30 MONTREAL PROTOCOL

**BACKGROUND** // SEPTEMBER 2017

# 1987–2017: 30th Anniversary of the Montreal Protocol

## From the phase-out of CFCs to the phase-down of hydrofluorocarbons

German Environment Agency

Umwelt Bundesamt

# Imprint

**Publisher:**
Umweltbundesamt (German Environment Agency)
Section III 1.4 Substance-related product issues
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**Design:**
Atelier Hauer + Dörfler GmbH, Berlin

**Publications as a pdf:**
www.umweltbundesamt.de/publikationen

**Photo credits:**
Title: shutterstock.com

Image 1: DLR (CC-BY 3.0); Image 2: Greenpeace/Zenit 1992; Image 3: Ludwig Ries; Image 4: Kerstin Martens; Image 5: Frigoteam Handels GmbH; Image 6: Hafner-Muschler Kälte- und Klimatechnik GmbH & Co. KG; Image 7: efficient energy; Image 8: UBA 2008; Image 9: DB Uwe Miethe, 2016

Timeline (chronological): Molina publication, UBA website, Hoffmann/ UBA 2017, 2. BImSchV (cover page), from Nasa. gov http://www.nasa.gov/topics/earth/earthday/earth-day_gallery.html – http://www.nasa.gov/images/content/ 324490main_ ozone_full.jpg, in the public domain, https:// commons.wikimedia.org/w/ index.php?curid=10044020, Dieter Vennemann/Greenpeace 1990, Kerstin Martens, By Avantique – Own work, CC BY-SA 3.0, https://commons.wiki-media.org/w/index.php?curid=17782178, Sabine Vielmo/ Greenpeace 1992, UBA

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As at: July 2017

ISSN 2363-8273

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## Acronyms used

| | |
|---|---|
| BMU | German Federal Ministry for the Environment, Nature Conservation and Nuclear safety |
| $CO_2$eq | $CO_2$-equivalent (global warming impact converted to $CO_2$) |
| CFC | chlorofluorocarbon |
| PFC | perfluorocarbon |
| GAW | Global Atmosphere Watch |
| GCOS | Global Climate Observing System |
| GWP | global warming potential |
| HCFC | hydrochlorofluorocarbon |
| HFC | hydrofluorocarbon |
| % m/m | percent by mass |
| ODP | ozone depletion potential |
| ODS | ozone depleting substances |
| ppt | parts per trillion ($10^{12}$) |
| PUR | polyurethane |
| $SF_6$ | sulphur hexafluoride, a greenhouse gas with a very high global warming potential |
| TEWI | total equivalent warming impact: the total greenhouse gas quantity due to emissions from the refrigerant and the energy required to operate a refrigeration or air conditioning system during its period of operation (stated in $CO_2$ equivalents) |
| UBA | Umweltbundesamt (German Environment Agency) |
| UNO | United Nations Organisation |

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# 1 CFCs – a threat to the ozone layer

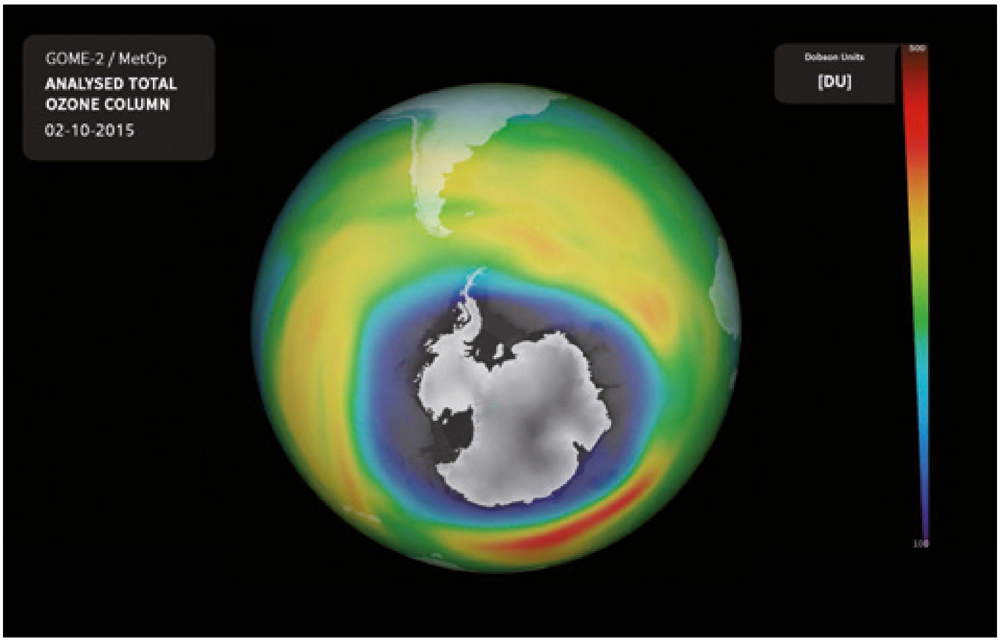
It is a sucess story that the term CFC has become almost unknown to the younger generation of today. After all, it shows that the substances responsible for one of the biggest environmental problems play almost no role in our everyday lives.

CFC is short for chlorofluorocarbons, a group of highly stable gases. Some 30 years ago, CFCs were used in very high quantities, for example as propellants in aerosol cans, as solvents, refrigerants, and foam blowing agents. These substances remain in the atmosphere for decades, and in some cases centuries, where they deplete the ozone layer. Other substances such as fire extinguishing agents (halons) deplete the ozone layer as well. Furthermore, CFCs and halons contribute to global warming due to their high global warming potential.

The ozone layer is located in the lower stratosphere, at a height of 15 to 30 kilometres above earth, protecting it against ultraviolet (UV-B) solar radiation. If the ozone concentration decreases, the increasing radiation is harmful to plants, animals and people. People can be at risk of developing skin cancer when exposed to the higher UV-B radiation. The ozone layer depletion is at its worst at the North and South Poles and is also referred to as the “ozone hole”.

The ozone hole above Antarctica was first confirmed in the autumn of 1985, but it was far earlier, in 1974, that Frank Sherwood Rowland and Mario Molina, chemists at the University of California in Irvine, published their ground-breaking theory in collaboration with Paul Crutzen that CFC molecules were damaging the ozone layer [2]. To finally transfer the scientists’ findings into actions to protect the ozone layer required a fundamental rethink, as CFCs were in widespread use and manufacturers in the world’s industrialised nations, including Germany, were not prepared to abandon CFCs from one day to the next. Additionally, some doubts questioning the destructive impact of the CFCs arose. In 1982, for a short period, some forecasters even believed that the predicted depletion of the ozone layer had been overestimated.

It was only pressure from scientists, environmentalists and ultimately the world of politics that paved the way to the phase-out of CFCs. We now know that the researchers far underestimated the risk, as the ozone layer is only recovering very slowly. In 1995, Rowland, Molina and Crutzen were presented with the Nobel Prize in Chemistry and thus received belated recognition for their work in the area of atmospheric chemistry.




The ozone layer above the South Pole in October 2015: The ozone hole reaches record proportions once again [1]. The deeper the blue, the lower the levels of ozone in the atmosphere.

# 2 The milestone – the 1987 Montreal Protocol

In March 1985 the Vienna Convention, a multilateral framework agreement was reached that called on the nations of the world to share information and take steps to protect the ozone layer. As a follow-up agreement, on 16th September 1987, the Montreal Protocol was signed by the first 24 nations and the European Community, for the first time obliging the signatories to undertake specific steps to reduce the manufacturing and use of ozone depleting substances. It entered into force on 1st January 1989.

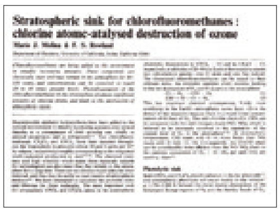
197 parties, among them all 193 UN member states, ratified the Montreal Protocol. At the annual conferences, the signatory states discuss the reduction measures and the future development of the Montreal Protocol. The Montreal Protocol, its revisions and a wide range of reports and information are available from the Ozone Secretariat of the United Nations [3].

At the 2016 Kigali conference, hydrofluorocarbons (HFCs) with high global warming potentials, were the most recent group of substances to be included in the Montreal Protocol. HFCs are used in large quantities as substitutes for ozone depleting substances. Unfortunately, they contribute to global warming. Therefore, their use is now being reduced on a step-by-step basis worldwide. Proven technical solutions which can replace HFCs are now available for all of their key areas of use. Developing countries which are still permitted to use certain ozone depleting substances could therefore easily leapfrog climate-damaging HFCs and move straight over to halogen-free substances and processes.

# 3 The success story

## Key events since 1974

### 1974


Stratospheric sink for chlorofluoromethanes : chlorine atomic-catalysed destruction of ozone

Scientists Rowland and Molina highlight the risk to the ozone layer due to CFCs for the first time.

### 1975

The German federal government conducts some initial studies on CFCs and supports more than 20 projects to explore the earth's atmosphere.

### 1977


Voluntary commitment by German industry to reduce the amount of CFCs used in aerosol cans to 30 % below the 1975 level by 1979.

**26th – 28th April:** the first international governmental conference on CFCs in Washington, DC calls for a reduction of CFC emissions, in particular from aerosols just as the second conference in Munich in 1978, which is organised by the German federal government.

### 1978


On the recommendation of the UBA, the *Jury Umweltzeichen* awards the Blue Angel ecolabel, one of the first environmental labels, to CFC-free aerosol cans (RAL-UZ 3).

CFCs in aerosol cans for cosmetic and household use are banned in the USA, followed by Canada, Sweden and Norway until 1981.

**30th May:** in a resolution, the Council of the European Community states its objective to prevent increasing production of CFC-11 and CFC-12. The world of industry is instructed to seek alternative products.

## 1980

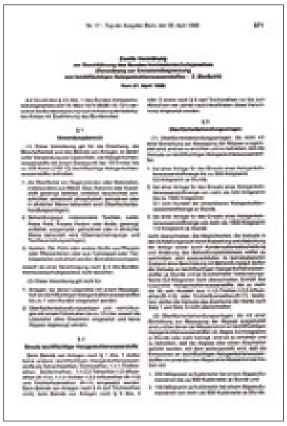
The Council of the European Community agrees on freezing the production capacity of CFC-11 and CFC-12 as well as on a 30 % reduction in the amount of CFCs used in aerosols by 1981.

## 1985

**22nd March:** 21 nations sign the Vienna Convention, the first international framework agreement to demand measures to protect the ozone layer. It enters into force on 22nd September 1988.

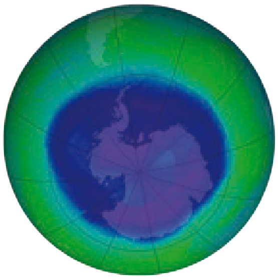
**Autumn:** following initial evidence pointing to its occurrence, in 1984, the discovery of the "ozone hole", the severe depletion of the ozone layer above Antarctica, is reported in Nature magazine.

## 1986



Germany specifies binding limit values for equipment emitting CFCs, for example solvents.

## 1987



**16th September:** adoption of the Montreal Protocol on Substances that Deplete the Ozone Layer. The signatory states commit to limit the production of eight key CFCs and halons. They aim to reduce the production and use of CFCs to half of the 1986 levels by the year 1999.

**16th October:** the German federal parliament agrees to establish a parliament's Enquete Commission "Preventive Measures to Protect the Earth's Atmosphere", which is convened on 3rd December 1987. The commission prepares proposals for the implementation of the Montreal Protocol in Germany – the UBA partakes from the start.

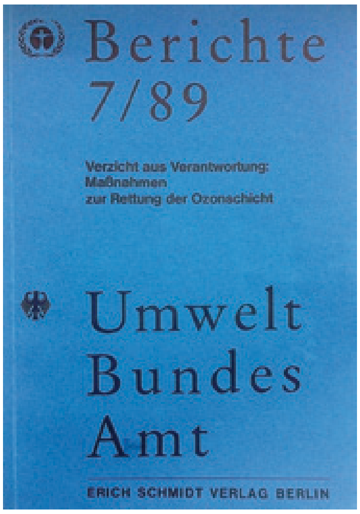
## Subsequent approach

### 1988

**14th October:** to implement the Montreal Protocol, the European Council Regulation on certain chlorofluorocarbons and halons which deplete the ozone layer (No 3322/88) is agreed. From 1st January 1989, it limits import, production and use of such substances.

**16th December:** Germany ratifies the Montreal Protocol.

### 1989




**The UBA report "Verzicht aus Verantwortung: Maßnahmen zur Rettung der Ozonschicht"** [Responsibility means doing without: how to rescue the ozone layer] provides a detailed description of the areas of use and possible substitutes for CFCs and halons.

### 1990

**June:** the second conference of signatory nations to the Montreal Protocol in London: significant tightening by ending the production and use of CFCs by the year 2000, the inclusion of additional ozone depleting substances and establishing of a Multilateral Fund to support developing countries.


From 1990 onwards, the environmental protection movement initiates a variety of actions to prevent the production and use of CFCs.


The **"Schutz der Erdatmosphäre"** [Protecting the earth's atmosphere] report is published, which provides an overview of the story behind and the wide-ranging work of the German parliament's Enquete Commission established in 1987. By 1994, the commission publishes four further reports, drawing on further findings from the UBA (for the publications, refer to the enclosed list of literature).

## The phase-out of CFCs and halons begins

### 1991


Termination of production of halon fire extinguishing agents in Germany.

**4th March:** to implement the London resolutions of the Montreal Protocol, the European Regulation on ozone depleting substances (No 594/91) is agreed.

With the Ordinance on the Prohibition of CFCs and Halons, Germany legislates to completely phase out these ozone depleting substances in almost every area of use by 1995 at the latest, thereby clearing the way for stricter regulations in both the EU and worldwide.

### 1992

The international conference on "Alternatives to CFCs and halons" in Berlin, which is co-organised by the UBA, makes a point of introducing possible alternative substances and technologies.

**November:** at the fourth conference of signatory nations in Copenhagen, the Montreal Protocol becomes yet stricter: halons will no longer be manufactured or used by 1994 and CFCs by 1996, while hydrochlorofluorocarbons (HCFCs) and methylbromide are also included in the Protocol, with their production being banned from 2020 onwards.

### 1993

**1st January:** the new European Council Regulation to speed up the phasing-out of substances that deplete the ozone layer (No 3952/92) enters into force. The production and imports of halons are banned from 1994, of CFCs from 1995, and of certain solvents from 1995/96 onwards.

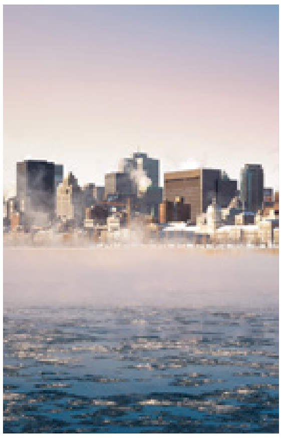

**March:** the worlds first CFC-free household refrigerator rolls off the assembly line of the company Foron in Germany.

## Further tightening and additional regulations

### 1994

**15th December:** revision and tightening of the European Council Regulation on substances that deplete the ozone layer (now No 3093/94).

### 1997



**September:** at the 9th conference of signatory nations to the Montreal Protocol in Montreal, the timetables for the phase-out of the production of ozone depleting substances are amended and measures to prevent them from being traded on the black market are agreed.

### 1999

**11th conference of signatory nations to the Montreal Protocol in Beijing:** inclusion of bromochloromethane and trade restrictions for HCFCs.

### 2000

The European Regulation on substances that deplete the ozone layer (No 2037/2000) is enacted. It applies in Germany with immediate effect and tightens certain rules.

# Phase-out of F-gases in Europe from 2006

## 2004


**The UBA report on "Fluorierte Treibhausgase in Produkten und Verfahren – Technische Maßnahmen zum Klimaschutz"** [Fluorinated greenhouse gases in products and processes – technical climate protection measures] illustrates the use and emissions of fluorinated substances which replaced CFCs and halons. The current situation, measures to reduce emissions and alternatives are discussed for fourteen areas in which fluorinated greenhouse gases are used.

## 2006

**European regulation and directive to reduce the emissions of fluorinated greenhouse gases** in refrigerators and air conditioning systems and other applications (No 842/2006 and 2006/40) are enacted. These also include guidelines considering leak testing and expertise, as well as the prohibitions for HFC and $SF_6$ in certain applications.

**The German Chemicals Ozone Layer Ordinance** replaces the Ordinance on the Prohibition of CFCs and Halons from 1991. It is adapted to the European regulations on the protection of the ozone layer and also contains regulations regarding expertise.

## 2007

**23rd/24th August:** The German federal government agrees to an integrated climate and energy programme (IEKP) in Meseberg. Point 23 includes steps to reduce HFC emissions and to support refrigeration systems which use natural refrigerants.

## "Phase-down" as supported by Regulation (EU) No 517/2014

### 2008

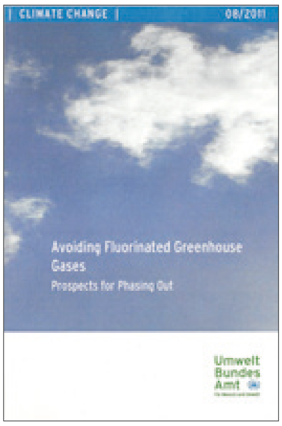
The UBA and the German Ministry for the Environment (BMU) host their first round table meeting on supermarket refrigeration in Germany with the objective of supporting the widespread market launch of energy efficient and climate friendly refrigeration systems that use natural refrigerants in supermarkets. This is followed by further events covering key topics such as $CO_2$ supermarket refrigeration systems, the use of flammable refrigerants and the use of natural refrigerants in smaller shops.

A **Chemicals Climate Protection Ordinance** is enacted in **Germany** for the first time. This supplements the European F-gas Regulation and also contains limit values for specific refrigerant losses in stationary systems.

### 2009

The European Regulation No 1005/2009 on substances that deplete the ozone layer replaces and tightens the regulation enacted in the year 2000. It applies in Germany with immediate effect.

### 2010




The President of the UBA presents the report **"Avoiding Fluorinated Greenhouse Gases – Prospects for Phasing Out"** in Brussels which shows alternatives for limiting and replacing fluorinated greenhouse gases.

### 2014

The new **European F-gas Regulation (No 517/2014)** with further bans and the step-by-step placing on the market limits ("phase-down") of hydrofluorocarbons (HFC) is agreed. By 2030, the quantity of HFCs on sale should be reduced to one fifth of the current quantity.

## 2016

**15th October:** at the 28th conference of the signatory nations of the Montreal Protocol **in Kigali (Rwanda), hydrofluorocarbons (HFC) are included in the Montreal Protocol**, as their use as a CFC-substitute is rapidly increasing. This heralds the dawn of a new era: although HFCs do not damage the ozone layer, they contribute to climate change. By the year 2047, their consumption is to be reduced to 15-20 % of the initial consumption.

## 2017

Amendment of the German Chemicals Climate Protection Ordinance from 2008 according to the new European F-gas Regulation.

## 2018

According to the F-gas Regulation, the HFC quantity available on the market will go down to 63 % of the initial quantity (calculated in tonnes of $CO_2$eq, based on the average annual quantity of the years 2009–2012).

## 2020

Refrigeration systems with HFC (GWP › 2,500) are banned, as well as mobile household air conditioning units with HFC (GWP › 150).

## 2030

Only 21 % of the initial quantity of HFC in 2015 is available to the European refrigerant market.

# 4 The search for alternatives

Chlorofluorocarbons (CFCs) are non-flammable compounds which saw widespread, large-scale use because of their technical properties. Halons (hydrobromofluorocarbons) were used as fire extinguishing agents. Some of the other halogenated substances[1] which also damage the ozone layer, such as carbon tetrachloride, were everyday laboratory chemicals.

When these substances were found to damage the ozone layer, the search for possible substitutes and new technologies began. Manufacturers initially looked for substances with very similar properties as alternatives to CFCs and halons, and therefore focused on chemically related substances. In some cases, they opted for hydrochlorofluorocarbons (HCFCs). However, as these also damage the ozone layer, albeit to a more limited degree than CFCs and halons, HCFCs are also largely banned today. Perfluorocarbons and hydrofluorocarbons (PFC and HFC) form another related group of substances which are still in use today. Although they do not damage the ozone layer they are potent greenhouses gases, so they must also be replaced (see section 7).

The German Environment Agency (UBA) played a very active role in the discussions surrounding the alternatives and demanded the rapid phase-out of CFCs and halons with the objective of introducing substances and processes with long-term sustainability.

Together with refrigeration and climate specialists and operators of refrigeration systems, the UBA sought sustainable substitutes for CFCs and subsequently, HFC refrigerants. Intermediately, the UBA became responsible for providing notifications of substitute refrigerants. From 1992 to 1993, the UBA supported the implementation of the Ordinance on the Prohibition of CFCs and Halons by issuing special permits for halon fire extinguishers.

The rapid phase-out of CFCs in a wide range of applications in Germany had an unexpected and positive side effect: as HFCs, which were subsequently strongly marketed as alternatives, were not yet available, halogen-free (natural) substances were established for some applications, and they remain in widespread use to this day.

Right from the start, the UBA called for a changeover to halogen-free substances and to avoid HFCs as substitutes due to their strong contribution to global warming. The UBA carried out several projects on innovative process conversions with production companies on the CFC-free manufacturing of polyurethane (PUR) rigid and flexible foams and on the degreasing of metal components without the use of CFC solvents.

In 1976, some 53,000 tonnes of CFCs were released into the atmosphere from aerosol cans in the Federal Republic of Germany alone. In 1977, German industry committed to a 30 % reduction in the quantity of CFCs used in aerosols by 1979. In 1978, the US Environmental Protection Agency (EPA) banned the use of CFCs as a propellant in household and cosmetics aerosol cans. Although it was not possible to implement such a ban in Germany at that time, in 1978 the UBA set an important signal with the first ecolabel (Blue Angel) for CFC-free aerosol cans. It is now a long time since CFCs have been used in aerosol cans.

With the support of Greenpeace and the UBA, in May 1992 the first "Greenfreeze" refrigerator without any halogenated propellants or refrigerants was built by the German company Foron. The UBA and the BMU supported the introduction of CFC-free refrigerators by specifying the appropriate ecolabel criteria, which forced other manufacturers to rethink. Nowadays, isobutane (R-600a) is used as the refrigerant in almost all household refrigerators.

1 Halogenated substances: substances which contain halogens, i.e. the elements of fluorine, chlorine, bromine or iodine.

Table 1

**Selection of CFCs, HFCs and their mixtures, as well as halogen-free compounds.**
**$GWP_{100}$: Calculation of the global warming potential over 100 years.**

| Chlorofluorocarbons (CFCs/HCFCs) | | | |
|---|---|---|---|
| industrial name | chemical name/mixing ratio | global warming potential ($GWP_{100}$) [4] | ozone depleting potential (ODP) [5] |
| CFC-11 / R-11 | trichlorofluoromethane | 4,750 | 1 |
| CFC-12 / R-12 | dichlorodifluoromethane | 10,900 | 1 |
| CFC-115 / R-115 | chloropentafluoroethane | 7,370 | 0.6 |
| HCFC-22 / R-22 | chlorodifluoromethane | 1,810 | 0.055 |
| HCFC-1233zd (E) | trans-1-chloro-3,3,3-trifluoroprop-1-ene | 4.5 [7] | 0.00034 [6] |
| R-502 (R-22/R-115) | 48.8 / 51.2 % m/m | 4,657 | 0.23 |

| Hydrofluorocarbons (HFCs) | | | |
|---|---|---|---|
| industrial name | chemical name/mixing ratio | global warming potential ($GWP_{100}$) [4] | ozone depleting potential (ODP) [5] |
| HFC-32 / R-32 | difluoromethane | 675 | 0 |
| HFC-125 / R-125 | pentafluoroethane | 3,500 | 0 |
| HFC-134a / R-134a | 1,1,1,2-tetrafluoroethane | 1,430 | 0 |
| HFC-143a / R-143a | 1,1,1-trifluoroethane | 4,470 | 0 |
| HFC-1234yf / R-1234yf | 2,3,3,3-tetrafluoropropene | 4 [7] | 0 |
| HFC-1234ze / R-1234ze (E) | trans-1,3,3,3-tetrafluoroprop-1-ene | 7 [7] | 0 |
| R-404A (R-125/ R-134a/ R-143a) | 44 / 4 / 52 % m/m | 3,922 | 0 |
| R-407C (R-32/ R-125/ R-134a) | 23 / 25 /52 % m/m | 1,774 | 0 |
| R-410A (R-32/ R-125) | 50 / 50 % m/m | 2,088 | 0 |

| Halogen-free compounds | | | |
|---|---|---|---|
| industrial name | chemical name/mixing ratio | global warming potential ($GWP_{100}$) [8] | ozone depleting potential (ODP) [5] |
| R-290 | propane | 3 | 0 |
| R-600 | n-butane | 4 | 0 |
| R-600a | isobutane | 3 | 0 |
| R-717 | ammonia | 0 | 0 |
| R-718 | water | 0 [4] | 0 |
| R-744 | carbon dioxide | 1 [4] | 0 |

Source: see references


The German company Foron and Greenpeace collect orders for the new CFC-free household refrigerator.

The list of products distinguished by avoiding ozone depleting or halogenated substances is still being written today. In this respect, for example, some supermarket chains have made a voluntary commitment to only use natural refrigerants such as $CO_2$ or propane in their new refrigeration systems. The UBA has supported this trend by developing ecolabel criteria for climate friendly supermarkets. Since 2013, food retail businesses which operate on a particularly energy-efficient basis and only use halogen-free refrigerants have been eligible for the Blue Angel ecolabel (DE-UZ 179).

The UBA continues to support the introduction of environmentally friendly and climate-neutral substances and technologies in a variety of different ways, with information on possible solutions, on current and on future problems, the development of solution strategies and supporting companies with their implementation.

As part of its public mandate, the UBA is also an information point for citizens as well as companies, organisations and law enforcement authorities. Our homepage lists the current national and international regulations, data and research results as well as reports from the UBA regarding emissions of fluorinated greenhouse gases to the European Commission and the Intergovernmental Panel on Climate Change (IPCC). A selection of reports and additional publications by the UBA is listed in section 9.1 of the appendix.

# 5 Measurements of halogenated gases in the atmosphere

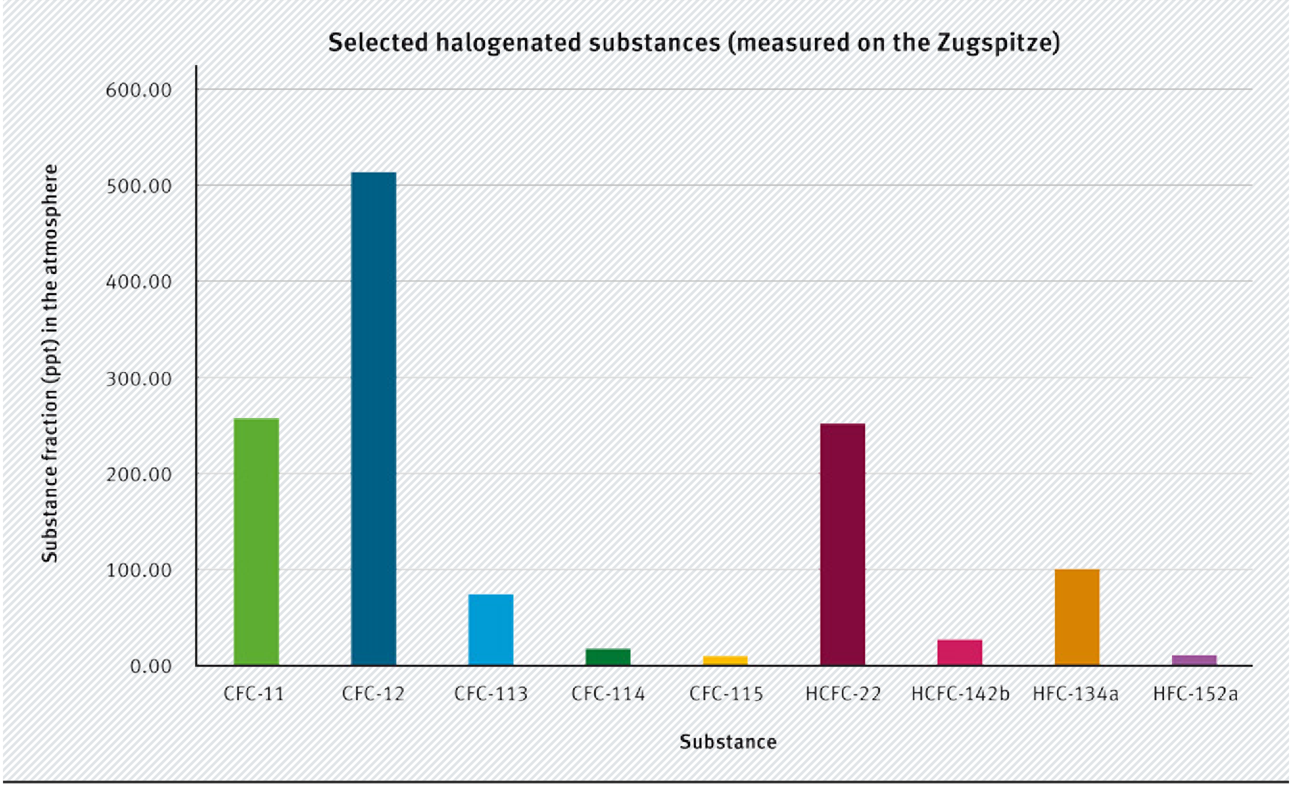
The UBA has been monitoring halogenated greenhouses gases in the lower free atmosphere, which also includes ozone depleting substances, since 2013. For this purpose, at Schneefernerhaus Environmental Research Station, UBA operates a measuring station on behalf of the GAW: the Zugspitze/Hohenpeissenberg Global Observatory. The Global Atmosphere Watch, or GAW, has the objective of compiling a high quality worldwide database for the Global Climate Observing System (GCOS) of the UNO. This also ensures the best possible comparability of the measurements according to the latest scientific knowledge to elaborate improved climate models and create more accurate analyses of the effectiveness of environmental policy measures, on the success of the Montreal Protocol, for instance. Another goal is to enable more accurate climate change forecasts in the interests of implementing more effective environmental policy measures.

The comparison of the atmospheric concentrations of halogenated substances that have been measured at the Zugspitze since 2013 (figure 1) with long term measurements of the key halogenated trace gases (figure 2) at other stations shows that the measured values for the individual substances correlate well.

Other measurement stations have been tracking CFC levels in the atmosphere since the 1970s. Their measurements show that CFC concentrations are no longer increasing (figure 2 b). This proves that the Montreal Protocol is fulfilling its purpose, and that today, very few of the worst ozone depleting substances are being released. Since the year 2000, the overall concentrations have only been falling very slowly, however, which means the ozone layer can only recover very slowly and the ozone hole remains very extensive (see image on page 4). This is due to the lifespan of CFCs in the atmosphere.

Figure 1

**Average monthly value (December 2016) of selected halogenated substances covered by the Montreal Protocol and monitored by the UBA on the Zugspitze since 2013. The atmospheric concentrations of trace greenhouse gases are stated in ppt as substance fractions or mole fractions.**




Source: UBA 2017

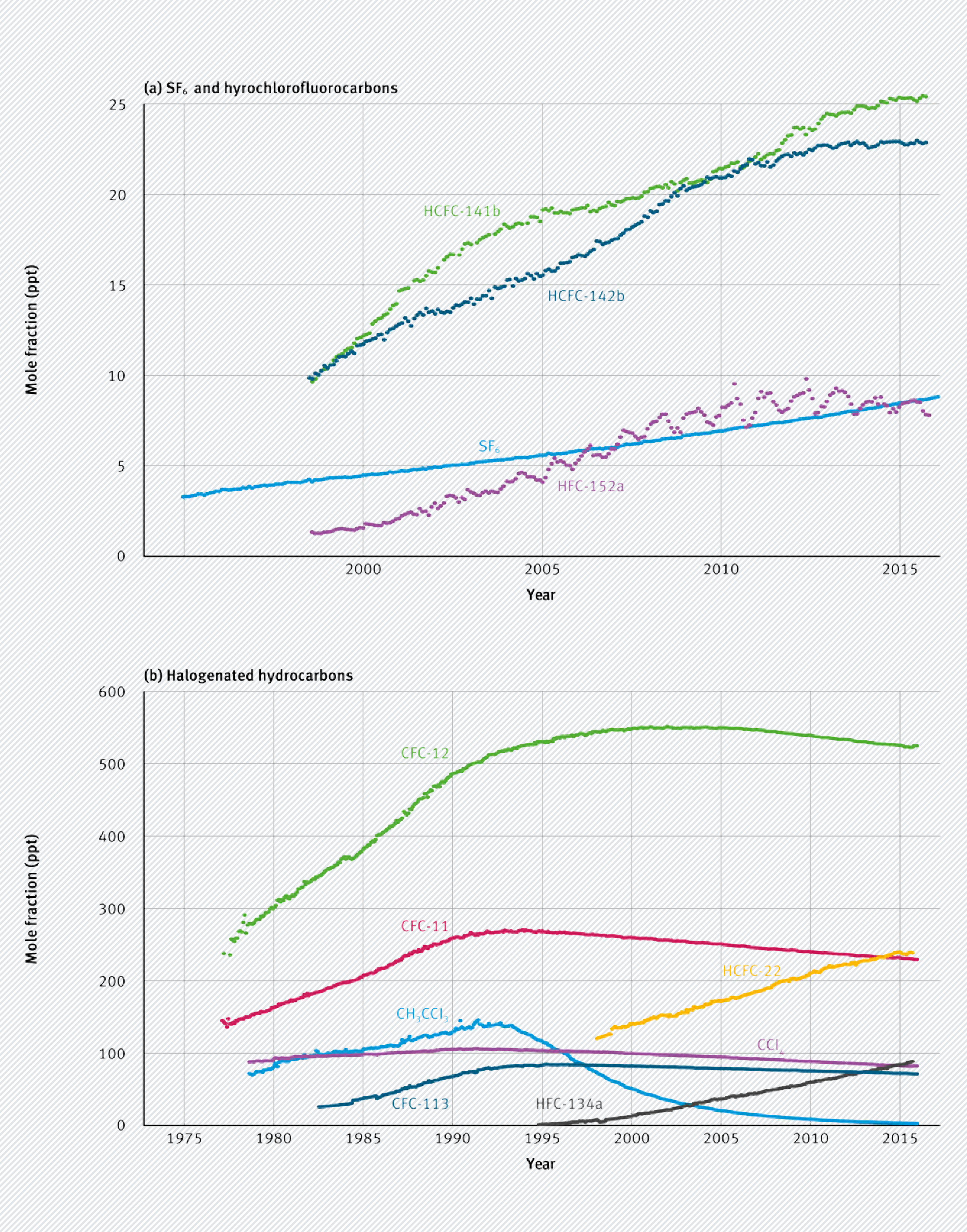
For CFC-11, this is 45 years, while for CFC-12 it is 100 years. If weighted according to ozone depleting potential (ODP), the current use of ozone depleting substances is nearing zero (see figure 3 in the following section). The ozone hole therefore continues to exist due to the impact of substances which were released into the atmosphere decades ago.

The UBA measuring station on the Zugspitze is the third station to monitor halogenated trace gases which are covered by the Montreal Protocol for the GAW programme in central Europe. With measurement data from two other stations in Switzerland and Italy, using dispersion calculation modelling techniques, it is therefore possible to quantify the emissions of halogenated greenhouse gases in central Europe and to confirm the annual emissions statistics in the individual countries.

Schneefernerhaus Environmental Research Station on the Zugspitze.

Figure 2

**Long-term trend in monthly average values of key ozone depleting halogenated (hydro)carbons (9). Sulphur hexafluoride ($SF_6$) and the two HFCs 152a and 134a are also tracked. The atmospheric concentrations are stated in ppt as substance fractions (mole fractions).**




Source: WMO Greenhouse Gas Bulletin [9]

# 6 The success of the Montreal Protocol in figures

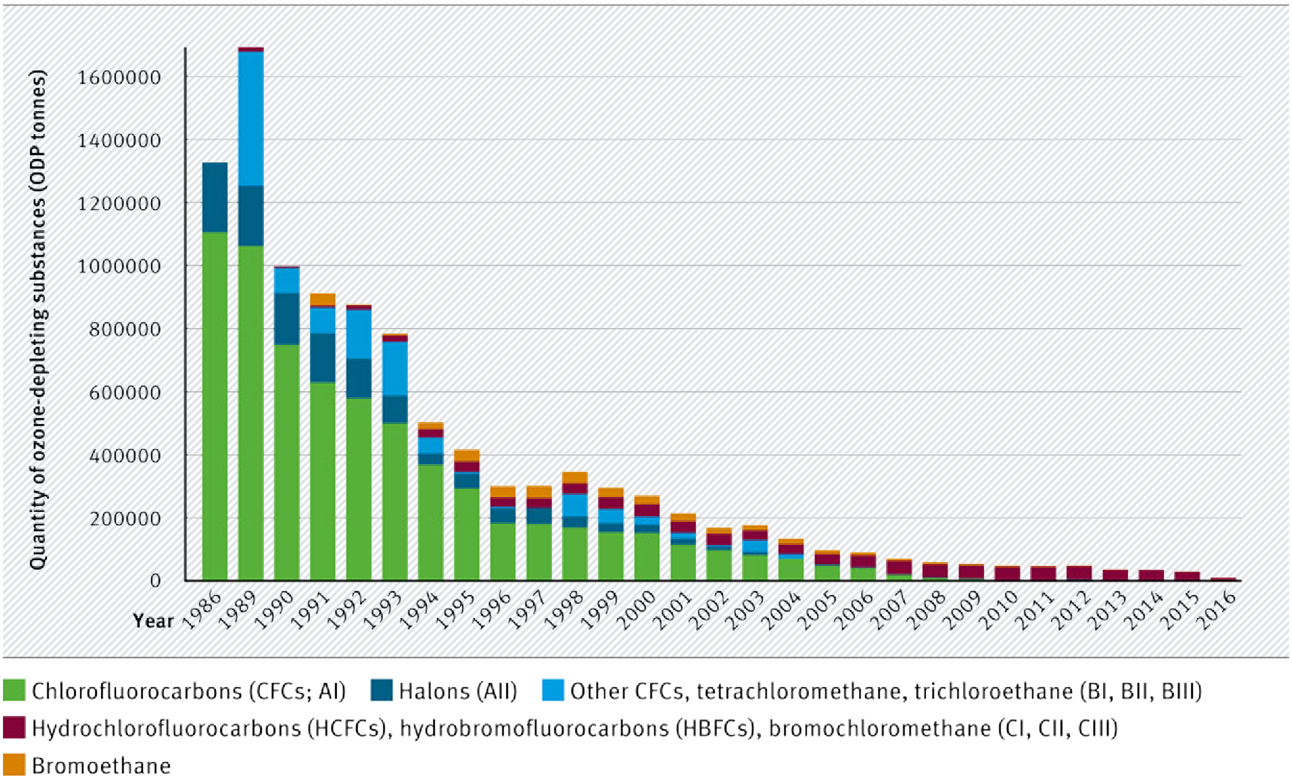
The Montreal Protocol and its amendments have brought the international community of states together to an extent never seen before. Since 16th September 2009, the Vienna Convention and the Montreal Protocol are the first treaties in the history of the United Nations to have been ratified by every nation in the world. Today, thirty years after the Montreal Protocol was signed, the results of the goals which were agreed upon are clearly visible.

Within a small number of years, globally, there has been a very sharp decline in the quantities of ozone depleting substances being manufactured and used (figure 3).

At the same time, the agreements of the Montreal Protocol have also prevented a further increase in greenhouse gas emissions. Despite such encouraging data, however, hard work will be necessary to reduce the emissions of halogenated compounds in the future. As shown by the latest research, increased emissions of chemicals which are not covered by the Montreal Protocol have caused a slowing in the regeneration of the ozone layer and may pose a long term risk to the achievements of the Montreal Protocol [11]. Furthermore, accounting today for an approximate 13 % share to global warming, halogenated compounds (CFCs, halons, HFCs and other fluorinated greenhouse gases) also make a major contribution to the greenhouse effect caused by human activity [12].

Figure 3

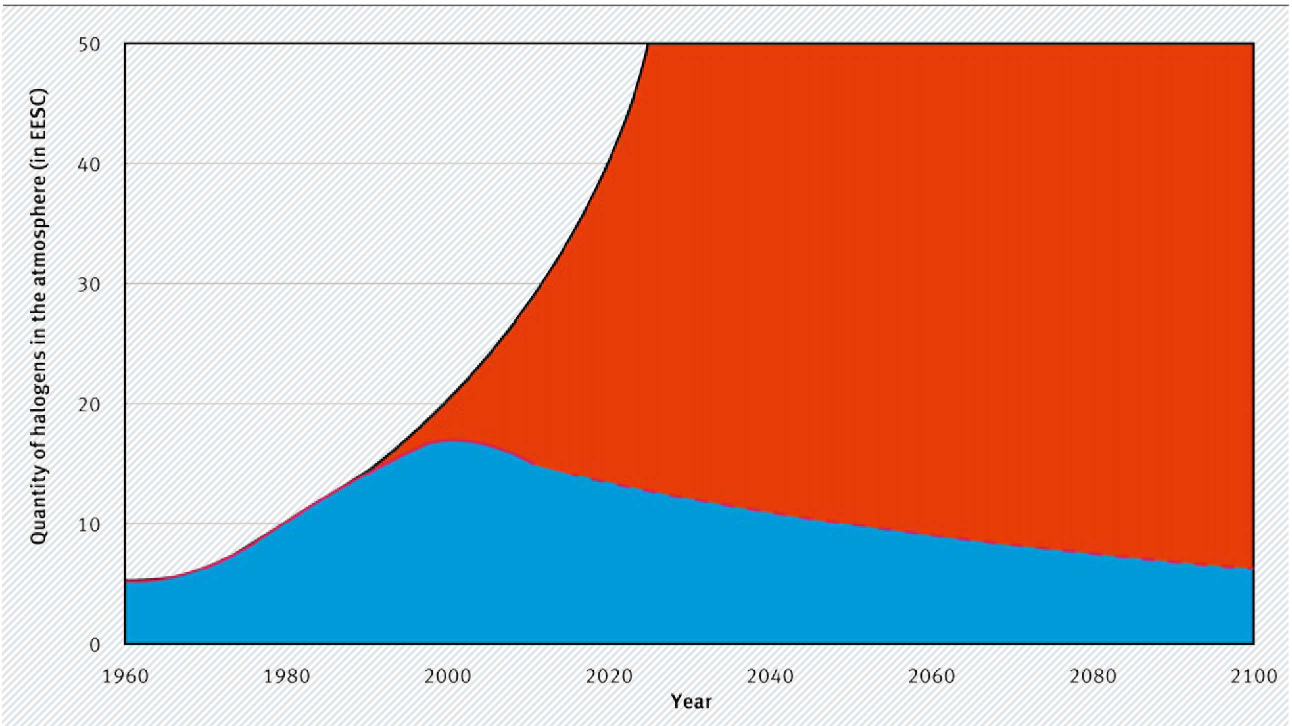
**Global consumption of substances harmful to the ozone layer anchored in the Montreal Protocol (in tonnes of ozone depleting potential (ODP), 1986–2016).**




Source: UNEP [10]

Figure 4

**Ozone depleting substances in the stratosphere in the past, today and in the future (blue area). Without the Montreal Protocol, the quantities would have increased strongly (red area). Ozone depleting substances are stated as equivalent effective stratospheric chlorine (EESC).**




Source: UNEP [13]

# 7 Current and future solutions

As CFCs were 30 years ago, today, HFCs are the standard refrigerants to be used in refrigeration, air conditioning and heat pump technology. And as it was the case for CFCs, HFCs no longer have any future. In terms of overall worldwide quantity, the use of HFCs as a refrigerant represents the biggest single area of use for fluorinated greenhouse gases. This is considered in further detail below.

In the 1980s, protecting the ozone layer was the focus of the phase-out of CFCs, and factors such as the climate impact of substitute substances and systems' levels of energy efficiency were barely discussed. HFCs, which only required relatively limited technical changes to systems, were available as a substitute for CFCs from the mid-1990s onwards. Apart from having to make increased use of mixtures, little changed for refrigeration technicians.

We are now faced with a different yet equally resolvable situation. Today, no wide range of chemical refrigerants is available which fulfils the requirements of not having an "ozone depleting potential" (ODP), having a "low global warming potential" (GWP) and also has the typical attributes of CFCs such as "non-flammable" and "non-toxic" (see table 1). The entire refrigeration and air conditioning sector will therefore need to change to refrigerants with other properties or completely different technologies.

The critical discussion regarding the high global warming potential of HFCs in recent decades has led to the development of new systems and technologies: the market offers solutions with halogen-free refrigerants to replace almost all quantitatively relevant HFC uses. The interest in such technologies is increasing constantly in the craft sector and among the users.

A form of refrigeration and air conditioning technology which is sustainable in the long run is no longer just an imaginary scenario. However, it will be necessary for all of those involved, such as system designers, component manufacturers, refrigeration plant assemblers, maintenance companies and operators to exploit and develop the available possibilities.

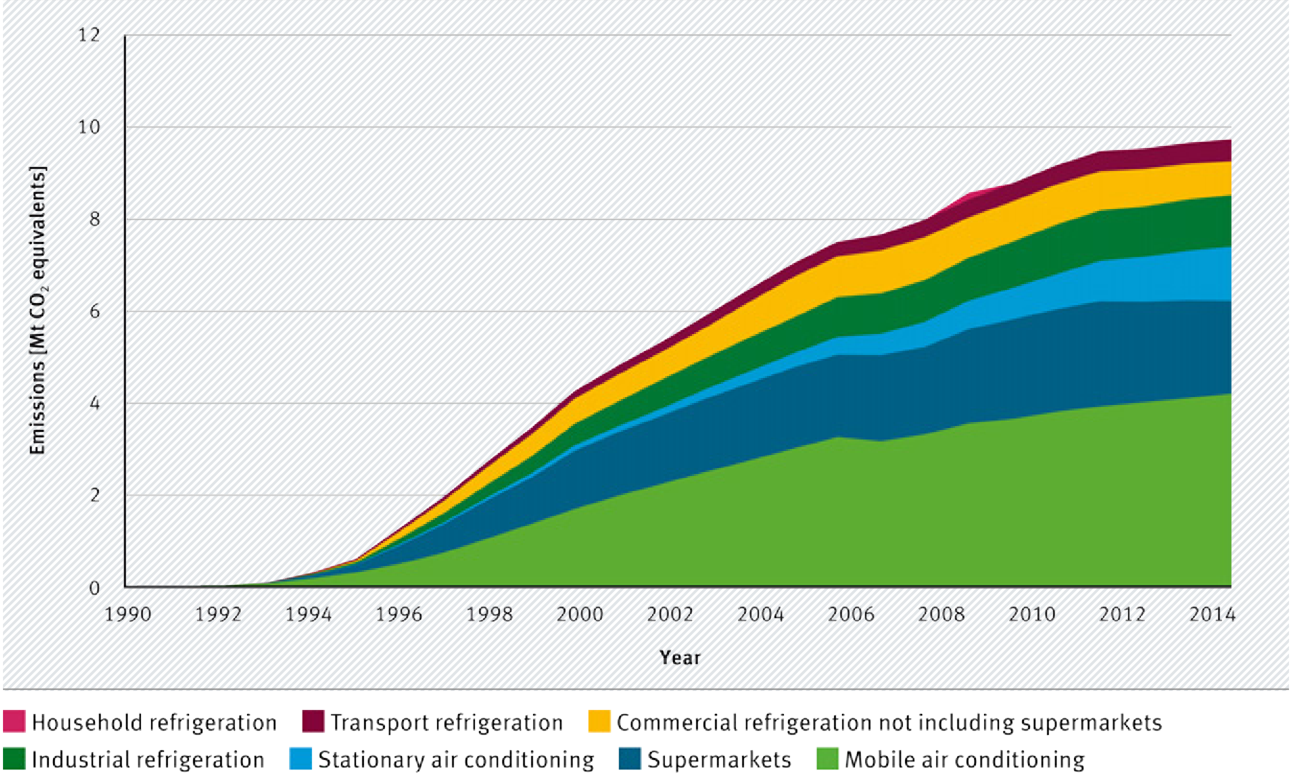
## 7.1 The use of refrigerants to date

Since 1990, climate-damaging emissions of HFCs used as refrigerants have been increasing strongly in both Germany and the rest of the world. This increase has now been acknowledged as a threat to the climate (figure 5).

The quantities of HFC refrigerants used in Germany are not decreasing and have been gradually increasing again since 2013. However, they have an increasingly lower global warming potential – the average GWP value of the quantities used in 2015 was 1,882. In 2013, it was 1,944. The greatest quantities of HFCs are used for the initial filling of refrigeration and air conditioning systems (figure 6).

Figure 5

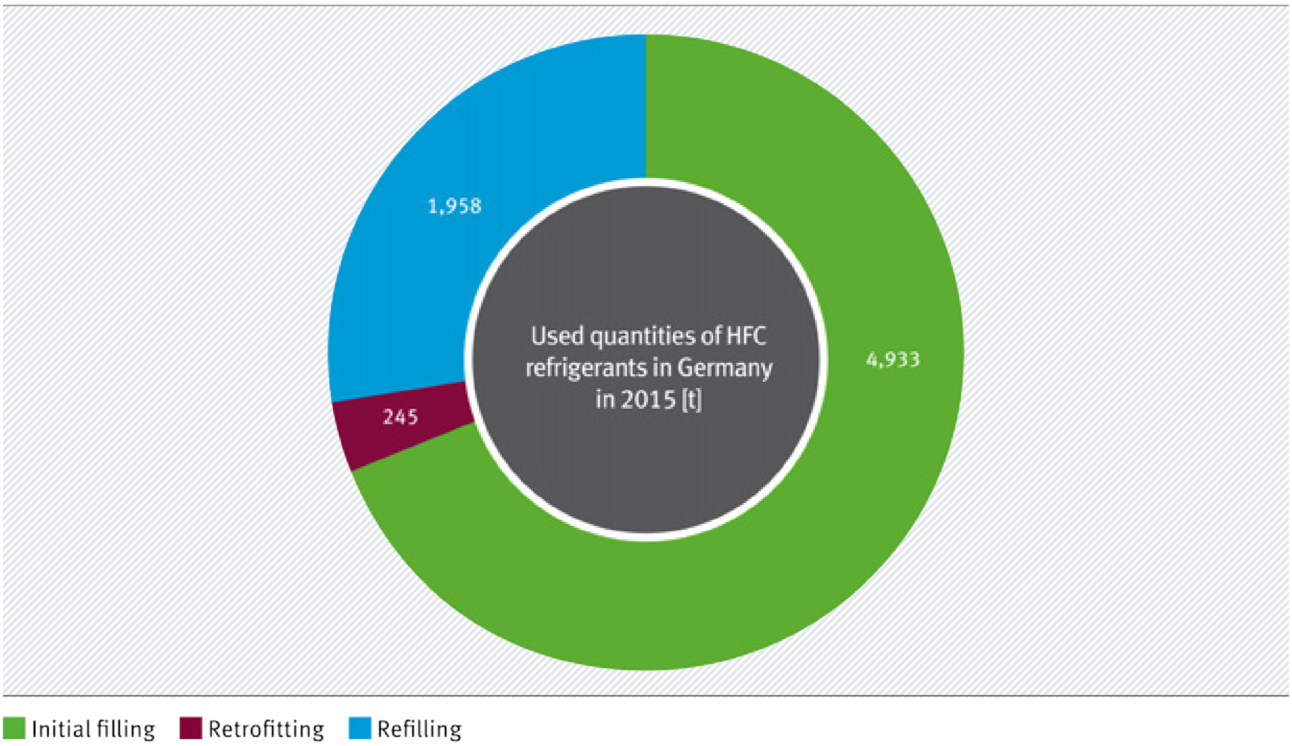
**Emissions of HFC refrigerants in Germany, 1990–2015.**




Source: UBA 2014 [14]

Figure 6

**Quantities of HFC refrigerants in metric tonnes for the purposes of initial filling, conversion and refilling in Germany in 2015.**




Source: German Federal Statistical Office 2015 [15]

## 7.2 Refrigerants for the future

In 2018, and in 2019 at the latest, currently used HFCs will only be available in considerably lower quantities. In a few years, the average GWP of all the refrigerants available on the market will be half the value of the year 2015. By 2030, Regulation (EU) No 517/2014 on fluorinated greenhouse gases, as well as the Kigali Amendment as part of the Montreal Protocol on the reduction of HFCs will restrict refrigerant availability tremendously. Refrigerants which today are widely available in developed countries will undergo shortages to such an extent that even the latest refrigeration systems with refrigerants with an average global warming potential, such as R-134a (GWP 1,430) or R-32 (GWP 675), are likely to become rarities.

The majority of available refrigerants will then have a global warming potential of less than 20. This criterion is fulfilled by all of the natural refrigerants (such as $CO_2$, propane, ammonia and water) but also by unsaturated fluorocarbons such as R-1234yf or R-1234ze. However, the mixtures which use these or similar fluorocarbons which are currently available on the market have such a high global warming potential that they cannot be considered for high-volume use.

Systems which use natural refrigerants are considered sustainable and future-proof solutions. Their energy efficiency has been proven many times (see section 9.1). Natural refrigerants have zero or only a very low global warming potential, and therefore contribute little to climate change. They are distinguished by their well-researched properties, the knowledge of their manufacturing path and the associated emissions as well as their decomposition products. Therefore, damaging effects due to the use of natural, halogen-free refrigerants which have not been predicted as of today should not be expected. The extent to which unsaturated fluorocarbons demonstrate their suitability as a solution for the distant future remains to be seen.

## 7.3 Food retail

Until the 1990s, CFCs were generally used as refrigerants in the food retail sector, primarily CFC-12, HCFC-22 and the CFC-containing mixture R-502. These refrigerants have been almost completely replaced by HFC-134a (for CFC-12) and by HFC mixtures (R-404A, R-407C, R-507A).

There have been repeated attempts to use natural refrigerants as a substitute for CFCs. Future-proof solutions with natural refrigerants, which are found in great number today, first started on their road to success in the year 2006, however, at a time when the changeover to HFCs was largely complete.

On the basis of TEWI[1] analyses, the UBA study project on the "Comparative Assessment of the Climate Relevance of Supermarket Refrigeration Systems and Equipment" which was published in 2008, demonstrated that in supermarkets and hypermarkets, the climate balance of $CO_2$ systems was far superior to that of the R-404A reference technology. However, operators of supermarket refrigeration systems were still using HFCs for cost reasons. With a share of 27 % of all refrigerant emissions, supermarket refrigeration systems remain the most relevant area of use in stationary refrigeration and air conditioning technology in Germany (figure 5). The positive results of the study led the UBA and the Federal Ministry for the Environment to host a "Round Table Supermarket Refrigeration". This enabled discussions between operators and manufacturers of systems and components with the world of politics and the craft sector. Its objective was to support the wide-ranging market launch of energy-efficient and climate-friendly refrigeration systems which use natural refrigerants in supermarkets.

The objective of the "Round Table Supermarket Refrigeration" has been achieved: the trend that witnessed an ever-increasing use of HFCs in supermarket refrigeration systems in recent years has now been reversed. Government grants and the approaching bans also contributed to the success. Several hundred systems which use natural refrigerants are now in use in Germany, and several thousand in Europe as a whole, with constantly growing numbers.

1 TEWI: Total Equivalent Warming Impact.

These systems mostly contain $CO_2$ or hydrocarbons as refrigerants. Their concepts are sometimes very different, and range from cascade and indirect systems to transcritical $CO_2$ refrigeration systems. They are now available from all leading manufacturers of refrigeration systems and are being improved continuously.

With the decision for a new system, however, the straightforward provision of refrigeration is no longer the sole focus. On the contrary, overall concepts are sought after, in which the provision of refrigeration and heating have been optimised for the market in a coordinated way. Possibilities on offer depend on the location and size of the market. In the case of a new building, a wider range of possibilities arise than with existing buildings.

CFCs were also initially replaced by HFCs in plug-in devices which are also used in food retail. Driven by the developments in the area of household refrigerators which have now long been using hydrocarbon refrigerants in Germany, hydrocarbons have become increasingly widespread in smaller plug-in devices. Today, the discussions surrounding halogen-free alternatives are mainly taking place for larger scale devices and decentralised individual systems with external condensing units. Condensing units without fluorinated refrigerants are already available, but not from every supplier or manufacturer, and not for all capacity ranges. Due to the bans and further regulations of HFCs that have already been agreed, the UBA predicts a considerable increase on the supply side.

Since 2016, the UBA is a partner in the EU SuperSmart project, which has the goal of supporting the uptake of efficient and environmentally friendly refrigeration and air conditioning technology in the supermarket sector. In this respect, information campaigns, workshops and trainings are being held, and the criteria for an EU Ecolabel for supermarkets is being developed.

- Further information on refrigeration in supermarkets is available under the following link: *http://www.umweltbundesamt.de/themen/wirtschaft-konsum/produkte/fluorierte-treibhausgase-fckw/anwendungsbereiche-emissionsminderung/supermaerkte*.

## 7.4 Heat pumps

In the future, heat pumps will play an increasingly important role in supplying heat to buildings, such as houses and apartment buildings, in the provision of domestic hot water as well as in the industry. This is due to the necessity to change the generation of energy, and therefore the way in which heat is provided, in order to achieve the national, European and global climate protection goals. The 2050 Climate Protection Plan of the German federal government [16] contains a “roadmap for a nearly climate-neutral building stock”. One of its conditions is the step-by-step phase-out of heating systems which use fossil fuels. In this context, the heat pump is one of the most important technologies [17].

Display cabinet of a transcritical $CO_2$ refrigeration plant in a supermarket.

A chiller which uses R-290 (propane) to refrigerate Munich’s wholesale market.

In 2016, some 66,500 heat pumps for heating purposes and 12,500 for domestic hot water generation were sold in Germany, and the total in Europe as a whole was 988,000 units. In the last 20 years, the share of heat pumps in newly built residential buildings in Germany has increased to more than 30 %, and in non-residential buildings to approximately 6 %. If refrigerants with high GWP values are used, emissions will increase with the number of installed heat pumps.

In the heat pump, a refrigerant circulates so as to raise the environmental heat (from the ground, the water or the air) to a higher temperature level. Due to their thermodynamic properties, heat pumps which use natural refrigerants are not only highly energy efficient, they are also very environmentally friendly. Large-scale heat pumps which use natural refrigerants are already in widespread use in industry. In industrial heat pumps, R-744 (carbon dioxide, $CO_2$), R-717 (ammonia, $NH_3$), R-723 (a mixture of ammonia and dimethyl ether) and hydrocarbons (e. g. R-290, propane) are used as halogen-free refrigerants. In household heat pumps, however, hydrofluorocarbons are mostly used. Only 5 % of the heat pumps available on the market contain a halogen-free refrigerant. To support the increased use of halogen-free refrigerants in heat pumps, in recent years, several projects have been completed on behalf of the UBA which have included emissions calculations and efficiency comparisons and which identify and assess the market barriers (see section 9.1). Various funding programmes are available for heat pumps. The UBA is committed to ensure that only heat pumps which use a halogen-free refrigerant will be eligible for funding.

- Further information on heat pumps is available at the following link: *http://www.umweltbundesamt.de/themen/wirtschaft-konsum/produkte/fluorierte-treibhausgase-fckw/anwendungsbereiche-emissionsminderung/waermepumpen*.


$CO_2$ high temperature heat pump.

Chiller using R-718 (water) as a refrigerant for process cooling and air conditioning.

## 7.5 Building air conditioning

In Germany, due to design and operational differences (glass facades without shading systems, large-scale internal sources of heat such as office equipment and server rooms) non-residential buildings such as office buildings, hotels and public buildings have an energy consumption caused by air conditioning which is up to 100 times higher than that of residential buildings. By 2030, a doubling of energy-related emissions of $CO_2$ from the air conditioning of non-residential buildings is expected in comparison with the year 2010.

Most buildings in Central Europe can be designed so that they require no or only little air conditioning, which prevents both the consumption of energy and refrigerant emissions. New buildings offer the greatest scope for action. However, some of the technologies which suit here can also be used successfully in existing buildings. To make the air conditioning of a building as climate-friendly as possible, holistic strategies are necessary. Technical concepts and their evaluation are described in the UBA brochure on "Climate friendly air conditioning in buildings" (see section 9.1).

For the air conditioning of larger buildings, centrally controlled systems with chiller and chilled water distribution networks are generally available for use. For this purpose, chillers with ammonia or propane are available from several manufacturers which reduce operational costs due to their superior energy efficiency compared with HFC systems and are therefore equal to comparable HFC systems as regards their lifecycle costs.

The most favourable solutions for both the climate and the operator's wallet are evaporative cooling systems. These require considerably more water than conventional compression cooling systems, but are distinguished by their significantly higher rates of energy efficiency and cost effectiveness. Several systems of this kind are already installed in residential and non-residential buildings in Germany.

Only approximately 3 % of the surface area of residential buildings in Germany are air conditioned. Portable or wall-mounted single-split appliances are mainly used here. The disadvantage of portable air conditioners is that their compact design means that the heat exchangers are relatively small, which results in poor energy efficiency. The exhaust heat also has to be discharged to the outside by a duct passed through an open window. This means that hot outside air returns to the room, making the operation of such systems not only less efficient, but also less effective compared to split appliances. So far, single-split appliances offered in Europe only use and operate with HFC refrigerants. To support alternatives, energy efficient appliances which use a natural refrigerant are now eligible for Blue Angel ecolabel (DE-UZ 204) certification. To date, single-split air conditioners with the natural refrigerant propane (R-290) are only available in India and are amongst the most efficient on the local market. In China, single-split appliances with R-290 are on the brink of being launched and smaller numbers of such units have already been installed all over the world.

- Further information on air conditioning in buildings is available at the following link: *http://www.umweltbundesamt.de/themen/wirtschaft-konsum/produkte/fluorierte-treibhausgase-fckw/anwendungsbereiche-emissionsminderung/gebaeudeklimatisierung.*

## 7.6 Mobile air conditioning

In 1995, the refrigerant CFC-12 was finally banned for use in mobile air conditioning systems in Europe and is banned worldwide by now. Since 1991, CFC-12 has been replaced in passenger cars and almost every mobile application by tetrafluoroethane (HFC-134a or R-134a), a hydrofluorocarbon with a high global warming potential.

In Germany, the percentage of new passenger cars equipped with air conditioning systems has increased from 25 % in 1995 to 98 % at present. The emissions of the HFC refrigerant R-134a from passenger cars have increased accordingly, and amounted to 2,500 tonnes, or 3.6 million tonnes of $CO_2$eq in the year 2015 alone.

Since 2011, European Directive 2006/40/EC on emissions from air-conditioning systems in motor vehicles, enacted 2006, has regulated the phase-out of HFCs in passenger cars and small commercial vehicles. As of 2017, only refrigerants with a very low global warming potential – below 150 – are permitted, consequently HFC-134a is banned in new passenger cars and small commercial vehicles throughout the EU.

The leading vehicle and component manufacturers began developing passenger cars using the natural refrigerant carbon dioxide ($CO_2$ or R-744) before 2006 – the first systems were demonstrated in the early 1990s. The use of ordinary hydrocarbons and flammable fluorinated refrigerants such as HFC-152a was discussed as well.

In a research project, funded by the German Federal Ministry for the Environment (BMU), the UBA equipped one of the passenger cars in its fleet with a prototype $CO_2$ air conditioning system, and presented it at the IAA international automotive trade show for commercial vehicles in 2008. Test on a chassis dynamometer demonstrated that the system cools very effectively and is energy efficient. The car was in daily use at the UBA from 2009 until 2017 and achieved a mileage of 210,000 kilometres. It was the first vehicle in the world with a $CO_2$ air conditioning system that was operated publicly outside of car industry research programs.

Since the European Directive came into effect, many other refrigerants have been proposed. The majority of these refrigerant blends with halogenated gases had to be rejected, due to their toxic and/or ozone depleting components. However, the flammable HFC-1234yf prevailed.

In 2009, the UBA commissioned the Federal Institute for Materials Research and Testing (BAM) to investigate the flammability behaviour of HFC-1234yf. Due to its flammability and chemical instability, the use of HFC-1234yf is associated with risks and additional environmental impacts.

As a consequence of the results of its own flammability tests in 2012, the German automotive industry restarted the development of air conditioning systems with the natural refrigerant $CO_2$ in 2013.


The UBA's official car with the $CO_2$ air conditioning system at the IAA trade show for commercial vehicles in 2008.

Interior of the new cold air system in the roof of the high speed train ICE 3 "Freiburg im Breisgau".

The first passenger cars equipped with an environmentally friendly $CO_2$ air conditioning system have been available since 2016 and are set to be joined by further models of passenger cars from German manufacturers in 2017.

$CO_2$ systems are also of interest for electrically powered vehicles: in addition to air conditioning in summer, they heat the vehicle efficiently in winter as a heat pump, thereby improving the vehicles range.

In buses and trains operated in Germany, CFCs have also been replaced by HFC-134a. Systems with the natural refrigerant $CO_2$ have been undergoing tests for use in buses and trains for several years. Some initial buses with $CO_2$ systems are now available in small series exworks.

In one series of German high speed (ICE) trains, the air conditioning is provided with cold air, which enables to completely omit conventional refrigerant products. The UBA is currently supporting a measurement programme on one ICE train equipped with a new generation of air cycle air conditioning system.

- Further information on mobile air conditioning systems is available at the following link: *http://www.umweltbundesamt.de/themen/wirtschaft-konsum/produkte/fluorierte-treibhausgase-fckw/anwendungsbereiche-emissionsminderung/klimaanlagen-in-auto-bus-bahn*

# 8 Conclusion

The Montreal Protocol is a milestone in international environmental legislation not only providing effective protection to the ozone layer, but also considerably contributes to climate protection. Targeted attention has been given to climate protection with the implementation of the Kigali Amendment and the associated phase-down of HFCs.

In the future, the critical monitoring of the increasing use of unsaturated (chloro)fluorocarbons, which may be climate-friendly but are not without risk in terms of their overall environmental impact, is necessary to ensure that they do not create any new problems. Alternatives with natural refrigerants are available even now and avoid these problems.

As the more recent research shows, high emissions of chlorinated compounds which are not yet covered by the Montreal Protocol are still contributing to a slowing of the ozone layer regeneration. There is a need for action here. To prevent the achievements of the Montreal Protocol from being put at risk, in the future negotiations, the signatory nations must assess the need to include further chlorinated compounds in the list of substances covered by the Montreal Protocol.

The worldwide phase-out of ozone depleting substances shows that effective environment protection measures are possible based on globel level treaties and lead to results which rise to the challenges. Therefore, the Montreal Protocol is also an incentive for the successful achievement of ambitious climate protection goals at the international level.

# 9 Appendix

## 9.1 Selection of projects and publications of the UBA

| Report / project | Content / results |
|---|---|
| 1989 UBA report, 7/89 “Verzicht aus Verantwortung: Maßnahmen zur Rettung der Ozonschicht” (Responsibility means doing without: measures to save the ozone layer), Erich Schmidt Verlag, 1989 | The report provides a comprehensive description of the substance group of CFCs and Halons, their areas of use and replacement options. The information supports the world of politics in shaping CFC phase-out. |
| 1993 Study project on the effect of substitutes for CFCs | Model-based study project on the destruction of the ozone layer and greenhouse effect due to halogenated hydrocarbons focusing on replacements for CFCs, UBA project No 104 02 729, June 1993. |
| 1993 Investment project “Herstellung von FCKW-freiem PUR-Hartschaum nach dem THANOZON®-Verfahren” (Manufacturing of CFC-free PUR rigid foam according to the THANOZON® process) | The UBA supports the introduction of the manufacturing of polyurethane (PUR) rigid foam with the hydrocarbon pentane to replace the previous ozone-damaging substances, final report in November 1995, signatory UBA-FB-AP-2063. |
| 1994 Study project “Ermittlung und Bewertung von Ersatzkältemitteln für FCKW in bestehenden Kälte-, Klima-und Wärmepumpenanlagen” (Determination and evaluation of substitute refrigerants for CFCs in existing refrigeration, air conditioning and heat pump systems) | On the basis of this study project, UBA publishes details of substitute refrigerants for products that contain R-12 according to the CFC-Halon Prohibition Ordinance, which leads to a faster conversion of old R-12 systems. |
| 1997 Investment project “VPF-Schäumverfahren zur Herstellung von FCKW-freien PUR-Weichschäumen” (VPF procedure for the production of CFC-free flexible PUR foams) | The UBA supports the manufacturing of flexible polyurethane (PUR) foams without CFC propellants, $CO_2$ is now used as a substitute, final report in January 1997, signature UBA-FB-AP-2068. |
| 1997 Study project “Ersatz von R-502 in bestehenden Kälte-, Klima- und Wärmepumpenanlagen” (Replacement of R-502 in existing refrigeration, air conditioning and heat pump systems) | The UBA announces details of substitute refrigerants for products that contain R-502 according to section 10, para. 2 of the German Ordinance on the Prohibition of CFC and Halons, allowing old R-502 systems to be promptly converted. |
| 1998 Study project “Ersatz des Kältemittels R-22 in bestehenden Kälte und Wärmepumpenanlagen” (Replacement of the refrigerant R-22 in existing refrigeration and air conditioning systems) | The study project comes to the conclusion that the use of HCFC-22 in existing plants can be permitted for the time being, and no details of substitute refrigerants are provided. |
| 2001 Study project “Ersatz des Kältemittels R-22 in bestehenden Kälte und Klimaanlagen – Aktueller Stand” (The replacement of the refrigerant R-22 in existing refrigeration and air conditioning systems – current situation) | With the European Regulation (EC) No 1005/2009 on substances which deplete the ozone layer, the use of HCFC-22 is completely prohibited from 1st January 2015 onwards. |
| 2004 UBA report “Fluorierte Treibhausgase in Produkten und Verfahren – Technische Maßnahmen zum Klimaschutz” (Fluorinated greenhouse gases in products and processes – technical measures for climate protection) | Fluorinated hydrocarbons are seeing increased use as substances to replace CFCs and Halons. The report provides information on the use and emissions of fluorinated hydrocarbons in 14 areas of use, and discusses the possible limits on their use and substitute products and processes. It supports the introduction and implementation of the European F-gas Regulation (Regulation (EC) No 842/2006). |
| 2007 International Conference “Co2ol Food – klimafreundlich Kühlen im Supermarkt” (Co2ol Food – climate-friendly refrigeration in the supermarket) on 23rd May 2007 in Berlin | The conference, which took place on the occasion of the German presidency of the EU Council and on the invitation of the German Federal Ministry for the Environment and the UBA, informed the international audience from the refrigeration sector and the worlds of retail and politics about energy efficient and climate-friendly refrigeration systems with natural refrigerants in the supermarket. |
| 2008 Report “Comparative assessment of the climate relevance of supermarket refrigeration systems and equipment” | The study project describes the refrigeration systems on offer for supermarket use in Germany and throughout Europe which contain natural, halogen-free refrigerants, and compares them with systems with synthetic refrigerants that contain halogens. The results provided the basis for funding decisions and legal measures. https://www.umweltbundesamt.de/publikationen/comparative-assessment-of-climate-relevance-of |
| 2008 – 2015 “Round-table on supermarket refrigeration” | The “Runder Tisch Supermarktkälte” (Round table on supermarket refrigeration) hosted by the German Federal Ministry for the Environment and the UBA serves the purpose of encouraging discussions between the operators and builders of systems and components with the world of politics and the craft sector. Its goal is to encourage the broadly based market launch of particularly energy-efficient and climate-friendly refrigeration systems that use natural refrigerants in supermarkets. http://www.umweltbundesamt.de/produkte/fckw/supermarkt/index.htm |
| 2009 UBA report “Projections of global emissions of fluorinated greenhouse gases in 2050” (in English) | The report provides an overview of the emissions of all fluorinated greenhouse gases in the year 2005 and includes projections regarding emissions until 2050. https://www.umweltbundesamt.de/publikationen/projections-of-global-emissions-of-fluorinated |

| Report / project | Content / results |
|---|---|
| 2010 UBA report "Avoiding fluorinated greenhouse gases – prospects for phasing out" | The report "Avoiding fluorinated greenhouse gases – prospects for phasing out" discusses the state of the art regarding applications with fluorinated hydrocarbons and their emissions. The technological advancements regarding reduction measures and substitute technology are especially clear in comparison with 2004. Among others, the results of the report support the amendment of the European F-gas Regulation; the report is available in English. https://www.umweltbundesamt.de/publikationen/avoiding-fluorinated-greenhouse-gases |
| 2011 Publication by Öko-Recherche, the UBA and the BMU: "High increase of global F-gas emissions until 2050" | The publication discusses the forecasted increase in global emissions of fluorinated greenhouse gases until 2050. http://www.tandfonline.com/doi/full/10.1080/20430779.2011.579352 |
| 2011 UBA report "Projektionen zu den Emissionen von HFKW, FKW und SF6 für Deutschland bis zum Jahr 2050" (Projections regarding the emissions of HFCs, PFCs and SF6 for Germany until the year 2050" | The report contains projections regarding emissions of fluorinated greenhouse gases (HFCs, PFCs, SF6) in Germany for the period up to 2050, shown according to sector and gas https://www.umweltbundesamt.de/publikationen/projektionen-zu-den-emissionen-von-hfkw-fkw-sf6 |
| Blue Angel ecolabel for "Klimafreundliche Verkaufsmärkte des Lebensmitteleinzelhandels" (Climate-friendly grocery stores in the food retail sector) (DE UZ 179) | Award criteria for particularly climate-friendly supermarkets which have to be operated on a very energy-efficient basis and are only permitted to use natural refrigerants. https://www.blauer-engel.de/en/products/business-municipality/klimafreundliche-verkaufsmaerkte/lebensmitteleinzelhandel |
| 2014 Report "Sustainable cooling supply for building air conditioning and industry in Germany" | The report describes cooling systems for air conditioning in buildings and process cooling, and compares HFC and halogen-free techniques on the basis of the calculations of greenhouse gas emissions in operation (emissions due to use of refrigerant and energy) and the costs. https://www.umweltbundesamt.de/publikationen/sustainable-cooling-supply-for-building-air |
| 2014 Brochure "Klimafreundliche Gebäudeklimatisierung" (Climate-friendly air conditioning in buildings) | This brochure contains a summary of the results and recommendations of the report "Sustainable cooling supply for building air conditioning and industry in Germany" for building owners, architects and planners. https://www.umweltbundesamt.de/publikationen/klimafreundliche-gebaeudeklimatisierung |
| 2014 Report "Dezentrale steckerfertige Kühlgeräte" (Decentralised plug-in refrigeration cabinets) | A comparison of energy efficiency, safety, costs and reliability of plug-in refrigeration cabinets and an evaluation of the market availability of devices that do not contain fluorinated refrigerants as the basis for the revision of Regulation (EC) No 842/2006. https://www.umweltbundesamt.de/publikationen/dezentrale-steckerfertige-kuehlgeraete |
| 2014 Report "Kohlenwasserstoffe sicher als Kältemittel einsetzen – Entwicklung einer Strategie zum vermehrten Einsatz von Kohlenwasserstoff-Kältemitteln als Beitrag zum deutschen Klimaschutzziel unter Berücksichtigung des Energieziels 2050" (The safe use of hydrocarbons as a refrigerant – development of a strategy for the increased use of hydrocarbon refrigerants as a contribution to the German climate protection objectives in terms of the energy goals for 2050) | Considers possible strategies for the more widespread use of hydrocarbons in room air conditioners, household heat pumps, refrigerated trucks and chillers. https://www.umweltbundesamt.de/publikationen/kohlenwasserstoffe-sicher-als-kaeltemittel |
| 2015 UBA brochure "Hauptsache Kalt?" (Cold: the main thing?) | A summary of the F-gas Regulation and guidelines of action for the phase-down of HFCs in refrigeration and air conditioning systems. https://www.umweltbundesamt.de/publikationen/hauptsache-kalt |
| 2015 Report "Maßnahmen zur Verbesserung der Marktdurchdringung klimafreundlicher Technologien ohne halogenierte Stoffe vor dem Hintergrund der Revision der Verordnung (EG) Nr. 842/2006" (Measures to improve the market penetration of climate-friendly technologies that do not contain halogenated substances in the context of the revision of Regulation (EC) No 842/2006) | Barriers and opportunities for halogen-free substances and/or technologies were identified in a variety of applications, listed in tabular overviews, and assessed in terms of their relevance. https://www.umweltbundesamt.de/publikationen/massnahmen-zur-verbesserung-der-marktdurchdringung |
| 2016 Guide "Recommendations to safety guidelines and standards for the use of natural refrigerants" (in English) | Contains recommendations regarding safety guidelines and standards for the use of flammable refrigerants. https://www.umweltbundesamt.de/publikationen/recommendations-to-safety-guidelines-standards-for |
| 2016 Report "Wärmepumpen mit natürlichen Kältemitteln" (Heat pumps with natural refrigerants) | Shows that heat pumps with natural refrigerants are superior to conventional HFC heat pumps from an ecological perspective, and contains a market overview of the available devices. https://www.umweltbundesamt.de/publikationen/waermepumpen-naturlichen-kaeltemitteln |

| Report / project | Content / results |
|---|---|
| Blue Angel ecolabel for stationary air conditioners (DE-UZ 204) | The key criteria for the awarding of this ecolabel are an advanced level of energy efficiency, the use of halogen-free refrigerants and low noise emissions. https://www.blauer-engel.de/en/products/electric-devices/klimageraete |
| 2016 – 2019 EU project "SuperSmart – Expertise hub for a market uptake of energy-efficient supermarkets by awareness raising, knowledge transfer and pre-preparation of an EU Ecolabel" | The website contains reports, training materials and presentations surrounding the topic climate-friendly supermarket refrigeration. The project is funded by the "Horizon 2020" framework programme of the European Union for research and innovation under the project number 696076. http://www.supersmart-supermarket.info/ |
| 2017 Report "Nachhaltige Kälteerzeugung – Untersuchung der Energieeffizienz natürlicher Kältemittel in Transportkälteanlagen" (Sustainable refrigeration – an examination of the energy efficiency of the natural refrigerants in transport refrigeration systems) | Calculations on the basis of laboratory measurements show that the energy efficiency and the annual greenhouse gas emissions of two-stage transport refrigeration systems can be reduced with the use of natural refrigerants such as R-1270 (propene) and R-744 (carbon dioxide). https://www.umweltbundesamt.de/publikationen/nachhaltige-kaelteerzeugung-untersuchung-der |

## 9.2 Literature

### Reports from the German parliament's Enquet Commission "Preventive measures to protect the earth's atmosphere"

Interim report of the German parliament's Enquet Commission of the 11th federal parliament of the Federal Republic of Germany "Vorsorge zum Schutz der Erdatmosphäre: Schutz der Erdatmosphäre – eine internationale Herausforderung." *(Preventive measures to protect the earth's atmosphere: protecting the earth's atmosphere – an international challenge)*. With plenary debate on 9th March 1989 and resolution of the German federal government on the German CFC-Halon Prohibition Ordinance dating from 30th May 1990, Economica, Karlsruhe, Müller, 1990 ISBN 3-926831-88- X (Economica)/ ISBN 3-7880-9817-1 (Müller).

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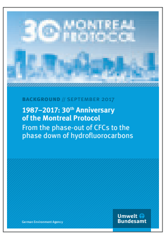


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