COPA
Cutting refrigerant emissions


# GLOBAL BANKS OF OZONE DEPLETING SUBSTANCES (ODS) AND HYDROFLUOROCARBONS (HFCS)

## A COUNTRY-LEVEL ESTIMATE 2024

Climate and Ozone Protection Alliance (COPA)
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Implemented by:
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**ODS/HFC BANKS ARE DEFINED AS "THE TOTAL AMOUNT OF SUBSTANCES CONTAINED IN EXISTING EQUIPMENT, CHEMICAL STOCKPILES, FOAMS AND OTHER PRODUCTS NOT YET RELEASED TO THE ATMOSPHERE".**

IPCC/TEAP, 2005

# CONTENTS



# ABBREVIATIONS

| | |
|---|---|
| A5 | Article 5 |
| AC | Air Conditioner |
| BMU | German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety |
| CFC | Chlorofluorocarbon |
| CCAC | Climate and Clean Air Coalition |
| COPA | Climate and Ozone Protection Alliance |
| EIA | Environmental Investigation Agency |
| EPR | Extended Producer Responsibility |
| EU | European Union |
| GHG | Greenhouse Gas |
| GIZ | Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH |
| GWP | Global Warming Potential |
| HCFC | Hydrochlorofluorocarbon |
| HFC | Hydrofluorocarbon |
| HPMP | HCFC Phase-out Management Plan |
| HS | Harmonised system |
| ICI | International Climate Initiative |
| IPCC | International Panel on Climate Change |
| KIP | Kigali Implementation Plan |
| LVC | Low Volume Countries |
| MCTOC | Medical and Chemicals Technical Options Committee |
| MLF | Multilateral Fund for the Implementation of the Montreal Protocol |
| ODS | Ozone depleting substance |
| PRO | Producer Responsibility Organisations |
| RAC | Refrigeration and air-conditioning (sector) |
| RACHP | Refrigeration, air-conditioning and heat pumps (sector) |
| RTOC | Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee |
| TEAP | Technology and Economic Assessment Panel |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WEEE | Waste Electrical and Electronic Equipment |
| XPS | Extruded Polystyrene |

# 1. BACKGROUND

This paper is part of the Climate and Ozone Protection Alliance (COPA)[1] initiative, funded by the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) under its International Climate Initiative (IKI) and implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. COPA collaborates with partner countries and diverse stakeholders from the private and public sectors to promote holistic solutions aimed at reducing ODS/HFC banks of ozone depleting substances (ODS), and hydrofluorocarbons (HFC) and advancing the transition to sustainable refrigerant management in the cooling sector. The purpose of this paper is to assess the climate impact of the existing ODS, and HFCs banks based on a country-level estimates. It highlights the significant potential for emission reductions through appropriate measures to collect and destroy ODS/HFC banks. The results of this analysis, combined with lessons learned from other project activities, are being used to develop international guidance on ODS and HFC bank management.

To highlight the magnitude of the emissions potentially caused by ODS/HFC banks and to place them in the context of global greenhouse gas (GHG) emissions, an estimate was made for ODS/HFC banks based on the five most widely used ODS and eight HFCs commonly used in refrigeration, air-conditioning and foam applications[2] (CFC-11, CFC-12, HCFC-22, HCFC-141b and HCFC-142b, HFC-125, HFC-134a, HFC143a, HFC-152, HFC-227ea, HFC-236fa, HFC-32, HFC-365mfc). The approach presented in this paper is new as it uses a country-based calculation derived from reported consumption data under Article 7 of the Montreal Protocol to determine bank size estimates at the country-level and make future projections. A detailed description of the methodology is provided in the Annex of this paper. The aim is to break down the global challenge by providing estimates for individual countries, which will also help raise awareness of the complex issue of ODS/HFC bank management at the national level.

Study results are given as the world's total and a break down between non-Article 5[3] and Article 5 countries in *Chapter 2*. *Chapters 3* and *4* propose measures and steps to be taken in particular in Article 5 countries to improve ODS/HFC bank management. Special attention is given to tools and guidelines developed within this project, such as the Gap Analysis helping countries in specifying their needs for support. The key issues are establishing and enforcing a suitable set of policy measures to organize the collection of ODS/HFCs.

This is the third version of this paper, prepared after the addition of the most common HFCs into the calculation of the banks in 2024.

1 COPA website: *https://www.copalliance.org/home*
2 Halons are not included because their management is organised in so-called halon bank initiatives, which reclaim large quantities of halon for existing long-term essential needs, such as civil aviation.
3 Article 5 countries and non-Article 5 countries as defined in Article 5 of Montreal Protocol:
"Any Party that is a developing country and whose annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol for it [...]"

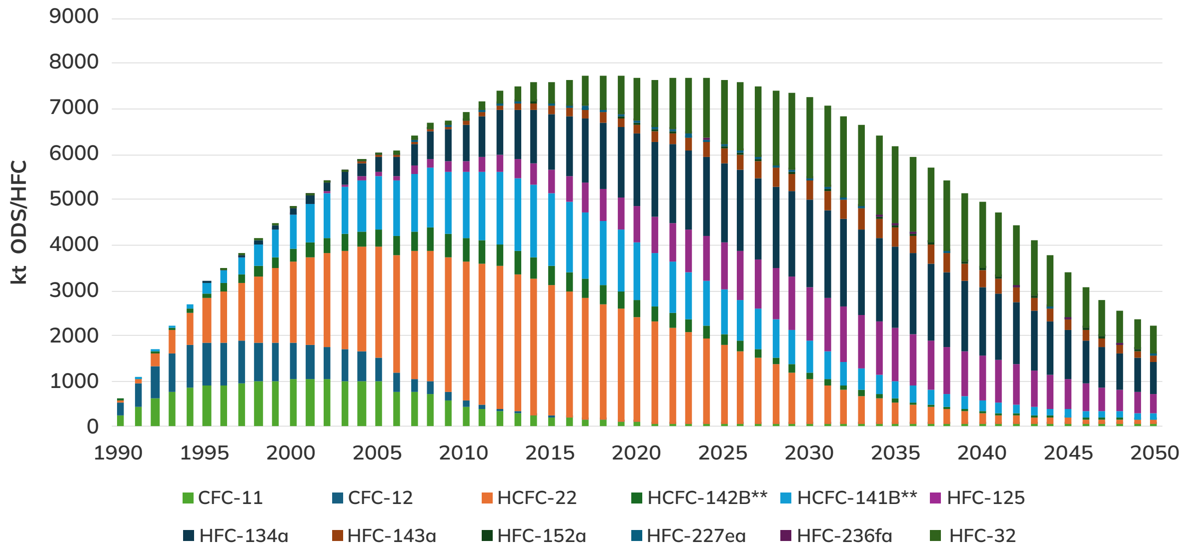
# 2. RESULTS

In 2022, global ODS/HFC banks were estimated to comprise 7680 kt of ODS and HFCs, equivalent to 13.4 Gt $CO_2$ equivalent ($CO_2$eq) in total (*Figure 1*). The projection until 2050 indicates that ODS banks are currently in decline. Following a peak in 2002 at 18.6 Gt $CO_2$eq, only 4.3 Gt $CO_2$eq is expected to remain by 2050 (*Figure 2*). A detailed description of the calculation methodology can be found in the *Annex* to this paper.

In comparison, the Technology and Economic Assessment Panel (TEAP) in the Medical and Chemicals Technical Options Committee (MCTOC) Report 2022[4] estimated a reachable bank[5] of around 8000 kt of ODS/HFC for 2010 alone, corresponding to a mitigation potential[6] which translates to 22.5 Gt $CO_2$eq for that year. TEAP's dataset provides cumulative data of ODS and HFCs, for the refrigeration, air conditioning and heat pumps (RACHP) and foams sectors combined. Our calculation estimates 6905 kt ODS and HFC, equivalent to 13.8 Gt $CO_2$eq for the reachable bank in the same year. For the year 2022 the TEAP estimates a bank of around 6000 kt of ODS/HFC equivalent to 16 Gt $CO_2$eq. Moreover, a publication by the US Environmental Investigation Agency (EIA), titled "the 90 Billion Opportunity" estimated the global ODS/HFC bank in 2022 to be 24 Gt $CO_2$eq. This contrasts with the findings of this paper, which calculated the ODS and HFC bank to be approximately 13.4 Gt $CO_2$eq for the same year.

Since ODS are partly replaced by high Global Warming Potential (GWP) HFCs, the overall amount of refrigerant and blowing agents in the RACHP and foam sector remain at a high level until 2030. While the ODS bank is declining, the HFC banks is increasing and is expected to continue to grow until around 2030 as the HFC baselines includes a "growth reserve" of 65% of the $CO_2$ weighted Hydrochlorofluorocarbons (HCFC) baseline. However, due to the HFC phase-down schedules the bank is expected to decline until 2050.

***Figure 1:*** *Global ODS banks in kt of substance. HCFC consumption is interpolated between 2023 and 2030 (deadline for the phase out in Article 5 countries).*

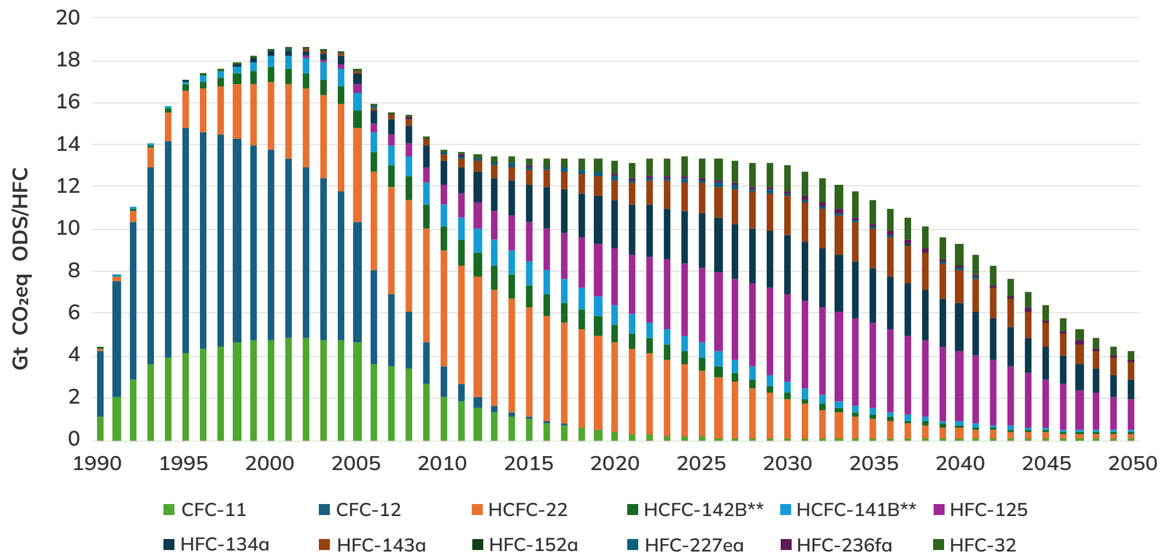



4 *https://ozone.unep.org/system/files/documents/MCTOC-Assessment-Report-2022.pdf*

5 The ODS bank is defined as 'reachable' if the ODS can be recovered when products and equipment enter the waste stream at their decommissioning. Equipment and products that end up landfilled or are left or treated at illegal sites are considered 'lost' and are therefore not included in the reachable bank.

6 The potential emission mitigation equals the reachable bank, converted to $CO_2$eq.

***Figure 2:*** *Global ODS/HFC banks in Gt $CO_2$eq. HCFC consumption is interpolated between 2023 and 2030 (deadline for the phase out in Article 5 countries).*

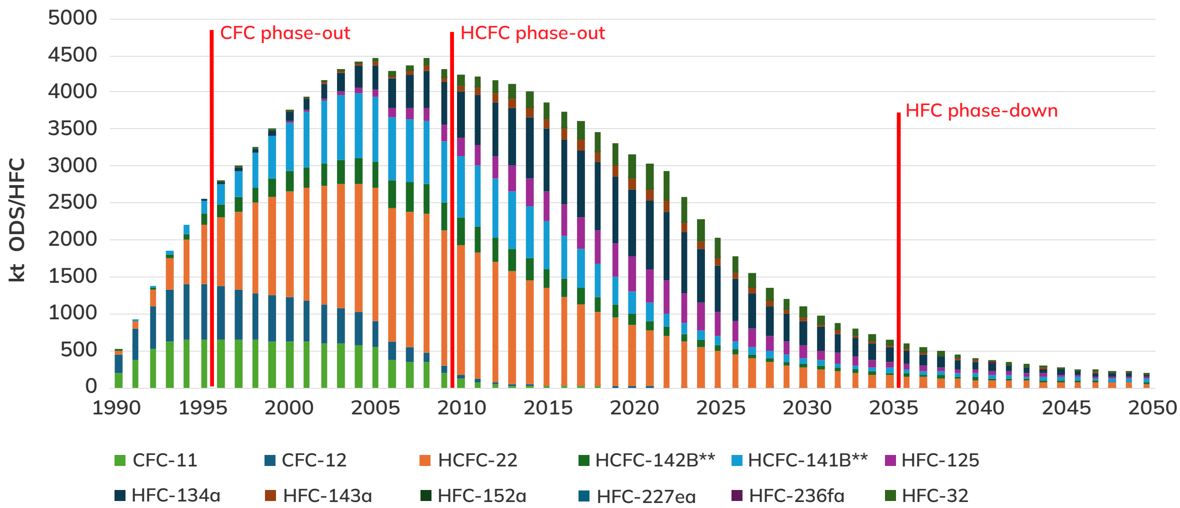



## 2.1 NON-ARTICLE 5 COUNTRIES

Total banks amounted to 4,041 kt ODS/HFC in 2014 (*Figure 3*) and 2,980 kt ODS/HFC in 2022. As a result of previous CFC and HCFC phase-outs, ODS/HFC banks peaked around 2004 and declined after 2008.

Great effort is undertaken in some non-Article 5 countries (e.g. the European Union member states) to collect the ODS and HFCs from the waste stream and destroy the ODS and reclaim or destroy the HFCs.

***Figure 3:*** *ODS/HFC banks in non-Article 5 countries*



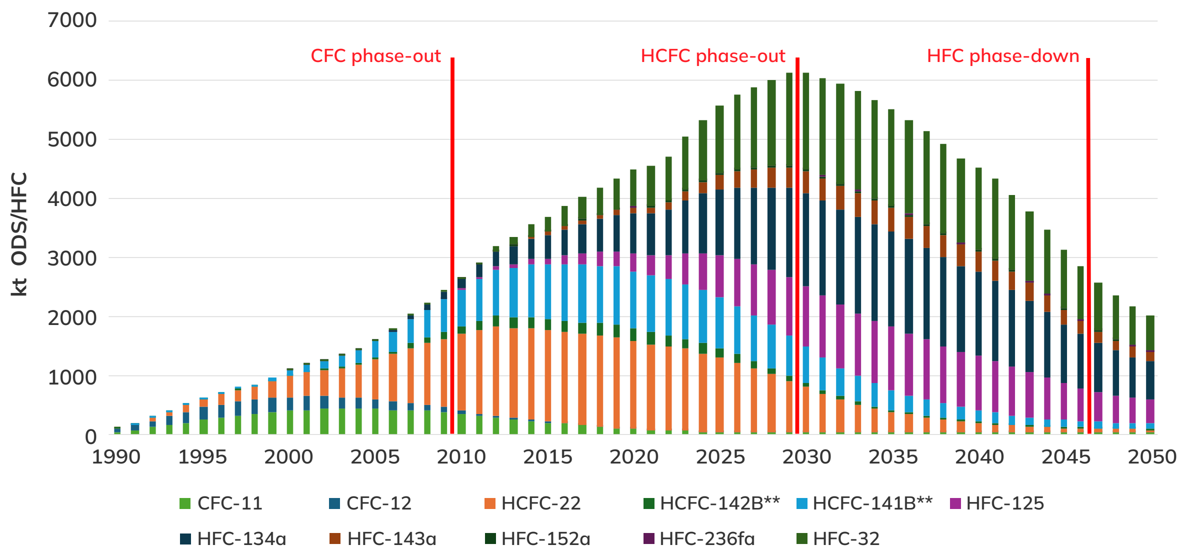
## 2.2 ARTICLE 5 COUNTRIES

The *figures below* illustrate an in-depth analysis of existing ODS/HFC banks in Article 5 countries.

In 2014, the total ODS/HFC banks in Article 5 countries amounted to 3,543 kt of ODS/HFC and 4,700 kt of ODS/HFC in 2022.

As shown in *Figure 4*, the total amount in the banks will peak in 2030, as the banks of HCFC-22 and HCFC-141b decline, while HFC consumption reaches its maximum in 2029. In 2022, about 56% of the banks were made up of ODS and 44% of HFCs, HCFC-22 was the dominant ODS in the RACHP sector followed by HFC-134a.

***Figure 4:*** *ODS/HFC banks in Article 5 countries*




The decline of chlorofluorocarbons (CFC) banks is primarily a result of the CFC phase-out, which was completed in 2010. The CFC bank peaked in 2002. Due to the substitution of CFC by HCFC, the HCFC bank built up until 2017. There are also some small remaining quantities of CFC-12 contained in refrigeration and air conditioning (RAC) equipment and CFC-11 contained foams. HFC banks are expected to rise until 2030 and then start to decline as result of the first reduction step in 2029.

The countries with the largest ODS/HFC banks are shown in *Figure 5*. China dominates the ranking, representing 29% of the total global ODS/HFC bank. In second, third and fourth place are Saudi Arabia, India and Brazil. This approach, however, may underestimate the export of pre-charged equipment and pre-blended polyol, potentially leading to an overestimated ODS/HFC banks. This particularly affects results from countries with significant manufacturing capacity for export, such as China.

Expressed in $CO_2$ equivalents, ODS/HFC banks of Article 5 countries amounted to 6.1 Gt $CO_2$eq in 2014 and to 7.6 Gt $CO_2$eq in 2022. Based on recent trends and the resulting shift away from ODS use, ODS banks are projected to decline until 2030, while HFC banks are expected to decrease until 2050.

***Figure 5:*** *Article 5 countries with the highest calculated ODS/HFC bank*

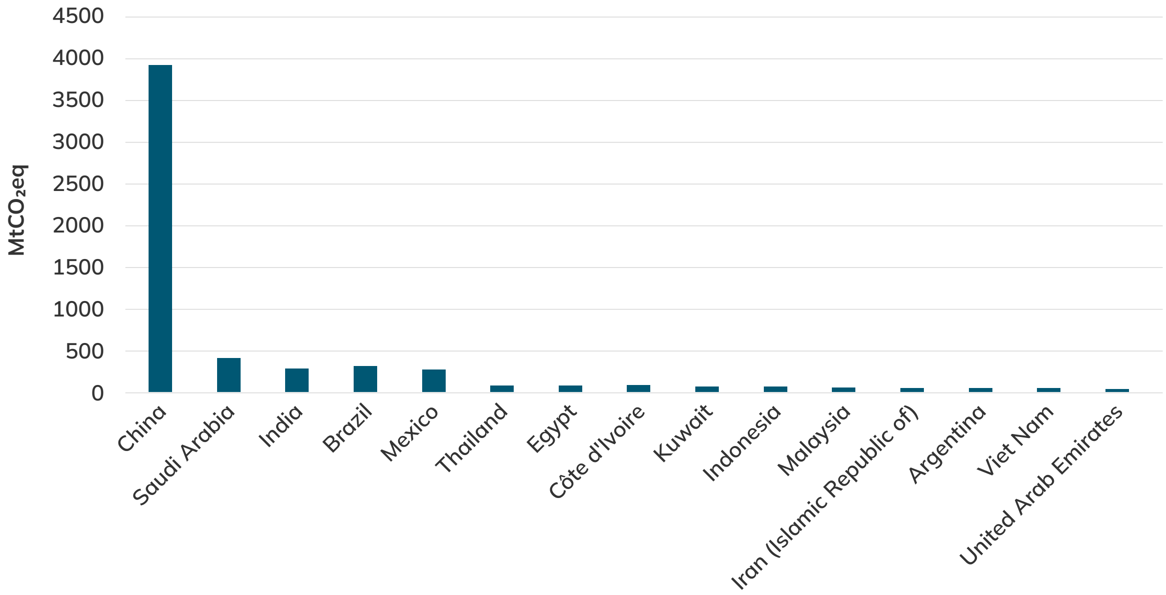
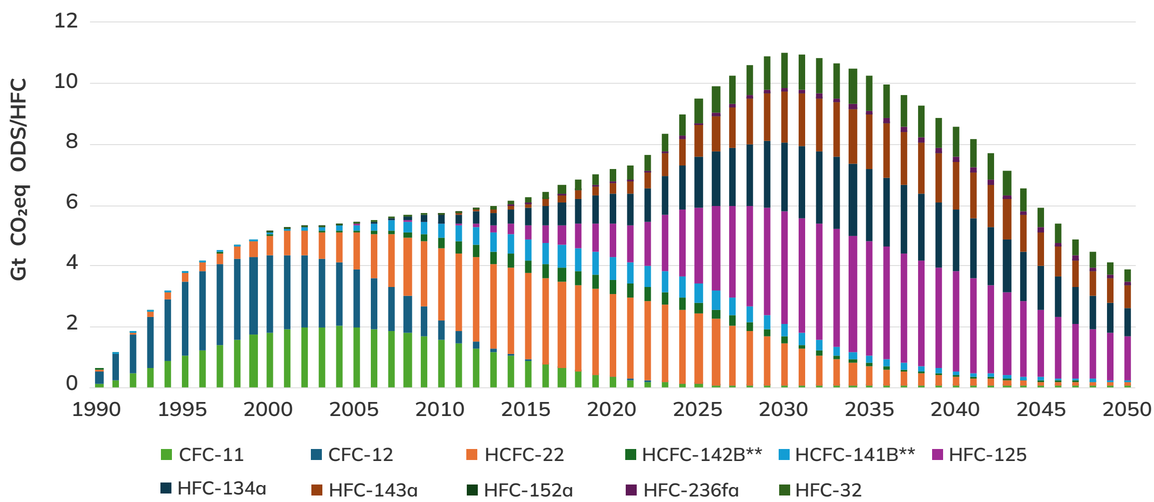



***Figure 6:*** *ODS/HFC bank in Article 5 countries*



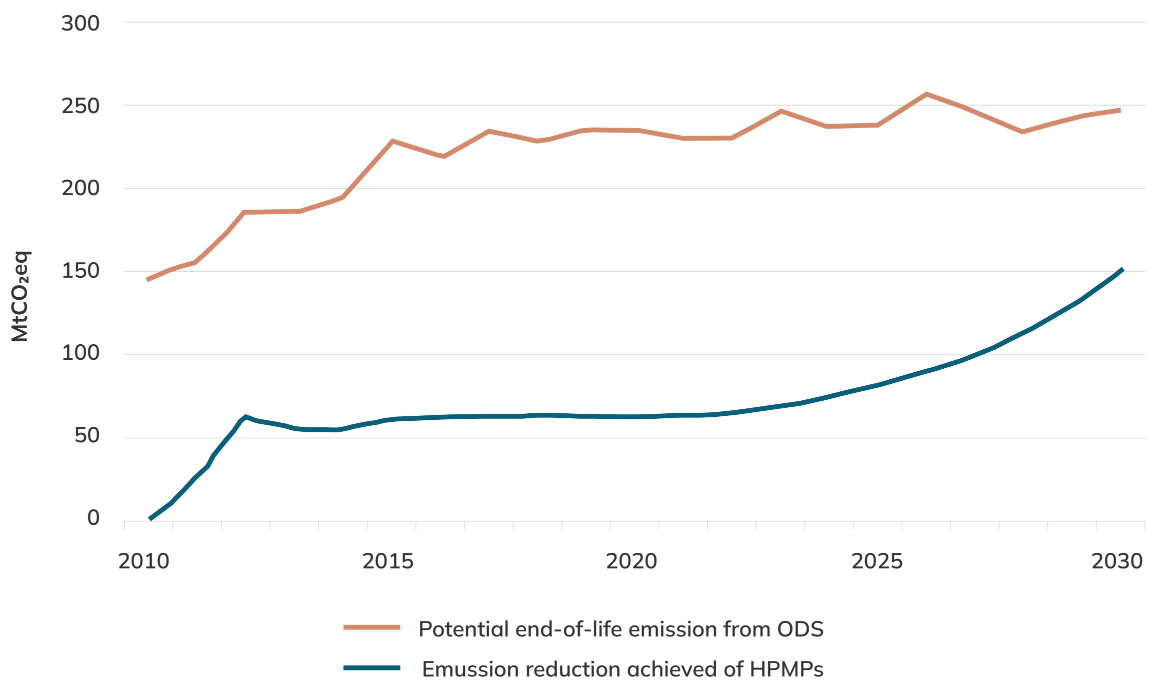
# 3. MANAGING ODS BANKS IN ARTICLE 5 COUNTRIES

The aim of ODS banks management is to contain the gases and ultimately reuse or destroy the ODS as well as HFC in the future.

The amount of ODS/HFC contained in units reaching their end of life is the amount annually available for recovery, and it is potentially lost when not adequately treated.

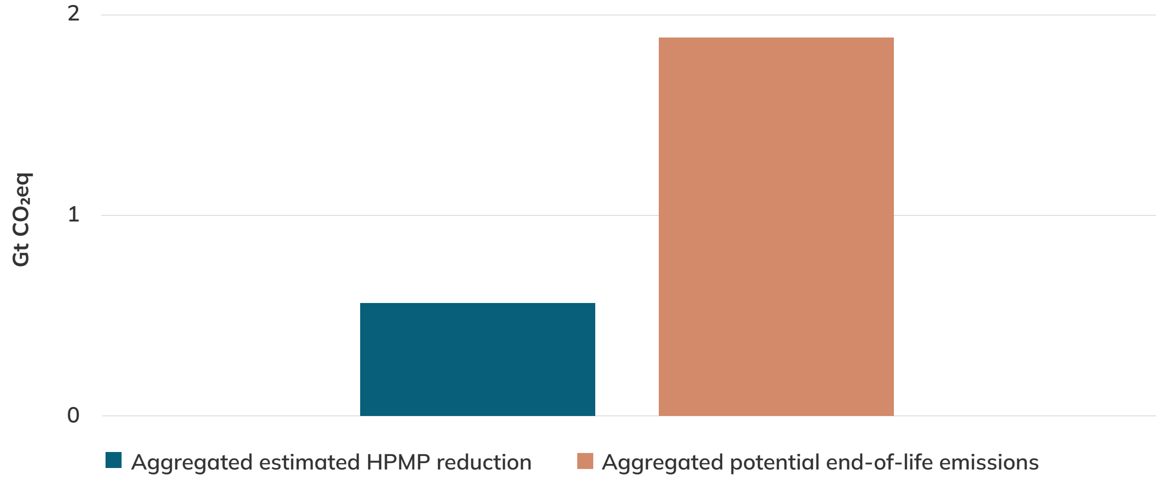
For Article 5 countries, the annual amount of ODS contained in the waste stream is about 0.2 Gt $CO_2$eq. This amount is emitted if not recovered. Until 2025, the potential mitigation is about three times the estimated reduction from the HCFC Phase-out Management Plans[7] (HPMPs). *Figures 7* and *8* illustrate these estimates.

***Figure 7:*** *Potential end-of-life emissions from ODS bank and estimated emission reduction due to HPMP activities*




7 The emission reduction through the HPMP is estimated by comparing the average GWP of the year 2010 (i.e. before HPMP activities started) with the GWP resulting from the phase-out schedule.

***Figure 8:*** *Aggregated potential emissions savings from HPMP activities and ODS bank management (2018-2025)*




## 3.1 COSTS OF ODS/HFC RECOVERY AND DISPOSAL

The costs for collecting ODS and HFCs from equipment and products vary greatly depending on the effort required. In case of low to medium effort and according to the TEAP 2009b and ICF 2010, the total costs for refrigerant recovery, transport and disposal from large installations are 9-13 USD/kg, from stationary AC 10-34 USD/kg, and from domestic and commercial refrigerators 27-45 USD/kg for the refrigerant and 37-65 USD/kg for the blowing agent[8].

However, the study does not take into account situations, where

- refrigerant recovery is obligatory,
- recycled gases are normally returned to refrigerant distributors,
- transport of returned bottles from distributors to filling stations is already occurring

The collection of refrigerants can be organised through the existing distributors' network without substantial funding. A similar approach can be taken where appliances are distributed through doorstep delivery systems, which is the case with many large stores that sell appliances.

The key issues are the existence of respective legislation and its enforcement. This type of practice already exists in many developed countries such as the EU, Australia and the US.

8 More information on costs is provided in the study 'Management and destruction of existing ozone depleting substances banks' and in the cited publications.

## 3.2 KEY ELEMENTS OF RESPONASIBLE ODS/HFC MANAGEMENT

**Promote onsite recycling**
In general, a refrigerant that is contained in a working system can be reused after onsite recycling is conducted, including dehumidification and oil separation. In this case, recycling units are in the market and provided in part through activities funded under the Multilateral Fund (MLF). It only requires additional effort to obtain a recovery unit and cylinder. The equipment will not suffer from any deterioration because the recycled charge will be dehumidified and cleaned of dirt and oil.

**Use of reusable cylinders.**
Allowing only reusable cylinders for refrigerants enables technicians to return excess or unusable refrigerants to the distributor. One-way cylinders should be banned, because they cannot be reused and undermine efforts for recovery.

**Adopt a take-back obligation with a deposit-and-refund scheme**
Take-back obligations are currently either implemented at no cost (e.g. France) or with a permitted charge (e.g. Germany). Funding would be supported through a levy or fee for the sale of virgin ODS/HFC.

Best practice examples on ODS/HFC bank management involving Extended Producer Responsibility (EPR) schemes can be found in member states of the European Union (EU) and Australia, among others. While the organisation of the schemes varies, a common feature is that costs for recovery, collection and reclamation/destruction are covered by producers and distributors. After studying several schemes, in 2016 the Environmental Investigation Agency stipulated key elements of national EPR schemes for the recovery and recycling, reclamation or destruction of ODS and HFCs. More recently, an analysis of EPR schemes in European countries conducted by Adelphi Consult in 2021[9] highlighted key factors for the successful implementation of EPR schemes.

These are:

- Competition between Producer Responsibility Organisations (PROs) can drive innovation and efficiency improvements, especially when these lead to economic incentives or competitive advantages. Measures that would increase producer costs (such as higher environmental standards) are more difficult to implement in competitive systems, as PROs risk losing customers to competitors.
- A strong coordinating body, independent of private interests, is essential for effective EPR implementation, especially in competitive environments. This body should coordinate collection responsibilities, monitor compliance and facilitate joint activities such as awareness campaigns between different PROs.
- Clear reporting and monitoring mechanisms through a public central registry are essential to prevent fraudulent activities and free-riding. The registry should require producers to report quantities and types of products placed on the market, with data verification procedures in place.

9 Adelphi, June of 2021. *https://adelphi.de/de/publikationen/analysis-of-extended-producer-responsibility-schemes*

The paper concludes by stressing that even with an improved regulatory framework, proper enforcement remains a key challenge. The paper notes that "both monopolistic and competitive systems need to be well regulated", but often face "a noticeable lack of enforcement (reporting to enforcement authorities, declaration of products subject to participation, treatment, etc.)".

**Ensure accessible collection points for refrigerants or waste appliances**
Without collection points that are easily accessible to technicians, take-back obligations alone are not effective. This aspect particularly depends on country-specific infrastructure, and cooperation with other waste recycling schemes should be explored.

**Ensure reclamation and destruction facilities**
Producers can assist in reclamation and destruction, if it is mandatory. Funding can be organised through a collective industry association (as e.g. in Australia) or through a government organisation.

From the perspective of resource efficiency, reclamation of refrigerants should be given priority over destruction except where there is no demand anymore. HCFC and HFC refrigerants contain Fluor which is a raw material whose natural deposits are limited. Only substances that cannot be reclaimed are to be destroyed.

Recycling and reclamation procedures range from simple cleaning to distillation columns, which enable separation of different substances contained in a mixture and reduce the waste stream. Reclamation of refrigerants may be more cost effective than destruction and provides an incentive for reselling reclaimed refrigerants.

**Building a quality infrastructure based on informed decision-making**
Further guidance on sound ODS and HFC banks management can be found in the documents and guidelines developed under this project:

- The Gap Analysis compares the status quo of ODS/HFC banks management in specific countries in terms of existing policy frameworks, financing options, the effectiveness of collection and recycling or access to destruction or reclamation and includes a best practice example. The assessment helps countries in specifying their needs for support.
- The global roadmap provides a framework for all activities in this area and includes a step-by-step guide for the improvement of ODS/HFC banks management.
- Several *COPA guidelines* provide detailed know-how on various aspects of ODS/HFC bank management:
  - The Tier 1 approach developed for the global calculation could be easily adopted for each individual country. With increasing experience and additional information on the sectoral use of ODS, the assumptions made could be targeted to specific countries and provide a better estimate of the existing ODS bank.
  - *Guideline to Conduct an Inventory of Used or Unwanted Controlled Substances: ODS/HFC banks* (2023)
  - *Guideline on policy measures for the management and destruction of ozone depleting substances* (2017)
  - *Potential Policy Framework For The Promotion Of Sustainable Ods/Hfc Banks Management* (2023)
  - *Guideline to establish a collection system for equipment containing ODS* (2017)
  - *Guideline for the transboundary movement of ODS waste* (2017)
  - *ODS/HFC Reclamation and Destruction Technologies. A review for Article 5 Countries* (2023)
  - *Destruction Of Ods/Hfc In Cement Kilns* (2024)

# 4. OUTLOOK

This study provides an estimate of the global bank of ozone depleting substances (ODS), and hydrofluorocarbon (HFC) banks based on a country-level estimates. It highlights the significant potential for emission reductions through appropriate measures to collect and destroy ODS/HFC banks. The ODS/HFC banks estimate provided is based on the reporting under Article 7 by countries operating under the Montreal Protocol. Further research in this area could be conducted to monitor and amend additional data on ODS/HFC stocks and emissions from other sources, such as appliance sales statistics, containment practices, recovery procedures, etc.

With the expected increasing consumption of HFCs, GHG emissions from the ODS/HFC banks will continue to remain high. The findings of the analysis and potential excessive emissions from ODS/HFC that are contained in existing banks point to the urgency to act quickly to prevent these from being emitted into the atmosphere. Every day about 1 Mt $CO_2$eq of ODS and HFCs are emitted, but a substantial percentage of this could be recovered.

By establishing an international registry of ODS/HFC banks under the Montreal Protocol, relevant reporting towards this could be performed when parties submit their Article 7 data under the Montreal Protocol. For assessment and reporting of banks, several tools have been developed that will enable countries to understand and develop their ODS banks inventories. For example, see the *COPA Publication on how to conduct an inventory of used or unwanted controlled substances*.

It is very difficult for Article 5 countries to act in isolation. Therefore, concerted political action at the international level could effectively support governments and initiatives that are seriously interested in reducing emissions from ODS/HFC banks on a broader scale. In view of current international discussions, a registry would be a first step.

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# 6. ANNEX: METHODOLOGY

## 6.1 DATA SOURCES

The ODS/HFC bank estimate is based on consumption data which are available as a result of the reporting obligations under Article 7 to the Montreal Protocol.

The consumption data accounts for bulk production, import, and export of ODS and HFCs in accordance with the definition of consumption under the Montreal Protocol[10]. The consumption was attributed to RAC and foam as the main ODS and HFCs consuming sectors, as well as 'other', which represents all uses that lead to instant emission and thus do not build a bank. Such uses include aerosols, solvents, agents for sterilisation, process agents, metered dose inhalers etc. The attribution to sectors is kept constant over time. For the attribution of CFCs, reports from TEAP (1997, 1998, 2006) as well as the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC 1998) were consulted. Due to very fragmentary data, available data points from the mid-1990s were used to estimate the attribution. CFC-11 was used primarily for foam blowing, but also as a refrigerant in centrifugal chillers. CFC-12 was predominantly used for RAC, but also as a blowing agent for extruded polystyrene (XPS) foam. Since XPS foam was not common in Article 5[11] (A5) countries, no CFC-12 is attributed to foam in developing countries. High differences between demand estimates from bottom-up analysis and reported consumption under Article 7 can have several reasons, however TEAP 2006 comes to the conclusion that apart from possible over- or underreporting, flushing of RAC systems with CFCs has been a common practice up to the late 1990s and reached on average percentages of 33% of the consumption, especially for CFC-11 in A5 countries. This is accounted for in the 'other' category, since this practice causes instant emission of the used CFCs.

The HCFC attribution is based on an analysis of the HCFC Phase-out Management Plans (HPMPs) of the 20 largest countries as presented in *Chapter 6.4*. The remaining countries are estimated based on the information that their RAC use of ODS is for servicing only.

The attribution to sectors was necessary to account for sector-specific patterns of bank accumulation. The resulting sectoral distribution of ODS consumption is shown in *Table 1*.

***Table 1:*** *Assumptions for the sectoral distribution of consumed ODS*

| | Non-A5 countries | | | A5 countries | | |
|---|---|---|---|---|---|---|
| | RAC | Foam | Other | RAC | Foam | Other |
| **CFC-11** | 5% | 80% | 15% | 10% | 57% | 33% |
| **CFC-12** | 75% | 10% | 15% | 72% | 2% | 26% |
| | Non-A5 countries | | | A5 countries other than the 20 largest consumers* | | |
| **HCFC-22** | 70% | 20% | 10% | 90% | | 10% |
| **HCFC-141b** | 10% | 80% | 10% | 90% | | 10% |
| **HCFC-142b** | | 90% | 10% | | 90% | 10% |

* For large A5 countries, HPMPs were analysed for the sectoral distribution; data is provided in annex 1

10 Article 1 of the Montreal Protocol: 'Consumption' means production plus imports minus exports of controlled substances.
11 Article 5 countries and non-Article 5 countries as defined in Article 5 of Montreal Protocol: "Any Party that is a developing country and whose annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol for it [...]"

HFC data reported under Article 7 of the Montreal Protocol was available, in the most cases, for the period between 2011-2013 for non-Article 5 countries and between 2019-2022 for most Article 5 countries. These two periods align with the calculation of the HFC baseline for non-Article 5 and Article 5 countries respectively. The data was interpolated for each substance and country from the earliest record backward (to the year of market introduction) and, where possible, between the two data periods (2011-2013 and 2019-2022). HFC consumption data for Algeria, Democratic People's Republic of Korea, Egypt, Iran, Iraq, Kuwait, Libya, Saudi Arabia and Thailand – where reported HFC consumption data was sparse or non-existent – was sourced from a study by the Climate and Clean Air Coalition (CCAC, 2022)[12]. Additionally, HFC consumption data for the period 2023-2050 was estimated based on the baselines established in the Kigali Implementation Plans (KIPs) and the HFC phase-down schedules for each country group.

For the HFC consumption in Article 5 countries, the sectoral distribution was taken from the study conducted by CCAC in 2022. In this study, Article 5 countries are divided into three categories[13] according to their consumption, and their sectoral distribution is estimated. The distribution in non-Article 5 countries was estimated using the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)[14]. The resulting sectoral distribution is shown in *Table 2*. Additionally, a distinction between servicing and manufacturing was made for the RAC sector. For Article 5 countries, the same source from the CCAC was used, as shown in *Table 3*. For non-Article 5 countries, this was calculated using the same guideline (IPCC, 2006)[13] that describes the sectoral distribution of a refrigerant over time, from its introduction to the market until it reaches stability within approximately 14 years. The guideline assumes that a refrigerant is used 100% for manufacturing in the first year, and 5% is transferred to servicing each year until a distribution of 35% manufacturing and 65% servicing is reached. This distribution was modified for HCFCs and HFCs during the respective phase-out/-down schedules in order to simulate a more realistic reduction in consumption, as the production of new equipment using these refrigerants is also phase-out/-down. For HCFCs, manufacturing is reduced after 1998 for non-Article 5 countries and 2013 for Article 5 countries, reaching zero in 2005 and 2020 respectively (0% manufacturing and 100% servicing). For HFCs, manufacturing is reduced after 2020 for non-Article 5 countries and 2029 for Article 5 countries, reaching almost zero in 2029 and 2040 respectively.

***Table 2:*** *Assumptions for the sectoral distribution of consumed HFCs*

| Substance | Non-A5 countries | | | A5 countries Category 1 | | |
|---|---|---|---|---|---|---|
| | RAC | Foam | Other | RAC | Foam | Other |
| HFC-125 | 100% | 0% | 0% | 100% | 0% | 0% |
| HFC-134a | 94% | 5% | 1% | 99% | 0% | 1% |
| HFC-143a | 100% | 0% | 0% | 100% | 0% | 0% |
| HFC-152a | 5% | 15% | 80% | 10% | 15% | 75% |
| HFC-227ea | 0% | 100% | 0% | 0% | 0% | 100% |
| HFC-245fa | 0% | 100% | 0% | 0% | 100% | 0% |
| HFC-32 | 100% | 0% | 0% | 100% | 0% | 0% |
| HFC-365mfc | 0% | 100% | 0% | 0% | 100% | 0% |

→

12 CCAC,2022: A study on the Impacts of HFC Consumption Trends in Article 5 Countries.
13 Category 1: China, Argentina, Brazil, India, Indonesia, Saudi Arabia, Turkey, Malaysia, Mexico and Thailand. Category 2: Other non-Low Volume Countries (non-LVCs), with a total of 45 countries. Category 3. Low Volume Countries (LVCs), with a total of 89 countries.
14 IPCC, 2006: Guidelines for National Greenhouse Gas Inventories, Intergovernmental Panel on Climate Change, Switzerland.

→

| Substance | A5 countries Category 2 | | | A5 countries Category 3 | | |
|---|---|---|---|---|---|---|
| | RAC | Foam | Other | RAC | Foam | Other |
| **HFC-125** | 100% | 0% | 0% | 100% | 0% | 0% |
| **HFC-134a** | 100% | 0% | 0% | 100% | 0% | 0% |
| **HFC-143a** | 100% | 0% | 0% | 100% | 0% | 0% |
| **HFC-152a** | 5% | 15% | 80% | 5% | 15% | 80% |
| **HFC-227ea** | 0% | 0% | 100% | 0% | 0% | 100% |
| **HFC-245fa** | 0% | 100% | 0% | 0% | 100% | 0% |
| **HFC-32** | 100% | 0% | 0% | 100% | 0% | 0% |
| **HFC-365mfc** | 0% | 100% | 0% | 0% | 100% | 0% |

To derive the existing ODS/HFC bank from consumption data, it is also important to consider transboundary trade of equipment that contains ODS/HFC ('pre-charged'), such as domestic refrigerators and freezers (refrigerant and blowing agent) or small AC units (refrigerant). In the context of the Montreal Protocol, consumption for such mass-produced, pre-charged equipment is accounted for in the country where the equipment is produced. However, for the calculation of banks, the consumption needs to be attributed to the country where the equipment is used. The same issue is applicable to pre-blended polyols, where the consumption is accounted for in the country where the pre-blending is carried out and the bank is formed in the country where the foam was blown and used. However, due to the lack of consistent data set, the issue of pre-blended polyol was not taken into account. This possibly leads to an overestimate of the foam bank in producing countries (most relevant for China) and underestimates of foam banks of importing countries.

***Table 3:*** *Assumptions for the HFC sectoral distribution in the RAC sector (only Article 5 countries)*

| Refrigerant | A5 Category 1 | | A5 Category 2 | | A5 Category 3 | |
|---|---|---|---|---|---|---|
| | Manufact | Servicing | Manufact | Servicing | Manufact | Servicing |
| **HFC-125** | 42% | 58% | 26% | 74% | 7% | 93% |
| **HFC-134a** | 47% | 53% | 20% | 80% | 0% | 100% |
| **HFC-143a** | 30% | 70% | 29% | 71% | 17% | 83% |
| **HFC-152a** | 50% | 50% | 0% | 100% | 0% | 100% |
| **HFC-32** | 50% | 50% | 24% | 76% | 0% | 100% |

* HFC-227ea, HFC-245fa, HFC-365mfc are not shown as they are considered to be used only as blowing agents for foams or other uses outside the RAC sector.

The UN COMTRADE database was utilised to extract import and export figures of pre-charged RAC equipment. This database uses the harmonised system (HS) code, which allows conclusions to be drawn regarding the corresponding RAC equipment (*Table 2*). The HS code version from 1988/92 was used to ensure that data series are consistent during the study period from 1990-2022.

***Table 4:*** *HS codes used by customs and corresponding RAC equipment*

| Version | Code | Official text |
|---|---|---|
| **HS 1988/92** | 841510 | Air conditioning machines: window or wall types, self-contained or 'split system' |
| **HS 1988/92** | 841581 | Air conditioning machines: incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps) |
| **HS 1988/92** | 841582 | Air conditioning machines: incorporating a refrigerating unit |
| **HS 1988/92** | 841810 | Combined refrigerator-freezers, fitted with separate external doors |
| **HS 1988/92** | 841821 | Refrigerators, household type, compression-type |
| **HS 1988/92** | 841829 | Refrigerators, household type, other |
| **HS 1988/92** | 841830 | Freezers of the chest type, not exceeding 800 l capacity |
| **HS 1988/92** | 841840 | Freezers of the upright type, not exceeding 900 l capacity |
| **HS 1988/92** | 841850 | Other refrigerating or freezing chests, cabinets display counters, showcases and similar refrigerating or freezing furniture |
| **HS 1988/92** | 841861 | Other refrigerating or freezing equipment; heat pumps: compression type units whose condensers are heat exchangers |
| **HS 1988/92** | 841869 | Other refrigerating or freezing equipment; heat pumps: other |

***Table 5:*** *Assumption of ODS and HFCs content in pre-charged equipment*

| | Refrigerant | Blowing agent |
|---|---|---|
| **Air-conditioners** | Charge per Item: 1.2 kg (US EPA 2011) | |
| | Assumed gradual replacement of HCFC-22 by non-ODS[15]:<br>< 2000: 100% HCFC-22<br>2005: 90% HCFC-22<br>2010: 70% HCFC-22<br>2015: 36% HCFC-22<br>> 2017: 0% HCFC-22<br>The gradual replacement of HCFC-22 by HFCs can be seen in *Figure 9*. | |
| **Fridges** | Charge per Item: 0.32 kg refrigerant[16] | Charge per Item: 0.87 kg blowing agent[17] |
| | Assumed gradual replacement of CFC-12 by non-ODS:<br>< 1995: 100% CFC-12<br>> 2004: 0% CFC-12<br>2000: 50% HFC-134a<br>2010: 75% HFC-134a<br>2022: 40% HFC-134a<br>HFC-134a is then gradually replace by natural refrigerants (mainly R-600a) | Assumed gradual replacement of CFC-11 by HCFC-141b and non-ODS:<br>< 1995: 100% CFC-11<br>2000: 50% HCFC-141b, 50% non-ODS<br>> 2014: 0% non-ODS |

15 Assumptions are based on qualitative analysis of current HPMPs regarding the transition of AC manufacture of pre-charged ACs to HFCs and other alternatives.

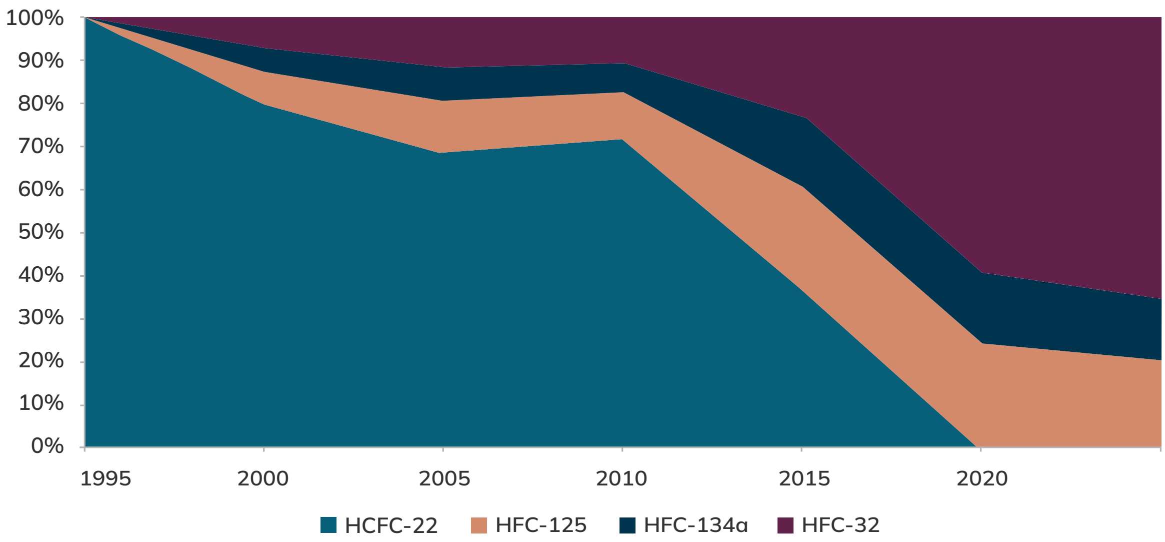
16 To account for different fridge sizes, the average of the European WEEE Forum Standard (0.128 kg) and an average given by the US EPA (0.51 kg) was used (Sources: WEEE 2007, US EPA 2011).

17 IPCC 2006, Chapter 7, page 7.14

Additional assumptions were made for the initial refrigerant charge and the blowing agent content of this equipment (*Table 3*). Data was derived from European Waste from Electrical and Electronic Equipment (WEEE) Forum Standard and US EPA. Since refrigerators and split ACs are similar all over the world the derived data set is used for non-Article 5 and Article 5 countries alike.

ODS/HFC flow from transboundary trade of pre-charged equipment is only a small portion of the total consumption. Due to fragmentary data, the global net trade flow of ODS/HFC in pre-charged equipment is negative. This is because more equipment is reported as exported than imported.

***Figure 9:*** *HCFC replacement by HFCs in air conditioners*




Consequently, the data from transboundary trade was corrected for the five most-widely used substances and for each of the foam and RAC uses for the time series between 1990 and 2014.

To increase the match of emission patterns, the RAC and the foam sectors are treated separately.

### 6.1.1 Projection of ODS and HFC consumption in the refrigeration, air conditioning and foam sector

HFC and HCFC consumption was projected into the future to estimate the development of the ODS/HFC banks for the period 2022-2050. For HCFCs, consumption data for the three substances considered in this study (HCFC-22, HCFC-141b, HCFC-142b) were interpolated between 2022 and 2030, assuming zero consumption in 2030. For HFCs, consumption was projected based on the HFC baselines agreed under the Kigali Implementation Plans (KIPs) and HFC phase-down schedules. For Article 5 countries, whose consumption was above 70% of the baseline, the consumption was projected to meet the first phase-down target in 2029 (90% consumption of baseline). For countries with HFC consumption far below their baseline, it was assumed that in 2029, the HFC consumption will not reach the "90% of the baseline-mark". Instead, the projected consumption in 2029 was informed by the consumption in 2022. For example, if the consumption in 2022 was 50% of the baseline, the consumption in 2029 is assumed to be 70% of the baseline. After 2029 the consumption continuously meets the other phase-down targets until 2047, after which consumption was kept constant (2047-2050). Similarly, for non-Article 5 countries, HFC consumption was projected to follow each reduction step until 2036. For the period 2036-2050, consumption was kept constant, except for the European Union Member States, which have a zero HFC consumption target in 2050. The HFC phase-down schedules were used individually for each country, depending on their group within their category[18], as agreed in the Kigali Amendment to the Montreal Protocol.

## 6.2 CALCULATION OF ODS/HFC BANKS IN THE REFRIGERATION AND AIR CONDITIONING SECTOR

The calculation is based on the methodology in the IPCC Good Practice Guidelines 2006 for Tier 1a (equation 7.2A)[14]. The formula follows the logic that all chemicals that are not emitted will build up the banks. The ODS/HFC contained in products and equipment in use is the most important part of the bank in the RAC sector (apart from others such as bulk stocks).

The ODS/HFC bank is defined as 'reachable' if the ODS/HFC can be recovered when products and equipment enter the waste stream at their decommissioning. Equipment and products that end up landfilled or are left or treated at illegal sites are considered 'lost' and are therefore not included in the reachable bank.

$$\mathbf{Bank}_{y} = \mathbf{Consumption}_{y} * (1 - \mathbf{EF}_{fy}) + \mathbf{Bank}_{y-1} * (1 - \mathbf{EF}_{bank}) - \mathbf{EOL}_{y}$$

$$\mathbf{EOL}_{y} = \mathbf{Consumption}_{y-LT} * \mathbf{R}_{IC}$$

| | |
|---|---|
| **y** | year |
| **LT** | Lifetime of equipment containing the refrigerant |
| **$EF_{fy}$** | Emission factor in the first year, accounting for transport losses, container heels, etc. |
| **$EF_{bank}$** | Emission factor of the bank, accounting for refrigerant leakages during use |
| **EOL** | Refrigerant contained in equipment that is taken out of use (decommissioned) |
| **$R_{IC}$** | Percentage of consumption that is used for the first fill of equipment (in contrast to topping up during servicing) |

The emission factors are different for developed and developing countries, accounting for varying standards in refrigerant handling and recycling procedures. Values are based on IPCC Tier 1 a/b approach and provided in *Table 4*.

The refrigerant contained in equipment reaching decommissioning is estimated by applying a percentage to the consumption ($R_{IC}$). This percentage is assumed to be 1/3 of the consumptionn[20]. This amount of ODS/HFC is assumed to be available for recovery, reclamation or destruction.

A limitation of the model is the divergence between calculated bank development and the calculation of refrigerant reaching decommissioning when the majority of bank accumulation took place before the available data series (before 1990) and refrigerants are phased-out. Because of the low annual addition resulting from the phase-out schedule, the bank disappears faster than the calculated decommissioned refrigerant. This is based on the consumption when the now decommissioned equipment entered the market. To avoid decommissioned refrigerant from a non-existing bank, those values where set to zero.

18 Among non-Article 5 countries, Belarus, Kazakhstan, the Russian Federation, Tajikistan and Uzbekistan have different initial two steps. (1) 5% reduction in 2020 and (2) 35% reduction in 2025. Article 5 countries are divided into two groups with different phase-down schedules. Group 1: Article 5 counties not part of Group 2 and Group 2: Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and the United Arab Emirates.

19 Although bank is referred to as 'ODS contained in equipment in use', the approach does not look at equipment numbers to calculate banks.

*Table 6: Assumptions for bank estimate in the RAC sector (Approach Tier 1a/b, weighted average of sub-applications listed in Table 7.9)*

| Parameter | IPCCs default values | Developed C. | Developing C. |
|---|---|---|---|
| $EF_{fy}$ | 0.2-3% | 2% | 10% |
| $EF_{bank}$ | 15% | 15% | 20% |
| Lifetime | 15 | 15 | 20 |
| $R_{IC}$ | 1/3 | 1/3 | 1/3 |

## 6.3 CALCULATION OF ODS/HFC BANKS IN THE FOAM SECTOR

The formula for the calculation of bank in the foam sector is based on assumptions for closed-cell foam laid out by Gamlen in the IPCC Guidelines 2006 in Table 7.5[21].

The same logic applies as in the RAC sector: all chemicals that are not emitted are part of the bank.

Only ODS/HFC foams from equipment or building materials that enter the waste stream at end of life are considered as a 'reachable' bank. Unwanted materials and equipment that end up landfilled or are illegally disposed are considered 'lost' and are therefore not included in the reachable bank.

$$\mathbf{Bank}_{y} = \mathbf{Consumption}_{y} * (1 - EF_{fy}) + \mathbf{Bank}_{y-1} * (1 - EF_{bank}) - \mathbf{EOL}_{y}$$

$$\mathbf{EOL}_{y} = \mathbf{Consumption}_{y-LT} * (1 - EF_{fy} - EF_{bank} * LT)$$

| | |
|---|---|
| **y** | year |
| **LT** | Lifetime of equipment containing the refrigerant |
| $EF_{fy}$ | Emission factor in the first year, accounting for transport losses, container heels, etc. |
| $EF_{bank}$ | Emission factor of the bank, accounting for refrigerant leakages during use |
| **EOL** | Refrigerant contained in equipment that is taken out of use (decommissioned) |

The deduction of blowing agent contained in equipment at decommissioning is determined based on an adapted Gamlen model. Originally, Gamlen (1986) states that the emission patterns of closed-cell foam are the least well-defined. The emission factors given as the IPCC default values aim at a conservative (meaning high) emission rate. This is justified for guiding the calculation of emissions. However, this exercise aims at estimating what is not emitted and thus proposes emission factors that do not lead to the (near) total loss of blowing agent over the lifetime. This approach is also supported by TEAP 2006, where is stated that it is very likely that the Gamlen model is overestimating emissions. The choice of emission factors also takes into account the broad variation of emission patters of different foam sub-applications, ranging from 100% loss of blowing agent in the first year to more than 92% of the blowing agents still being present at decommissioning[22]. Emissions also depend on foam-type as well as on used blowing agents and surfactants. Emission factors are different for developed and developing countries, accounting for varying standards in blowing agent handling and foam production. Values are provided in *Table 5*.

20 IPCC 2006, Chapter 7, page 7.45: 'In a mature market, two thirds of the sales of a refrigerant are used for servicing and one third is used to charge new equipment.' In a premature market, a larger portion of the sales are used for the charge of new equipment, whereas during transition to substitute refrigerants, the portion used for charging new equipment will decline. Nevertheless, as an average, the given ratio is used to estimate the amount of refrigerant contained in the fleet of equipment in a single year.

21 IPCC 2006, Chapter 7, page 7.35.

22 IPCC 2006, Chapter 7, page 7.37, tables 7.6 and 7.7

***Table 7:*** *Assumptions for foam sector bank calculation*

| Parameter | Default values (Gamlen[21]) | Developed countries | Developing countries |
|---|---|---|---|
| $EF_{fy}$ | 5-10% | 5% | 10% |
| $EF_{bank}$ | 4.5% | 2% | 2% |
| Lifetime | 20 | 20 | 20 |
| Blowing agent left at EOL (% of Initial Charge) | 0-5% | 55% | 50% |

## 6.4 SUBSTANCE USE EXTRACTED FROM HPMPS OF 20 ARTICLE 5 COUNTRIES WITH HIGHEST CONSUMPTION

High percentages of HCFC-141b and HCFC-142b for RAC often represent quite small amounts in absolute numbers and are reported as used for servicing.

The actual amounts cannot be given here due to confidentiality issues.

***Table 8:*** *A Use of HCFCs extracted from the HPMPs of the 20 Article 5 countries with highest consumption*

| Country | Substance | Data year | RAC use | Foam use | Other use |
|---|---|---|---|---|---|
| Argentina | HCFC-141b | 2010 | 12% | 83% | 5% |
| Argentina | HCFC-142b | 2010 | 87% | 12% | 1% |
| Argentina | HCFC-22 | 2010 | 96% | 0% | 4% |
| Bangladesh | HCFC-141b | 2010 | 0% | 100% | 0% |
| Bangladesh | HCFC-142b | 2010 | 100% | 0% | 0% |
| Bangladesh | HCFC-22 | 2010 | 100% | 0% | 0% |
| Brazil | HCFC-141b | 2009 | 0% | 95% | 5% |
| Brazil | HCFC-142b | 2009 | 0% | 100% | 0% |
| Brazil | HCFC-22 | 2009 | 100% | 0% | 0% |
| China | HCFC-141b | 2013 | 0% | 92% | 8% |
| China | HCFC-142b | 2013 | 12% | 88% | 0% |
| China | HCFC-22 | 2013 | 85% | 15% | 0% |
| Cote d' Ivoire | HCFC-22 | 2010 | 100% | 0% | 0% |
| Democratic People's Republic of Korea | HCFC-141B | 2013 | 0% | 100% | 0% |
| Democratic People's Republic of Korea | HCFC-22 | 2013 | 100% | 0% | 0% |
| Egypt | HCFC-141b | 2010 | 0% | 100% | 0% |
| Egypt | HCFC-22 | 2010 | 99% | 1% | 0% |
| India | HCFC-141b | 2009 | 0% | 96% | 4% |
| India | HCFC-142b | 2009 | 92% | 8% | 0% |
| India | HCFC-22 | 2009 | 97% | 3% | 40 |
| Indonesia | HCFC-141B | 2009 | 35% | 65% | 0% |
| Indonesia | HCFC-22 | 2009 | 100% | 0% | 0% |

| Country | Substance | Data year | RAC use | Foam use | Other use |
|---|---|---|---|---|---|
| Iran (Islamic Republic of) | HCFC-141B | 2011 | 45% | 55% | 0% |
| Iran (Islamic Republic of) | HCFC-22 | 2011 | 99% | 1% | 0% |
| Iraq | HCFC-124 | 2010 | 100% | 0% | 0% |
| Iraq | HCFC-142B | 2010 | 100% | 0% | 0% |
| Iraq | HCFC-22 | 2010 | 100% | 0% | 0% |
| Kuwait | HCFC-141B | 2012 | 0% | 100% | 0% |
| Kuwait | HCFC-142B | 2012 | 0% | 100% | 0% |
| Kuwait | HCFC-22 | 2012 | 85% | 15% | 0% |
| Malaysia | HCFC-141b | 2009 | 0% | 100% | 0% |
| Malaysia | HCFC-22 | 2009 | 100% | 0% | 0% |
| Mexico | HCFC-141B | 2010 | 35% | 60% | 5% |
| Mexico | HCFC-142B | 2010 | 0% | 100% | 0% |
| Mexico | HCFC-22 | 2010 | 87% | 7% | 6% |
| Nigeria | HCFC-141B | 2010 | 60% | 40% | 0% |
| Nigeria | HCFC-22 | 2010 | 100% | 0% | 0% |
| Pakistan | HCFC 141b | 2009 | 0% | 100% | 0% |
| Pakistan | HCFC-22 | 2009 | 100% | 0% | 0% |
| Paraguay | HCFC-141b | 2009 | 0% | 100% | 0% |
| Paraguay | HCFC-142b | 2009 | 100% | 0% | 0% |
| Paraguay | HCFC-22 | 2009 | 100% | 0% | 0% |
| Philippines | HCFC-141B | 2011 | 31% | 69% | 0% |
| Philippines | HCFC-22 | 2011 | 100% | 0% | 0% |
| Saudi Arabia | HCFC-141b | 2010 | 5% | 95% | 0% |
| Saudi Arabia | HCFC-142b | 2010 | 0% | 100% | 0% |
| Saudi Arabia | HCFC-22 | 2010 | 93% | 7% | 0% |
| Senegal | HCFC-22 | 2009 | 100% | 0% | 0% |
| South Africa | HCFC-141B | 2010 | 0% | 98% | 2% |
| South Africa | HCFC-142B | 2010 | 100% | 0% | 0% |
| South Africa | HCFC-22 | 2010 | 97% | 3% | 0% |
| Thailand | HCFC-141B | 2010 | 0% | 90% | 10% |
| Thailand | HCFC-22 | 2010 | 100% | 0% | 0% |
| Venezuela (Bolivarian Republic of) | HCFC-141B | 2009 | 0% | 100% | 0% |
| Venezuela (Bolivarian Republic of) | HCFC-142B | 2009 | 100% | 0% | 0% |
| Venezuela (Bolivarian Republic of) | HCFC-22 | 2009 | 100% | 0% | 0% |
| Viet Nam | HCFC-141B | 2012 | 0% | 100% | 0% |
| Viet Nam | HCFC-22 | 2012 | 100% | 0% | 0% |

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