38,500	95,500	136,500	146,100
Not reduced in 25 HFC sectors	93,100	49,200	21,300	15,200
thereof heat pump/spray foam/rail MAC	*7,500*	*8,300*	*10,800*	*12,100*
Metered Dose inhalers	8,200	8,200	8,500	8,900
Passenger Car MAC	25,800	14,200	3,500	3,600
Other HFCs	0,500	0,500	0,600	0,700

* HFC supply excludes CHF_3 (HFC-23) as etching gas in semiconductor industry, and HFC-134a used as SF_6 replacement in magnesium die casting. These quantities are comparably small.

[337] Remaining demand for first fill in MACs of buses and trucks is included in (1) Unabated HFCs in the 25 reduction sectors.

In figure 8-3, the upper curve (WM) reflects the impact of the MAC Directive (passenger cars) and the existing F-gas Regulation on the HFC supply. The lower curve displays the reduction trend of the HFC supply on the basis of full application of sub-option D-6, which assumes that technically feasible abatement technology with emission abatement cost of less than 50 €/t CO_2 eq replaces conventional HFC technology to the maximum extent as outlined in chapter 6 and annex V and VI.

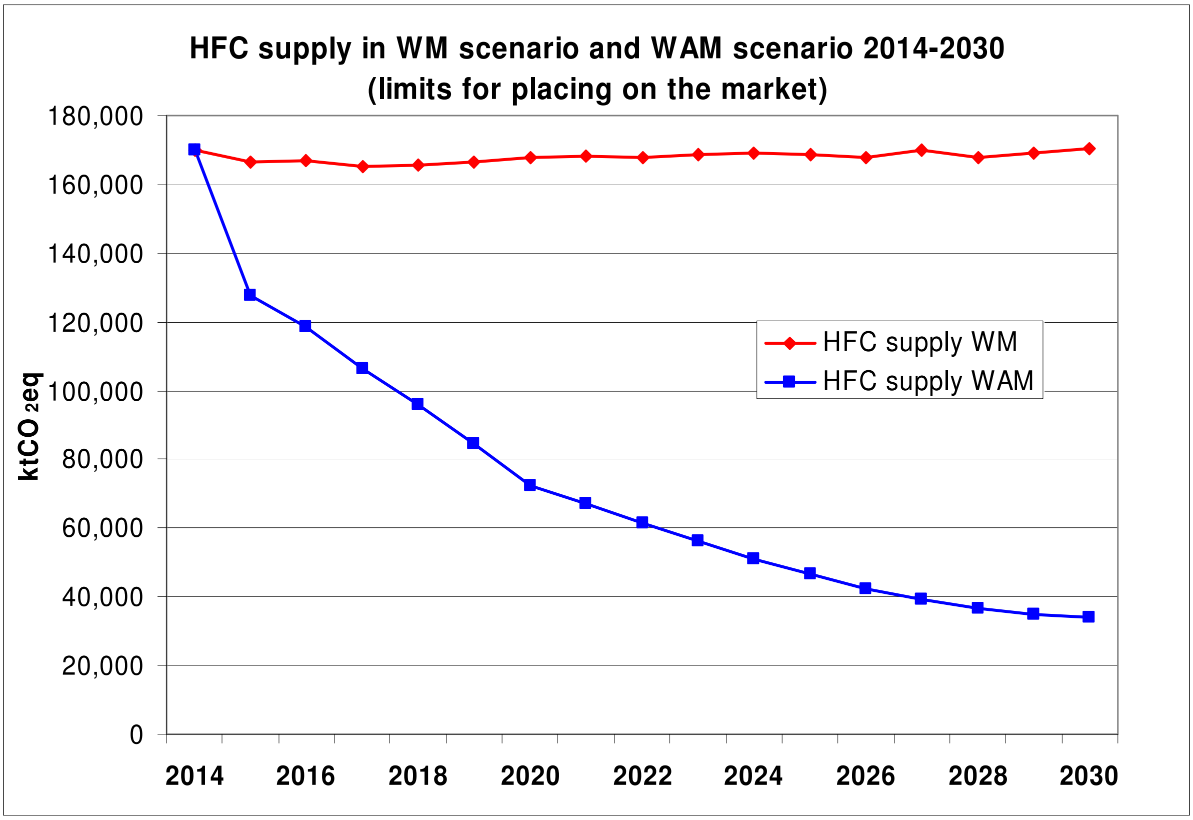

Figure 8-3: HFC supply in EU-27 in the period 2014-2030 (kt CO_2 eq) in the WM scenario (which includes application of F-gas Regulation and MAC Directive) and the WAM scenario, which relies on full establishment of the technically feasible HFC replacement potential at emission abatement costs below €50/t CO_2 eq from 2015 onwards. The remaining HFC supply is 33,900 kt CO_2 eq in 2030 (compared to 170,400 kt CO_2 eq in the WM scenario).

If HFCs would be used only in new equipment for which technically feasible alternatives are too expensive or not available from 2015 onwards (which includes first fill of passenger car MACs for export and also MDI where feasibility of alternatives is subject to further investigation), the demand for HFCs only would decrease to 33,900 kt CO_2 eq by 2030 which is 20% of the total HFC demand of 170,400 kt CO_2 eq under the WM scenario.

Sub-option D-6 could therefore allow such large reductions of HFC demand and thereby emissions. It could be used for the implementation of international HFC phase down schedules (see chapter 7) in case these are eventually agreed.

Furthermore, this option could also be implemented independently from international action of HFCs. If implemented at EU level without an international HFC agreement in place, production caps for HFC manufacturers located in EU-27 should be avoided. Controls should focus on HFCs.

This option could also be complemented by control measures for HFC-23 by-product emissions, which is also discussed at international level (chapter 5).

Sub-option D-7: Development and dissemination of BAT and BREF notes and documents

Directive 2008/1/EC concerning integrated pollution prevention and control (IPPC Directive) established the concept of best available techniques (BAT) (recast in 2010: Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (Recast)[338]) (chapter 3). The decision to issue a permit for a certain industrial or agricultural facility contains certain specific requirements including also the monitoring of substances released and sets Emission Limit Values (ELVs) for pollutants based on BAT. The Directive does not set standards or thresholds for the prevention or control of emissions, or other environmental aspects, but leaves this responsibility to the Member States, who must ensure that the ELVs were fulfilled. The application of BATs is based on BAT Reference Documents (BREFs) developed by the European Commission.

BREFs are technical documents which contain information leading up to the conclusions of what are considered to be "best available techniques" (BAT) in a general sense for the sector concerned. BREFs are intended to serve as drivers towards improved environmental performance across the European Union but neither to interpret the IPPC Directive nor remove the obligations on operators and Member States. They do not prescribe techniques or ELVs. For sectors and industry related to F-gases, several BREFs already apply (chapter 3).

ELVs refer to polluting substances with the exception of greenhouse gases if the emission trading scheme applies. A permit issued in compliance with the IPPC Directive is hence not obliged to contain the emission limit values for greenhouse gases if these are subject to an emission trading scheme and provided that there is no local pollution problem.

Hence emissions from aluminium industry could be addressed through BREFs but PFC emissions would not be in the focus of the permit as they will be included in EU-ETS from 2013.

BREFs are the outcome of an exchange of information carried out with a dedicated Technical Working Group constituted for the purpose. The Technical Working Group gathers and assesses all information required for BREFs. The European IPPC Bureau acts as neutral technically competent secretariat to all Technical Working Groups.[339]

The decision to start reviewing a BREF is taken by the Commission based on the recommendation of the Information Exchange Forum of the European IPPC Bureau on the work programme. Within the review of an existing BREF, which takes between 23 and 32 months[340], it is expected that a final draft for the reviewed BREF based on substantial data input from industry and the competent authorities in the Member States will be completed within two years and will include three plenary meetings of the Technical Working Group and the preparation of one intermediate draft BREF.

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[338] OJ L334, 17.10.2010, p. 17.

[339] European IPPC Bureau: IPPC BREF Outline and Guide, updated December 2005. ftp://ftp.jrc.es/users/eippcb/public/doc/BREF_outline_and_guide_2005.pdf

[340] European Commission: Updated Generic Schedule for the review of BREFs, May 2009.

In case of the establishment of a totally new BREF, it is expected that a final draft will be completed within about two or three years from the start of the work. The procedure to create the final draft will normally include two plenary meetings of the Technical Working Group.

BREFs constitute a rather soft instrument for environmental protection in general as they provide technical information rather than legally binding standards. Particular sectors where BREFs could be used for emission reductions include e.g. HFC-23 emissions from the production of halocarbons, F-gas emissions from photovoltaics industry.

The actual implementation of BATs based on BREFs is likely to vary between sectors and Member States and follows the lifetime of industry facilities. F-gas emission reductions caused by the implementation of BATs are difficult to quantify and project and cannot be expected to reduce emissions in the short term. Therefore, this option is not assessed further in the context of this study.

Sub-option D-8: Obligation to destroy HFC-23 emissions from halocarbon production

In Europe, HFC-23 by-product emissions formed during manufacture of HCFC-22 and HFC-32 are currently not addressed by legislation. Abatement systems have been installed by most chemical companies voluntarily and resulted in significant reductions of HFC-23 emissions since 1995 (see chapter 5.4). These emissions should be destroyed to the extent technically possible due to the high global warming potential of HFC-23 (GWP 14,800).

Under the Montreal Protocol, control measures to destroy HFC-23 as by-product of the production of HCFC-22 are being discussed[341]. If such measures are eventually agreed, HFC-23 destruction hence would need to be regulated in EU although most facilities are equipped with destruction technology already.

An obligation for the installation of HFC-23 abatement technology is hence suggested as a regulatory measure at EU level and should refer to production of all kinds of halocarbons (i.e. HCFC-22, HFC-32, new substances).

[341] UNEP 2010: Report of the Twenty-Second Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, November 2010. http://ozone.unep.org/Meeting_Documents/mop/22mop/MOP-22-9E.pdf

8.1.5 Option E: Marked-based approaches

Sub-option E-1: Include additional activities under the EU-ETS

The scope for inclusion of fluorinated gases under the EU-ETS Directive is rather limited. The Directive applies either to industrial installations that directly emit greenhouse gases or to aircraft operators but not to household or industrial appliances that mostly contribute to emissions via leakages, at the end of the lifetime or through the use of a product. PFCs from aluminium production are already covered under the Directive.

There are only few remaining sources of fluorinated gases that are directly emitted from industrial installations. One potential application is the use of SF_6 in magnesium die casting. However, most installations already phased out SF_6 and further installations are addressed by option D-4a.

Sub-option E-2: Tax schemes

Financial incentives, in particular taxes, have been mentioned by many experts as important instruments to reduce demand and supply and improve recovery of F-gases.

A recent study on behalf of the EU Commission[342] (2010) assessed taxes on virgin refrigerant sales and rebates on the return of used refrigerants for destruction as a policy option for promoting the recovery and destruction of ODS/HFCs from banks. It is suggested to promote reclamation for reuse in certain cases instead of strict destruction since it was often more cost effective and less energy-intensive to reclaim used refrigerant than to produce virgin refrigerant. Moreover, if the reclamation of used refrigerant could displace the production of new refrigerant in EU or abroad, this was an important benefit that should not be overlooked.

The lack of economic incentives, in particular for smaller companies, has been identified as the main influencing factor in a recent study for the European Commission[343] for recovery of F-gases from products and equipment at end of life. “Currently the only compelling driver for recovery at end of life is compliance with EU and national regulations”. This finding has also been confirmed by stakeholders contacted within this project. In addition, reclamation of F-gases is a complex technical process which leads to high costs for reclaimed substances compared to virgin gases.

Therefore, tax schemes should include not only production and import of virgin substances but also provide:

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[342] ICF International: Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-gases) Banked in Products and Equipment; Final Report prepared for the European Commission, May 2010; p. 57.

[343] ICF International: Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-gases) Banked in Products and Equipment; Final Report prepared for the European Commission, May 2010; p. 54. Other barriers perceived by stakeholders include legal issues arising from waste shipment legislation (Regulation (EC) No 1013/2006) and unclear roles and responsibilities for recovery of F-gases from large equipment in some Member States.

- Incentives for recovery and recycling of F-gases during service and at end of life: Reuse of recovered quantities can limit total F-gas demand and supply as tax applies to virgin substances only.
- Incentives for reclamation and destruction in appropriate facilities by tax refund at delivery of used F-gas quantities to specialized facilities.

If linked to the climate impact of the specific substance (GWP), taxes might promote the use of low or zero GWP alternatives.

Taxes on virgin sales of bulk F-gases would not address the fluorinated gases in imported products. Furthermore they would increase the price for domestically manufactured products with F-gases and could render these products less competitive. As a considerable share of F-gases emitted in the EU derives from F-gases from imported products, this option would therefore potentially not reduce F-gas emissions from banks substantially, but would render EU manufacturers of appliances using F-gases less competitive.

On the other hand a tax on F-gases in manufactured products could also address the emissions from imported appliances. As the analysis of this study has shown, there are many cost-efficient alternative options already available in many sectors. Despite negative costs the alternatives are currently not implemented. An increase in costs of HFCs induced by the tax would further improve the cost efficiency of the alternatives and could therefore lead to enhanced use of such alternatives. However, the effect will strongly depend on the tax level chosen and on the development of prices for HFCs and other fluorinated gases. As many patents for HFC production recently expired, production in Asia is strongly increasing and HFC producers may react with price decreases for HFCs to counterbalance the effects of new taxes introduced in order to keep HFC production competitive relative to alternative substances. It is rather difficult to assess price elasticity for F-gases in the context of the future development of global markets with significant growth projections of production levels in Asian countries. In this situation, it is rather uncertain, which would be the appropriate tax level. The uncertainties around the future development of prices for F-gases with an uncertain level of production growth in emerging countries are a feature which is clearly distinct from other environmental taxes on products with more stable prices. Once established, a specific tax level would stay implemented for a while and is unlikely to be changed quickly after the introduction. Therefore tax schemes that due to the uncertainty of information would set tax levels that are too low, would not result in emission reductions and it is unlikely that the lack of effectiveness can quickly be corrected.

The tax systems in place in Member States provide for substantial exemptions which render the instrument less effective in terms of emission reductions. A “Study on Environmental Taxes and Charges in the EU” (ECOTEC et al. 2001) concluded that “practice with [environmental] taxes show that most were set at low rates (with the exception of some user charges), and ramped up over time. While many express concern at this ‘ratcheting effect’, it is often the case that the rates do not increase that significantly (in real terms over time), as increased get blocked by government concern for the supposed fragility of specific industry sectors and lobbying by interest groups. This does not necessarily mean that the tax in principle is ineffective, but rather that the current form, level and associated exemptions can make the tax less effective.” Given the considerable amount of country-specific applications with F-gases, it is not unlikely that an EU tax system would also include substantial exemptions. A tax scheme complementing the lack of timely implementation of the current F-gas regulation is therefore likely to further postpone cost-effective emission reductions in the F-gas sector.

Furthermore, substantial administrative effort to establish, operate and control such tax scheme for fluorinated gases at EU level would be needed over several years, in particular for a tax that is imposed on F-gases in manufactured products due to the wide range of such products on the market charged with different F-gases.

In the past, it was difficult to agree on harmonized taxation schemes in the EU (proposals to implement a CO_2 tax failed in the past, minimum energy taxation remains at a rather low level, environmental tax schemes for pesticides, NOx, landfills, wastewater are only implemented at Member State level, not at EU level), because Member States have different national preferences in this area and some government have strong reservations against tax increases or new taxes or levies. ECOTEC et al. also conclude that "the approach has generally been for countries to adopt levies unilaterally rather than implementing them in co-ordination with other countries." From a political point of view a taxation scheme at EU level may therefore be politically more challenging than other options proposed in this section.

Experiences from Denmark and Norway have been presented in chapter 3.2. The following important aspects should be considered when implementing tax schemes:

- Set up of the scheme (including infrastructure), administration and control as well as related costs should be covered.
- As the scheme intends to enhance reclamation and destruction in specialized facilities as opposed to venting of used gases, sums needed for tax rebates are likely to increase over time. Attention should be given to imports of used F-gases from other Member States and/or countries from outside of EU-27 which might not have been placed on the national market and were hence not subject to taxation before.
- Exemptions from tax should be chosen carefully.
- The level of taxes needs to be determined nationally and should allow regular adjustments to the economic situation.
- The introduction of a maximum tax per kg in a scheme which is linked to the GWP of gases might advantage producers and importers of substances with high GWP since no additional efforts would be made to reduce the quantity used or the choice of alternatives with lower GWP to substances with very high GWP.

Sub-option E-3: Deposit and refund schemes

Financial incentives can efficiently reduce demand and supply and foster responsible use of F-gases, enhance recovery, recycling and reclamation, and support the use of low or zero GWP substances if linked to the GWP of specific substances.

The level of the financial incentives needs to be determined on Member State level and should take into account the following aspects in addition to national socio-economic circumstances in order to constitute a cost-effective tool to limit F-gas emissions:

- reclamation costs of recovered refrigerants (including costs for transport to reclamation facilities),
- initial costs for set up of the scheme (including infrastructure) and current costs of administration and control,
- costs for refunds or rebates.

Furthermore, the scheme should allow regular adjustments to the economic situation.

Generally, financial incentives at a certain level can be effective tools to avoid both, use-phase emissions through recovery and containment and the increase of potential emissions banked in equipment, in a comprehensive manner.

Nevertheless, the following particularities of financial incentive schemes should be noted:

- The time period required until F-gas emissions reach a stable level takes several years.
- Enforcement and control of compliance with the scheme is needed in order to ensure effectiveness and stable markets.
- If financial incentive schemes are introduced in few Member States only, market imbalances and implications on employment are likely, in particular if alternative technologies to current applications of F-gases are not available at equal cost.
- Deposit and refund schemes need to reflect the structure of supply of F-gases, which are likely to vary substantially from one use to another and from one Member State to another. Therefore, no generic scheme seems to be universally applicable in EU-27.
- The introduction of deposit-refund schemes might depend highly on political circumstances at national level.

Existing experiences on the establishment of financial incentive schemes should be taken into account by Member States when establishing national schemes.

8.2 Screening and ranking of options

The policy options presented in the previous section were assessed against the following criteria:

- **Effectiveness:** The effectiveness criterion addresses the expected contribution of specific policy options to the EU emission reductions until 2030 (2030 was chosen as time horizon for the modelling work). An expected emission reduction of 1,000 kt CO_2 eq (1 million t CO_2 eq) or more was used as a threshold to qualify specific policy options. 1,000 kt CO_2 eq is equivalent to 1% of current EU-27 emissions of fluorinated gases (as reported in GHG inventories 2008) or 0.02% of total EU-27 GHG emissions without LULUCF). Policies with an emission reduction potential below 1,000 kt CO_2 eq for the EU-27 would contribute to a very limited extent to the overall necessary emissions reduction. Yet, this threshold is used in a soft way and in combination with other qualitative criteria (see below).
- **Efficiency:** A public intervention could be considered as 'efficient' or 'cost effective' if its set objectives are achieved at least cost, or if its desired impact is maximized at a given level of resources. In deciding on the climate and energy package in 2008 it was found that a marginal cost of 30 €/t CO_2 eq was required for reaching a 20% reduction in GHG emissions in 2020 compared to 1990 for the GHG emissions under the ETS Directive and the Effort Sharing Decision. The time horizon used in this study is longer and extends until 2030; therefore a slightly higher threshold of 50 €/ t CO_2 eq of mitigation costs in 2030 was used in this assessment. The 50 €/t CO_2 eq is based on GHG emission reductions in the EU in 2030 that are consistent with meeting a 2 degree Celsius target and derived from the analytical work underlying the roadmap for a competitive low carbon economy.[344] Where mitigation costs of a specific policy were estimated to be higher than 50 €/t CO_2 eq, the option was discarded.
- **Technical constraints:** Some policy options face technical constraints, in particular related to the replacement of current HFC technology by abatement options. In specific applications technical requirements do not allow a full replacement in all types of applications or across the whole of the EU. In some cases technical constraints can potentially be addressed via exceptions from legal provisions. However, there are cases where such exceptions would not be applicable in an equal way in all Member States or where the definition of such exceptions would be difficult.
- **Other qualitative criteria** were used, such as the implementation of a coherent and consistent policy approach at EU level or experiences with the implementation of a policy approach. The additional qualitative criteria were mostly used in cases where additional reasons are relevant against the promotion of a policy option.

[344] A roadmap for moving to a competitive low carbon economy in 2050 (COM(2011)112 final. See i.e. Summary of the impact assessment (SEC(2011)289 final (page 8) that mentions a price of €50 to €60/tonne CO_2 eq in 2030. http://ec.europa.eu/clima/documentation/roadmap/docs/sec_2011_289_en.pdf

C-1 Environmental agreements and self-regulation

The screening of the sub-options for voluntary agreements (VA) is summarized in table 8-15.

Table 8-15: Options to address F-gas emissions in EU-27 through voluntary agreements.

Self-regulation or co-regulation	**Add. em. red. 2030**	**Abate ment costs 2030**	**Effective ness**	**Effic iency**	**Technical feasibility / penetration rates**	**Other qualitative criteria**	**Final evaluat ion**
	kt CO_2 eq	€/ t CO_2 eq	Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq			
VA with industry to phase-out/down HFCs in centralized systems, commercial hermetics, condensing units	18,818	-0.8 to 23.7	++	++	alternatives available, penetration rate 100% in 2020		Include
New VA with photovoltaic industry to replace SF_6 and NF_3	100	n.a.	-	+	alternatives available, penetration rate 100% in 2015	Photovoltaics industry likely to be willing to engage	Include
Update international VA with semiconductor industry for PFCs, NF_3, HFC-23 and SF_6	reduction potential n.e.	n.a.	-	+		VA expired in 2010	Include
New VA for XPS foams (HFC-134a)	1,553	1.0	+	+	penetration rate 100% in 2015		Include
New VA for domestic refrigeration	12	1.0	-	+	penetration rate 100%	Very small number of units containing F-gases remaining	exclude
New VA for HFC-23 in fire protection	961	3.1	+/-	+	penetration rate 100%	Very high GWP. No use in >20 MS, alternatives available	Include
New VA for HFC-23 by-product emissions	370	<2	-	+	destruction technology is available	HFC-23 destruction technology installed by most producers, only 1 production facility without	Include
Total	**21,702***						

* without semiconductor and photovoltaic industry, and domestic refrigeration; n.a.: not applicable; n.e.: not estimated.

With regard to emission reduction potentials, the most attractive option among the voluntary agreements with industry to phase-out of HFCs is in centralized systems, commercial hermetic systems and condensing units because of a high effectiveness with a potential additional emission reduction of 18.8 Mt CO_2 eq by 2030 and a high efficiency due to low abatement costs ranging from -0.8 €/t CO_2 to 23.7 €/t CO_2 eq. No technical constraints were identified in the detailed technical analysis and alternatives are available to achieve a replacement of high-GWP-HFCs by 2020. The refrigeration industry already announced a voluntary commitment which needs some further specification of objectives and monitoring and reporting procedures to turn it into a functioning environmental agreement.

The second attractive option among the proposed voluntary agreements is a new voluntary agreement for XPS foams where presently HFC-134a is used. Such agreement could potentially achieve a high effectiveness with a potential additional emission reduction of almost 1.6 Mt CO_2 eq by 2030 and a high efficiency with mitigation costs of 1 €/t CO_2 eq.

The option ranking third among the voluntary agreement options is a new voluntary agreement for HFC-23 in fire protection. Such agreement could potentially achieve a moderate effectiveness with a potential additional emission reduction of 0.96 Mt CO_2 eq by 2030 and a high efficiency with mitigation costs of 3.1 €/t CO_2 eq. There are no technical constraints for the replacement of HFC-23 with a very high GWP by e.g. the fluorinated ketone FK 5-1-12. Currently, HFC-23 is used as fire extinguishing agent in only 6 remaining Member States (in particular in Spain with >95% of European use). Due to this uneven use in Member States it may be preferable if the respective Member States take domestic measures and enter voluntary agreements for HFC-23 in fire protection.

The remaining options considered for voluntary agreements show a rather low effectiveness and emission reduction potentials of less than 1 Mt CO_2 eq by 2030, but a high efficiency with very low abatement costs. Despite the limited effectiveness, it seems useful to explore the willingness of industry to adopt further voluntary agreements for the applications with negative mitigation costs and no technical constraints.

However, as also voluntary agreements require monitoring and reporting provisions as well as administrative work to prepare the agreement, it seems uncertain whether the emission reductions for these options justify the administrative burden for the implementation.

The limited emission reduction potential of the option “voluntary agreements” is highlighted in figure 8-4 in comparison to total F-gas emissions in the periods 2015-2050 in the WM scenario.

Under the assumption that the reduction potential of VAs follows the penetration rates, i.e. that all technically feasible replacement solutions for new equipment are annually installed according to the penetration mix (chapter 6), maximum emission reduction potentials of ca. 21.7 Mt CO_2 eq until 2030 and ca. 24.7 Mt CO_2 eq until 2050 can be achieved. This would from 2015 onwards significantly reduce the projected F-gas emissions (WM) to a minimum of 82.0 Mt CO_2 eq (WAM) in 2030 and to an only slightly higher quantity of 86.6 Mt CO_2 eq in 2050.

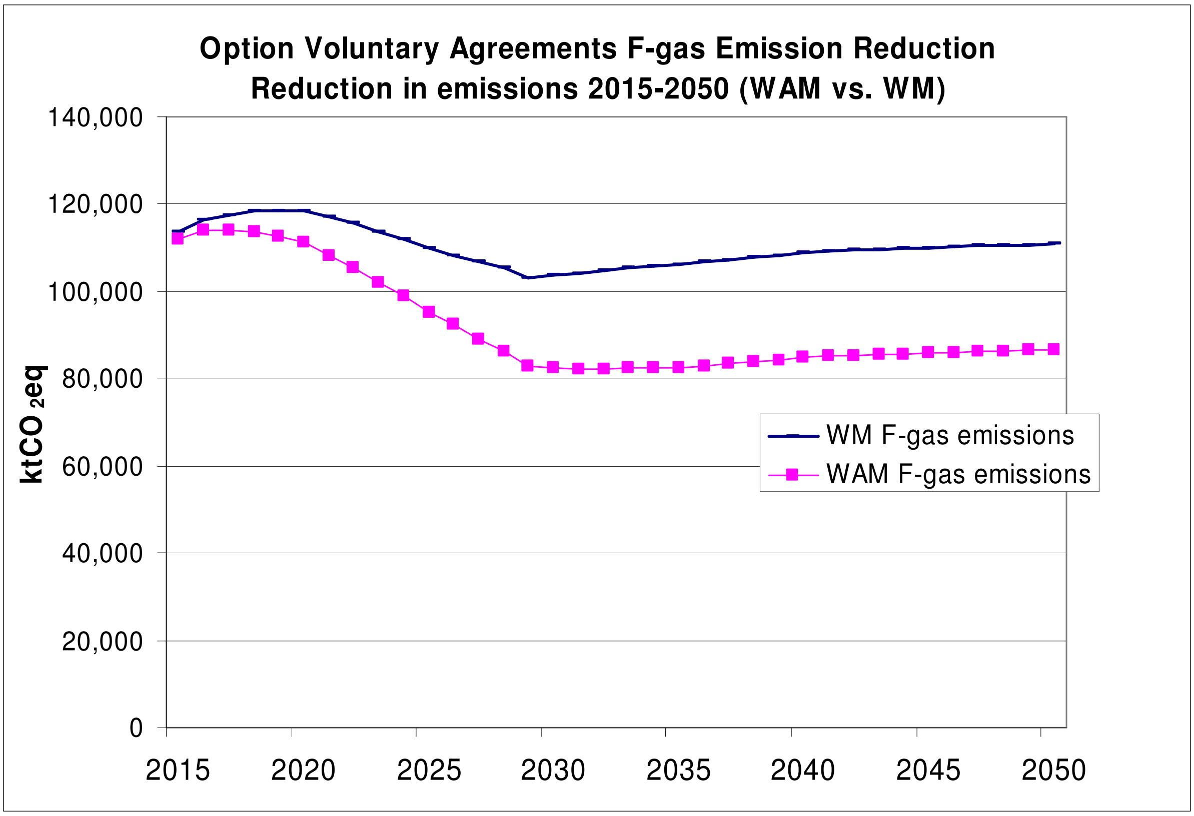

Figure 8-4: Maximum F-gas emission reduction potential (WAM) of the option "voluntary agreements", compared to F-gas emissions in the WM scenario in the period 2015-2050.

D-1: Include F-gases currently not included in Annex I of the F-gas regulation

This option is not expected to contribute to significant F-gas emission reductions but could be pursued in combination with other options as part of a wider revision of the F-gas Regulation. This option is not analysed further in this report.

D-2: Enhance application and monitoring of the Regulation

The effectiveness of the three sub-options (D-2a,b,c) under this policy option cannot be quantitatively assessed. They are not expected to achieve significant emission reductions on their own but could be pursued in combination with other options as part of a wider revision of the F-gas Regulation. This option is not analysed further in this report.

D-3 Improve containment and recovery in certain sectors

The screening of this option is presented in table 8-15.

The only option in this area that passed the assessment criteria is the inclusion of trucks and trailers in transport refrigeration under the scope of Articles 3 and 4 of the F-gas Regulation as also recommended by an earlier study for the EU Commission on this matter[345]. The inclusion of trucks and trailers shows an additional emission reduction of 1.5 Mt CO_2 eq by 2030 and an acceptable efficiency of 46 €/t CO_2 eq.

The inclusion of refrigeration in fishing vessels and air conditioning in maritime transport under the scope of the F-gas Regulation shows high efficiency, but very limited effectiveness. It is not recommended to include this sector in the F-gas Regulation, because the Regulation does not seem to be the most appropriate instrument to address F-gas emissions from this particular sector:

The Commission is currently considering general policy options to reduce GHG emissions from the maritime sector and it seems preferable to tackle fluorinated gases within such general coherent policy approach and not in a separate instrument. In the maritime sector specific circumstances apply. At the moment fluorinated gases from international maritime transport are not estimated and reported at all in GHG inventories and it would be necessary to establish new monitoring requirements at EU level for the maritime sector in order to be able to monitor emissions. For a policy instrument in the maritime sector, it is also necessary to deal with the problem of accounting of emissions from maritime transport, this means to define a particular way to allocate these international emissions to individual Member States or operators which are subsequently responsible for the emission reductions and the implementation of monitoring and reporting requirements. In the maritime sector specific international legal rules apply. The jurisdiction of countries with regard to internationally travelling vessels is based on the international law of the sea (UNCLOS 1982), which grants the International Maritime Organization (IMO) the right to establish provisions on setting Construction, Design, Equipment and Manning standards for ships. Within port states jurisdiction UNCLOS provides for the possibility for states to adopt requirements as a condition for the entry of vessels into their ports. Internal waters and ports for jurisdictional purpose are assimilated to land territory and as such a port state jurisdiction can adopt stricter standards as condition of entry of vessels including construction, design, equipment, and manning. These specific problems related to monitoring and reporting, to accounting and to the legal situation can be resolved, but they can be better addressed within a coherent EU policy instrument for all greenhouse gases from the international maritime sector than as part of the inclusion of the international maritime sector in the revision of the F-gas Regulation.

The option of lowering the applicable threshold for F-gas charges of certain equipment already covered by Article 4(1) is not analyzed further due to low effectiveness and very low efficiency. Options for all types of appliances show mitigation costs of >1,000 €/t CO_2 eq. This indicates that the cost-efficient options are already covered by Article 4(1) and that an extension cannot be justified.

[345] BIPRO 2008: Study on the potential application of Art 3 and 4 of Regulation (EC) no 842/2006 to air conditioning and refrigeration systems contained in different transport modes. Final Report on behalf of the EU Commission.

Some policy options in this area could not be quantified and they are therefore assessed based on qualitative criteria. The establishment of maximum leakage rates pursuant to Article 10(2e) of the F-gas Regulation for air conditioning and refrigeration equipment could not be quantified because better and more detailed data on actual leakage rates and compliance with legislation in place would be necessary. The establishment of additional maximum leakage rates as part of the F-gas Regulation for air conditioning and refrigeration equipment is not recommended because of the following reasons:

- Technical problems in accurately determining low leakage rates by common leak detection systems and devices.
- Maximum leakage rates do not encourage the use of equipment with low charges of F-gases or equipment with low-GWP alternatives, although high losses of a substance with high GWP causes higher global warming emissions than leakage of a refrigerant with low GWP.
- Maximum leakage rates apply during normal operation of equipment and do not include losses of refrigerant during accidents and other damage. Thus, significant emissions can still occur during equipment damage or at end of life and the establishment of large banks of HFCs continues.
- It would be very difficult to define appropriate maximum leakage rates for all Member States at EU level taken into account the differences in operation and maintenance practices.
- Such policy is likely to affect small and medium enterprises more significantly than large enterprises. Small companies operating refrigeration and air conditioning equipment would be less compliant with maximum leakage rates than large companies.
- The control of compliance with maximum leakage rates is extremely difficult and cooperative approaches in assisting companies in decreasing leakage seem more effective than the setting of limits.

The introduction of an obligation for producers and suppliers of F-Gases to take back recovered F-Gases for reclamation and destruction could also not be assessed quantitatively in the report. Industry experts contacted within the project pointed out that reclamation of used F-gases was rarely possible for technical reasons and linked to high costs of the reclamation process. This conclusion differs from a previous study on behalf of the Commission[346] that claimed low costs for this option.

[346] ICF International: Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-gases) Banked in Products and Equipment; Final Report prepared for the European Commission, May 2010.

Table 8-15: Options to address F-gas emissions through improvement of containment and recovery in certain sectors

Improve containment and recovery in certain sectors	**Add. em. red. 2030**	**Abate. costs 2030**	**Effectiveness**	**Efficiency**	**Other qualitative criteria**	**Final evaluation**
	kt CO_2 eq	€/t CO_2 eq	Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq		
Improve containment and recovery						
Inclusion in the scope of Articles 4 (1): *Refrigerated road transport - vans*	11	291	-	--	Difficult implementation and verification due to high number of operators	exclude
Inclusion in the scope of Articles 3 and 4: *Refrigerated road transport – trucks and trailers*	1,430	46	+	+		include
Inclusion in the scope of Articles 3 and 4: *Rail transport*	16	340	-	--	80% of operators already fulfil service requirements	exclude
Inclusion in the scope of Articles 3 and 4: *Refrigerated maritime transport – cargo ships*	273	10.5	-	+	F-Gas Regulation not the most appropriate instrument to address this sector: The Commission is currently considering options to reduce GHG emissions from the maritime sector, taking into account its international nature and unique characteristics. It would be appropriate to also consider addressing F-gases in such coherent approach.	exclude
Inclusion in the scope of Articles 3 and 4: *Refrigerated maritime transport – passenger ships*	405	8.5	-	+		
Inclusion in the scope of Articles 3 and 4: *Refrigerated maritime transport – fishing vessels*	360	0.5	-	+		
Lowering the applicable charge threshold of certain equipment containing F-gases already covered by Article 4(1)						
Domestic refrigeration	1	324,722	-	---		exclude
Commercial hermetics	13	29,575	-	---		
Moveable air conditioners	644	3,707	-	---		
Split air conditioners	6,057	2,204	+	---		
Heat pumps	740	1,756	-	---		

Improve containment and recovery in certain sectors (cont.)	**Add. em. reduction 2030**	**Abate. costs 2030**	**Effectiveness**	**Efficiency**	**Other qualitative criteria**	**Final evaluation**
	kt CO_2 eq		Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq		
Extending the training and certification requirements to personnel undertaking activities currently not covered under Article 5						
	Not quantifiable	Not quantifiable			Effectiveness likely to be very low.	exclude
Introducing maximum leakage rates for certain systems and equipment containing F-gases						
	Not available	Not available			Does not include accidents; problems related to measurability of leakage rates; effectiveness likely to be low	exclude
Introducing obligation for producers and suppliers of F-Gases to take back recovered F-gases for reclamation and destruction						
	Not available	Not available			Include as an area for coordination and exchange of best practice as specific measures may vary across Member States.	exclude

From the sub-options considered, only the sub option “Inclusion in the scope of Articles 3 and 4: Refrigerated road transport – trucks and trailers” meets the screening criteria. The emission reduction potential of 1,430 kt CO_2 eq is sufficiently high and the abatement costs of 46 €/t CO_2 eq are below the screening threshold.

This option provides benefits as it could be implemented immediately (e.g. in 2015). It can be assumed that after some years (general estimate in this work: 5 years) use-phase emissions in this sector, can be reduced by 40% and disposal emissions by 33% as compared to the WM scenario.

However, emission reductions that can be achieved by application of Articles 3 and 4(1) to refrigerated trucks and trailers are rather small and amount to only 1.4% of projected total F-gas emissions of 103.7 Mt CO_2 eq (2030) and 1.3% of projected 110.8 Mt CO_2 eq (2050) (figure 8-5).

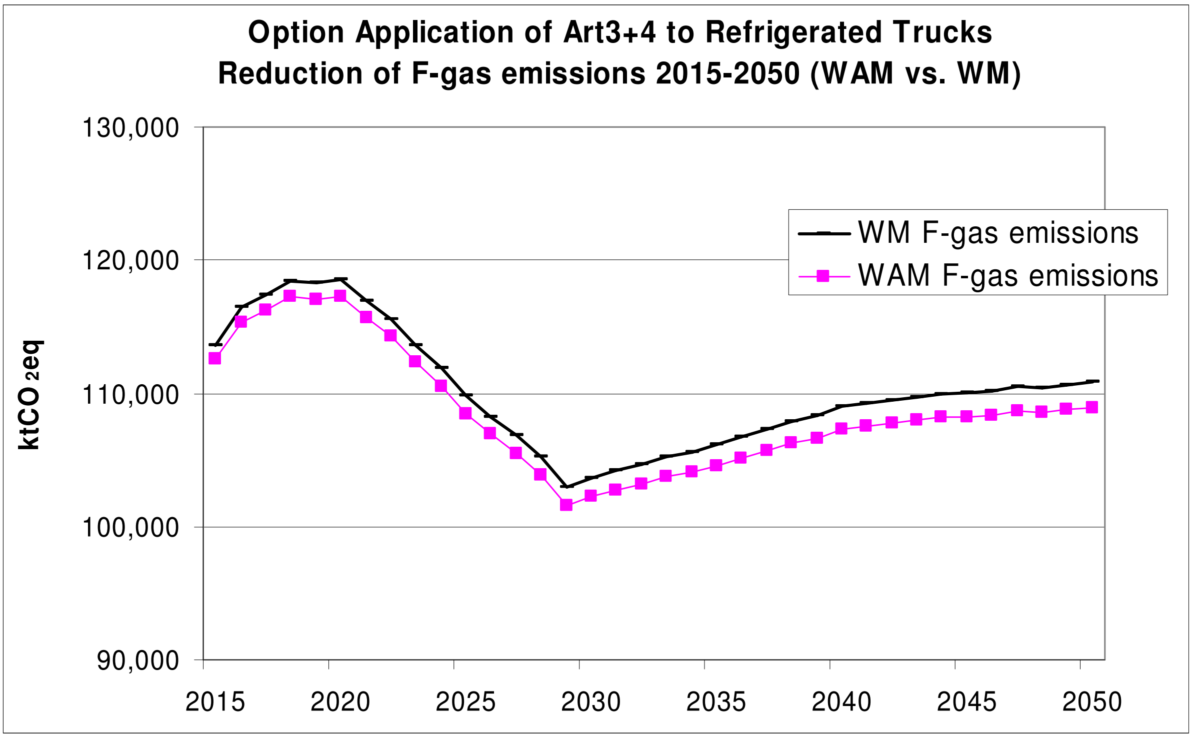

Figure 8-5: F-gas emission reduction potential (WAM) of the option "Inclusion in the scope of Articles 3 and 4: Refrigerated road transport – trucks and trailers" compared to total F-gas emissions in the WM scenario in 2015-2050. Please note that the Y-axis does not start from 0 but from 90,000 kt CO_2eq in order to better illustrate the difference between WM and WAM scenario. The reduction is 1,800 kt CO_2 eq (1.3%) in 2050 at the maximum.

In combination with other measures, this option can increase in the short term the overall emission reduction potential, as it becomes effective already in 2015.

As an example, the following figure 8-6 illustrates the additional reduction potential that can be achieved through the combination of the option "Inclusion in the scope of Articles 3 and 4: Refrigerated road transport – trucks and trailers" and the option "Ban the POM of closed applications containing F-gases: Refrigerated trucks and trailers" (start of the ban in 2030). In the period 2015-2030, the reduction potential is determined only by containment and recovery measures for this sector and amounts to 1,075 kt CO_2 eq (2015) and 1,430 kt CO_2 eq (2030).

The option "ban" becomes fully effective from 2030 and reduces the dominating impact of containment and recovery measures on emission reductions gradually until 2050. In the period 2015-2040, additional emission reductions can be achieved through containment and recovery measures, which however decrease from 2030 onwards as replacement of HFC equipment proceeds.

In figure 8-6, the combined emission reduction potential in the period 2015-2040 is indicated. Please note that this combination of options serves as example and is not the only possible combination.

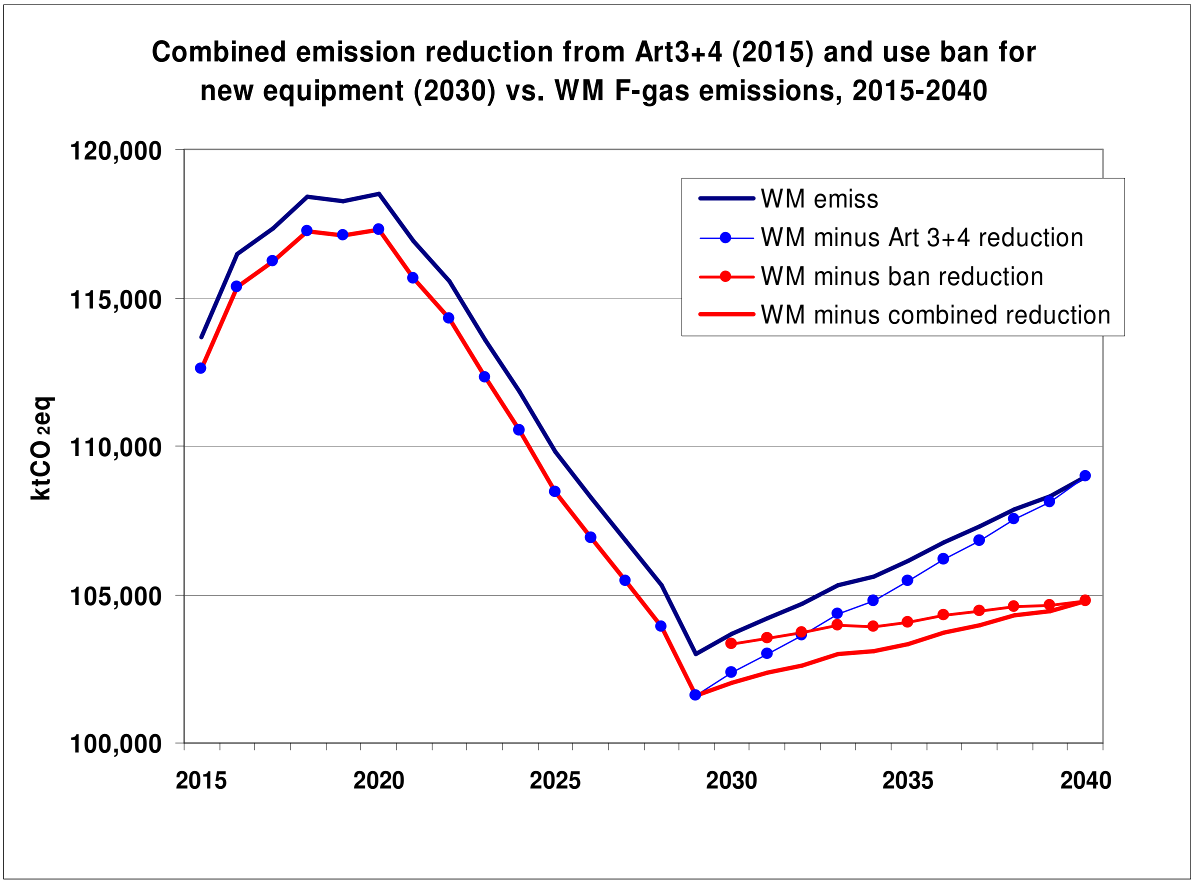

Figure 8-6: Combined F-gas mission reduction potential from application of the option "Inclusion in the scope of Articles 3 and 4: Refrigerated road transport – trucks and trailers" and the option "Ban the POM of closed applications containing F-gases: Refrigerated trucks and trailers" (start of the ban in 2030). From 2015 to 2030 the application of Articles 3+4 (blue line: WM minus Art3+4 reduction) causes emission reductions of 1,430 kt CO_2 eq in 2030. From 2030 onwards the reduction from the ban (red line: WM minus ban reduction) starts and from 2033 onwards, it is higher than that from the application of Articles 3+4 which decreases with the number of vehicles not yet replaced. The combined emission reduction potential is indicated by the bottom red line (WM minus combined reduction). Please note that the X-axis starts at 100,000 kt CO_2 eq.

It should be noted here that the option "Inclusion in the scope of Articles 3 and 4: *Refrigerated road transport – trucks and trailers*" is not included in the WAM scenario of the model AnaFgas. This is because the additional emission reduction effect is not considered high enough to substantially increase the overall reduction potential by the option "Set quantitative limits to placing on the market" which does not start from 2030 but from 2015, like the application of Art 3 and 4.

D-4 Bans of the placing on the market or use of open applications

a) SF_6 in magnesium industry

Operators have already started replacing SF_6 and seem to be ready to phase-out SF_6 in this application. Mitigation costs are low at <1 €/t CO_2 eq. Larger installations mostly phased out SF_6 while smaller installations and recyclers continue using SF_6; with a ban a consistent implementation would be achieved. Despite a rather low emission reduction potential of 0.25 Mt CO_2 eq it is nevertheless recommended to include the use of SF_6 in magnesium die casting and recycling of die casting alloys under the scope of Article 8 (table 8-16).

Table 8-16: Options to address SF_6 emissions from open applications in EU-27 through use bans

Ban the use of SF_6 in open applications	Add. em. red. 2030	Abate ment costs 2030	Effective ness	Effic iency	technical feasibility / penetration rates	Other qualitative criteria	Final evaluat ion
	kt CO_2 eq	€/ t CO_2 eq	Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq			
Inclusion of magnesium die casting <850 kg/ y and recycling of die casting alloys in the scope of Article 8							
	250	0.4	-	+	100% in 2015	Operators have started replacing SF_6, are ready to phase-out. Costs are low, smaller installations could be treated in the same way as larger ones (consistency).	include

b) HFCs in open applications

The maximum emission reduction potential had been discussed in chapter 8.1 and was presented in table 8-9 (open applications).

The screening of the sub-options for bans of use in open applications is presented in table 8-17. Open applications of F-gases result in 100% emissions during use and/or at end of life and are therefore considered separately from closed applications.

The most attractive option among the bans of use in different open applications is the ban of HFCs in technical aerosols because of a high effectiveness with a potential additional emission reduction of 3.6 Mt CO_2 eq by 2030 and a high efficiency due to low abatement costs ranging of about 10 €/t CO_2 eq. No technical constraints were identified in the detailed technical analysis (annex VI).

Bans of use would also be feasible for HFC-134a in XPS foams with an effectiveness of 1.5 Mt CO_2 eq by 2030 and an efficiency of 1.0 €/t CO_2 eq.

Other policy options that are proposed to be discarded from further analysis are

- a ban of HFC-365mfc or HFC-245fa in PU spray foam
- a ban of HFC-152a in XPS foam blowing, and

- a ban of HFC in other PU foam applications.

This is due to low efficiency in case of spray foam and due to the limited effectiveness in XPS with HFC-152a and in other PU foam which does not seem to qualify for a strong regulatory measure such as a ban. For bans in other PU foam blowing applications, technical constraints apply and exemptions are considered to be difficult to define, in particular because the sector is very heterogeneous, comprising many sub sectors with only small extent of HFC application.

Table 8-17: Options to address HFC emissions from open applications in EU-27 through placing on the market or use bans

Ban the POM of open F-gas applications	**Add. em. red. 2030**	**Abate ment costs 2030**	**Effective ness**	**Effic iency**	**technical feasibility / penetration rates**	**Other qualitative criteria**	**Final evaluat ion**
	kt CO_2 eq	€/t CO_2 eq	Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq			
Inclusion of open applications of technical aerosols and XPS and PU foam in the scope of Article 9							
Ban of HFCs in technical aerosols	3,637	10	+	+	95% in 2020	Exemptions need to be defined	include
Ban of HFC-152a in XPS foam blowing in 2015	460	-1.60	-	++	100% in 2015	GWP of 152a is much lower (124) than GWP of 134a (1,430). Could possibly be considered combined with HFC-134a.	exclude
Ban of HFC-134a in XPS foam blowing in 2015	1,553	1.0	+	++	100% in 2015	Very few companies in EU	include
Ban of HFC in PU spray foam blowing	1,369	61.6	+	+/-	100% in 2015	Relevant mainly in Spain and Portugal	exclude
Ban of HFC in other PU foam blowing	587	3.5	-	+	up to 95% in 2015	Exemptions need to be defined.	exclude
Total	**5,190***						

* only the sub-options included for further analysis

Figure 8-7 illustrates the emission reduction potential from bans of the POM of two open applications (HFCs) to be included in further analysis, technical aerosols and XPS-foam with HFC-134a. The total emission reduction potential of a placing on the market ban in these two applications amounts to 5.2 Mt CO_2 eq (2030; 5%) and 5.5 Mt CO_2 eq (2050; 5%) as compared to the total F-gas emissions of 103.7 Mt CO_2 eq. (2030) and 110.8 Mt CO_2 eq. in the WM scenario.

Compared to total F-Gas emissions in the WM scenario, the emission reduction potential of this option is limited if this option is considered separately and not in combination with other policy options.

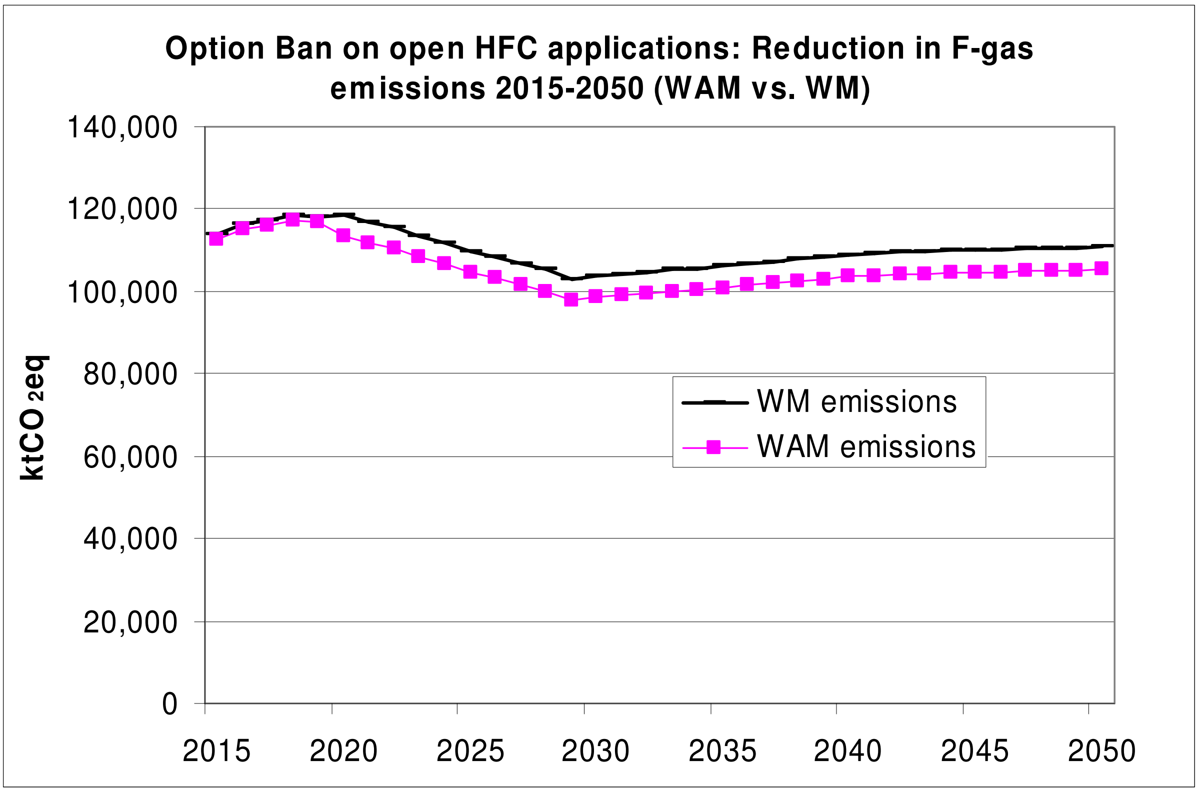

Figure 8-7: Emission reduction potential (WAM) of the option "ban of use of HFCs for open applications" compared to total F-gas emissions of the WM scenario in the period 2015-2050.

D-5 Ban of placing on the market of certain closed applications containing F-gases

A large number of closed applications were considered for a potential ban of their placing on the market in chapter 8.1 and are listed in table 8-11. The screening is shown in table 8-18.

Table 8-18: Options to address F-gas emissions from closed applications in EU-27 by placing on the market bans

Ban the placing on the market of certain closed F-gas applications	**Add. em. red. 2030**	**Abatement costs 2030**	**Effectiveness**	**Efficiency**	**technical feasibility / penetration rates**	**Other qualitative criteria**	**Final evaluation**
	kt CO_2 eq	€/t CO_2 eq	Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq			
Domestic refrigeration	12	1.0	-	+	2015		exclude
Commercial hermetic systems	147	-0.8	--	++	2020		include
Condensing units	2,849	1.2	+	+	2020		include
Centralized systems	12,055	23.7	++	+	2020		include
Small industrial refrigeration	67	-0.9	+/-	++	95% in 2030	Exemptions need to be defined for small systems, e.g. <50 kg (similar to Sweden).	include
Large industrial refrigeration	202	-21.6	+	++	95% in 2030	Exemptions need to be defined. Combination of small + large ref. possible (threshold 50 kg)	include
Moveable AC	2,781	8.9	+	+	2020		include
Single split AC	22,970	19.0	++	+	2020		include

<table>
<tr><th rowspan="2">Ban placing on the market of certain closed F-gas applications (cont.)</th><th>Add. em. red. 2030</th><th>Abate. costs 2030</th><th>Effectiveness</th><th>Effici-ency</th><th>technical feasibility / penetration rates</th><th>Other qualitative criteria</th><th>Final evaluation</th></tr>
<tr><td>kt CO_2 eq</td><td>€/t CO_2 eq</td><td>Threshold: 1,000 kt CO_2 eq</td><td>Threshold: 50€/tCO_2 eq</td><td></td><td></td><td></td></tr>
<tr><td>Multi split AC</td><td>2,172</td><td>13.1</td><td>+</td><td>++</td><td>2020</td><td></td><td>include</td></tr>
<tr><td>Rooftop AC systems</td><td>573</td><td>8.2</td><td>-</td><td>++</td><td>2020</td><td></td><td>include</td></tr>
<tr><td>Displacement chillers</td><td>1,989</td><td>5.9</td><td>+</td><td>++</td><td>2020</td><td></td><td>include</td></tr>
<tr><td>Centrifugal chillers</td><td>9</td><td>7.5</td><td>-</td><td>++</td><td>2030</td><td></td><td>exclude</td></tr>
<tr><td>Refrigerated vans</td><td>421</td><td>45.1</td><td>-</td><td>+/-</td><td>2020</td><td></td><td>exclude</td></tr>
<tr><td>Heat pumps</td><td>1,356</td><td>130.2</td><td></td><td>-</td><td>2020</td><td></td><td>exclude</td></tr>
<tr><td>Fishing vessels</td><td>27</td><td>3.4</td><td>-</td><td>+</td><td>penetration rate not 100%</td><td rowspan="3">F-gas Reg. is not the most appropriate instrument to address this sector: The Commission is currently considering options to reduce GHG emissions from the maritime sector, taking into account its international nature and unique characteristics. It would be appropriate to also consider addressing F-gases in such coherent approach.</td><td rowspan="3">exclude</td></tr>
<tr><td>Cargo ship AC</td><td>232</td><td>16.7</td><td>-</td><td>+</td><td>2020</td></tr>
<tr><td>Passenger ship AC</td><td>97</td><td>35,0</td><td>-</td><td>+</td><td>penetration rate not 100%</td></tr>
</table>

Ban the placing on the market of certain closed F-gas applications (cont.)	Add. em. red. 2030	Abate. costs 2030	Effective ness	Effici-ency	technical feasibility / penetration rates	Other qualitative criteria	Final evaluat ion
	kt CO_2 eq	€/t CO_2 eq	Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq			
Refrigerated trucks and trailers	322	2.6	-	+	2030		include
Rail vehicle AC	16	555.6	--	-	penetration rate not 100%		exclude
HFC-23 in fire protection	961	3.1	+/-	+	2015	Very high GWP. No use in 21 MS, alternatives available	include
HFC-227ea in fire protection	167	22.3	-	+	penetration rate not 100%		exclude
Medium Voltage secondary switchgear	61	347.7	-	-	penetration rate not 100%		exclude
Total	**47,089***	**16.9***					

* only sub-options included for further analysis

By far most effective sub-option among the bans of the placing on the market is the one on single split room air conditioners with a potential additional emission reduction of 22,970 kt CO_2 eq by 2030 at a moderate efficiency due to low abatement costs of €19.0. No technical constraints were identified in the detailed technical analysis for this option. The aggregated penetration mix of three low-GWP refrigerant-options is expected to reach 100% in 2020. Because of the lifetime of 10 years, the full emission reduction potential can be achieved by 2030.

With regard to further stationary air conditioning applications, moveable AC systems, multi split AC systems, rooftop systems as well as displacement chillers could possibly be considered in a ban from 2020, when the penetration rate mix has reached 100%. Rooftop systems feature abatement cost of 8.2 €/t CO_2 eq but an emission reduction potential of less than 1,000 kt CO_2 eq, with 573 kt CO_2 eq. Nevertheless they could be grouped together with multisplit systems and/or small displacement chillers systems for a wider potential ban on stationary AC systems of medium size.

The most attractive option among the bans of placing on the market in stationary refrigeration is the ban of HFCs in centralized refrigeration systems because of a high effectiveness with a potential additional emission reduction of 12.1 Mt CO_2 eq by 2030 and a moderate efficiency due to low abatement costs ranging of 23.7 €/t CO_2 eq. No technical constraints were identified in the detailed technical analysis for this option.

Another highly attractive option is a ban of HFCs in condensing units with an effectiveness of about 2.9 Mt CO_2 eq by 2030 and low mitigation costs of 1.2 €/t CO_2 eq. in 2030. These options were also addressed as part of the most attractive options for voluntary agreements. A ban may be considered in particular if a strong voluntary agreement with detailed targets, timelines and monitoring and reporting requirements cannot be realized.

Commercial stand-alone (hermetic) systems show low (even negative) abatement cost, and can be replaced 100% from 2020 onwards. The low emission reduction potential of 147 kt CO_2 eq would exclude them from a specific ban under a threshold of 1,000 kt CO_2 eq. However, as part of the sector of commercial refrigeration they could be included into a wider HFC ban for closed systems.

Refrigerated trucks and trailers which could also be addressed by improved containment and recovery measures could be considered for a placing on the market ban from 2030 at high efficiency. The emission reduction potential, which is still low in 2030, will increase to more than 3,000 kt CO_2 eq by 2040.

As already discussed under voluntary agreements (option C-1g), HFC-23 in fire protection could be considered for a ban as of 2015 because very few uses in few Member States remain and most Member States already use more sustainable alternatives. There are no technical constraints for the replacement of HFC-23 (GWP 14,800) by e.g. the fluorinated ketone FK 5-1-12. Currently, HFC-23 it is no longer used as fire extinguishing agent in 21 Member States, but only in 6 remaining Member States (in particular in Spain).

Domestic refrigeration has been identified as a sector with rather low mitigation costs of 1.0 €/t CO_2 eq by 2030 if HFC-134a would be completely phased out. However, the achievable emission reduction is limited to about 12 kt CO_2 eq until 2030 as only very few units containing F-gases are imported from outside Europe.

A ban of HFCs in industrial refrigeration would not be feasible before 2030. The emission reduction potential in the same year is rather low at 67 and 202 kt CO_2 eq in large and small systems respectively, it will however significantly grow after 2030 to > 8,000 kt CO_2 eq because of the delay due to very long equipment lifetime of 30 years. Therefore, this sub-option is not discarded. As the penetration mix reaches only 95% by 2030, exemptions need to be identified.

The qualifying bans to be included for further analysis, in total would achieve an additional emission reduction potential of about 47.1 Mt CO_2 eq by 2030.

Apart from the recommended bans described above, bans are not recommended for the following applications and reasons:

- because of low effectiveness for refrigerated vans, domestic refrigeration, rail and maritime transport, centrifugal chillers, and medium voltage secondary switchgear. A strict regulatory instrument such as a ban would need to be justified with a substantial contribution to the EU's emission reduction targets. This is unlikely, given the limited potential of these options;
- because of low efficiency and high mitigation costs for rail transport, MV secondary switchgear and heat pumps;

- due to limited availability of alternatives for HFC- 227ea in fire protection, by 2030.

Figure 8-8 illustrates the high emission reduction potential of the option „ban of the POM of closed applications containing HFCs“ compared to total F-gas emissions in the WM scenario in 2015-2050.

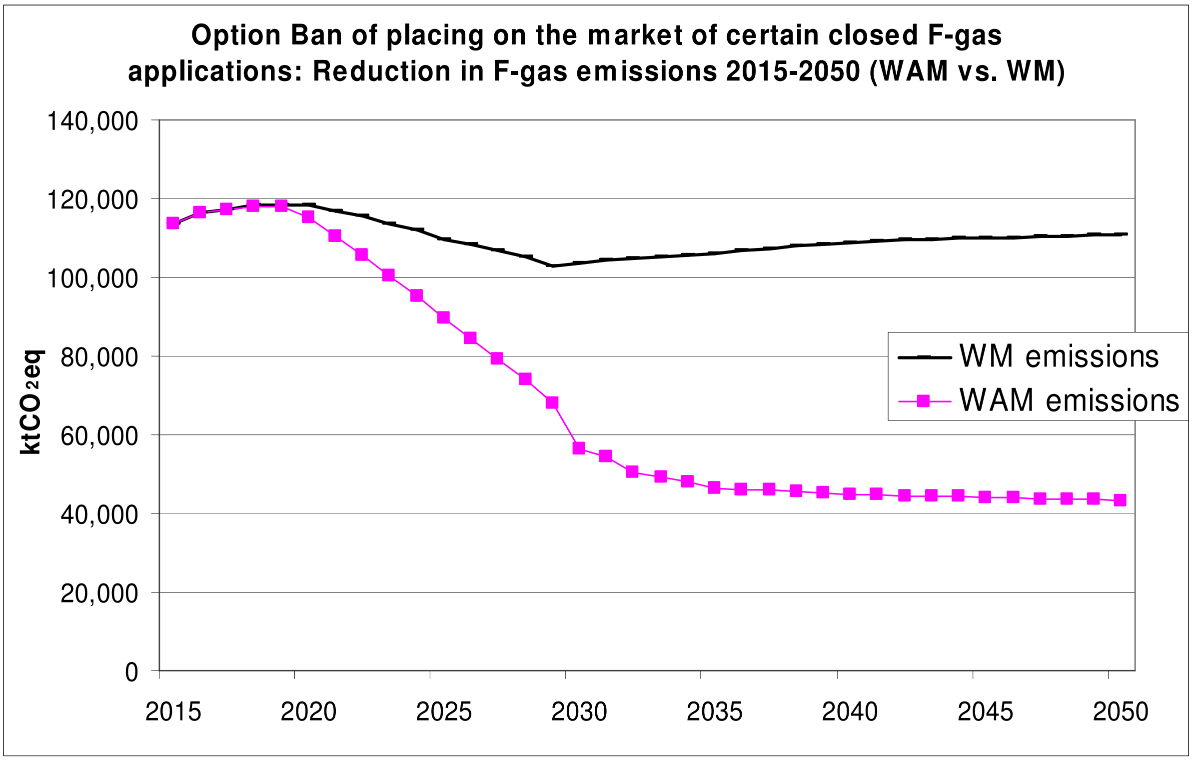

Figure 8-8: Emission reduction potential (WAM) of the option "ban of the POM of certain closed applications containing HFCs" compared to total F-gas emissions of the WM scenario in the period 2015-2050. The emission reduction potential in 2030 amounts to 47.1 Mt CO_2 eq, which is 45% of the total F-gas emissions of 103.7 Mt CO_2 eq in 2030.

In the option "voluntary agreements" it was assumed that the reduction potential of replacement solutions follows the penetration rates of alternative technologies, i.e. that every year all available replacement solutions for new equipment are installed according to the penetration mix. In this option, however, a ban can be established only when the penetration mix is at 100% (or less provided that specific exemptions can clearly be identified). This leads to a delay of emission reductions compared to the option "voluntary agreements" in sectors where both options are feasible.

However, the option „ban of the POM of certain closed applications containing HFCs“ includes a larger number of sectors which results in a high emission reduction potential of 47.1 Mt CO_2 eq in 2030 and 67.5 Mt CO_2 eq in 2050 (ban effective in all sectors not subject to exemptions). The share of the emission reduction potential in the total F-gas emissions amounts to 45% (2030) and 61% (2050).

D-6 Quantitative limits for the placing on the market of F-gases in the EU

In sub-option D-6 establishing quantitative limits for placing on the market of certain F-gases in the EU was discussed and the reduction potential for supply and thereby demand and emissions of HFCs was presented in table 8-14 by sectors. This option addresses supply ($supply_{ext2}$) of HFCs to all applications. Therefore the SF_6 applications are not relevant in this option.

As explained in chapter 8.1.4, for setting the aggregate supply limits under this option, potential reductions in three sectors of HFC applications with extraordinary high abatement cost in €/t CO_2 eq are not counted: rail air conditioning and heat pumps with abatement cost per t CO_2 eq of €556.6 and €130.2, respectively, and PU spray foam with abatement cost per t CO_2 eq of €61.5. Furthermore reductions to MDIs were also not considered as they represent a use which requires special investigation by experts from the medical and pharmaceutical industry. On the other hand, reductions from a potential technology transition in mobile air conditioning of trucks and buses (abatement cost <€ 50/t CO_2 eq) are considered.

Therefore the option D-6, while relates to all sectors relying on HFCs, relies upon technology transitions in 25 individual sectors of HFC application.

The main parameters of option D-6 are presented in table 8-19.

Table 8-19: Option to address F-gas supply in EU-27 through quantitative limits for the placing on the market of F-gases. WAM vs. WM scenario. Reference year 2030.

Set quantitative limits for the placing on the market of HFCs	Add. emission reduction 2030	Averge emission abatement costs 2030	Effective ness	Efficiency	Technical feasibility / penetration rates	Other qualita-tive criteria	Final evaluat ion
	kt CO_2 eq	€/t CO_2 eq	Threshold: 1,000 kt CO_2 eq.	Threshold: 50€/tCO_2 eq			
Maximum supply reductions in all sectors relying on HFCs : 136,500 kt CO_2 eq	71,740	16.2	+++	++	See annex VI and chapter 6	High flexibility	include

In principle, this option is suitable to implement a potential international HFC phase-down agreement under the Montreal Protocol. However, the term “supply” ($supply_{ext2}$) which is controlled under this option is wider than the term “consumption” under the Montreal Protocol, and to which the proposed amendments (NA, FSM) refer (see chapter 7). This is because this supply includes quantities of HFCs contained in imported equipment which is pre-charged outside the EU (see chapter 2.2.4 on the “second extension” of the terms supply and demand). Whilst these supply steps are derived from a bottom-up approach by considering technically feasible and cost-effective reductions to the demand on a sub-sector basis, this option would only establish the framework of the overall supply reduction and would leave the choice of technology and the timeline for replacement of HFCs in specific applications up to industry. Member States could still implement specific measures such as taxes, containment and recovery measures in order to reduce HFC supply. This option, which is considered to drive transitions to low-GWP options, could also be implemented in parallel with certain bans at EU level.

As previously explained, the underlying assessment aggregates the emission reduction potentials across different HFC applications. The potential emissions reductions that can be achieved by 2030 with quantitative limits for the placing of the market can reach 71.7 Mt CO_2 eq if all relevant sectors with marginal emission abatement cost below 50 €/t CO_2 eq make the assumed transitions to low-GWP options, and would achieve the largest emission reduction effect from all policy options considered at estimated average emission abatement cost of 16.2 €/t CO_2 eq. Thus the option taken as a whole is efficient and highly effective. Technical constraints should not apply because the aggregate limits are derived on the basis of uninterrupted use in those areas where abatement technologies do not yet exist or where they are considerably more expensive than conventional HFC technologies.

Compared to total F-gas emissions in 2015-2050 in the WM scenario, this option shows a particularly high emission reduction potential (figure 8-9). In contrast to the option for placing on the market bans, this option assumes that the emission reduction potential follows the gradual growth of the penetration rates of alternative technologies, i.e. that each year all technically feasible replacement solutions for new equipment are exploited according to the penetration mix even though the full market penetration potential might not have been achieved yet.

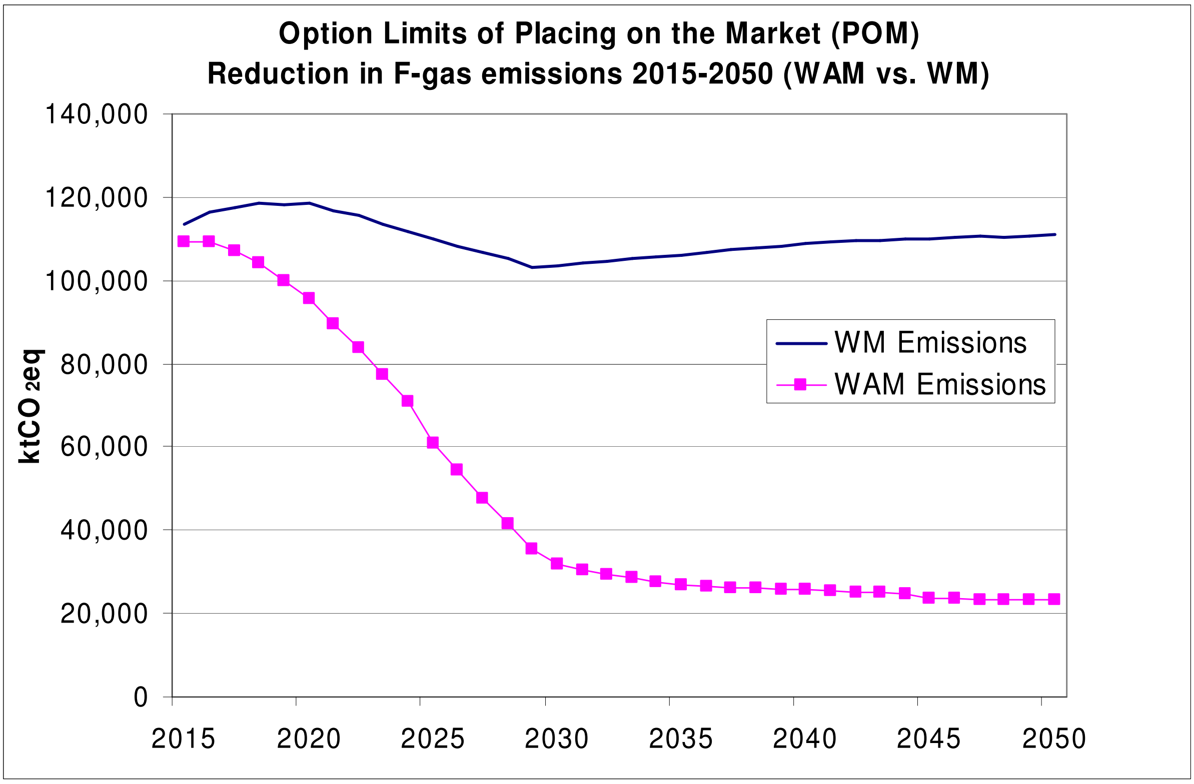

Figure 8-9: F-gas emission reduction potential (WAM) of the option "Limits of Placing on the Market of HFCs" compared to total F-gas emissions in all sectors in the WM scenario.

The emission reduction potential in 2030 is significantly higher than in the option "bans of use" and amounts to 71.7 Mt CO_2 eq representing almost 70% of total F-gas emissions in the WM scenario (103.7 Mt CO_2 eq). In 2050, it reaches at 87.6 Mt CO_2 eq (79% of total HFC emissions of 110.8 Mt CO_2 eq in the WM scenario in 2050).

This option relies on the limitation and gradual reduction of supply of HFCs. The HFC supply, which is assumed to be identical to HFC demand in a certain year, is closely connected to the emissions from the existing conventional HFC technologies in that year. The supply serves not only the demand for first fill of equipment but also for the refill which compensates for use-emissions. First fill means also the charge in pre-charged equipment which is imported to the EU, and the charge in equipment which is pre-charged in the EU for export from the EU to third countries.

As a consequence, the reduction in supply which follows the reduction in the demand during the development of the penetration rates of alternative technologies, leads at the same time to a reduction in the corresponding emissions from conventional technologies. This assumption is illustrated in figure 8-10. Please note that reference is not the total of F-gases but of HFCs only.

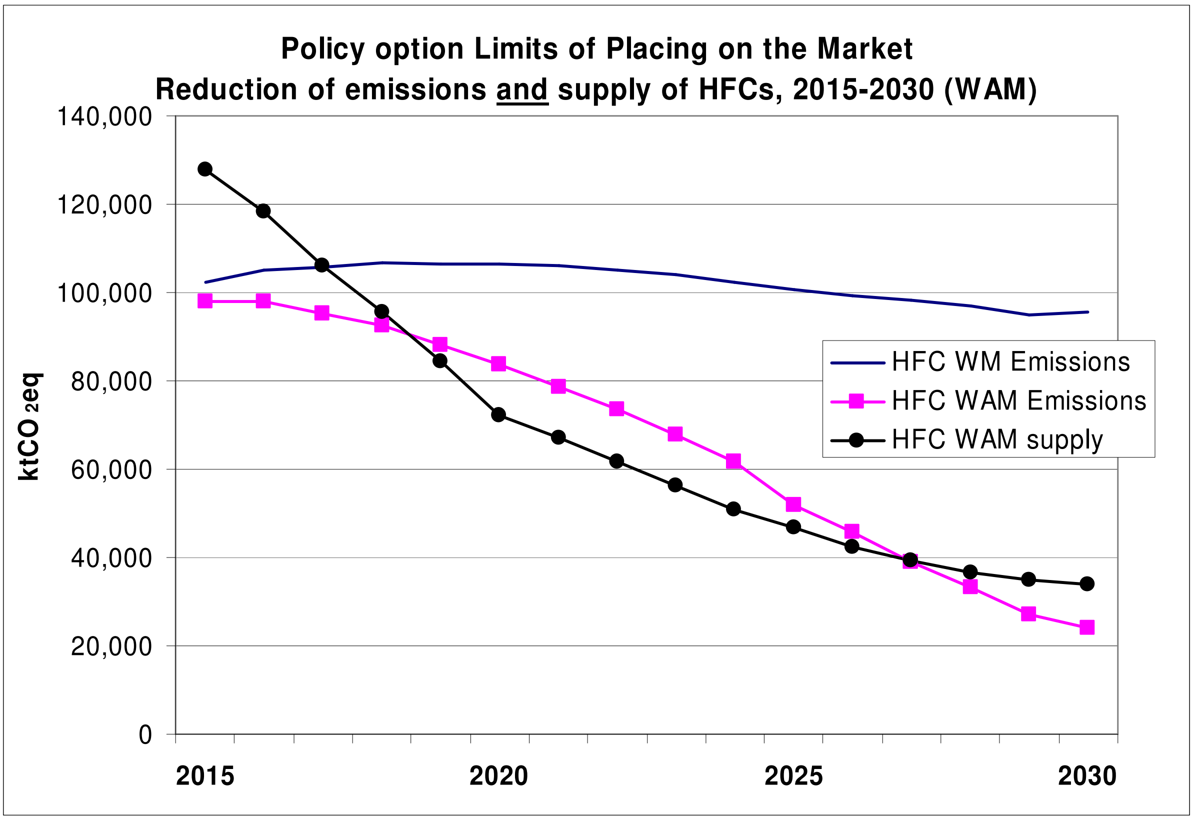

Figure 8-10: Technically feasible and cost-effective reduction of HFC supply (WAM) for implementation of the option "Limits of Placing on the Market of F-gases" and corresponding reduction of HFC emissions (WAM) compared to total emissions in the WM scenario in all sectors of deliberate HFC application in the period 2015-2030. The supply curve starts in 2015 at a higher level than the emission curve. From 2018 onwards it runs below the emission curve, because the MAC Directive shows effect and the HFC supply for first fills of equipment in the other sectors can be reduced comparably fast so that supply is increasingly limited to servicing of existing HFC technology.

The gradual limitation of the HFC supply, which leads indirectly to reduction in HFC emissions, follows the gradual development of the penetration rates of alternative technologies. However, the intervals between two reduction steps may be longer. If, merely as an example, policy makers would decide for three years intervals, the supply limits could look as displayed in figure 8-11.

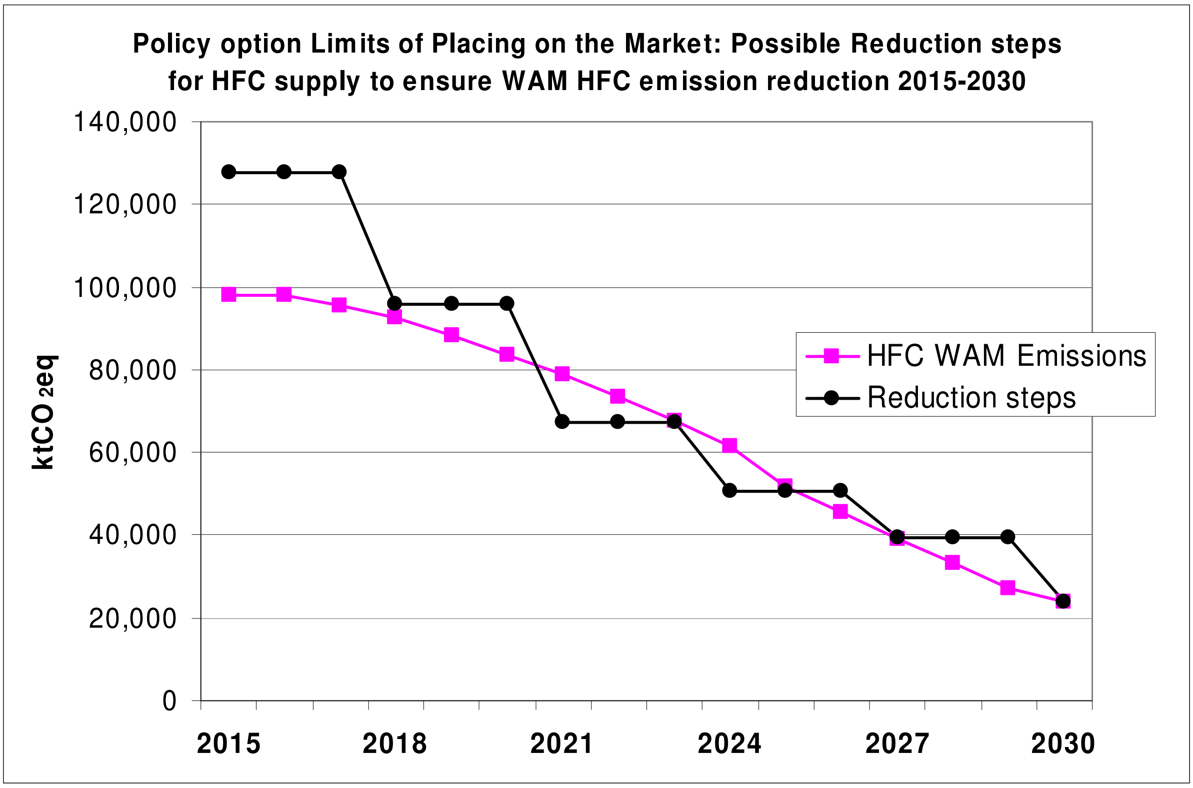

Figure 8-11: Possible reduction steps for HFC supply to achieve the HFC emission reductions according to the policy option "Limits of Placing on the Market".

D-8 Obligation to destroy HFC-23 emissions from halocarbon production

This sub-option considers the introduction of an obligation for destruction of inadvertent by-product emissions from halocarbon production. While the emission reduction potential of this option is comparably low, the very high GWP of HFC-23 and the fact that the formation of these emissions is not a deliberate application but an industrial process underline the need for a separate policy option here. Furthermore, such option may potentially be needed for implementation of international commitments under the Montreal Protocol, if such control measures currently proposed by Parties are agreed.

The screening of this option is presented in table 8-20.

Table 8-20: Options to address inadvertent HFC-23 emissions in EU-27 through the obligation for destruction of these emissions.

HFC.23 emissions from halocarbon production	**Add. em. red. 2030**	**Abatement costs 2030**	**Effective ness**	**Efficiency**	**Technical feasibility / penetration rates**	**Other qualita-tive criteria**	**Final evaluat ion**
	kt CO_2 eq	€/t CO_2 eq	Threshold: 1,000 kt CO_2 eq	Threshold: 50€/tCO_2 eq			
Destruction of HFC-23 emissions from halocarbon production to the extent technically feasible	370	<2	+	+++	100%	Industrial process emiss.; very high GWP; internatio nal commitm ents	include

E-1 to E-3 Market-based instruments

As already explained in section 8.1.5 there are rather few remaining sources of fluorinated gases that are directly emitted from industrial installations. The ETS Directive does not cover industrial appliances that mostly contribute to emissions via leakages, at the end of the lifetime or through the use of a product.

One potential application is the use of SF_6 in magnesium die casting, however most installations already phased out SF_6 and the remaining use can be better addressed by a ban as proposed above. In addition the revision of the ETS Directive was completed after a long stakeholder consultation process and the inclusion of sectors is defined until 2020, therefore there is currently no scope to increase the coverage of the EU-ETS.

A general tax schemes for the use of HFCs at EU level seems to be a strong policy intervention. Taxes on sales of virgin refrigerants would address the same appliances that are currently already regulated under the F-gas Regulation. As the analysis of this study has shown, there are many cost-effective alternatives options already available in many sectors. Despite negative abatement costs the alternatives are currently not implemented to a large scale, and a small increase in costs of HFCs would further improve the cost efficiency of the alternatives. However, this may still not be sufficient to implement alternatives at a larger scale in the EU.

In the past, it has been difficult to agree on harmonized taxation schemes in the EU because Member States have different national preferences in this area. Furthermore, substantial administrative effort to establish, operate and control such scheme at EU level might be needed over several years.

Nevertheless, tax schemes can be used as additional policy instruments at national level in the Member States and complement EU policies. In this way, the particular situation of certain sectors in each Member State could be taken into account, e.g. through exemptions from tax or the level of taxes.

Deposit and refund schemes are implemented in some Member States and require a considerable amount of administrative and financial detail and will depend on Member States infrastructure. As the general framework for reclamation and reuse is already set by the F-gas Regulation, deposit and refund schemes seem to be options for Member States to implement the regulation, similar to tax schemes, which might also take into account the recovery, reclamation and destruction of F-gases. A detailed scheme at EU level may not be necessary.

Overall ranking of policy options

Table 8-21 summarizes the screening of policy options presented in this section. The setting of quantitative limits for the placing on the market of HFCs results in the policy options with the largest emission reduction effect of about 71.7 Mt CO_2 eq by 2030.

The emission reductions presented in this table are not cumulative, since they cover at least partially the same applications.

Table 8-21: Summary of potential emission reductions (kt CO_2 eq) resulting from the key policy options in 2030

Proposed policy option	**Additional emission reduction potential in 2030 (kt CO_2 eq)**
C-1 Voluntary agreements	21,700
D-1 Include F-gases currently not included in the Regulation	Low. Not quantified
D-2 Enhance application and monitoring of the Regulation]	Low. Not quantified
D-3 Improve containment and recovery under F-gas Regulation: Refrigerated trucks and trailers	1,430
D-4 Ban the POM of certain open applications containing HFCs	5,190
D-4 Ban the use of SF_6 in open applications	250
D-5 Ban the POM of certain closed applications containing F-Gases	47,100
D-6 Set quantitative limits for the placing on the market of F-gases in EU	71,740
D-8 Obligation for destruction of HFC-23 emissions from halocarbon production	370

Potential combinations of options and implications

The overview table 8-22 presents the correlation of the key policy options per sectors.

Table 8-22: Key policy options per sectors

Sectors	F-gas	Policy options considered
Domestic refrigeration	HFCs	Set quantitative limits for the placing on the market of HFCs in EU
Commercial refrigeration	HFCs	Voluntary agreement to phase out/down the use of HFCs
		Ban the POM of certain closed applications containing HFCs
		Set quantitative limits for the placing on the market of HFCs in EU
Industrial refrigeration	HFCs	Set quantitative limits for the placing on the market of HFCs in EU
Transport refrigeration	HFCs	Improve containment and recovery under F-gas Regulation: Refrigerated trucks and trailers
		Ban the POM of certain closed applications containing HFCs
		Set quantitative limits for the placing on the market of HFCs in EU
Stationary air conditioning	HFCs	Ban the POM of certain closed applications containing HFCs
		Set quantitative limits for the placing on the market of HFCs in EU
Mobile AC ship/rail	HFCs	Set quantitative limits for the placing on the market of HFCs in EU
Foam	HFCs	Voluntary agreement to phase out/down the use of HFCs
		Ban the POM of certain open applications containing HFCs
		Set quantitative limits for the placing on the market of HFCs in EU
Fire protection	HFCs	Voluntary agreement to phase out the use of HFC-23
		Ban the POM of HFC-23 fire protection
		Set quantitative limits for the placing on the market of HFCs in EU
Aerosols	HFCs	Ban the POM of certain open applications containing HFCs
		Set quantitative limits for the placing on the market of HFCs in EU
Magnesium industry	SF_6	Ban the use of SF_6 in certain open applications
Semiconductor industry	PFCs, NF_3, SF_6, HFC-23	Renew voluntary agreement to reduce PFC, SF_6, NF_3, HFC-23 emissions
Photovoltaics industry	SF_6, NF_3	Voluntary agreement to phase out the use of NF_3 and SF_6
Halocarbon production	HFC-23	Voluntary agreement for HFC-23 destruction to the extent technically possible
		Obligation for HFC-23 destruction to the extent technically possible

All of these options could be supplemented by the approaches listed under options D-1, which suggests including F-gases currently not covered by the F-gas Regulation, and D-2 aiming at enhanced application and monitoring of the existing legislation (chapter 8.1.4). Although emission reduction potentials and related costs of such measures are not estimated in this report, they could contribute to improved F-gas bank management and monitoring.

The policy options “VAs”, “Placing on the market bans for certain open applications (HFCs)”, “Placing on the market bans for closed applications” and “Limits for the placing on the market of HFCs” address several sectors while the policy options “Containment and recovery” and “HFC-23 destruction” relate to one particular sector each. Certain sectors are addressed by one policy option only, such as semiconductor and photovoltaic industries (voluntary agreements) and magnesium industry (use ban for open applications).

Voluntary agreements

- This option can cover several sectors.
- The existing regulation remains in place.
- Additional measures are agreed upon by means of voluntary commitments by industry and should include comprehensive monitoring and reporting requirements as well as quantitative targets for F-gas emission reductions and a defined timeline.
- The implementation of this option depends on a high number of players which vary between sectors.
- Individual VAs could be implemented both separately and in addition to regulatory options.

This option could be combined with other options:

- A phase-down of HFCs could be combined with VAs in certain sectors.

Containment and recovery in transport refrigeration (trucks and trailers)

- This option refers to one sector only.
- This option would be in line with the concept applied by the F-gas Regulation, which could be amended by additional requirements for containment and recovery of F-gases in refrigerated road transport (trucks and trailers).
- Requirements would cover existing and new road transport refrigeration equipment containing F-gases.

This option could be combined with other regulatory options:

- A ban of the POM of transport refrigeration containing HFCs from 2030.
  Implications: Emissions from existing equipment would be lowered by improved containment and recovery while the equipment would continue to be produced, placed on the market and used until the ban enters into force. Bans for other sectors could be established in addition.
- Limits for placing on the market of HFCs.
  Implications: Emissions from existing equipment would be lowered by improved containment and recovery while use of low GWP options in new transport refrigeration would be driven by the HFC phase down.
- Destruction of HFC-23 emissions from halocarbon production.
  Implications: No overlap between these measures.

Bans for the POM of certain open applications (HFCs)

- This option relates to the use of HFCs as propellants in technical aerosols and the use of HFCs as foam blowing agents in the foam sectors (XPS foam, PU spray foam, other PU foam).

- The option relies upon changes of the production lines and production processes.
- The bans would need to start at defined dates per sector/application, which vary between 2015 and 2020.
- Sub-options could be implemented separately.
- This option would be in line with the concept already applied by the F-gas Regulation, which could be amended to include bans for the open applications (e.g. Art 9; novelty aerosols, one-component-foam etc.).

This option could be combined with other regulatory and voluntary options:

- VAs addressing other sectors: Semiconductor industry, photovoltaic industry, halocarbon production.
- Requirements for containment and recovery of F-gases in transport refrigeration (trucks and trailers).
  Implications: No overlap between these measures.
- Bans for the use of F-gases in open applications (SF_6).
  Implications: No overlap between these measures.
- Bans for the POM of certain closed applications containing F-gases.
  Implications: No overlap between these measures.
- Limits for placing on the market of HFCs.
  Implications: HFC supply in foam and aerosol sectors no longer necessary.
- Destruction of HFC-23 emissions from halocarbon production
  Implications: No overlap between these measures.

Bans for the use of F-gases in open applications (SF_6)

- This option relates to the use of SF_6 in magnesium die casting (industrial process).
- The option relies upon changes of the production processes in small Mg die casting facilities (<850 kg) and recycling of alloys.
- This option would be in line with the concept already applied by the F-gas Regulation, which could be amended to include bans these open applications (e.g. Article 8 “Control of use”).

This option could be combined with other regulatory and voluntary options:

- All VAs suggested.
- Requirements for containment and recovery of F-gases in transport refrigeration (trucks and trailers).
  Implications: No overlap between these measures.
- Bans for the use of F-gases in open applications (SF_6).
  Implications: No overlap between these measures.
- Bans for the POM of closed applications containing F-gases.

Implications: No overlap between these measures.

- Limits for placing on the market of HFCs.
  Implications: No overlap between these measures.
- Destruction of HFC-23 emissions from halocarbon production.
  Implications: No overlap between these measures.

<u>Bans for the POM of certain closed applications containing F-gases</u>

- This option relates to several sectors and applications.
- The option covers new equipment only.
- Bans would need to start at defined dates per sector/application, which vary between 2015 and 2030.
- Sub-options could be implemented separately.
- Current requirements of the F-gas Regulation should continue for existing equipment containing F-gases.

This option could be complemented by other regulatory and voluntary options:

- VAs addressing other sectors: Semiconductor industry, photovoltaic industry, halocarbon production.
- Requirements for containment and recovery of F-gases in transport refrigeration (trucks and trailers).
  Implications: Total emission reductions from the transport refrigeration sector would increase through a combination of containment/recovery measures for existing equipment and a ban for the POM of new transport refrigeration equipment (see option D-3, figure 8-6).
- Bans for the POM of open applications (HFCs).
  Implications: No overlap between these measures.
- Bans for the use of F-gases in open applications (SF_6).
  Implications: No overlap between these measures.
- Limits for placing on the market of HFCs.
  Implications: Particular bans could potentially facilitate the option “Limits for placing on the market of HFCs” as they could eliminate some of the demand that will be served by the limited supply instead of living all sectors to adjust to the limited supply on their own.
- Destruction of HFC-23 emissions from halocarbon production.
  Implications: No overlap between these measures.

<u>Limits for POM of HFCs</u>

- This option would address all sectors using HFCs.
- This option could be applied in two scenarios:

a) Independently from an international agreement on HFC phase down, to contribute to GHG emission reductions and the EU's related targets.

b) To implement a potential international agreement on HFC phase down.

- High flexibility would be provided to industry and industrial planning schedules could be respected due to the long time span of several decades.

This option could be complemented by other regulatory and voluntary options:

- All VAs suggested.
  Implications: No overlap between these measures.
- Containment and recovery in transport refrigeration (trucks and trailers) could precede limits for placing on the market of HFCs used in transport refrigeration. Implications: Emissions from existing equipment would be lowered by improved containment and recovery. This would possibly lower the demand in this sector.
- Ban of the POM of certain open applications containing F-gases.
  Implications: Bans could help the management of the option “Limits for placing on the market of HFCs” as they would set priorities for sectors subject to HFC phase out.
- Ban of the use of F-gases in open applications (SF_6).
  Implications: No overlap between these measures.
- Ban the POM of closed applications containing F-gases.
  Implications: Bans could help the management of the option “Limits for placing on the market of HFCs” as they would set priorities for sectors subject to HFC phase out.
- Destruction of HFC-23 emissions from halocarbon production.
  Implications: No overlap between these measures.

<u>Destruction of HFC-23 emissions from halocarbons production</u>

- This option refers to one sector only and could start very soon.
- This option relies upon installation of destruction technology in few installations, monitoring and reporting.
- This option may be needed for implementation of international commitments, currently proposed under the Montreal Protocol.

This option could be complemented by other regulatory and voluntary options:

- VAs addressing other gases: All other VAs.
  Implications: No overlap between these measures.
- Requirements for containment and recovery of F-gases in transport refrigeration (trucks and trailers).
  Implications: No overlap between these measures.
- Bans for the POM of F-gases open applications (HFCs).
  Implications: No overlap between these measures.

- Bans for the use of F-gases in open applications (SF_6).
  Implications: No overlap between these measures.
- Bans for the POM of closed applications containing F-gases.
  Implications: No overlap between these measures.
- Limits for POM of HFCs.
  Implications: No overlap between these measures.

The maximum emission reduction potential in the reference year 2030 could be achieved by the package of options presented in table 8-23. 2015 has been determined as the start year although some options could technically be implemented earlier than 2015.

Table 8-23: Combination of options which would lead to the maximum additional emission reduction potential in 2030[347]

Proposed policy option	Sectors concerned	Suggested start	Additional emission reduction potential in 2030 (kt CO_2 eq)
Limits for POM of HFCs	HFC applications	2015	71,740
Ban the use of F-gases in magnesium die casting <850 kg/yr and recycling of alloys	Magnesium industry	2015	250
Destruction of HFC-23 emissions from halocarbon production	Chemical industry	2015	370
Certain VAs	Semiconductor industry, photovoltaic industry	2015	Ca. 120
TOTAL			**Ca. 72,500**

[347] The option on containment/recovery in the transport refrigeration sector has not been included in the maximum additional emission reduction potential because the emission reductions that could be achieved through this type of measure at comparably high cost are small compared to the reductions that could be gained through the option of limiting the POM of HFCs in the same sector.

8.3. Key impacts and comparison of policy options

In chapter 8.1 a number of policy options have been presented, and in chapter 8.2 these options were subject to screening. In addition to the detailed assessment of the impact of those measures on supply/demand and emissions of F-gases presented in previous chapters, annex VII also considers other key environmental, economical and social impacts, likely to occur as a result of the remaining options considered .The largest emission reductions can be achieved with policy option D-6, quantitative limits for the placing on the market of fluorinated gases, which can lead to an emission reduction of 71,740 kt CO_2 eq of direct emissions and potentially up to a further reduction of 1,580 kt CO_2 eq of indirect emissions in 2030. Policy option D-5, the ban of the POM of closed applications containing F-gases, could also achieve a very substantial emission reduction of about 47,100 kt CO_2 eq of direct F-gas emissions and up to 715 kt CO_2 eq of indirect emissions in 2030. The third largest direct emission reduction of 21,700 kt CO_2 eq of F-gas emissions and 510 kt CO_2 eq of indirect emissions could be achieved via policy option C-1, the voluntary agreements.

These three policy options address mainly the same subsectors and therefore their emission reductions cannot be aggregated under a combination of the individual options. The different level emission reduction effects of these three policy options are due to the different scope of subsectors of the options. For example, for voluntary agreements (C-1) it was assumed that only sectors with very low marginal abatement costs for alternative substances would commit to voluntary agreements. Therefore the analysis for key impacts of voluntary agreements includes a smaller number of subsectors than for the bans of application (D-5) or the quantitative limits for placing on the market (D-6). The scope of subsectors for the quantitative limits for placing on the market (D-6) is larger than for the ban in closed applications as a result of the increased flexibility that the policy option of the quantitative limits for placing on the market offers. Furthermore, the option D-6 also considers a technology transition of mobile air conditioning of buses and trucks. On the other hand a ban in this sub-sector would be more appropriate as part of the review of the MAC Directive rather than of the F-Gas Regulation (option D-5). The emission reductions that are achievable by the other policy options are rather low compared to these three options and also compared with the total magnitude of EU emissions from fluorinated gases.

The estimated abatement costs for the three main policy options with high emission reduction effects are at comparable level (14 - 17 €/ t CO_2 eq) and clearly fall in the range of cost-efficient abatement costs that have been selected as a threshold for the implementation of policies and measures in moving the EU to a competitive low-carbon economy in 2050.

The direct net costs for the sectors affected are highest at estimated 1,500 M€/year for policy option D-6, the quantitative limits for the placing on the market, due to the large number of sectors affected by individual measures, followed by policy option D-5, the ban of the POM of closed applications containing F-gases, with 1,055 M€/year.

The same ranking appears for the equipment investment costs which are the highest for policy option D-6, the quantitative limits for the placing on the market, with 5,613 M€/year in 2030 and for policy options D-5, the ban of the POM of closed applications containing F-gases, with 2,860 M€/year. Due to the fact that these options release the largest new investments in the affected subsectors, they will also have the highest positive effects on the creation of additional jobs at equipment suppliers. However, the replacement of fluorinated gases by alternatives with low GWPs will decrease the costs for maintenance and service required under the current F-gas Regulation in the long-term and will therefore negatively affect the number of jobs in the areas of maintenance and service. However, the positive job effects due to the additional investments will be considerable larger.

Tables 8-24 and 8-25 provide a summary of these findings as a basis for comparison of the key policy options and for their further consideration.

Table 8-24: Overview of key environmental, economic and social impacts in 2030

	Environmental impacts			Economic impacts			Social impacts		
Subsectors affected	Number of units in 2030 (replaced, serviced)	Reduction of direct F-gas emissions in 2030	Reduction of indirect energy-rel. CO_2 emiss.	Marginal emission abatement cost	Direct net costs to sector	Direct cost per operator	Equipment investment cost / sales of equipment suppliers[c]	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Employ-ment (equipment + service)
	No.	kt CO_2 eq	kt CO_2 eq	€/tCO_2 eq	M€/year	€ /year	M€/year	M€/year	
Option C-1 Voluntary agreements									
Commercial hermetics	5,737,309	150	79	-0.8	-0.12	-0.02	81.3	-14.3	++
Condensing units	3,020,046	3,930	202	1.2	105.0	2.9	752.7	-185.9	+++
Centralized systems	144,901	14,740	234	23.7	418.8	2,283	773.9	-86.3	+++
Fire protection HFC-23	24,455	960	n.a.	3.1	3.18	130	0.0	-2.2	0[d]
XPS-134a	13 (production lines)	1,550	n.a.	1.0	1.2	98,000	2.5		+
Photovoltaic industry to replace SF_6 and NF_3	n.e.	80 (SF_6) 20 (NF_3)	n.a.	~ 0	~ 0	~ 0	~ 0		0
Semiconductor industry	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.		n.e.
HFC-23 by-product emissions	1 destruction plant	370	n.e.	< 2	0.55	0.55	0.3		+
Total voluntary agreements	**8,926,711**	**21,700[a]**	**515**	**16.8[b]**	**528.6[a]**	**-**	**1,610.7[a]**	**-288.9**	**+++**

	Environmental impacts			Economic impacts			Social impacts		
Subsectors affected	Number of units in 2030 (replaced, serviced)	Reduction of direct F-gas emissions in 2030	Reduction of indirect energy-rel. CO_2 emiss.	Marginal emission abatement cost	Direct net costs to sector	Direct cost per operator	Equipment investment cost / sales of equipment suppliers[c]	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Employ-ment (equipment + service)
	No.	kt CO_2 eq	kt CO_2 eq	€/tCO_2 eq	M€/year	€ /year	M€/year	M€/year	
Option D-3 Improved containment and recovery									
Trucks and trailers	631,000	1,430	n.a.	46	66.4	105.2	n.a.	+71.3	++
Sub option D-4a Ban the use of F-gases in open applications (SF_6)									
SF_6 in Mg die casting and recycling of die casting alloys	20 plants	250	0	0.4	0.01	500	0.1	n.a.	0
Sub option D-4b Ban the POM of certain open applications containing F-gases									
Aerosols	9,082,589 cans	3,640	0	10	36.3	n. e.	0	n.a.	0[d]
XPS-134a	13 prod. lines	1,550	0	1	1.2	98,000	2.5	n.a.	+
Total ban open appl.		**5,190**	**0**	**7**	**37.5**	**3.2**	**2.5**[b]	**n.a.**	**+**
Option D-5 Ban the POM of certain closed applications containing F-gases									
Commercial hermetics	5,307,011	150	73	-0.8	-4.64	-0.02	70.7	-13.3	++
Condensing units	2,421,320	2,850	162	1.2	82.44	2.9	602.2	-157.1	+++
Centralized systems	134,032	12,060	220	23.7	380.1	2,283	714.1	-80.0	+++
Industrial Ref small	462	70	6	-0.9	-0.07	-153	5.2	+0.5	+
Industrial Ref large	225	200	52	-21.6	-5.10	-22,642	38.6	+0.3	+++
Refrigerated Trucks	63,185	320	12	2.6	0.96	15.2	16.5	+0.04	+
Moveable AC systems			n.e.						0
	34,283,827	2,780		8.9	18.76	0.5	74.4	-85.7	

	Environmental impacts			Economic impacts			Social impacts		
Subsectors affected	Number of units in 2030 (replaced, serviced)	Reduction of direct F-gas emissions in 2030	Reduction of indirect energy-rel. CO_2 emiss.	Marginal emission abatement cost	Direct net costs to sector	Direct cost per operator	Equipment investment cost / sales of equipment suppliers[c]	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Employ-ment (equipment + service)
	No.	kt CO_2 eq	kt CO_2 eq	€/tCO_2 eq	M€/year	€ /year	M€/year	M€/year	
Split AC systems	96,697,511	22,970	n.e.	19.0	488.72	5.1	630.4	-483.5	+++
Multi split AC systems	1,376,202	2,170	n.e.	13.1	45.74	26.4	278.4	-228.4	++
Rooftop AC systems	522,524	570	n.e.	8.2	11.78	9.0	99.2	-85.3	+
Chillers	714,570	1,989	191	5.9	33.05	25.2	330.5	-134.1	+++
Fire protection 23	24,455	960	n.e.	3.1	3.18	130.1	0	-2.2	0[d]
Total ban closed appl.	**141,545,325**	**47,089**	**716.6**	**16.9**	**1,055,0**	**-**	**2,860.2**	**-1,270.2**	**+++**
Option D-6 Quantitative limits for the placing on the market of HFCs									
Domestic Refrigeration	2,783,424	12	1.8	1.0	0.01	0.004	2.0	-0.3	+
Commercial hermetics	5,737,309	149	79	-0.8	-0.12	-0.02	81.3	-14.3	++
Condensing units	3,020,046	3,927	202	1,2	105.0	2.9	752.7	-185.9	+++
Centralized systems	144,901	14,741	234	23.7	418.8	2,283	773.9	-86.3	+++
Industrial Ref small	5,968	871	75	-0.9	-0.92	-153	67.3	-6.5	++
Industrial Ref large	2,909	2,612	668	-21.6	-65.9	-22,642	498.7	-3.6	+++
Refrigerated Vans	601,764	421	7	45.1	20.9	31.8	17.8	+1.5	+
Refrigerated Trucks	532,335	2,990	100	2.6	16.8	15.2	141.7	+3.7	++
Fishing vessels	365	405	9	3.4	1.96	5,368	6.3	+0.7	+
Cargo ship AC	3,715	320	1	16.7	5.60	1,504	4.1	+0.01	+
Passenger ship AC	469	125		35.0	2.90	6,190	0.7	+0.0	0
Bus AC	609,411	1,616		48.5	107.1	158	1,011.4		+++
Truck AC	19,520,29	4,170		43.1	227.9	11.7	724.2		+++
Moveable AC systems	34,283,82	2,781		8.9	18.7	0.55	74.4	-85.7	0
Split AC systems	96,697,51	22,970		19,0	488.7	5.1	630.4	-483.5	+++
Multi split AC systems	1,570,583	2,827		13.1	53.5	26.4	316.6	-256.0	++
Rooftop AC systems	522,524	573	207	8.2	11.8	9.0	99.2	-85.3	+

	Environmental impacts			Economic impacts			Social impacts		
Subsectors affected	Number of units in 2030 (replaced, serviced)	Reduction of direct F-gas emissions in 2030	Reduction of indirect energy-rel. CO_2 emiss.	Marginal emission abatement cost	Direct net costs to sector	Direct cost per operator	Equipment investment cost / sales of equipment suppliers[c]	Loss (-) / Gains (+) from service Art 3+4 or new service for NH_3+CO_2 M€/y	Employ-ment (equipment + service)
	No.	kt CO_2 eq	kt CO_2 eq	€/tCO_2 eq	M€/year	€ /year	M€/year	M€/year	
Chillers	771,866	2,512		5.9	36.3	25.2	357.0	-143.7	+++
Centrifugal chillers	3,799	82		11.1	1.51	318	3.0	-3.1	0
Fire protection 227ea	48,550	440		22,3	10.9	225	5.4	-4.4	0[d]
Fire protection 23	24,455	961		3.1	3.18	130	0.0	-2.2	0[d]
Aerosols	9,082,589 cans	3,637		10.0	36.3	4.0	0		0[d]
XPS-152a	13 prod. lines	460		-1.6	-0.7	-56,400	2.5		+
XPS-134a	13 prod. lines	1,553		1.0	1.2	98,000	2.5		+
PU other	77 prod. lines	587		3.5	0.32	4,130	3.3		+
Total limits placing on market	**166,886,028[e]**	**71,740**	**1,583**	**16.2**	**1,500.0**	**-**	**5,612.8**	**-1,355.7**	**+++**
Option D-8 Mandatory destruction of HFC-23 emissions from halocarbon production									
Destruction of HFC-23 emissions to the extent possible	1 plant	370	n.a.	<2	0.55	n.a.	0.3	n.a.	0

n.e. = not estimated
n.a. = not applicable
[a] Without semiconductor and photovoltaic industries.
[b] Without photovoltaic and semiconductor industry, and without HFC-23 by-product emissions.
[c] Equipment without first fill of substance.
[d] Employment effect on suppliers of low-GWP substances (propellant gas or fire extinguishing agents) is not considered.

Table 8-25: Summary of environmental, economic and social key impacts in 2030

Impacts	Unit	Option C-1	Option D-3	Option D-4a	Option D-4b	Option D-5	Option D-6	Option D-8
Environmental impacts								
Reduction of direct F-gas emissions in 2030	kt CO_2 eq	21,700	1,430	250	5,190	47,090	71,740	370
Reduction of indirect energy-related emissions in 2030	kt CO_2 eq	514	n.a.	0	n.a.	716	1,583	n.a.
Economic impacts								
Marginal emission abatement costs	€/t CO_2 eq	17	46	0.4	7	17	16	< 2
Direct net costs to sectors	M€/year	528.6	66.4	0.01	37.5	1,055.0	1,500.0	0.55
Direct cost per operator	€/year	-	105.2	500	3.2	-	-	n.a.
Social impacts								
Equipment investment cost	M€/year	1,610.7	n.a.	0.1	2.5	2,860.2	5,612.8	0.3
Losses (-) from ceased service under Art 3+4	M€/year	-289	71.3	n.a.	n.a.	-1,270.2	-1,355.7	n.a.
Employment		+++	++	0	+	+++	+++	0

ANNEXES

Separate annex documents include:

- Annex I: Questionnaires to authorities and industry
- Annex II: Cost data
- Annex III: Description of the model AnaFgas
- Annex IV: Global Data Input Sheets
- Annex V: EU Sector Sheets
- Annex VI: Abatement technologies by sectors
- Annex VII: Analysis of key impacts

ABBREVIATIONS

AC	Air conditioning
ACRIB	Air Conditioning and Refrigeration Industry Board
ADEME	French Agency for the Environment and Energy Management
AFBEL	Spanish Association of high-voltage switchgear industry
AFCE	Alliance Froid Climatisation Environnement (France)
AFEAS	Alternative Fluorocarbons Environmental Acceptability Study (industry organisation)
AHRI	Air Conditioning, Heating and Refrigeration Institute (USA)
AnaFgas	Analysis of Fluorinated greenhouse gases in the EU-27 (model)
ANIE	Federazione Nazionale Imprese Elettrotecniche ed Elettroniche (Italy)
AO	Abatement Option
AR	Assessment Report
AREA	Air conditioning and Refrigeration European Association
ASSURE	European Association for Responsible Use of HFCs in Fire Fighting
ATF/Italy	Associazione dei Tecnici (Italy)
BAT	Best Available Techniques
BAU	Business as usual
BREF	BAT Reference Document
BSRIA	Building Services Research and Information Association
BWP	Bundesverband Wärmepumpe
CAA	Clean Air Act
CAPIEL	Coordinating Committee for the Associations of Manufacturers of Industrial Electrical Switchgear and Control
Cat.	Category
CDM	Clean Development Mechanism under the Kyoto Protocol
CECED	European Committee of Domestic Equipment Manufacturers
CEFIC	European Chemical Industry Council
CEI	Central European Initiative
CFCs	Chlorofluorocarbons
CFF	PU Sandwich panels with flexible facings, boardstock
ChemKlimSchVO	Chemikalien-Klimaschutz-Verordnung
CIBSE	Chartered Institution of Building Services Engineers
CME	PU sandwich panels with metal facings, continuous
COP	Conference of the Parties
COR	PU insulation for commercial refrigeration
CRF	Common Reporting Format
CSS	Carbon Capture and Storage
DEC	Department of Energy and Climate Change (UK)
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DIP	PU Sandwich panels with metal facings, discontinuous
DIS	Data Input Sheets
DKK	Danish krone
DKV	Deutscher Kälte- und Klimatechnischer Verein (Germany)
DNV	Det Norske Veritas a classification society with the objective of "Safeguarding life, property, and the environment"
DOR	PU insulation for domestic refrigeration
DPI	Dry Powder Inhaler

DTI	Deutsches Tiefkühlinstitut (Germany)
EC	European Commission
ECA	Enhanced Capital Allowance
ECCP	European Climate Change Programme
ECHA	European Chemicals Agency
ECSLA	European Cold Storage and Logistics Association
ECCA	European Electronic Component Manufacturers Association
EERC	Estonian Environmental Research Centre
EFCTC	European Fluorocarbons Technical Committee
EHPA	European Heat Pump Association
EIA	Environmental Investigation Agency (non-governmental organization)
ELV	End of Life Vehicles
ELV	Emission Limit Value
EMAS	Eco-Management and Audit Scheme
EMEA	European Medicines Agency
EN	European norm
EPA	Environmental Protection Agency
EPB Directive	Energy Performance of Buildings Directive
EPEE	European Partnership for Energy and Environment
ESIA	European Semiconductor Industry Association
ESO	European Standardization Organizations
EU-15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.
EU-27	EU-15 plus Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia.
EU-ETS	European Emissions Trading System
EuP Directive	Energy using Products Directive
EURELECTRIC	Union of the Electricity Industry
EUROFEU	The European Committee of the Manufacturers of Fire Protection Equipment and Fire Fighting Vehicles
EUROSTAT	Eurostatistics
EVA	European Vending Association
ExCOM	Executive Committee (of the Multilateral Funds)
EXIBA	European Extruded Polystyrene Insulation Board Association
Exp.	Expenses
FAO	Food and Agriculture Organization of the United Nations
FEA	European Aerosol Federation (Fédération Européenne des Aérosols)
FPS	Fire Protection System
FSM	Federated States of Micronesia
GDP	Gross Domestic Product
GEF	Green European Foundation
GESTIS	database on international limit values
GGAP	Greenhouse Gas Abatement Program
GHG	Greenhouse gas
GINA	Global Initiative for Asthma
GSHP	ground source heat pump
GTP	Global Temperature Potential
GWP	Global Warming Potential
HARMONAC	Harmonizing Air Conditioning Inspection and Audit Procedures in Tertiary Building Sector
HBFCs	Hydrobromofluorocarbons

HC	Hydrocarbon
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HEEP	HFC Emissions Estimating Programme
HVAC	Heating, Ventilating, and Air Conditioning
HV	High Voltage
HVS	High Voltage Switchgear
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IED	Industrial Emissions Directive
IET	International Emissions Trading
IMPEL	Implementation and Enforcement of Environmental Law
IMS Health	Intercontinental Medical Statistics Health
INV	Inventaires des émissions des fluides frigorigènes et de leurs émissions
INT	Integral foams for automotive and furniture sectors
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control
ISO	International Standard
ISOPA	European Diisocyanate and Polyol Producers Association
JI	Joint Implementation Mechanism under the Kyoto Protocol
JRAIA	Japanese Refrigeration and Air conditioning Industry Association
KFCh	National Refrigeration Forum (NRF) (Poland)
KMO	Danish Refrigerant Installers (organisation)
LCD	Liquid Crystal Displays
LT	Low Temperature
MAC	Mobile Air Conditioning
MACC	Marginal Abatement Cost Curve
MEAs	Multilateral Environmental Agreements
MDI	Metered-dose Inhalers
MLF	Multilateral Funds of the Montreal Protocol
MOP	Meeting of the Parties (to the Montreal Protocol)
MS	Member State
MT	Medium Temperature
MV	Medium Voltage
NA	North American
NAMA	National Appropriate Mitigation Action
NERA	National Economic Research Associates
NGO	Non-governmental organisation
NIR	National Inventory Report
NMBC	National Monitoring and Certification Body (Hungary)
OCF	One-Component Foam
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substances
OEM	Original Equipment Manufacturer
OFN	Oxygen Free Nitrogen
ORC	Organic Rankine Cycle
PED	Pressure Equipment Directive
PFCs	Perfluorocarbons
ppm	parts per million

PRTR	Pollutant Release and Transfer Register
PU	Polyurethane
QPS	Quarantine and Preshipment
RAC	refrigeration and air conditioning
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RED (scenario)	Reduction scenario
RED10 (scenario)	Reduction scenario incl. abatement at cost <10 €/t CO_2 eq
RRRD	Recovery, recycling, reclamation, destruction
RTRU	PU insulation for refrigerated trucks and reefer containers (RTRU)
SERCOBE	Asociación Española de Fabricantes de Bienes de Equipo (Spain)
SF_6	Sulfur hexafluoride
SIRAPA	Portuguese Environment Protection Agency
SKM Enviros	Eco-Efficiency Study of Supermarket Refrigeration
SNEFCCA	French Association of companies active in the refrigerant sector
SPVD	Single Pressure Vessels Directive
SRAC/HP	stationary refrigeration, air conditioning and heat pumps
SROC	Special Report on Safeguarding the Ozone Layer and the Global Climate System by UNEP TEAP/IPCC (2005)
SSA	substances stable in air
SWEDAC	Swedish Board for Accreditation and Conformity Assessment
SYKE	Finnish Environment Institute
T&D Europe	European Association of the Electricity Transmission and Distribution Equipment and Services Industry
TEAP	Technology and Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TFA	Trifluoroacetic acid
TOC	Technical Options Committee
TPED	Transportable Pressure Equipment Directive
uHFC	Unsaturated HFCs
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESA	Asociación Española de la Industria Eléctrica
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	U.S. Environmental Protection Agency
VAT	Value added tax
VDE	Association for Electrical, Electronic and Information Technologies (Germany)
VDKF-LEC	Verband Deutscher Kälte-Klima-Fachbetriebe - Leakage and Energy Control
VDKL	Verband Deutscher Kühlhäuser und Kühllogistikunternehmen e.V (Germany)
VDMA	Verband Deutscher Maschinen- und Anlagenbau e.V.
VdS Schadenverhütung	Verband der Sachversicherer Schadenverhütung GmbH
VOC	Volatile Organic Compound
VRF	Variable Refrigerant Flow
WAM (scenario)	With Additional Measures (scenario)
WEEE	Waste Electrical and Electronic Equipment
WM (scenario)	With Measures (scenario)
WOM (scenario)	Without Measures (scenario)
XPS	Extruded polystyrene foam (insulation foam boards)
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (Germany)