A Study on the Impacts of HFC Consumption Trends in Article 5 Countries

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CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

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ACRONYMS AND ABBREVIATIONS

AC	Air conditioner
BAU	Business-as-usual
CCAC	Climate and Clean Air Coalition
CFC	Chlorofluorocarbon
CO_2eq	Carbon dioxide equivalent
CP	Country programme
DR	Domestic refrigerator
GWP	Global Warming Potential
HC	Hydrocarbons
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HPMP	HCFC Phase-out Management Plan
ICR	Industrial and commercial refrigeration
kt	Kilotonnes
KIPs	Kigali HFC implementation plans
LVC	Low-volume consuming
MAC	Mobile air conditioner
MLF	Multilateral Fund
Mt	Megatonnes
mt	Metric Tons
ODS	Ozone-depleting substances
RAC	Refrigeration and air-conditioning
RTOC	Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee
SAC	Stationary air conditioner
TEAP	Technology and Economic Assessment Panel

EXECUTIVE SUMMARY

As part of the workplan agreed under the workstream to complement the implementation of the Kigali Amendment, the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) has commissioned a study to provide a profile of current and projected hydrofluorocarbon (HFC) consumption in Montreal Protocol Article 5 countries (developing countries), and to outline opportunities for near-term control or reduction of HFC consumption. The aim of the study is to inform stakeholders on the potential benefits of an accelerated/optimized HFC phase-down and identify likely countries and sectors for near-term action.

This report presents the findings of the HFC consumption assessment of Article 5 countries in the Montreal Protocol. The study was conducted from October 2021 to June 2022 based on publicly available information on HFC consumption in various Article 5 countries.

Approach

The study includes a total of 144 Article 5 countries. Of these, 89 are low-volume consuming (LVC) countries and 55 are non-LVC countries according to the categorization used under the Multilateral Fund for hydrofluorocarbons. As of 1 December 2021, 57 LVC countries and 25 non-LVC countries had either ratified or accepted the Kigali Amendment to the Montreal Protocol (a total of 82 Article 5 countries).

The HFCs which are the focus of this study are the most widely used ones and include HFC-32, HFC-134a, HFC-404A, HFC-407C, HFC-410A, HFC-507A and HFC-245fa. Consumption of these HFCs represents more than 97% of total HFC consumption (TEAP, 2015). HFC-23 is a by-product that is produced in the HCFC-22 manufacturing process and is not considered in the analysis described here.

HFC consumption projections are made for each Article 5 country and aggregated for all Article 5 countries. The study initially considers three different possible growth trajectories to illustrate how HFC consumption may increase under varying growth scenarios. An average of these scenarios is then used for the rest of the study.

Consumption has been estimated per HFC type and per HFC-consuming sector and subsector for all Article 5 countries in the year 2020 and then projected until 2050. For the sectoral analysis, countries are grouped into three categories as per their consumption profiles. The 10 largest hydrofluorocarbon (HCFC) consuming countries are in Category 1, contributing 82.9% of the HCFC baseline. Category 2 consists of the remaining non-low-volume consuming (LVC) countries, contributing 15.1% of the HCFC baseline. Category 3 represents all the LVCs contributing 2% of the HCFC baseline.

Given that the 2024 HFC consumption freeze for Article 5 Group 1 countries is less than two years from the year this study was undertaken, the report examines the situation of countries with respect

to meeting this freeze level and identifies those which may have difficulty in meeting their first HFC phase-down compliance goal (freeze in year 2024 for Group 1 Article 5 Parties) if no near-term action is taken. The report then identifies potential actions that could be undertaken in these countries in the short term to ensure their compliance with the near-term targets of the Kigali Amendment.

Based on the sectoral analysis undertaken and a review of the status of alternatives to HFCs, the report develops two HFC mitigation scenarios, one that uses a particular technology pathway to meet the Kigali Amendment's phase-down schedule and another, more ambitious but feasible, pathway that aims to accelerate reductions in consumption to maximize climate benefits.

It is acknowledged that there is significant level of uncertainty both in estimating current HFC consumption for countries that have not reported data and in projecting HFC consumption in the future, especially growth rates during 2020-2024. Therefore, the HFC consumption data in this report should be seen as best estimates, based on available information and the methodology described above.

Key findings

Under the average business-as-usual (BAU) scenario, total HFC consumption in Article 5 countries is projected to grow from 1,001 Mt CO_2eq in 2020 to 2,367 Mt CO_2eq by 2032, the year of the HFC freeze for Group 2 countries. Projections are that growth will reach 4,853 Mt CO_2eq by 2050. Strict compliance with the Kigali Amendment would reduce this consumption to 319 Mt CO_2eq by 2050.

Within certain data limitations that are explained in the study, it is estimated that 56.4% of HFC consumption in all Article 5 countries is in the refrigeration servicing sector, 39.8% is in the manufacturing sector (including local installation and assembly) and less than 4% is in the foam, aerosol, fire suppression and solvent sectors. In the manufacturing sector, most HFC consumption is in stationary air-conditioning equipment, which contributes about half of the total consumption for manufacturing.

According to the analysis performed in this study, 28 out of 135 Group 1 countries will be above their baseline target levels in the year 2024 unless rapid action is taken to limit or reduce HFC consumption. Since the freeze level needs to be sustained after 2024, the projected baselines were compared with the projected consumption in 2025 and 2026. According to this analysis, an additional 27 Group 1 countries will be above their baseline level in 2025 and/or 2026. Therefore, considering the countries' abilities to meet and sustain the 2024 freeze up to 2026, there are 55 countries overall that would not comply with their target unless prompt action is taken to limit or reduce HFC consumption. Forty-eight of these countries will have estimated HFC consumption levels above 110% of the baseline level by 2026.

HFC consumption growth during 2021-2024 has a major impact on how far or close countries will be from their baseline levels in the 2024-2026 period. The growth projections under the BAU scenario considered in this report are subject to significant uncertainty, particularly given the lack of reported HFC consumption data by many countries and changes in economic growth brought about by the COVID-19 pandemic.

Many countries have delayed several of the initial steps and measures to enable compliance, partly as a result of the COVID-19 pandemic during 2020 and 2021. The Kigali HFC Implementation Plans (KIPs) have also yet to be approved under the Montreal Protocol's Multilateral Fund (only the preparation of KIPs has been approved to date). Consequently, there is now a short window of time for the 55 countries identified (and possibly others) to ensure their compliance with the first control measure under the Kigali Amendment. The study suggests that in manufacturing countries, the initial reductions required to meet and sustain the HFC freeze could likely be achieved by phasing out HFCs in sectors where alternatives are readily available, such as for domestic refrigeration, stand-alone commercial refrigeration and insulation foams, perhaps combined with action in the refrigeration servicing and local installation and assembly sectors. However, this depends on the specific sectoral distribution of individual countries. For LVC countries, actions need to focus on reducing consumption in the refrigeration servicing sector and possibly in local installation and assembly where significant.

Despite these short-term challenges, and given that many alternatives with lower global warming potential (GWP) exist in the sectors where high-GWP HFCs are used, over the medium to longer term there is an opportunity for Article 5 countries to achieve more significant HFC consumption reductions than strictly required under the Kigali Amendment in order to increase climate benefits.

To meet the Kigali Amendment, the climate benefits between 2024 and 2050, in terms of avoided HFC cumulative consumption, are estimated to be 54,415 Mt CO_2eq and 65,148 Mt CO_2eq in a more ambitious scenario. There are, however, technical and financial challenges to the adoption of some alternatives and these need to be considered in every HFC phase-down scenario.

1. Introduction

1.1. CCAC and HFC phase-down

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) is a voluntary global partnership of governments, intergovernmental organizations, business, scientific institutions and civil society committed to catalysing concrete, substantial action to improve air quality and protect the climate by reducing emissions of "short-lived climate pollutants" – methane, black carbon and hydrofluorocarbons.

Under the former CCAC's HFC Initiative and the new workstream to complement the implementation of the Kigali Amendment (Kigali Workstream), national governments, non-state entities and private sector companies aim to mobilize the efforts of all non-state players and governments to reduce the projected growth in use and emissions of HFCs through various activities that complement the work of the Montreal Protocol and its Multilateral Fund. The overall goal is to significantly reduce the projected growth in the use and emissions of high-GWP HFCs in the coming decades.

1.2. Objective of the study

As part of the workplan agreed under the Kigali Workstream, the CCAC has commissioned a study to provide a profile of current and projected HFC consumption in Montreal Protocol Article 5 countries, and to outline opportunities for near-term control or reduction of HFC consumption. The aim of the study is to inform stakeholders on the potential benefits of an accelerated/optimized HFC phase-down and identify likely countries and sectors for near-term action. The study was conducted from October 2021 to June 2022.

1.3. HFCs and their climate impact

HFCs are synthetic chemicals primarily used in refrigeration, air conditioning and insulating foams, with minor uses as aerosol propellants, solvents and for fire protection. HFCs are commonly used alternatives to ozone-depleting substances (ODS). While not ODS themselves, HFCs are greenhouse gases that can have high or very high GWP, as high as 14,800, with the most widely used ranging between 1,430 and 4,000.

HFCs were first commercialized in the early 1990s and currently amount to about 1.5% of total emissions from all long-lived greenhouse gases expressed in carbon dioxide equivalent emissions (CO_2eq) as per the Scientific Assessment of Ozone Depletion, 2018 (WMO, 2018).

However, production, consumption and emissions of these gases are growing rapidly and they are the fastest-growing climate pollutants in many developing countries. While many developed countries have started to control or reduce their HFC use, in light of the adoption of the Kigali Amendment to the Montreal Protocol and regional controls, significant growth in HFC use is expected to continue in developing countries because of economic growth, population growth, rapid urbanization, electrification and changing consumer patterns. This growth is compounded by the impact of the Montreal Protocol phase-out of ozone-depleting HCFCs, for which HFCs are often selected as replacements.

Without implementation of the Kigali Amendment, it is estimated that global HFC emissions could amount to 5-11% of total CO_2 emissions by 2050 (Velders et al, 2015). Atmospheric observations in recent years suggest that the rate of increase of HFC emissions has slowed down. According to some of the latest projections, HFC emissions in 2050 are estimated to range from 1.9 to 3.6 Gt CO_2eq, which is lower than previously projected, but still very significant (Velders et al, 2022).

1.4. The Montreal Protocol and its Kigali Amendment

The Montreal Protocol on Substances that Deplete the Ozone Layer is a global agreement to protect the Earth's ozone layer by phasing out the chemicals that deplete it. This phase-out plan applies to both the production and consumption of ozone-depleting substances. The landmark agreement was signed in 1987 and entered into force in 1989.

The Kigali Amendment to phase down HFCs under the Montreal Protocol entered into force in 2019. Under the Kigali Amendment, the goal is to achieve a gradual phase-down of HFC consumption and production, up to an 85% reduction in non-Article 5 countries (developed countries) by 2036, an 80% reduction in Group 1 Article 5 countries (developing countries) by 2045 and an 85% reduction by 2047 in Group 2 Article 5 countries. By the end of this century, full compliance with the Kigali Amendment is estimated to avoid 0.2°C-0.4°C additional warming. The first reductions by most Article 5 countries started in 2019. Most Article 5 countries (Group 1) will freeze HFC consumption levels in 2024, while Group 2 Article 5 countries need to freeze HFC consumption in 2028.

For Article 5 countries, baselines for the HFC phase-down under the Kigali Amendment will be calculated using a combination of past HCFC consumption baselines plus average HFC consumption over 2020-2022 or 2024-2026 for Group 1 and Group 2 Article 5 Parties, respectively. The basis for including both HFC consumption and a percentage of HCFC baseline consumption is that, while HCFCs are being phased out through HCFC Phase-out Management Plans (HPMPs) approved under the Montreal Protocol's Multilateral Fund, HFCs may be used as alternatives for a proportion of the HCFCs being phased out.

Table 1: HFC baselines and phase-down schedules

	A5 countries-Group 1	A5 countries-Group 2*	Non-A5 countries (main group)	Other Non-A5 countries**
Baseline Formula	**Average HFC consumption for 2020-2022 +65% HCFC baseline (CO2eq)**	**Average HFC consumption for 2024-2026 +65% HCFC baseline (CO2eq)**	**Average HFC consumption for 2011-2013 +15% HCFC baseline (CO2eq)**	**Average HFC consumption for 2011-2013 +25% HCFC baseline (CO2eq)**
Freeze	2024	2028	-	-
1st reduction	2029-10% below baseline	2032-10% below baseline	2019-10% below baseline	2020-5% below baseline
2nd reduction	2035-30% below baseline	2037-30% below baseline	2024-40% below baseline	2025-35% below baseline
3rd reduction	2040-50% below baseline	2042-50% below baseline	2029-70% below baseline	2029-70% below baseline
4th reduction	-	-	2034-80% below baseline	2034-80% below baseline
Plateau (final reduction)	2045-80% below baseline	2047-85% below baseline	2036-85% below baseline	2036-85% below baseline

*Group 2 includes Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and United Arab Emirates. Group 1 includes other developing countries not included in Group 2.
** Belarus, Kazakhstan, Russian Federation, Tajikistan and Uzbekistan

2. Methodology

2.1. Profile of countries included in the study

A total of 144 Article 5 countries are included in the study. Of these, 89 are low-volume consuming (LVC) countries and 55 are non-LVC countries, according to the categorization used under the Multilateral Fund for HCFCs. As of 1 December 2021, 57 LVC countries and 25 non-LVC countries had either ratified or accepted the Kigali Amendment to the Montreal Protocol (a total of 82 Article 5 countries).

Regarding the income profile of countries, as classified by the World Bank in 2021, 81 of the Article 5 countries belong to low-income or lower-middle-income groups and the remainder belong to either the high-income group or upper-middle-income group.

The table below shows the regional distribution of Article 5 countries.

Table 2: Regional distribution of Article 5 countries

East Asia and Pacific: 27 countries	Europe and Central Asia: 11 countries	Latin America and Caribbean: 33 countries
Middle East and North Africa: 17 countries	South Asia: 8 countries	Sub-Saharan Africa: 48 countries

2.2. Main data sources

Country-specific HFC consumption

Article 5 countries submit data on their production, imports and exports of controlled substances in their annual reports to the Ozone Secretariat pursuant to Article 7 of the Montreal Protocol (Article 7 data), from which their consumption (production + import – export) is calculated. Article 5 countries also submit sectoral consumption data to the Multilateral Fund Secretariat under their annual country programme reporting (CP data).

Of the 104 Article 5 countries that have provided HFC consumption data under Article 7 by 22 May 2022, a total of 80 countries have reported data for both 2019 and 2020. Only 39 countries have provided 2021 data. The remaining countries have provided either 2019 or 2020 data. One hundred and two of these 104 countries belong to Group 1 and two countries belong to Group 2 (Oman and Pakistan) as per the definition in the Kigali Amendment.

For other countries that have not provided HFC consumption data under Article 7, HFC consumption data for 2019-21 is estimated using the following two methods.

- If past consumption survey data on ODS alternatives is available from Multilateral Fund (MLF)-supported ODS alternatives surveys, or HFC inventories supported by the CCAC (these normally have data until 2015-16), or if data is available in funding requests for the preparation of Kigali HFC implementation plans (KIPs) submitted to MLF (these normally have data until 2020), HFC consumption is extrapolated from these reports.

- If the above-mentioned information is not available, or is considered unreliable, then the total HFC consumption for a country is estimated on the basis of its share of the total HCFC baseline in CO_2eq (see HCFC proxy method: Table 3). In this method, a country's HFC consumption is assumed to be in the same proportion as its share of the total HCFC baseline consumption for Article 5 countries. For many large HCFC-consuming countries, including India, Indonesia, Saudi Arabia and Thailand, this method is used to estimate HFC consumption.

Table 3: Estimated HFC consumption under HCFC proxy method

a: reported HFC consumption data in Article 7 by Article 5 countries (average of 2019 and 2020), metric ton (mt) CO_2eq b: per cent share in HCFC baseline by those who have reported HFC consumption data c: total estimated HFC consumption of A5 countries = a/b mt CO_2eq
Country-specific HFC consumption (mt CO_2eq) = country's % share of HCFC baseline (CO_2eq) multiplied by c
HFC baseline: (average HFC consumption [2020–22 for Group 1 countries or 2024–26 for Group 2 countries] + 65% of HCFC baseline) in mt CO_2eq

It is acknowledged that there is a significant level of uncertainty both in estimating current HFC consumption for countries that have not reported data and in projecting HFC consumption in the future. Therefore, the extrapolated HFC consumption data as determined in this report should be seen as best estimates, based on available information and the methodology described above.

<u>Consumption per HFC type and per sector</u>

The HFCs which are the focus of this study are the most widely used ones and include HFC-32, HFC-134a, HFC-404A, HFC-407C, HFC-410A, HFC-507A and HFC-245fa. Consumption of these HFCs represents more than 97% of the total HFC consumption (TEAP, 2015). HFC-23 is a by-product that is produced in the HCFC-22 manufacturing process and is not considered in the analysis described here.

A major challenge to conducting such an analysis is the lack of available country-specific substance and sector-wise data.

- Many large countries, including India, Indonesia, the Islamic Republic of Iran, Kuwait, Saudi Arabia and Thailand, have not reported HFC consumption data in either Article 7 or country programme (CP) reports.

- Article 7 data for countries consist of total HFC (production and) consumption data per year on a CO_2eq basis only. Substance or sectoral data are not reported under Article 7.
- Countries provide consumption data per HFC type in CP reporting, and only a summary of such data is available in the public domain (MLF, 2021). As can be observed in the case of Article 7 HFC data, only a few large-volume consuming countries have provided HFC data in CP reports.

Recently, 39 countries have submitted their HFC KIPs preparation requests under the MLF. Some of these requests include recent consumption per HFC type and sectoral information. There are also a few ODS alternatives surveys (undertaken between 2013 and 2015) and research papers available (referenced in latter sections) in the public domain with substance/sectoral information for certain countries. The study uses the data in these reports to extrapolate the consumption per HFC type and per sector for countries with similar consumption profiles.

2.3. Business-as-usual (BAU) scenario

The BAU scenario is constructed assuming that HFC consumption will increase unabated annually without considering the HFC phase-down steps of the Kigali Amendment. The starting point for HFC consumption is the 2019, 2020 or 2021 data reported by countries or the estimated consumption as described above. In general, the HFC consumption growth in each market is a factor of:

- the economic growth rate;
- cooling demand, which could be a function of per capita ownership of refrigerators and air conditioners, and other equipment containing/using HFCs in that country; and
- policies and measures adopted in the HPMP which may create a replacement demand for non-HCFC based systems.

Given multiple factors affecting future HFC demand and a long period for projections (2022–2050), the study looked at different growth rate options to model HFC consumption projections. The following three growth trajectories were considered to construct the BAU scenario. In these, growth rates vary from 5.4% to 15% during 2022-24 and 5% to 10% during 2025-32.

- Option 1: a growth rate as per the assumption in the (TEAP, 2015) and (TEAP, 2016) report: Overall growth rate between 2020 and 2030 = 8.0% (2020-2024: 9.41%, 2024-2029: 7.30%, and 2029-2035: 4.92%). These assumptions were also later validated by the Replenishment Task Force (RTF) of the Technology and Economic Assessment Panel (TEAP) (TEAP, 2021).

- Option 2: a higher growth rate of 10% during the years 2022–2024 is assumed to compensate for lower growth rates between 2019 and 2020 and between 2020 and 2021 primarily caused by the impact of COVID-19, and to account for the possibility that during the implementation of quota and licensing systems, importers will attempt to maximize imports to gain a higher quota allocation. After 2024, HFC consumption is assumed to grow at a GDP growth rate + 4% until 2030.[1] After 2030, the growth rate is assumed to be the same as GDP growth rate for individual countries. World Bank data (The World Bank, 2021) is used for GDP growth rates for the period 2016-2019 (2020 data is excluded to remove the COVID-19 impact). If the average GDP growth rate of a country between 2016 and 2019 is less than 3%, then 3% is taken as the long-term growth rate (average for Article 5 countries).

- Option 3: Continuation of recent growth trends. One hundred and nineteen Article 5 countries had conducted ODS alternatives surveys funded by the MLF. These surveys mostly included information until the year 2015. For a few of these countries which have provided past and present consumption data, growth rates were estimated based on such data. The growth rate based on past performance (ODS survey data 2015 versus current Article 7 data) is assumed to continue until 2035, and GDP growth rates are applied thereafter.

These different possible growth trajectories are considered to understand how HFC consumption may increase under varying growth scenarios. To compare with potential mitigation scenarios until 2050 in the latter sections of the report, the BAU HFC consumption is calculated by taking an average of the above three growth options.

2.4. Mitigation scenarios

There are several opportunities for Article 5 countries to implement the HFC phase-down under the Kigali Amendment of the Montreal Protocol and even to achieve more significant reductions than required under this Amendment. Most sectors where HFCs are used already have technically and economically viable lower-GWP alternatives, such as in-room air conditioning, domestic refrigeration, commercial and industrial refrigeration, mobile air conditioning (MAC), chillers and rigid insulation foams. There are, however, technical and financial challenges to the adoption of some of these alternatives, and these need to be considered in every HFC phase-down scenario. Furthermore, opportunities for quick reductions in the refrigeration servicing sector are somewhat more limited, given that the lifetime of HFC-based equipment is 10-20 years for different subsectors.

Based on an analysis of potential opportunities and challenges in the various sectors and subsectors, reductions of HFC consumption in each key sector and subsector where HFCs are used are modelled to construct two potential mitigation scenarios, one scenario in which Article 5 countries, as a group, meet or slightly exceed the phase-down required under the Kigali Amendment, and one scenario in which Article 5 countries significantly exceed this phase-down, in other words, reduce consumption faster than required under the Amendment. In terms of HFC consumption phased out

1 Maximum growth rate capped at 10%.

or avoided, the climate benefits are estimated for each of these scenarios and compared with the BAU scenario. The potential climate benefits resulting from changes in the energy efficiency of various types of equipment are not considered.

3. HFC consumption in Article 5 countries

In this section, the methodology described in section 2 is applied to estimate HFC consumption under BAU in Article 5 countries. The section is structured into the following subsections:

(a) HFC consumption projections are provided initially only until the year 2032 (thus covering the years of the freeze and 10% reduction steps for Group 1 and Group 2 countries) for all 144 Article 5 countries using the three options for growth rates identified in section 2. Included in these projections are estimates of the HFC baseline for all countries.

(b) Consumption is estimated per HFC type for all Article 5 countries and then projected until 2050. For this analysis, countries are grouped into three categories as per their consumption profiles for reasons that will be explained in subsequent sections.

(c) Consumption is estimated per HFC-consuming sector and subsector for all Article 5 countries and then projected until 2050 (also by grouping countries according to three categories of consumption profiles).

(d) Based on the above, total HFC consumption is estimated for all Article 5 countries up to 2050.

3.1. HFC consumption projections until the Kigali Amendment 10% phase-down step

To estimate baseline levels and compare these to projected HFC consumption during the years of the Kigali freeze (2024 for Group 1 and 2028 for Group 2) and 10% reduction steps (2029 for Group 1 and 2032 for Group 2), this section provides a forecast of HFC consumption in Article 5 countries under BAU until 2032. Total consumption levels are projected in CO_2eq emissions only. In subsequent sections, estimated consumption in metric tons (mt) for HFC types and sectors are also provided.

Figure 1 below illustrates the aggregated results of the HFC consumption projections conducted under each of the three growth options described in section 2 above and an average of these three options, as compared to the HFC phase-down under the Kigali Amendment. HFC consumption is provided in Mt CO_2eq.

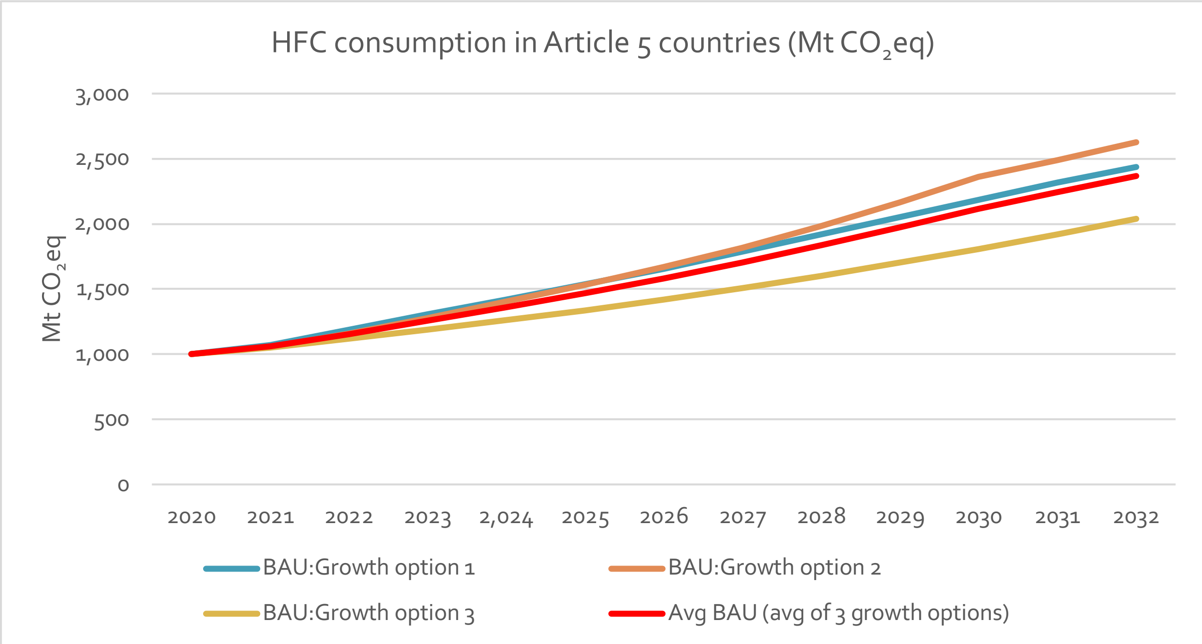

Figure 1: HFC consumption during 2020-2032 in Article 5 countries (Mt CO_2eq)

According to these projections, total HFC consumption in Article 5 countries will grow from 1,001 Mt CO_2eq in 2020 to 2,367 Mt CO_2eq by 2032 under the average BAU scenario for the three growth options, representing a growth rate of 7.44% per annum. For comparison, by 2032, the aggregated HFC consumption of all Article 5 countries under the Kigali Amendment, should be no higher than 1,439 Mt CO_2eq, which is almost 40% lower than the average BAU scenario. This illustrates the large reduction in HFC consumption that is needed over the next ten years for all Article 5 countries to comply with the Kigali Amendment.

It should be noted that 65 out of 80 countries that have reported HFC consumption data (Article 7) during 2019 and 2020 have witnessed a decrease in refrigerant demand during 2020. Seventeen out of 38 countries which have reported both 2020 and 2021 data have experienced a decline in consumption during 2021 compared with the year 2020. One possible reason could be the economic impact of COVID-19 (though there could be other reasons, including a lack of HFC licensing systems during 2020-2021 resulting in less reliable data collection). As the COVID-19 impact continued during 2021, along with supply chain disruptions resulting in import issues, many countries may still report lower than normal consumption for 2021. If the COVID-19 impact continues in 2022, then the baseline consumption data will be lower for Group 1 countries than what it would have been without COVID-19.

Tables 4 and 5 below provide the actual or estimated consumption for each Article 5 country during the applicable baseline years, the year of the freeze, and the year of the 10% reduction. Projections are based on the BAU scenario averaging the three growth options.

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Table 4: Growth projections for Group 1 countries – BAU scenario (in kt CO_2eq)

Country	LVC/non-LVC	Data reported by countries or estimated using various methods described in section 1.2	2020	2021	2022	HFC baseline	2024	2029
Afghanistan	Non-LVC	Reported	283	303	331	809	390	545
Albania	LVC	Reported	179	156	171	296	205	302
Algeria	Non-LVC	Estimation	1,952	2,091	2,279	3,436	2,684	3,756
Angola	LVC	Reported	3,812	4,122	4,533	4,498	5,433	7,954
Antigua and Barbuda	LVC	Reported	35	38	42	45	50	76
Argentina	Non-LVC	Reported	12,191	13,059	14,234	21,732	16,765	23,460
Armenia	LVC	Reported	196	317	349	436	418	632
Bahamas	LVC	Estimation	137	148	162	252	195	285
Bangladesh	Non-LVC	Estimation	4,049	4,337	4,727	5,924	5,568	8,189
Barbados	LVC	Reported	319	151	166	291	199	291
Belize	LVC	Estimation	80	86	95	147	114	166
Benin	Non-LVC	Reported	1,254	1,279	1,394	1,818	1,642	2,400
Bhutan	LVC	Reported	3	8	9	13	10	16
Bolivia	LVC	Reported	426	348	383	498	459	679
Bosnia and Herzegovina	LVC	Estimation	151	163	179	265	215	315
Botswana	LVC	Reported	174	188	206	425	247	371
Brazil	Non-LVC	Reported	39,896	50,519	55,055	67,797	64,836	90,702
Brunei Darussalam	LVC	Reported	543	281	309	508	370	542
Burkina Faso	LVC	Reported	509	550	605	1,173	725	1,112
Burundi	LVC	Reported	52	56	62	208	74	108
Cabo Verde	LVC	Reported	23	3	3	32	4	6
Cambodia	LVC	Reported	885	928	1,021	1,265	1,223	1,876
Cameroon	Non-LVC	Reported	3,364	3,165	3,449	4,849	4,062	5,764
Central African Republic	LVC	Estimation	401	433	476	693	571	849
Chad	LVC	Estimation	528	571	628	920	752	1,102
Chile	Non-LVC	Reported	4,465	4,971	5,417	6,145	6,380	8,925
China	Non-LVC	Reported	529,799	567,528	618,580	884,969	728,593	1,071,608
Colombia	Non-LVC	Reported	5,064	5,086	5,543	7,413	6,528	9,132
Comoros	LVC	Reported	36	39	43	42	51	75
Congo	LVC	Estimation	288	311	342	531	410	601
Cook Islands	LVC	Reported	2	7	7	6	9	13
Costa Rica	LVC	Reported	1,099	1,188	1,307	1,437	1,566	2,304
Côte d'Ivoire	Non-LVC	Estimation	2,153	2,307	2,514	3,689	2,961	4,356
Cuba	LVC	Reported	504	519	570	848	684	1,000

Country	LVC/non-LVC	Data reported by countries or estimated using various methods described in section 1.2	2020	2021	2022	HFC baseline	2024	2029
Democratic People's Republic of Korea	Non-LVC	Reported	496	511	556	2,190	655	917
Democratic Republic of the Congo	LVC	Estimation	2,230	2,411	2,652	3,847	3,178	4,729
Djibouti	LVC	Estimation	23	25	28	40	33	51
Dominica	LVC	Estimation	3	3	4	8	5	7
Dominican Republic	Non-LVC	Reported	2,473	2,072	2,258	3,348	2,659	3,900
Ecuador	LVC	Reported	2,212	1,912	2,103	2,557	2,520	3,688
Egypt	Non-LVC	Estimation	13,245	14,188	15,465	22,563	18,215	26,274
El Salvador	LVC	Estimation	568	985	1,083	1,129	1,298	1,900
Equatorial Guinea	LVC	Reported	280	73	80	279	96	141
Eritrea	LVC	Estimation	36	39	43	63	51	78
Eswatini	LVC	Reported	32	35	39	72	46	68
Ethiopia	LVC	Reported	164	103	114	245	136	209
Fiji	LVC	Reported	224	237	261	363	313	458
Gabon	Non-LVC	Reported	1,805	2,064	2,249	2,685	2,649	3,706
Gambia	LVC	Reported	173	282	311	287	372	562
Georgia	LVC	Estimation	164	177	195	292	233	349
Ghana	Non-LVC	Reported	471	550	600	1,790	706	1,038
Grenada	LVC	Reported	32	43	48	59	57	84
Guatemala	LVC	Reported	972	892	981	1,105	1,176	1,727
Guinea	Non-LVC	Reported	1,488	1,391	1,516	1,949	1,785	2,626
Guinea Bissau	LVC	Reported	620	602	662	688	794	1,189
Guyana	LVC	Reported	61	112	123	135	148	221
Haiti	LVC	Reported	75	99	109	172	130	191
Honduras	LVC	Estimation	1,426	1,227	1,349	1,727	1,617	2,396
Indonesia	Non-LVC	Estimation	13,094	14,027	15,289	20,435	18,008	26,073
Jamaica	LVC	Estimation	486	525	577	878	692	1,013
Jordan	Non-LVC	Reported	1,343	1,438	1,568	3,225	1,846	2,584
Kenya	Non-LVC	Reported	604	365	398	1,571	469	674
Kiribati	LVC	Reported	7	10	11	11	14	20
Kyrgyzstan	LVC	Reported	292	363	400	426	479	716
Lao People's Democratic Republic	LVC	Reported	77	83	91	133	110	168
Lebanon	Non-LVC	Reported	1,743	1,605	1,749	2,628	2,059	2,881
Lesotho	LVC	Reported	47	26	29	108	35	51
Liberia	LVC	Reported	73	85	94	196	112	164

Country	LVC/non-LVC	Data reported by countries or estimated using various methods described in section 1.2	2020	2021	2022	HFC baseline	2024	2029
Libya	Non-LVC	Estimation	1,897	2,033	2,215	4,581	2,609	3,838
Madagascar	Non-LVC	Reported	1,091	1,437	1,566	1,898	1,844	2,618
Malawi	LVC	Reported	196	197	216	434	259	385
Malaysia	Non-LVC	Reported	14,570	13,508	14,721	22,466	17,337	25,020
Maldives	LVC	Reported	289	316	347	403	416	638
Mali	LVC	Reported	81	88	96	409	116	175
Marshall Islands	LVC	Reported	7	8	8	12	10	15
Mauritania	Non-LVC	Estimation	667	714	778	764	917	1,314
Mauritius	LVC	Reported	504	336	369	572	443	654
Mexico	Non-LVC	Reported	48,211	47,755	52,043	62,362	61,289	85,739
Micronesia (Federated States of)	LVC	Reported	8	9	9	12	11	17
Moldova	LVC	Estimation	376	406	447	2,942	535	799
Mongolia	LVC	Estimation	79	86	94	116	113	171
Montenegro	LVC	Reported	170	109	120	149	144	214
Morocco	Non-LVC	Estimation	1,593	1,706	1,860	2,818	2,191	3,066
Mozambique	LVC	Reported	349	439	482	609	578	850
Myanmar	LVC	Estimation	152	164	181	258	217	318
Namibia	LVC	Reported	796	353	388	687	465	681
Nauru	LVC	Estimation	9	11	12	15	15	22
Nepal	LVC	Estimation	36	39	42	62	51	78
Nicaragua	LVC	Reported	462	500	550	637	659	964
Niger	Non-LVC	Reported	986	843	919	1,258	1,083	1,591
Nigeria	Non-LVC	Reported	2,617	8,454	9,213	12,491	10,850	15,179
Niue	LVC	Estimation	8	0	0	6	0	0
North Macedonia	LVC	Reported	361	344	379	400	454	664
Palau	LVC	Reported	8	7	7	11	9	13
Panama	Non-LVC	Reported	1,264	1,947	2,121	2,267	2,498	3,570
Papua New Guinea	LVC	Estimation	105	114	125	186	150	221
Paraguay	LVC	Reported	1,462	892	981	1,490	1,175	1,720
Peru	Non-LVC	Reported	2,179	1,605	1,749	2,389	2,060	2,890
Philippines	Non-LVC	Reported	7,171	6,011	6,551	9,107	7,715	11,348
Rwanda	LVC	Reported	269	290	319	377	383	587
Saint Kitts and Nevis	LVC	Estimation	14	15	17	26	20	31
Saint Lucia	LVC	Reported	56	29	32	62	39	57
Saint Vincent and the Grenadines	LVC	Reported	17	25	28	29	33	49

Country	LVC/non-LVC	Data reported by countries or estimated using various methods described in section 1.2	2020	2021	2022	HFC baseline	2024	2029
Samoa	LVC	Reported	25	10	11	21	13	19
Democratic Republic of Sao Tome and Principe	LVC	Reported	18	29	32	72	38	56
Senegal	Non-LVC	Reported	1,830	1,960	2,137	2,749	2,517	3,701
Serbia	LVC	Reported	2,645	2,859	3,145	3,063	3,769	5,565
Seychelles	LVC	Reported	140	234	257	240	308	451
Sierra Leone	LVC	Reported	250	271	298	309	357	536
Solomon Islands	LVC	Estimation	63	68	75	112	90	134
Somalia	Non-LVC	Reported	895	959	1,045	1,063	1,231	1,810
South Africa	Non-LVC	Reported	8,222	8,807	9,600	14,073	11,307	15,822
South Sudan	LVC	Estimation	173	167	184	262	220	322
Sri Lanka	LVC	Reported	478	478	526	759	631	929
Sudan	Non-LVC	Reported	1,244	1,333	1,453	1,775	1,711	2,395
Suriname	LVC	Reported	238	257	283	302	339	496
Syrian Arab Republic	Non-LVC	Estimation	22,941	9,467	10,316	17,129	12,149	16,996
Thailand	Non-LVC	Estimation	28,835	30,889	33,667	46,341	39,655	55,957
Timor-Leste	LVC	Reported	14	15	17	26	20	30
Togo	Non-LVC	Reported	608	635	692	1,072	815	1,180
Tonga	LVC	Reported	4	2	2	6	3	4
Trinidad and Tobago	Non-LVC	Reported	4,425	5,201	5,668	6,029	6,676	9,339
Tunisia	Non-LVC	Reported	1,720	1,842	2,008	2,699	2,365	3,309
Turkey	Non-LVC	Reported	14,914	15,976	17,413	24,755	20,510	29,015
Turkmenistan	LVC	Reported	586	510	561	608	672	1,031
Tuvalu	LVC	Reported	0	0	0	2	0	1
Uganda	LVC	Reported	49	46	51	52	61	92
United Republic of Tanzania	LVC	Reported	253	273	301	312	360	552
Uruguay	Non-LVC	Reported	614	657	716	1,134	844	1,181
Vanuatu	LVC	Reported	11	14	15	19	18	27
Venezuela (Bolivarian Republic of)	Non-LVC	Reported	635	799	871	4,527	1,026	1,435
Viet Nam	Non-LVC	Reported	9,416	10,470	11,410	14,238	13,437	19,764
Yemen	Non-LVC	Estimation	4,998	5,354	5,836	8,780	6,874	9,618
Zambia	LVC	Reported	282	305	336	413	402	590
Zimbabwe	LVC	Reported	1,009	733	806	1,214	966	1,414

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Table 5: Growth projections for Group 2 countries – BAU scenario (kt CO2e)

Country	LVC/non-LVC	Data reported or estimated	2024	2025	2026	HFC baseline	2028	2032
Bahrain	Non-LVC	Estimation	2,243	2,403	2,570	3,515	2,942	3,680
India	Non-LVC	Estimation	67,907	73,446	79,309	99,588	92,630	120,985
Iran (Islamic Republic of)	Non-LVC	Estimation	9,012	9,655	10,324	17,803	11,819	14,776
Iraq	Non-LVC	Estimation	4,162	4,489	4,833	6,813	5,612	7,218
Kuwait	Non-LVC	Estimation	5,186	5,556	5,941	14,516	6,802	8,503
Oman	Non-LVC	Reported	2,804	3,004	3,212	3,662	3,677	4,596
Pakistan	Non-LVC	Reported	13,211	14,220	15,281	17,183	17,667	22,526
Qatar	Non-LVC	Reported	29,018	31,085	33,241	32,982	38,054	47,574
Saudi Arabia	Non-LVC	Estimation	64,119	68,688	73,451	100,170	84,086	105,124

3.2. Estimated HFC consumption per HFC type

There is a lack of data on the consumption of specific types of HFCs in most of the countries. To model both consumption per HFC type and per sector, countries are grouped according to their consumption profiles and then consumption of specific types and sectors is estimated for each group.

This is an adaptation of an approach taken by the Technology and Assessment Panel of the Montreal Protocol (TEAP, 2021) that divides countries in different brackets according to their total HCFC consumption during baseline years (HCFC consumption taken as a proxy for HFC consumption profiles). The TEAP's 2021 report (TEAP, 2021) groups countries into five consumption brackets as shown in Table 6.

- Bracket A is based on baseline HCFC consumption over 25,000 mt (China).
- Bracket B is based on baseline HCFC consumption from 10,001 to 25,000 mt.
- Bracket C is based on baseline HCFC consumption from 2,001 to 10,000 mt.
- Bracket D is based on baseline HCFC consumption from 360 to 2,000 mt.
- Bracket E is based on the list of HCFC LVCs.

Table 6: Allocation of countries in consumption brackets as per their HCFC consumption in the TEAP 2021 report

Bracket (mt HCFCs)	Countries
A: Over 25,000	***Group 1:*** China
B: 10,001 to 25,000	***Group 1:*** Brazil, Mexico, Thailand ***Group 2:*** India, Saudi Arabia
C: 2,001 to 10,000	***Group 1:*** Argentina, Colombia, Egypt, Indonesia, Malaysia, Nigeria, Philippines, South Africa, Turkey, Venezuela (Bolivian Republic of), Viet Nam, Yemen ***Group 2:*** Iran (Islamic Republic of), Kuwait, Pakistan
D: 360 to 2,000	***Group 1:*** Afghanistan, Algeria, Bangladesh, Benin, Cameroon, Chile, Côte d'Ivoire, Democratic People's Republic of Korea, Dominican Republic, Gabon, Ghana, Guinea, Jordan, Kenya, Lebanon, Libya, Madagascar, Mauritania, Morocco, Niger, Panama, Peru, Senegal, Somalia, Sudan, Syrian Arab Republic, Togo, Trinidad and Tobago, Tunisia, Uruguay ***Group 2:*** Bahrain, Iraq, Oman, Qatar
E: HCFC LVCs	***Group 1:*** Albania, Angola, Antigua and Barbuda, Armenia, Bahamas, Barbados, Belize, Bhutan, Bolivia (Plurinational State of), Bosnia and Herzegovina, Botswana, Brunei Darussalam, Burkina Faso, Burundi, Cambodia, Cabo Verde, Central African Republic, Chad, Comoros, Congo, Cook Islands, Costa Rica, Cuba, Democratic Republic of the Congo, Djibouti, Dominica, Ecuador, El Salvador, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Fiji, Gambia, Georgia, Grenada, Guatemala, Guinea Bissau, Guyana, Haiti, Honduras, Jamaica, Kiribati, Kyrgyzstan, Lao People's Democratic Republic, Lesotho, Liberia, Malawi, Maldives, Mali, Marshall Islands, Mauritius, Micronesia (Federated States of), Mongolia, Montenegro, Mozambique, Myanmar, Namibia, Nauru, Nepal, Nicaragua, Niue, North Macedonia, Palau, Papua New Guinea, Paraguay, Republic of Moldova, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Sao Tome and Principe, Serbia, Seychelles, Sierra Leone, Solomon Islands, South Sudan, Sri Lanka, Suriname, Timor-Leste, Tonga, Turkmenistan, Tuvalu, Uganda, United Republic of Tanzania, Vanuatu, Zambia, Zimbabwe

This study uses three categories[2] to group countries according to their level of consumption to arrive at substance-wise consumption. It is assumed that the countries in each category have similar consumption profiles in terms of consumption volume, local manufacturing base, import/export and types of refrigeration and air conditioning (RAC) equipment.

The ten largest countries are in Category 1 and contribute 82.9% of the HCFC baseline. Category 2 consists of the remaining non-LVC countries, contributing 15.1% of the HCFC baseline. Category 3 represents all the LVCs, contributing 2% of HCFC baseline. The 10 largest are further divided into three subcategories (Table 7) based on their RAC equipment manufacturing base and local consumption and export profiles.

Table 7: Allocation of countries as per their consumption profiles

Category	Countries	Consumption characteristics
1	Subcategory A: China	China has a large manufacturing base to meet local consumption and export demand. It accounts for 33.6% of global AC manufacturing (OEC, 2022). China is also the largest global producer and exporter of HFCs and blends (NREL, 2020).
	Subcategory B: Argentina, Brazil, India, Indonesia, Saudi Arabia, Turkey	Consumption in these countries is characterized by sizeable local HFC consumption. Local demand for RAC equipment in these countries is met both by local manufacturing and imports of equipment, and is higher than the exports from these countries (OEC, 2022) (JRAIA, June 2019).
	Subcategory C: Malaysia, Mexico, Thailand	These countries have a large manufacturing base with a focus on exports. Local demand for RAC equipment is high but lower than the exports (OEC, 2022) (JRAIA, June 2019).
2	Other non-LVCs (total 45 countries)	Local demand is mostly met through imports since local manufacturing capacities are limited. Most HFC consumption is in the refrigeration servicing sector and some in local assembly.
3	LVCs (total 89 countries)	Demand is met through imports. HFC consumption is in most cases only for the refrigeration servicing sector, with some consumption for local assembly.

The main HFCs considered for the study include HFC-32, HFC-134a, HFC-404A, HFC-407C, HFC-410A and HFC-507A, as these are the primary substances used in the RAC sector. For other substances, including HFC-245fa, HFC-125, HFC-227ea, HFC-365mfc, which are primarily used in the foam, fire protection or solvent sector, the study mainly uses the assumptions in (TEAP, 2021) for their sectoral distribution.

2 The term “category” is used to avoid confusion with brackets which are used in (TEAP, 2021).

The following paragraphs describe how consumption for specific HFCs was estimated for each category of countries and provides the best possible way of identifying each of the main HFCs listed above.

Category 1: as mentioned above, the ten largest HFC-consuming countries are included in this category, assuming that the ten largest countries for HCFC baseline consumption are also the largest HFC-consuming countries. For China and India, the study referred to various published reports. Some of these reports use atmospheric measurements to estimate emissions, whereas others use a bottom-up approach for specific sectors to arrive at refrigerant demand.

- Subcategory A (China): China has accepted the Kigali Amendment to phase down HFCs in the year 2021. Its HFC consumption data for the year 2020 is reported via Article 7 reporting or in the CP report. There are a limited number of studies which provide estimates of HFC consumption on a sectoral basis in China. A few of the reports reviewed for this study include (Yi-Xi, et al., 2019), (Yi-Xi, et al., 2019), (Wang, et al., 2020), (Du, et al., 2016) and (Fang, et al., 2016). Inputs from these reports were utilized to verify and modify consumption data for the country.
- Subcategory B (Argentina, Brazil, India, Indonesia, Saudi Arabia, Turkey):
  - Argentina, Brazil and Turkey have reported HFC consumption data under Article 7 (Ozone Secretariat, 2022) and the CP report. For Turkey, 2019-20 sectoral data is also available in the KIP (2022).
  - For Indonesia, the HFC Inventory (CCAC, 2014) has HFC data per substance. For Brazil, the Fourth Biennial Update Report submitted to the UNFCCC (Brazil, 2020) also has HFC usage data.
  - For India, this study refers to several reports which provide HFC consumption data. These reports include (MOP, India, 2018), (TERI, 2019) (Purohit, et al., 2016) and (Say, et al., 2018).
  - The study uses the above data to model substance-wise consumption for the entire subcategory.[3]
- Subcategory C (Malaysia, Mexico and Thailand): Mexico[4] and Malaysia[5] have reported HFC consumption data under Article 7 and have also provided consumption data in KIP preparation requests. Detailed data for Mexico and Malaysia is also available publicly (SEMARNAT Mexico, 2018), (Malaysia, 2020). Data from these two countries is used to

3 Other countries in this subcategory are assumed to have similar consumption by type of HFC.

4 UNEP/OzL.Pro/ExCom/86/35.

5 UNEP/OzL.Pro/ExCom/87/18.

model a subcategory C consumption pattern (data for Thailand was further adjusted based on publicly available information for HFC-32 usage in the RAC sector (CLASP, 2019)).

The HFC consumption by type is further adjusted based on a proportional share of a specific subcategory (HCFC baseline) to arrive at a consumption profile for the entire Category 1. There is a wide range of usage by type of HFC for countries in each subcategory (Table 8).

Table 8: Estimated share of consumption per HFC type in Category 1 countries

Substance	% share range (mt)	Estimated % share (mt)	Estimated % share ($C0_2eq$)
HFC-32	0.1-21%	9.80%	3.45%
HFC-134a	19-45.8%	33.40%	24.89%
HFC-404A	6.9-19.6%	8.89%	18.17%
HFC-407C	0.56-10.8%	4.80%	4.44%
HFC-410A	16.94-47%	35.81%	38.96%
HFC-507A	0.25-5%	3.00%	6.23%
HFC-245fa HFC-125, HFC-227ea, HFC-365mfc[6]		3.30%	3.01%
Others (1% is assigned to other HFCs, these may have their main use in RAC sector, but are not so well reported)		1%	0.85%
Total		**100%**	**100%**

There is a significant growth in HFC-32 usage in all Category 1 countries, except in Mexico where the reported HFC-32 consumption in 2020 is less than 0.5%. The other nine countries have a higher HFC-32 consumption share (5.6-21 %).

The following chart shows refrigerant types used in residential ACs produced in China from 2018 to 2020 (data.chinaiol.com, 2022). This includes equipment used in the domestic market and also exported to other countries (Figure 2).

6 Due to a lack of detailed data on other sectors (foam, solvent, aerosols, fire suppression) (TEAP, 2021) assumptions are adjusted for consumption for these types of HFCs and subsectors.

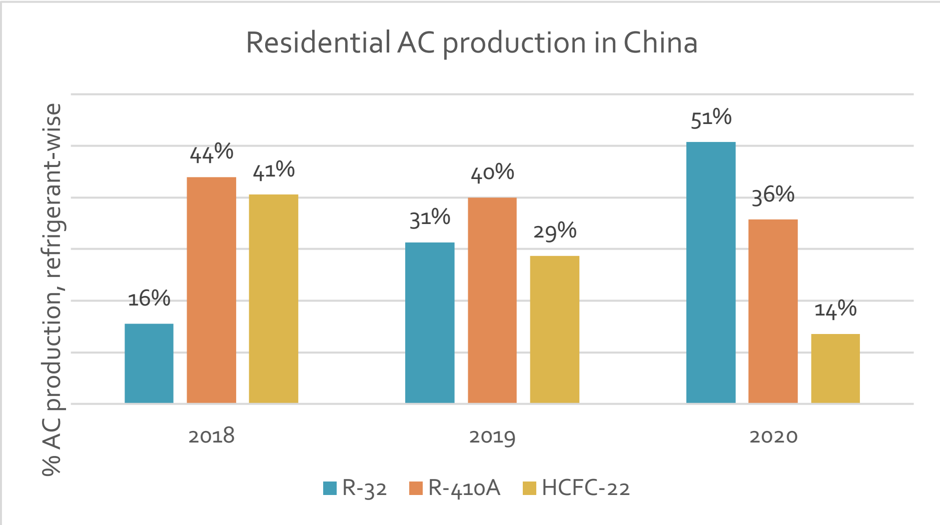

Figure 2: Refrigerants used in residential AC production in China (2018-20)

Similarly, a study in India (TERI, 2019) projected the HFC-32-based new AC market share as 15-17% and the hydrocarbon, HC-290, market share as 4-6% in 2017-18. (CLASP, 2019) estimates the new HFC-32 air conditioners' share as 33% in the Thailand air conditioner market. (The World Bank, 2020) shows the HFC-32 share as 21% in Malaysia in 2018. The growing use of HFC-32 in several Category 1 countries is considered when estimating the average consumption in this category.

Category 2: all remaining 45 non-LVC countries are included in this group and the share of their consumption of each type of HFC is shown in Table 9. Fourteen non-LVCs (excluding the largest ten in this category) have submitted substance-wise data in KIP preparation requests submitted to the MLF (MLF, 2020) (MLF, 2021). The summary of the sector distribution of aggregated HFC consumption for the 31 non-LVC countries that have submitted 2019 CP data is also presented in UNEP/OzL.Pro/ExCom/87/6 (MLF, 2021). CCAC HFC alternative survey reports for various non-LVCs were also analysed for this category.

Table 9: Estimated share of consumption per HFC type in Category 2 countries

Substance	% share range (mt)	Estimated % share (mt)	Estimated % share (C02eq)
HFC-32	0.1-18%	5.67%	1.96%
HFC-134a	29.2-53.9%	41.30%	30.22%
HFC-404A	7.9-19%	10.30%	20.67%
HFC-407C	1.6-11%	3.83%	3.48%
HFC-410A	6-47%	33%	35.50%
HFC-507A	0.25-5%	2.68%	5.47%
HFC-245fa HFC-125, HFC-227ea, HFC-365mfc[7]		2.00%	1.86%

7 Due to a lack of detailed data on other sectors (foam, solvent, aerosols, fire suppression) (TEAP, 2021) assumptions are adjusted for consumption for these types of HFCs and subsectors.

Others (1% is assigned to other HFCs, these may have their main use in RAC sector but are not so well reported)		1.00%	0.84%
Total		100%	100%

Category 3: this category includes all LVCs. Twenty-one LVCs have provided recent data (2018-2020) as part of their KIP preparation proposals. The CP Data and Prospect for Compliance Report[8] (MLF, 2021) prepared by the Secretariat of the MLF provides a sectoral summary for 55 LVCs for their year 2019 HFC consumption data. Using these reports, the study models the consumption pattern for all the countries in this group.

Table 10: Estimated consumption per HFC type in Category 3 countries

Substance	% share range	Estimated % share (mt)	Estimated % share ($C0_2$eq)
HFC-32	0-12%	0.5%	0.16%
HFC-134a	12-89%	49.8%	34.41%
HFC-404A	5-20%	16.5%	31.27%
HFC-407C	0-11%	2.6%	2.23%
HFC-410A	7-37.2%	28.0%	28.25%
HFC-507A	0-3.7%	1.40%	2.70%
Others (0.2% identified in foam, solvent, aerosol and fire suppression). The remainder are other HFCs which may have a use in the RAC sector (1% assigned value)		1.2%	0.99%
Total		100%	100%

As shown in Tables 8, 9 and 10, the consumption of specific HFCs varies widely, even within the same consumption categories. This variation may be a factor of current cooling requirements, trade practices and HCFC phase-out measures. Figure 3 shows the consumption profile for each type of HFC aggregated for all Article 5 countries. It should be noted that while precise percentages have been provided for the share of each HFCs, these are still estimates that take into account the data limitations mentioned above.

8 UNEP/OzL.Pro/ExCom/87/6.

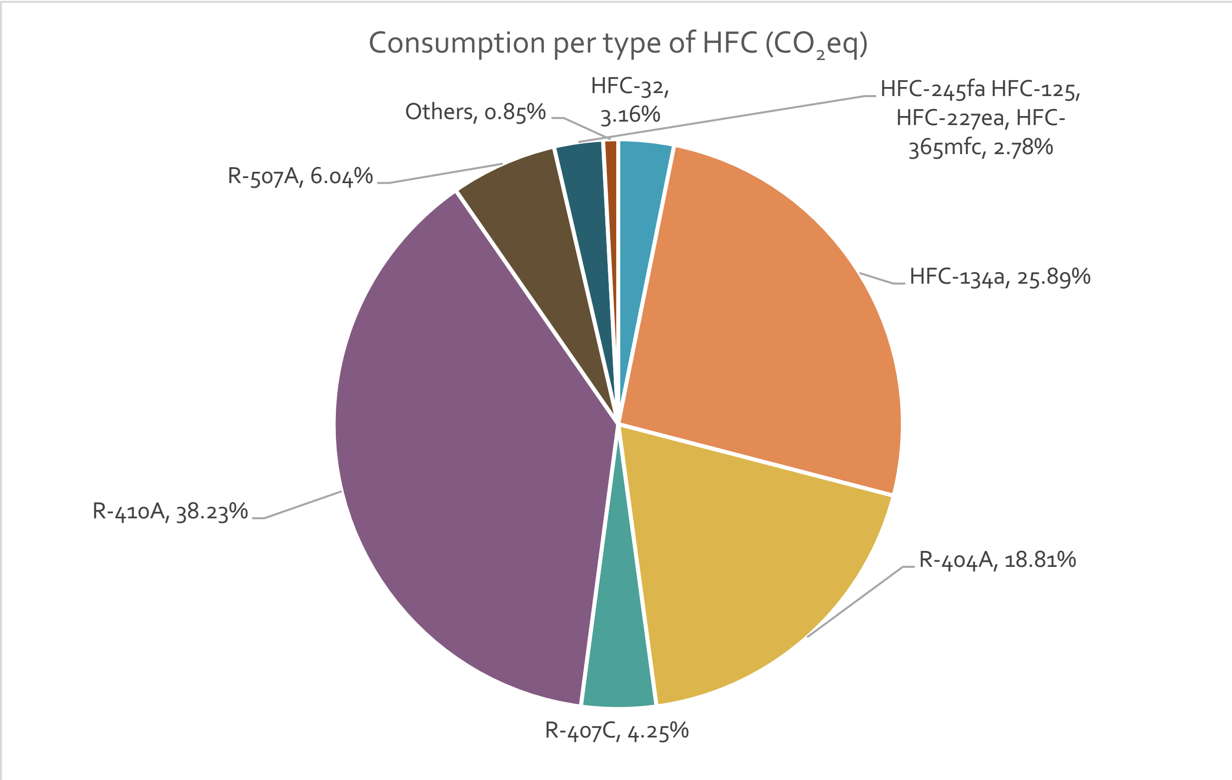

Figure 3: Estimated shares of consumption per HFC type in Article 5 countries (in CO_2eq)

3.3. Estimated HFC consumption per sector

This part of the study will forecast consumption on a sectoral basis. Each subsector has different characteristics, especially regarding the amount of refrigerant used for manufacturing and servicing. HFC demand across these sectors may vary widely based on the RAC equipment or foam manufacturing base in the country, the maturity and penetration of RAC equipment, growth in cooling demand and HCFC phase-out measures. The following are the subsectors considered in this study:

- Stationary air conditioners (SAC): this market sector includes air-conditioning units used to cool rooms in residential and commercial buildings. For this study, AC equipment (with the exception of chillers) has been categorized as either "small" or "large" using the criteria from the factsheet, *Transitioning to low-GWP alternatives in residential and commercial air conditioning and chillers*, (US EPA, 2021).[9] As such, small AC systems are defined as having a capacity generally ranging from 2 to 12kW and refrigerant charges generally ranging from 0.2 to 3kg, and include self-contained and mini-split AC. Large AC systems are defined as having a capacity generally ranging from 10 to 750kW and refrigerant charges ranging from 3 to 200kg, and include most commercial single-split and multi-split systems, variable refrigerant flow systems, and ducted and packaged rooftop units. HFC-410A is the primary HFC-based refrigerant used in this subsector. Other HFCs used in this subsector are HFC-32 for the residential AC sector and HFC-407C in the commercial AC sector. There is growing though limited HC-290 (propane) use in small ACs. In addition, this sector includes chillers, from small/medium-sized scroll and screw chillers that typically use HFC-410A, to large centrifugal chillers that use HFC-134a. In recent years, hydrofluoroolefins (HFOs) have started to be used in large centrifugal chillers in non-A5 countries.
- Mobile air conditioners (MAC): in developing countries, HFC-134a is the dominant refrigerant used in this subsector, while in developed countries HFO-1234yf has become the dominant refrigerant for new equipment. The MAC sector includes air conditioning systems in buses, cars, light- and heavy-duty trucks and coaches on railways.
- Industrial and commercial refrigeration (ICR): this market sector includes refrigeration systems and appliances used to store and display products in food or manufacturing and process industries.
    - There are three main distinct types of equipment that use HFCs in this sector: stand-alone factory-sealed equipment, condensing units and centralized systems. HFC-134a is the dominant refrigerant used in stand-alone units, although there is also some use of HFC-404A in low-temperature stand-alone appliances. HFC-404A and, to a lesser extent, HFC-507A are the primary refrigerants used for condensing and centralized systems.

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9 https://www.epa.gov/sites/default/files/2021-02/documents/transitioning_to_low-gwp_alternatives_in_res_and_com_ac_chillers.pdf

- Condensing units and centralized systems are used in the commercial sector (retail food, supermarkets) and the industrial sector (food processing, cold storage). For this analysis, the commercial and industrial sectors have been grouped together as the technologies are essentially the same. In most countries, total HFC use for industrial applications is much lower than for commercial applications.
- It is also important to note that condensing units and centralized systems are usually designed and assembled for specific locations and charged with refrigerant on site, unlike pre-charged stand-alone units. Such refrigerant consumption is known as consumption for the local installation and assembly subsector and is usually reported under the Multilateral Fund as part of refrigeration servicing consumption. For the purpose of this study, however, consumption for new systems in the local installation and assembly subsector is considered as manufacturing consumption because the activities involved in phasing out HFCs in this subsector can be more similar to activities required to phase out HFCs in the manufacturing sector than in the servicing sector. This is discussed in more detail in section 4.1.3.

- Transport refrigeration (TR): this market sector includes refrigeration systems used in various modes of transport. Most transport refrigeration systems are used for the carriage of frozen or chilled food and beverage products. These systems are used for trucks, trailers, reefer containers, fishing vessels and cargo ships. HFC-404A and HFC-134a are the primary refrigerants used in this subsector.
- Domestic refrigerators (DR): this market sector includes domestic refrigeration appliances such as refrigerators and freezers used for the storage of chilled and frozen food and drink products. HFC-134 is the most widely used HFC refrigerant in this subsector. (RTOC, 2018) projected that by 2020 only 25% of new refrigerators would be based on HFC-134a and the rest would be using HC-600a. For countries with no local manufacturing for DR, 100% of the demand is for servicing existing equipment. For other countries, it is assumed that 20-40% of the demand is for manufacturing new DRs and the rest is consumed in servicing existing DR stock.
- Foam sector: rigid polyurethanes (PU) and extruded polystyrene (XPS) foam require blowing agents for foam production. HFC-245fa and HFC-365mfc are the main HFCs used in rigid PU foam, and HFC-134a is the main HFC used in rigid XPS foam. While HFC consumption for the foam sector in Article 5 countries is small, as most HCFC consumption was converted to hydrocarbons under HPMPs, it is the second largest HFC-consuming sector next to the RAC sector.
- Other sectors where HFCs are used include the aerosol, fire suppression and solvent sectors. However, all available data suggests HFC consumption for these three sectors is very small. Therefore, for the purpose of this study, they have been grouped in a sector called “other”.

There is a lack of published data for the subsectoral distribution of HFC usage for most Article 5 countries. The study takes sectoral distribution assumptions (Table 11) adjusted for the categories of countries used in this study, taken from the (TEAP, 2021) report as a first step towards building a subsectoral profile.[10] However, these are not the assumptions which are ultimately used in the study. This sectoral distribution is modified based on available data to arrive at more appropriate subsectoral consumption estimates.

Table 11: Subsectoral consumption as per (TEAP, 2021), % CO_2eq

Countries	Servicing	DR	ICR	SAC	MAC	Foam XPS	Foam PUR	Aerosol	Fire Sup.	Solvents
Category 1	22.34%	2.44%	23.02%	22.80%	7.33%	1.16%	1.19%	1.22%	0.04%	0.10%
Category 2	49.54%	2.88%	17.72%	17.50%	8.63%	0.88%	1.28%	1.43%	0.08%	0.10%
Category 3	87.70%	2.64%	0.13%	0.13%	7.80%	0.13%	0.13%	1.30%	0.03%	0.01%

As a second step, consumption by type of HFC is used to modify consumption in different sectors. In general, usage of many HFCs is primarily limited to a few sectors. For instance, HFC-404A is used primarily in the ICR and transport refrigeration sectors; HFC-410A and HFC-32 in stationary AC and HFC-407C in commercial AC. HFC-134a has a broader use in multiple sectors such as MAC, DR, ICR, chillers, XPS foam etc. However, based on available subsectoral data, it can be inferred that HFC-134a has a dominant use in MAC, ICR (stand-alone equipment) and chillers. Using this approach, a broad assessment in terms of HFC usage in each sector can be obtained from such data.

In this step, the study also looked at publicly available information, including the CP data summary for 89 countries (MLF, 2021), KIP preparation requests submitted by 36 countries and country-specific data including (SEMARNAT Mexico, 2018), (Malaysia, 2020), (Yi-Xi, et al., 2019) (Purohit, et al., 2016), (CLASP, 2019) and (data.chinaiol.com, 2022).

The final step includes distributing HFC usage for manufacturing and servicing in each subsector. The manufacturing of equipment typically meets the growing cooling demand and replacement demand after the retirement of aged or end-of-life equipment. Servicing demand is related to the stock of existing equipment in the country, leakage rates and servicing practices. The study uses equipment lifetime, refrigerant charge size and equipment leakage rates (TEAP, 2018) in different subsectors to arrive at estimates of servicing and manufacturing demand.

In the ICR sector (consisting of condensing units and centralized systems), HFC consumption to charge new systems in the local installation and assembly subsector is normally tracked under servicing sector consumption. There is little data available indicating which proportion of refrigerant used in this subsector is to charge new systems and which proportion is for actual servicing, in other

10 TEAP RTF indicated that the percentage for MAC includes both consumption for manufacturing and servicing.

words, refilling existing systems). An estimate of these proportions has been made based on the typical annual emissions and lifetimes of condensing units and centralized systems. Based on this, about 30% of HFC consumption in the ICR sector for these applications is attributed to manufacturing and/or local assembly, while about 70% is attributed to servicing.

Category 1 countries. In this consumption category, demand in CO_2eq terms in the air-conditioning sector contributes to 52.3% of total HFC demand, followed by 27.2% in ICR and 11.2% in the MAC sector. It is estimated that less than 2% of HFCs are used in the foam sector, while slightly more than 2% are used for solvents, aerosols and fire suppression, three subsectors are grouped as "other" in this study. The "other" grouping could also include very minor quantities of other types of HFCs used in the RAC sector. However, as the study focuses on the main HFCs, and limited information is available about other types of HFCs, these other types of HFCs have not been allocated specific subsectors.

It is estimated that the manufacturing sector (including local assembly in ICR, foam, aerosol, solvent and fire suppression) consumes 49.1% of HFC consumption and 50.9% of HFCs are consumed in the RAC servicing sector. Figures 4 and 5 provide sectoral consumption in CO_2eq and mt terms for Category 1 countries. Again, it should be mentioned that while the study calculates the share of HFCs per sector and subsector in precise percentages, there is a significant level of uncertainty in these estimates given the data limitations discussed above.

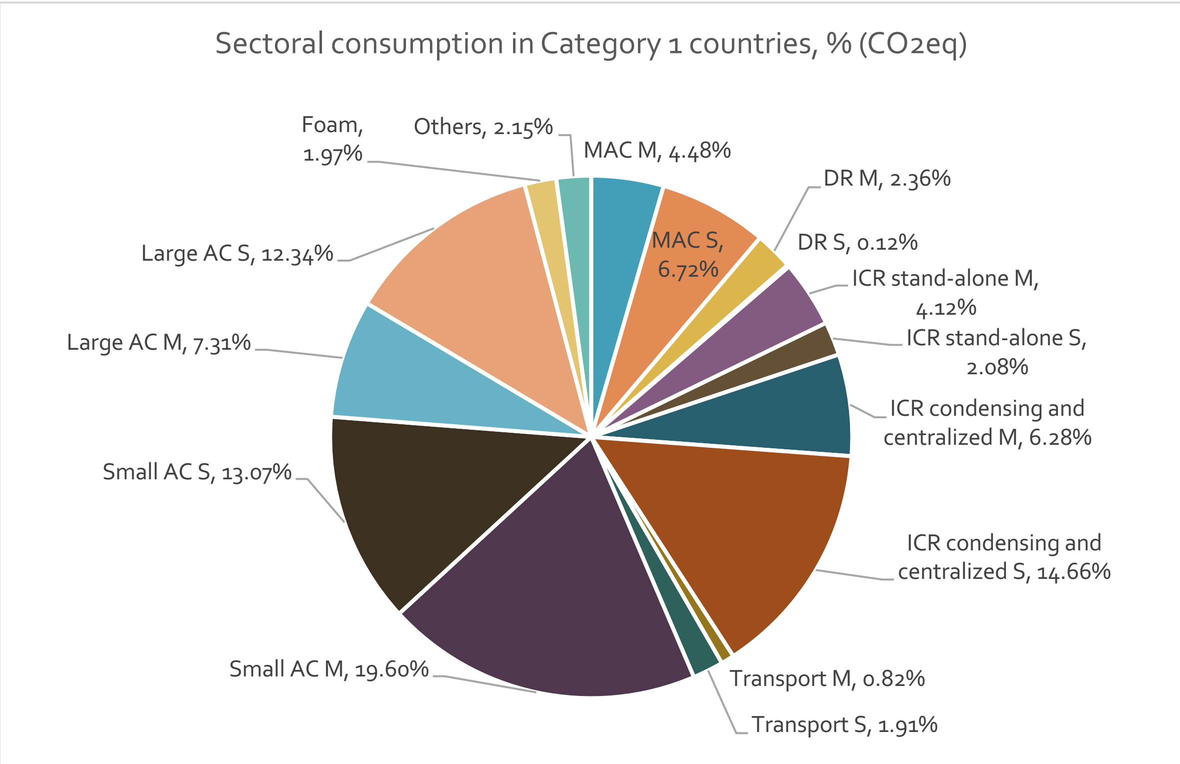

Figure 4: Sectoral consumption in Category 1 countries, % (CO_2eq)

(M: Manufacturing; S: Servicing)

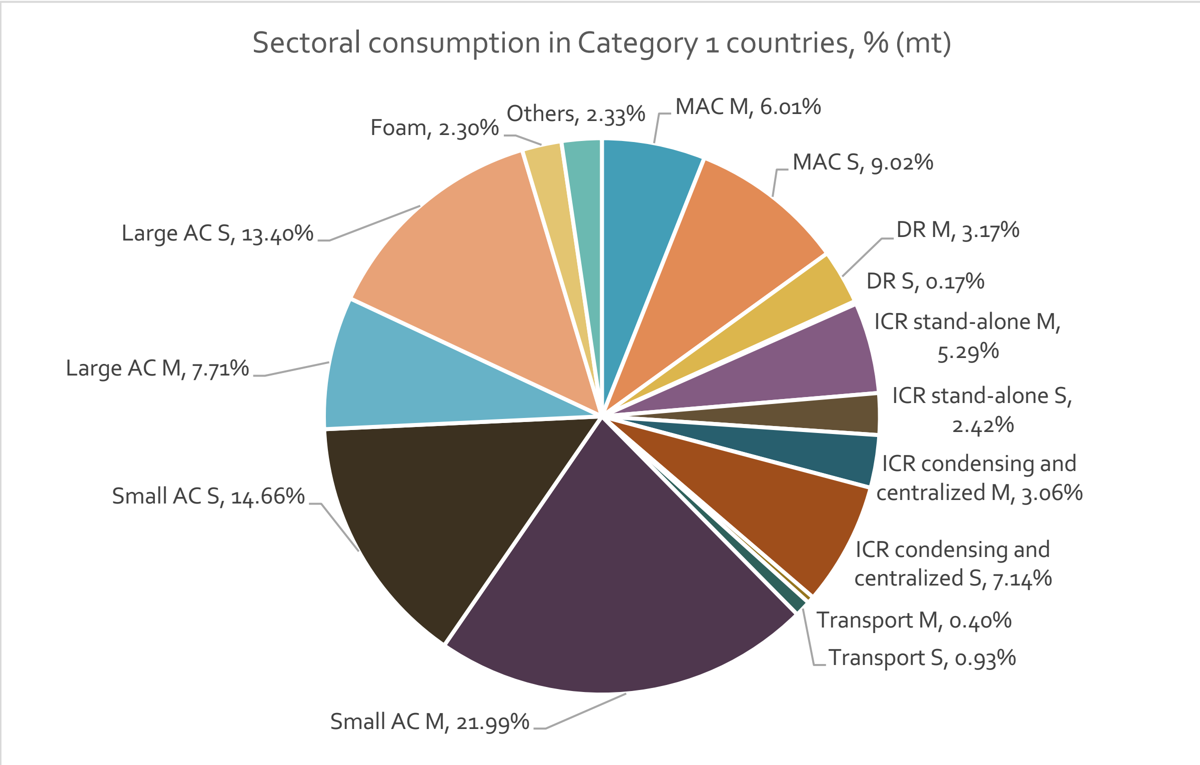

Figure 5: Sectoral consumption in Category 1 countries, % (mt)

(M: Manufacturing; S: Servicing)

Category 2 countries. In this consumption category, demand in the air-conditioning sector contributes to 46.9% of total HFC demand, followed by 29.0% in ICR and 15.1% in the MAC sector in CO_2eq. It is estimated that the manufacturing sector (including local assembly in ICR) consumes 17.6% of HFC and 82.4% HFCs are consumed in the RAC servicing sector. Figures 6 and 7 show the sectoral consumption in CO_2eq and mt terms for Category 2 countries.

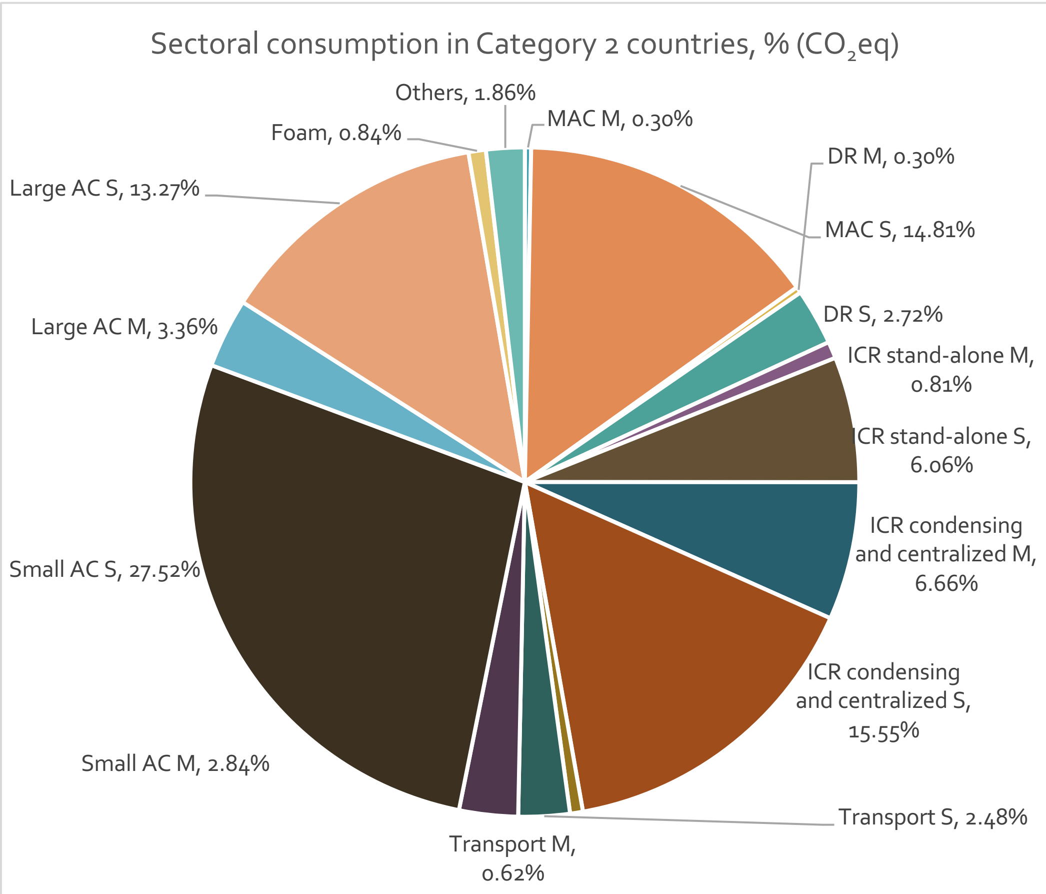

Figure 6: Sectoral consumption in Category 2 countries, % (CO_2eq)
(M: Manufacturing; S: Servicing)

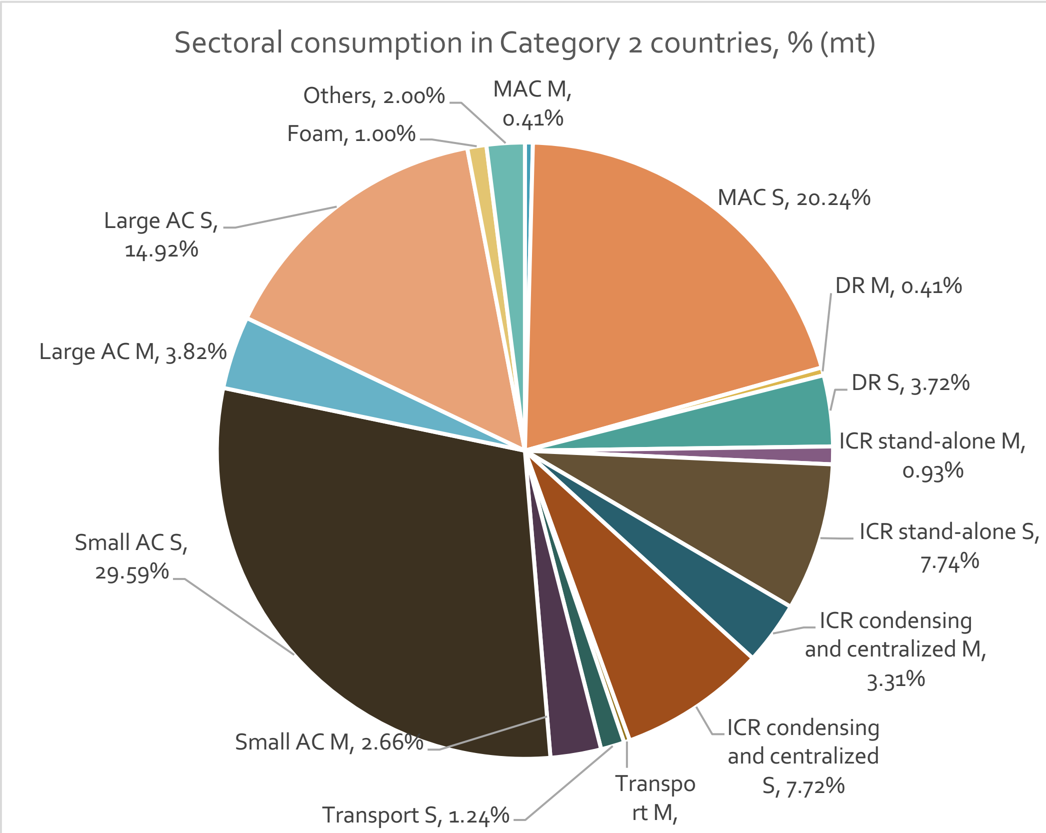

Figure 7: Sectoral consumption in Category 2 countries, % (mt)

(M: Manufacturing; S: Servicing)

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<u>Category 3 countries.</u> LVC countries are generally dependent on imports of substances and RAC equipment to meet local demand. Most LVC countries do not have local manufacturing enterprises, with the exception of local assemblers in some countries. For LVC countries, based on CP data for 2019 and 2020 (MLF, 2021), the RAC servicing sector is the main area for HFC consumption. Ninety-two per cent of HFC consumption is estimated to take place in the RAC servicing sector, 7.0% in ICR local assembly and installation and the remaining 0.99% in various subsectors including foam, fire extinguishers and solvent in terms of CO_2eq. Figures 8 and 9 provide sectoral consumption in CO_2eq and mt terms for Category 3 countries.

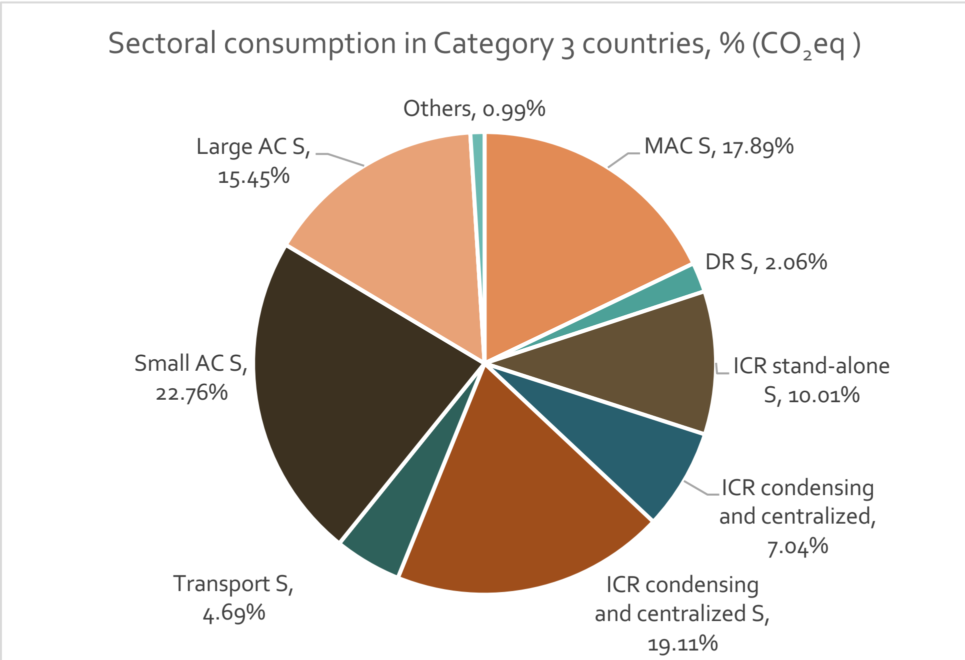

Figure 8: Sectoral consumption in Category 3 countries, % (CO_2eq)
(M: Manufacturing; S: Servicing)

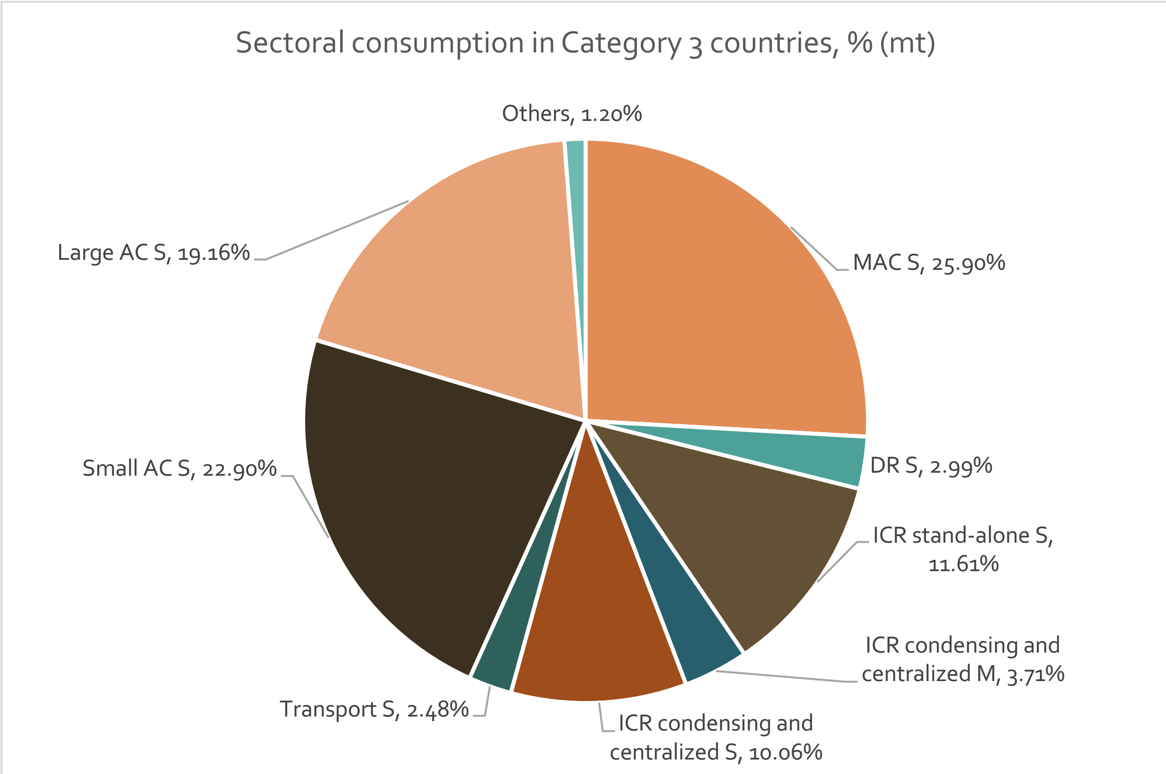

Figure 9: Sectoral consumption in Category 3 countries, % (mt)

(M: Manufacturing; S: Servicing)

The following two Figures 10 and 11 illustrate the total estimated sectoral consumption for the three categories of Article 5 countries considered in this study, in CO_2eq and mt terms respectively. The proportion of consumption used for servicing is aggregated for all subsectors. It is interesting to note that, in mt, the proportion of HFCs used in the servicing sector (54.3%), as compared to manufacturing (45.7%), is higher than was the case for HCFCs (about 40% for servicing). If ICR local assembly and installation is considered to be part of servicing, then the proportion used for servicing is 62%. This indicates that there is proportionally less use of HFCs in the manufacturing sectors in Article 5 countries than was the case for HCFCs.

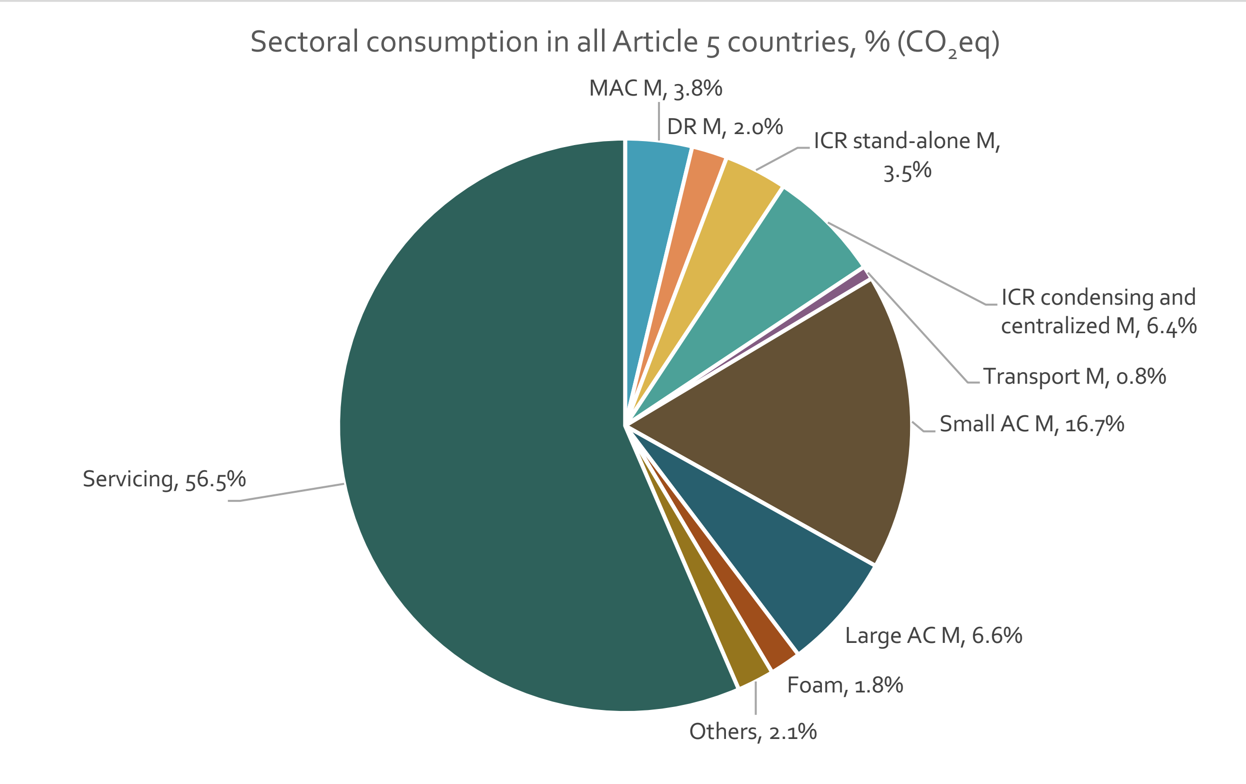

Figure 10: Sectoral consumption in all Article 5 countries, % (CO_2eq)

(M: Manufacturing; S: Servicing)

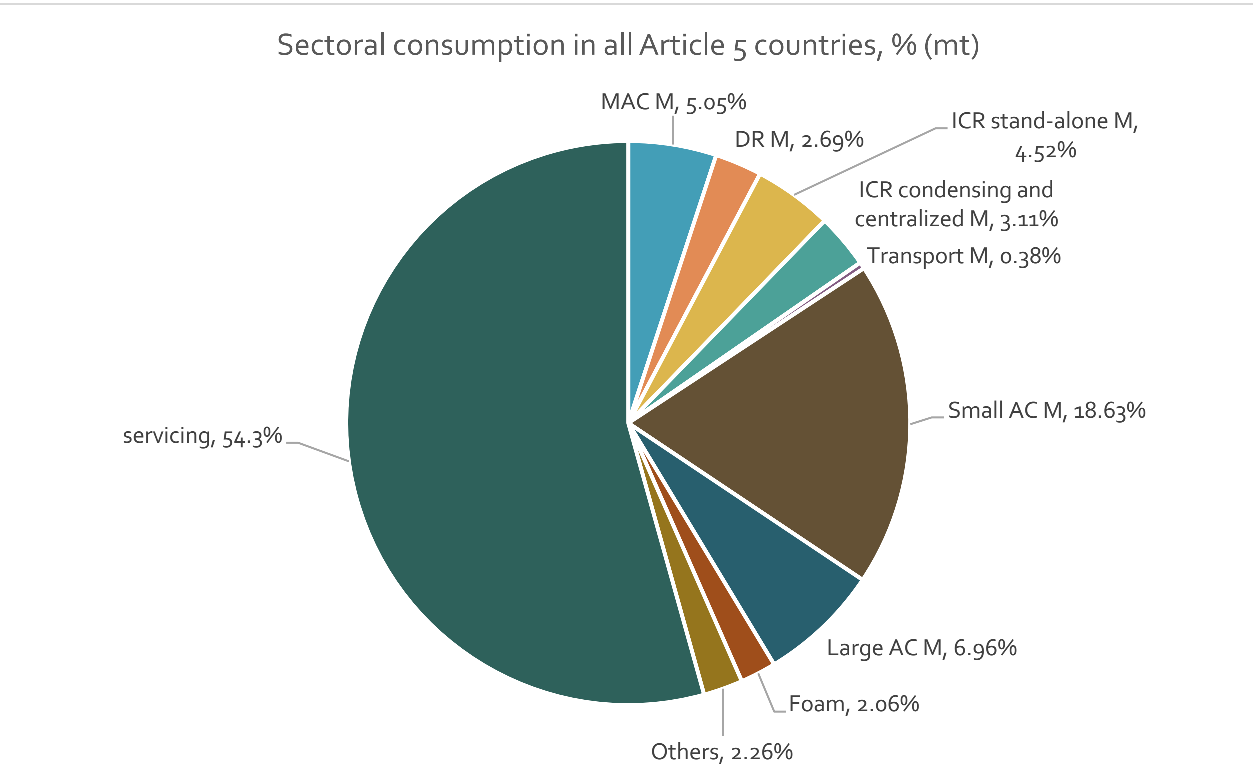

Figure 11: Sectoral consumption in all Article 5 countries, % (mt)

(M: Manufacturing; S: Servicing)

Table 12 provides the overall estimated sectoral consumption in all Article 5 countries.

Table 12: Estimated sectoral consumption in Article 5 countries, % CO_2eq

Subsector	Manufacturing (including local assembly)	Servicing	Total
Small AC	16.7%	15.4%	32.1%
Large AC	6.6%	12.5%	19.1%
MAC	3.8%	8.2%	11.9%
Domestic refrigeration	2.0%	0.6%	2.6%
ICR stand-alone	3.5%	2.8%	6.4%
ICR condensing and centralized	6.4%	14.9%	21.2%
Transport	0.8%	2.0%	2.8%
Subtotal RAC	39.8%	56.4%	96.2%
Foam	1.8%		
Others	2.1%		
Total	43.5%	56.5%	100%

3.4. HFC consumption projections in Article 5 countries up to 2050

A BAU scenario for Article 5 HFC consumption (144 countries) has been constructed using the analysis in sections 3.1., 3.2 and 3.3 of this report. Under BAU, the HFC consumption is projected to be 4,853 Mt CO_2eq (Figure 12) in 2050. The BAU scenario is an average of three growth trajectories used in section 3.1.

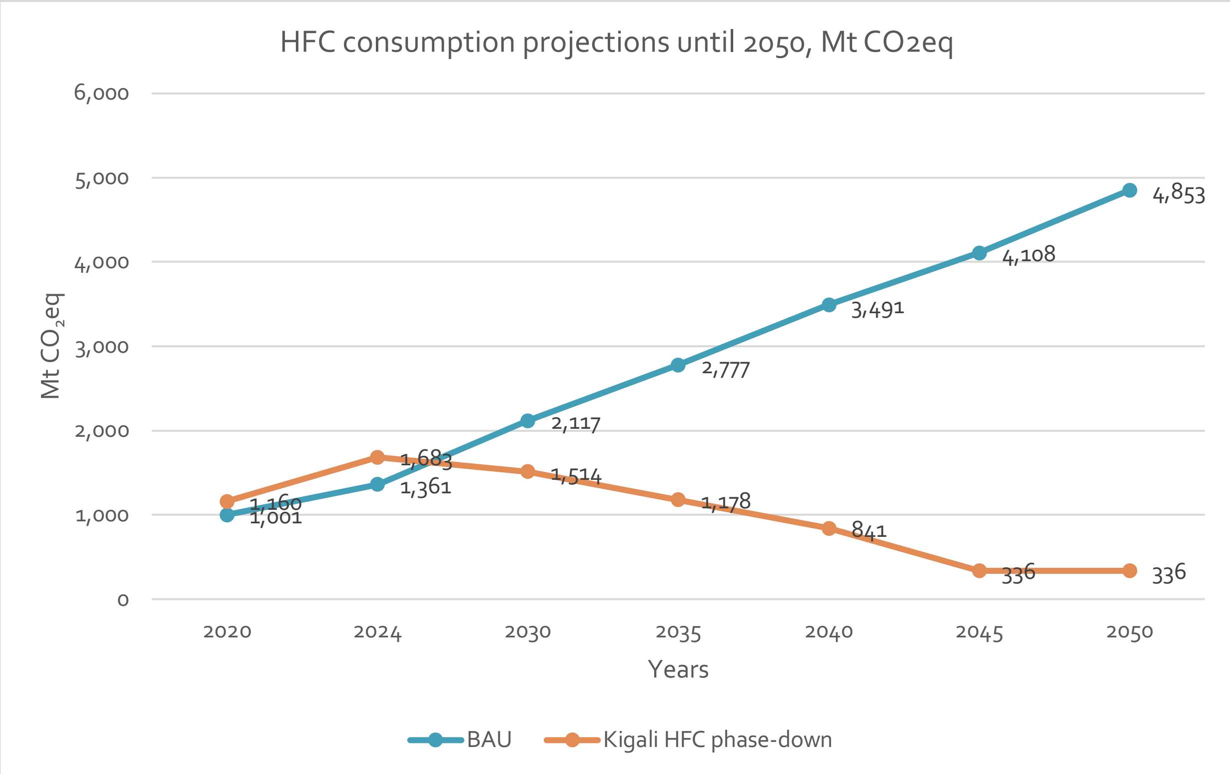

Figure 12: HFC consumption projections 2020–2050 in all Article 5 countries, Mt CO_2eq

Different subsectors may witness different growth rates depending on the availability of alternative technologies. However, for this study, the same growth rate is assumed for all substances in the BAU scenario. Figure 13 below shows consumption growth per HFC type aggregated for Article 5 countries during 2020–2050.

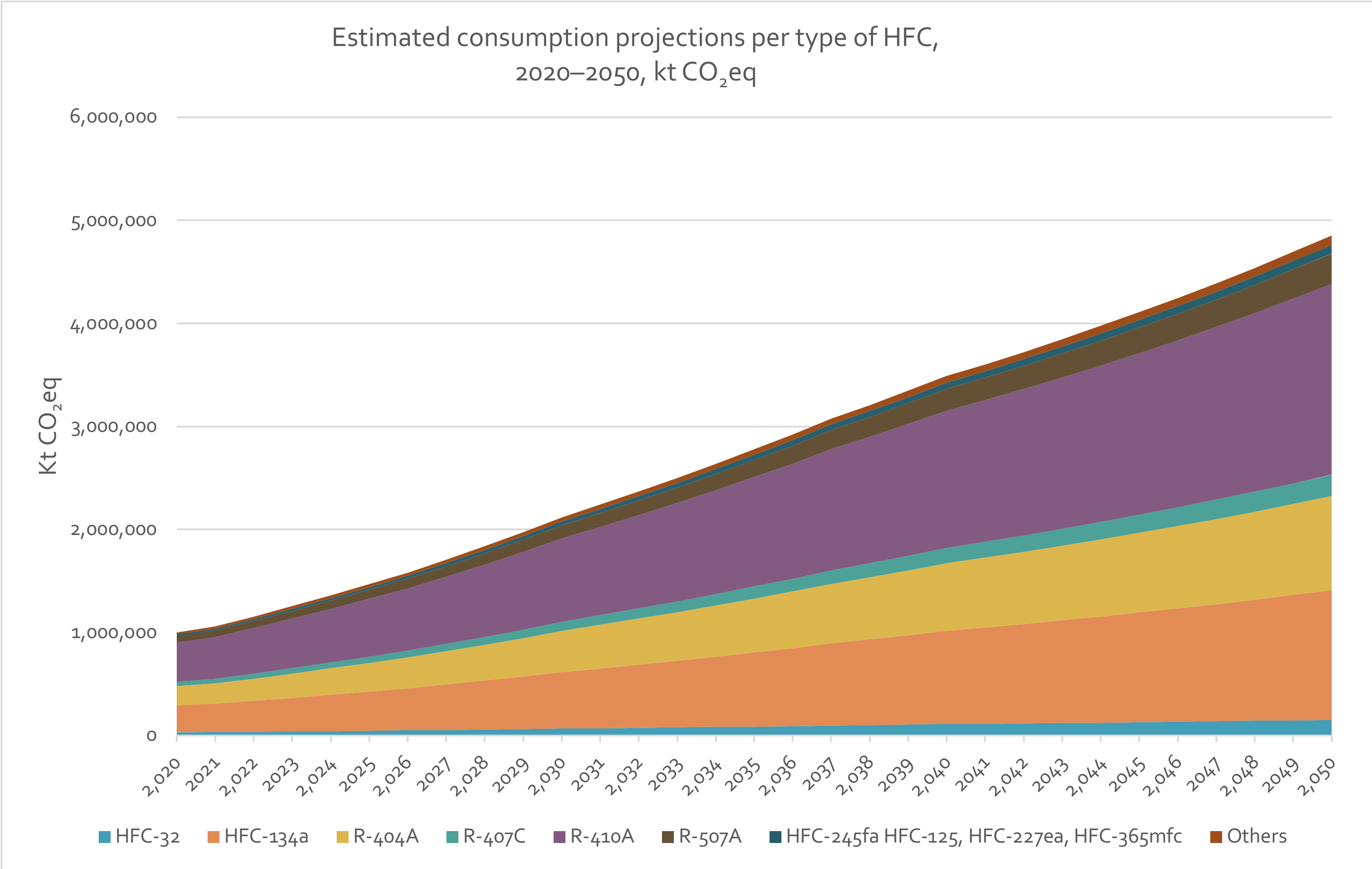

Figure 13: Estimated consumption projections per type of HFC, 2020–2050, kt CO_2eq

In the study, it is assumed that LVCs and non-LVCs will retain the same HFC consumption share till the year 2050 as they have in the estimated HFC baseline consumption. Figure 14 below illustrates the projected HFC consumption per sector up to 2050 aggregated for all Article 5 countries. For a more detailed representation of sectoral consumption for each of the three categories of countries, refer to the tables in Annex 1.

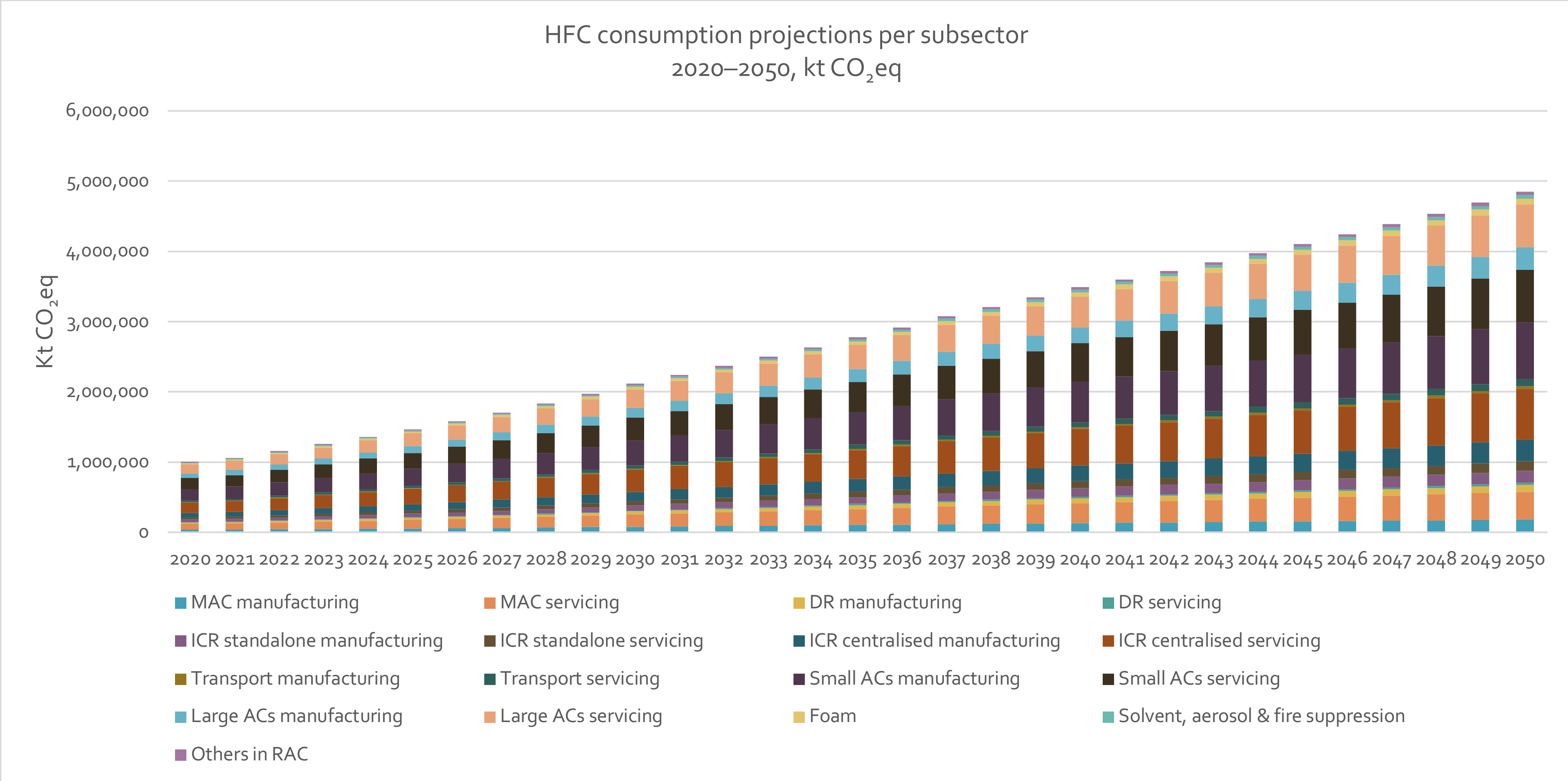

Figure 14: HFC consumption projections per subsector 2020–2050 for all Article 5 countries, kt CO_2eq

3.5. Forecast for compliance with HFC consumption freeze

Given that the 2024 HFC consumption freeze for Article 5 Group 1 countries is less than two years from the year this study is undertaken, this part of the report examines the situation of countries with respect to meeting this freeze level, based on the BAU scenario[11] presented in the preceding sections. It should be noted that this BAU scenario does not take into account the implementation of KIPs that are or will be prepared and funded under the Multilateral Fund.

As a first step, the projected baseline of each Group 1 country was compared with its projected consumption level in 2024. According to this analysis, 28 out of 135 Group 1 countries (Table 12) will be above their baseline target levels in the year 2024, unless rapid action is taken to limit or reduce HFC consumption. As a second step, since the freeze level needs to be sustained after 2024, the projected baselines were compared with projected consumption in 2025 and 2026. In this exercise, there are an additional 27 Group 1 countries that will be above their baseline level in 2025 and/or 2026 (Figure 15).

Therefore, considering the countries' abilities to meet and sustain the 2024 freeze up to 2026, there are 55 countries overall that would not comply with their target unless action is taken soon to limit or reduce HFC consumption. Forty-eight of these countries have estimated HFC consumption levels above 110% of baseline levels by 2026. It should be noted that of the 55 countries identified, as of 8 April 2022, there are still ten countries[12] that have not ratified the Kigali Amendment and therefore do not have any obligations to comply with the phase-down schedule. However, for the purpose of this study, it is assumed that these countries will all have ratified the Amendment by 2024 and will therefore need to ensure compliance with the HFC freeze.

Of course, it is crucial to consider the compliance of all Article 5 countries (Group 1 and Group 2) beyond 2026. However, to identify countries requiring "high-priority" action, 2026 was deemed appropriate as it typically takes 3–4 years to fully implement phase-out activities and projects approved under the Multilateral Fund. A time frame extending to 2026 is admittedly arbitrary to some extent and does not provide a complete forecast of compliance for all Article 5 countries, which would be beyond the scope of this report, as the aim here is to prioritize near-term compliance and identify where efforts may need to be focused in the short term.

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11 The BAU scenario is an average of three growth trajectories used in section 3.1.

12 Antigua and Barbuda, Brazil, Guatemala, Indonesia, Madagascar, Mauritania, Mongolia, Nauru, Sudan and Suriname.

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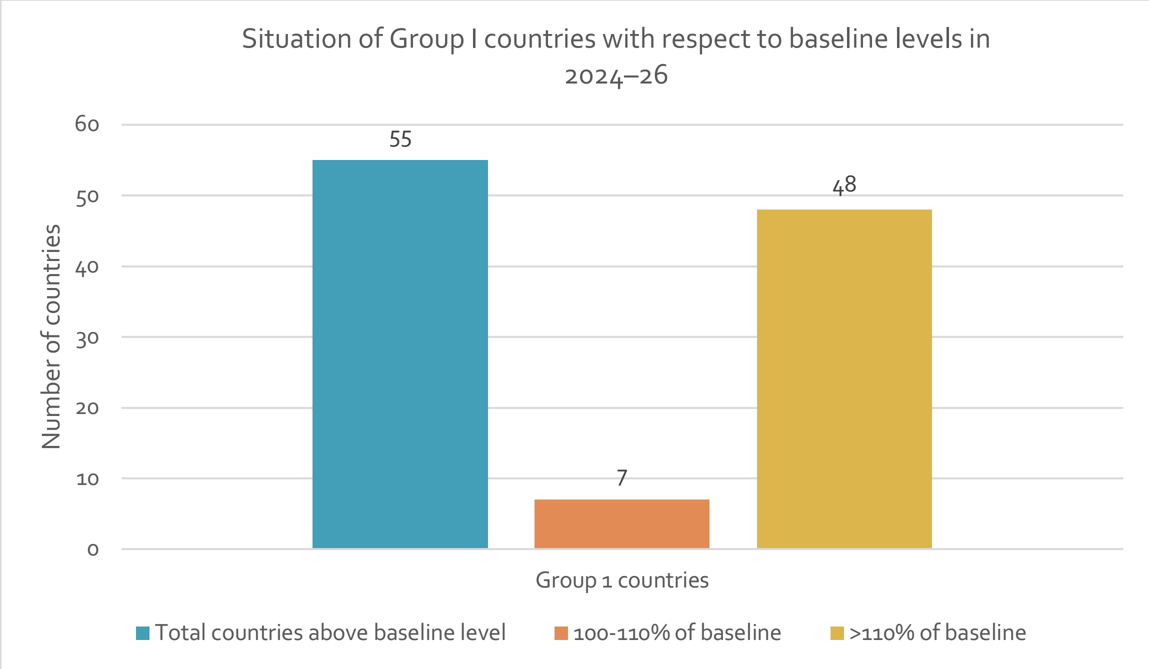

Figure 15: Situation of Group 1 countries with respect to meeting the HFC consumption freeze 2024, 2025 and 2026 under BAU

It may also be worth noting that by 2029, all but 22 countries in Group 1 are projected to be above the 10% reduction target under BAU (Table 4). However, it may be expected that these countries will have made progress under KIPs before that time to help them meet that target.

Similarly, four out of nine countries in Group 2, under BAU, will be above their baseline level in 2028, and seven countries will be above their 10% reduction target in 2032.

HFC consumption growth during 2021-2024 of course has a major impact on how far or close countries will be from their baseline levels in the 2024–2026 period. The growth projections under the BAU scenario considered in this report are subject to significant uncertainty, particularly given the lack of reported HFC consumption data by many countries and changes in economic growth brought about by the COVID-19 pandemic. The following chart (Figure 16) shows the number of countries above their baseline level in the year 2024 depending on an assumed average growth rate during 2021-2024. Based on this model, at a 5% annual growth rate, only 14 countries would be above their baseline in 2024, whereas at a 15% growth rate 80 countries will find it difficult to meet the first compliance target.

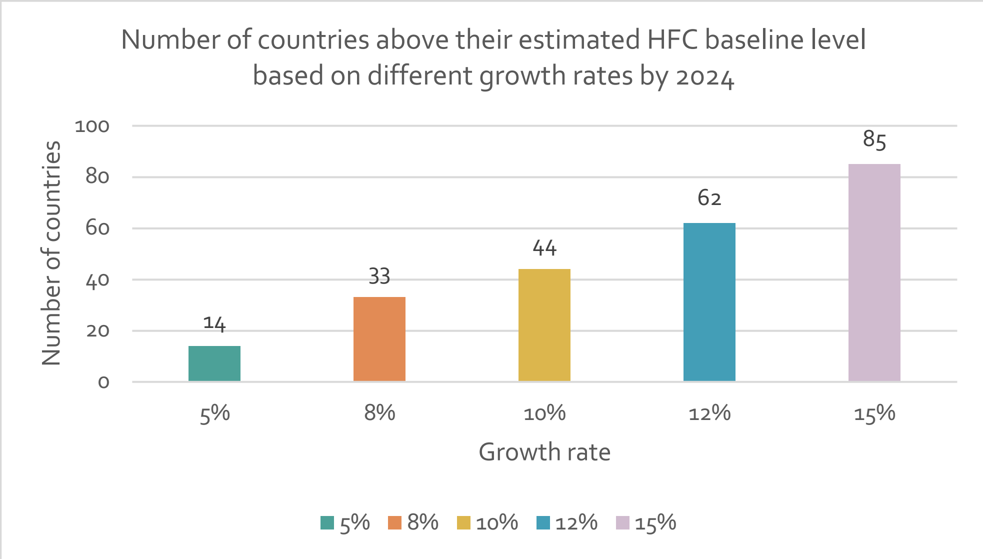

Figure 16: Number of countries above their estimated HFC baseline level based on different growth rates by 2024

Table 13 identifies the 55 Group 1 countries at risk of exceeding the 2024 freeze level in the 2024-2026 period, listed by the extent to which the baseline would be exceeded and the year in which that level would be exceeded under BAU. Of the 55 countries, 37 are LVCs (from 89 countries) and 18 are non-LVCs (from 46 countries). For this report, these countries are considered "high-priority countries for early action" (provided they have ratified the Kigali Amendment).

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Table 13: High-priority countries (Group 1) for early action to meet compliance targets (kt CO_2eq)

Country	LVC/Non-LVC	Total HFC baseline	2024	Consumption 2024/HFC baseline	2025	Consumption 2025/HFC baseline	2026	Consumption 2026/HFC baseline
Cook Islands	LVC	6	9	141%	9	152%	10	164%
Gambia	LVC	287	372	130%	405	141%	440	153%
Seychelles	LVC	240	308	129%	333	139%	359	150%
Kiribati	LVC	11	14	127%	15	138%	16	149%
Serbia	LVC	3,063	3,769	123%	4,080	133%	4,410	144%
Comoros	LVC	42	51	122%	55	132%	60	142%
Angola	LVC	4,498	5,433	121%	5,872	131%	6,336	141%
Uganda	LVC	52	61	118%	66	128%	72	139%
Mauritania	Non-LVC	764	917	120%	987	129%	1,060	139%
United Republic of Tanzania	LVC	312	360	115%	393	126%	428	137%
Sierra Leone	LVC	309	357	115%	388	125%	421	136%
Guinea Bissau	LVC	688	794	115%	862	125%	934	136%
Somalia	Non-LVC	1,063	1,231	116%	1,331	125%	1,437	135%
El Salvador	LVC	1,129	1,298	115%	1,403	124%	1,514	134%
Saint Vincent and the Grenadines	LVC	29	33	114%	36	123%	39	133%
North Macedonia	LVC	400	454	114%	491	123%	529	132%
Kyrgyzstan	LVC	426	479	112%	520	122%	563	132%
Antigua and Barbuda	LVC	45	50	112%	55	122%	59	132%
Turkmenistan	LVC	608	672	111%	734	121%	799	131%
Suriname	LVC	302	339	112%	366	121%	395	131%
Guyana	LVC	135	148	109%	161	119%	174	129%
Costa Rica	LVC	1,437	1,566	109%	1,694	118%	1,830	127%

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Panama	Non-LVC	2,267	2,498	110%	2,687	119%	2,886	127%
Trinidad and Tobago	Non-LVC	6,029	6,676	111%	7,151	119%	7,646	127%
Guatemala	LVC	1,105	1,176	106%	1,272	115%	1,373	124%
Maldives	LVC	403	416	103%	454	113%	494	123%
Rwanda	LVC	377	383	102%	418	111%	455	121%
Nicaragua	LVC	637	659	103%	712	112%	768	121%
Chile	Non-LVC	6,145	6,380	104%	6,834	111%	7,307	119%
Nauru	LVC	15	15	100%	16	109%	17	117%
Ecuador	LVC	2,557	2,520	99%	2,724	107%	2,939	115%
Cambodia	LVC	1,265	1,223	97%	1,334	105%	1,453	115%
Mongolia	LVC	116	113	97%	123	106%	134	115%
Grenada	LVC	59	57	97%	62	105%	67	114%
Zambia	LVC	413	402	97%	435	105%	470	114%
Armenia	LVC	436	418	96%	455	104%	494	113%
Gabon	Non-LVC	2,685	2,649	99%	2,837	106%	3,034	113%
Montenegro	LVC	149	144	96%	156	104%	169	113%
Micronesia (Federated States of)	LVC	12	11	97%	12	104%	13	113%
Mexico	Cat1	62,362	61,289	98%	65,650	105%	70,199	113%
Madagascar	Non-LVC	1,898	1,844	97%	1,981	104%	2,125	112%
Vanuatu	LVC	19	18	94%	20	102%	21	111%
Mozambique	LVC	609	578	95%	625	103%	675	111%
Sudan	Non-LVC	1,775	1,711	96%	1,833	103%	1,960	110%
Viet Nam	Non-LVC	14,238	13,437	94%	14,533	102%	15,693	110%
Bangladesh	Non-LVC	5,924	5,568	94%	6,022	102%	6,503	110%
Honduras	LVC	1,727	1,617	94%	1,752	101%	1,895	110%
Brazil	Cat1	67,797	64,836	96%	69,450	102%	74,262	110%
Bolivia	LVC	498	459	92%	497	100%	537	108%

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Guinea	Non-LVC	1,949	1,785	92%	1,931	99%	2,085	107%
Senegal	Non-LVC	2,749	2,517	92%	2,722	99%	2,939	107%
Benin	Non-LVC	1,818	1,642	90%	1,773	98%	1,913	105%
Indonesia	Cat1	20,435	18,008	88%	19,419	95%	20,906	102%
Colombia	Non-LVC	7,413	6,528	88%	6,992	94%	7,477	101%
Niger	Non-LVC	1,258	1,083	86%	1,171	93%	1,264	101%

3.6. Potential action that could be taken to ensure compliance with the 2024 HFC consumption freeze in high-priority countries

In the preceding subsection, 28 Group 1 countries were identified as being potentially at risk of not meeting the 2024 HFC consumption freeze. Twenty-seven more Group 1 countries were identified as having the same risk by 2025 or 2026. This section outlines potential action that could be taken for these countries to ensure their compliance with the 2024 HFC consumption freeze, considering their sectoral distribution of HFC consumption, and the possibility for certain sectors to transition to low-GWP alternatives in the short term.

Section 4 of this report provides a more detailed overview of alternatives in all key sectors where HFCs are used. For the present section, we are only concerned with a handful of key sectors where action is needed or can be focused on to reduce HFC consumption within the next 2-5 years. It is of course also important to consider compliance with the Kigali Amendment beyond the year 2026 and, accordingly, section 4 will look at more long-term phase-down scenarios for all Article 5 countries. However, given the length of time required to prepare and implement measures and projects to reduce HFC consumption, a specific short-term focus that considers only the challenge of meeting and sustaining the 2024 freeze until 2026 is warranted.

At the outset, it is evident that all countries will need to ensure their compliance with the consumption freeze by enacting legislation and/or regulations that limit their consumption by the year of the freeze to a level no higher than their baseline level under the Kigali Amendment. Some or many Article 5 countries may already be in the process of developing or amending legislation to comply with the HFC phase-down schedule, and such efforts need to be prioritized in all Article 5 countries, particularly in the high-priority countries identified above. However, legislation/regulations alone may not succeed in reducing HFC demand if actions are not taken to transition towards low-GWP alternatives or otherwise reduce this demand. If HFC demand is not reduced roughly in proportion with the Kigali HFC consumption control limits, the result could be economic hardship for the country concerned and/or increased risk of illegal trade of HFCs to satisfy a demand not met through the available HFC quotas.

Recalling the three categories of Article 5 countries proposed in Chapter 2 of this report, of the 55 high-priority countries identified, three are Category 1 countries (high-consuming countries with a large manufacturing sector, 15 are Category 2 countries (other non-LVC countries with a relatively small manufacturing sector, or no manufacturing sector at all) and 37 are Category 3 countries (LVC countries with all or nearly all consumption in the refrigeration servicing sector).

In Category 1 countries, the proportion of HFC consumption in the manufacturing of (1) domestic refrigeration, (2) stand-alone commercial refrigeration, (3) PU and XPS foam and (4) industrial/commercial refrigeration, including local installation and assembly of centralized/condensing units were estimated to be 2.36%, 4.12%, 1.97% and 6.28% respectively. Given the availability of proven hydrocarbon alternatives for the manufacturing of domestic and stand-alone commercial refrigeration equipment, as well as very low-GWP alternatives in the PU and XPS foam sectors, if Category 1 countries prioritized the immediate conversion of all manufacturers of these appliances and foam manufacturing lines, as a group, they could achieve about an 8.45% reduction of HFC consumption, which should be enough to ensure near-term compliance with the HFC consumption freeze for countries which are at risk in this category. Depending on their sectoral distribution, some of these countries may need to address additional sectors to achieve the required reduction. In this case, the commercial/industrial refrigeration sector may provide the next immediate opportunity for a significant long-term reduction, given the wide availability of lower-GWP options to HFCs used in this sector. However, a large segment of consumption in this sector is for the local installation and assembly subsector, which provides a particular challenge to address. This challenge, and the possibility of addressing it, are discussed further in section 4 of this report. For the present discussion, we note that the commercial/industrial sector is one where Category 1 countries could also focus efforts in the short term to achieve reductions needed to comply with the 2024 consumption freeze.

In Category 2 countries, the proportion of HFC consumption in the manufacturing of (1) domestic refrigeration, (2) stand-alone commercial refrigeration, (3) industrial/commercial refrigeration, including local installation and assembly of centralized/condensing units, and (4) foam were estimated to be 0.3%, 0.81%, 6.66% and 0.84% respectively. Therefore, domestic and stand-alone commercial refrigeration, and foams, could at most contribute to a reduction of about 1.95% for these countries, as a group. For most high-priority countries in Category 2, it appears that addressing these sectors alone would not be sufficient to achieve the short-term reductions needed to comply with the 2024 consumption freeze. Therefore, countries would need to consider additional sectors where alternatives are already available. Apart from the ICR/local assembly sector, which could contribute up to a 6.66% reduction (not including servicing), about 2.84% of Category 2 consumption is for the manufacturing of small air conditioners, for which hydrocarbons and HFC-32 are alternatives. However, it would be challenging to transition to hydrocarbons in the AC sector in the very short time frame considered here, given the need to revise or develop safety standards, ensure adequate training and market acceptance of highly flammable refrigerants. HFC-32 could help achieve the necessary reduction in the short term. However, as discussed in the next section, it would likely require an eventual second conversion to a very low-GWP or zero-GWP solution, due to its GWP of 675. Furthermore, since a number of Category 2 countries consume HFCs mainly or even only for refrigeration servicing, at least some of these countries should also consider action in the servicing sector. Such actions are briefly discussed below, in reference to Category 3 countries, and more comprehensively in section 4 of this report.

Category 3 countries may face the greatest challenge in reducing HFC consumption and demand in the short term because virtually all of their consumption is for the servicing of imported HFC products, and they have no control over the transitions in the manufacturing sectors in the countries they import these products from. These countries will therefore have to reduce almost all of their consumption for HFCs by reducing the demand for HFCs for RAC servicing. Depending on the country, measures to reduce HFC demand could be achieved through a mix of improved containment practices, in other words, best practices to minimize emissions of HFCs in existing equipment, recovery and recycling, retrofits (if cost-effective, safe alternatives are available) and, possibly, restrictions on the import of HFC-based products in sectors where the same products are being manufactured in exporting countries with low-GWP alternatives (such as in the domestic refrigeration and commercial stand-alone sectors). In addition, most of these countries have a small consumption of HFCs for the local installation and assembly of commercial refrigeration systems, and action there could further contribute to the reduction needed to ensure compliance with the 2024 freeze. Both the servicing sector and the local installation and assembly sector are discussed further in the next section of this report, which looks at opportunities for both near-term and long-term reductions in all Article 5 countries for them to comply and exceed the phase-down schedule under the Kigali Amendment.

It should be noted that the potential actions outlined above are only meant to provide examples of how the 2024 freeze could be met and sustained through rapidly implemented activities/projects that, in principle, should be feasible in all the high-priority countries identified. Depending on the specific circumstances of each country, the actions could of course be very different to those suggested above. With the exception of the importance of putting in place the regulatory measures to ensure compliance with the Kigali Amendment, it is not the intention of this study to prescribe any particular action in any specific country, but simply to point out actions that should be possible to undertake to reduce HFC consumption.

An additional consideration, which fell outside of the scope of this report, is the level of Article 5 countries' HFC consumption in manufacturing associated with enterprises in developed countries, in other words, foreign ownership). Such consumption is not eligible for funding under the Multilateral Fund. While this study does not estimate the proportion of HFC consumption associated with foreign ownership (this would require significantly more detailed HFC data from Article 5 countries), there are indications that this proportion is overall higher than in the case of HCFCs, particularly in some non-LVC countries. The opportunities and challenges to addressing such HFC consumption early on, possibly by Article 5 and/or non-Article 5 parties requiring the enterprises concerned to transition to lower-GWP alternatives already used in non-Article parties, would need to be considered in any strategy to ensure near-term compliance, discussed in this section, or long-term compliance and accelerated phase-down, as discussed in the following section.

4. Mitigation scenarios for meeting or exceeding the Kigali Amendment in Article 5 countries

4.1. Overview of opportunities for phasing down HFCs

The focus of this section is to explore potential HFC consumption reductions in various subsectors for Article 5 countries to: (1) comply with or slightly exceed the time-dependent phase-down limit under the Kigali Amendment and (2) significantly exceed this phase-down limit. Based on an assessment of feasible potential scenarios for reducing HFC consumption in each significant subsector, this section presents one overall scenario of sectoral reductions to meet the Kigali Amendment, and a more ambitious scenario of sectoral reductions to surpass the requirements of the Amendment. The climate benefits of each of these scenarios are then assessed and compared.

There are opportunities for consumption reductions through the application of technologies that are currently commercially available though, as mentioned, there are also challenges to the adoption of technologies that must be factored in any phase-down scenario. The study looks at such technology options and the impact of their adoption in reducing consumption in Article 5 countries up to 2050. Though it does not explicitly examine cost elements involved with various options, it prioritizes technologies that are gaining prominence and are relatively affordable in Article 5 countries.

In most of the primary HFC-consuming subsectors, several climate-friendly, energy-efficient, safe (as allowed under relevant safety standards) and proven alternatives to HFCs are currently available, but there is no "one size fits all" solution. The suitability of a particular alternative must be determined specifically for each type of application and, in some circumstances, the geographical region where the product and equipment are utilized must also be taken into account.

4.1.1. Stationary air-conditioning

Air conditioning (residential, commercial and chillers) is the largest sector consuming HFCs. It accounts for nearly 51.24% of total HFC consumption (in mt CO_2eq) for both manufacturing and servicing (594,380 mt CO_2eq in the year 2020) in Article 5 countries. The current state of alternatives for the manufacturing of AC equipment is very different if one considers small AC equipment or large AC equipment, using the categorization of small and large equipment taken from the aforementioned U.S. Environmental Protection Agency factsheet (while acknowledging that there is not necessarily a clear line between small and large equipment). It is therefore meaningful to consider the percentage of HFC consumption used in small AC, versus the percentage of consumption used in large AC (inclusive of chillers), as per Table 14 below.

Table 14: Air conditioners' share of HFC consumption (CO_2eq)

Category	Small AC		Large AC	
	Manufacturing	Servicing	Manufacturing	Servicing
Category 1	19.60%	13.07%	7.31%	12.34%
Category 2	2.84%	27.52%	3.36%	13.27%
Category 3	0.0%	22.8%	0.0%	15.4%
Total (pro rata)	16.7%	15.4%	6.6%	12.5%

HFC-410A is presently the most frequently used HFC refrigerant in residential air conditioners in Article 5 countries. HFC-407C and HFC-134a have a wider use in commercial ACs, large ACs and chillers. There is significant growth in HFC-32-based stationary AC manufacturing in large exporting nations, including China, Thailand and India, and relatively small production of hydrocarbon (HC-290)-based room air conditioners in China and India. There are several lower-GWP alternatives (Table 15) that can be adopted for wider application, particularly for small AC equipment and chillers.

Table 15: Technologies in stationary air conditioners

System	Conventional Refrigerant	Alternative Refrigerants (medium and low-GWP)
Small ACs	HFC-410A (GWP 2088), HFC-32 (GWP 675)	Already in use: HFC-32, HC-290 (propane, GWP 3) Potential/emerging: HFC-161 (GWP 12), HC-1270, R-444B (GWP 293), R-452B (GWP 697)
Large unitary ACs (not including chillers)	HFC-410A, HFC-407C (GWP 1774)	Limited use: HFC-32, R-744 (CO_2, GWP 1) for some large ducted systems Potential/emerging: R-444B(GWP 1386), R-446A(GWP 459), R-447A (GWP 582), R-718 (GWP 1)
Chillers	HFC-134a GWP 1430), HFC-410A	Large centrifugal chillers: HFO-1234yf (GWP 4) HFO-1234ze(E) (GWP 6), Solstice 1233zd(E) (GWP 4.7-7), R-744, R-717 (ammonia, for industrial applications, GWP 0) Small and medium-size chillers: R-450A (GWP 631) and HFC-513A (GWP 601), R-290 Not-in-kind cooling options

While there are a number of actual and potential alternatives to HFC-410A in air conditioning, it is important to note that the fluorinated refrigerants mentioned above have GWPs ranging from 293 (R-444B) to 675 (HFC-32). According to the modelling performed in this study, such medium-GWP refrigerants would allow significant reductions of HFC consumption in the short term, but given the high level of growth of the AC sector in A5 countries, these reductions would not be sustained over the longer term in most countries and, therefore, a second conversion to an even lower- or zero-GWP alternative would be needed to ensure sustained compliance with the Kigali Amendment.[13] Annex 2 shows total projected HFC consumption up to 2050 if the AC sector converted entirely to HFC-32, while applying mitigation scenario 1 (developed under this study) for the rest of the sectors, as compared with consumption levels to comply with the Kigali phase-down schedule.

[13] Decision XXVIII/2: decision related to the amendment phasing down hydrofluorocarbons has set funding criteria for projects involving double conversion.

In this analysis, projections have been made until 2050 to ensure that the potential reductions proposed ensure the compliance of A5 countries with the 80% (Group 1 countries) or 85% (Group 2 countries) phase-down step up to 2050. Further analysis would be needed to determine whether second conversions would be needed after that time for compliance to be sustained beyond 2050.

Not-in-kind technologies, including passive cooling and district cooling, could also play a role in reducing consumption of HFCs in this sector. However, at this time, the penetration of such technologies is low, so they have not been considered in this analysis, but could be considered in future work.

The proposed technology pathway for the air-conditioning sector is based on the availability of alternative lower-GWP technologies for different subsectors and a realistic timeline for conversion or partial conversions in those subsectors, considering that the alternatives are either flammable or mildly flammable and therefore require time for standards and training to be implemented.

Mitigation scenario 1 (Mit-1)

- In small AC (self-contained and mini-split systems) manufacturing: a gradual shift to HC-290 and HFC-32 between 2026 and 2032 to achieve an average GWP of 170 for the sector (note, this would imply a roughly 75/25 split between HC-290 and HFC-32). A conversion to more HFC-32 would help achieve significant reductions in the short to medium term but, as mentioned, over the long term it would likely not ensure sustained compliance with later phase-down targets. It is assumed that post-2045, zero or ultra-low-GWP alternatives would be used in this subsector.
- In large AC (including packaged and multi-split systems) manufacturing: a shift to HFC-32 and a mix of lower-GWP HFC/HFO blends between 2029 and 2040 to achieve an average GWP of 600. Hydrocarbons (HC-290) could also be an alternative for some of these applications but presents more of a challenge due to the relatively high charges involved (and lack of standards allowing for higher charge size) along with market acceptability; it has therefore not been considered in this analysis. Post-2040, it is assumed that an alternative mix averaging a GWP of about 150 will be achieved using new alternatives which are in development or HC-290 with the introduction of appropriate standards.
- In chillers manufacturing: a shift to HFO-1234yz and ammonia in chillers (to achieve an average GWP of zero) and a mix of R-450A, R-513A and hydrocarbons in screw chillers (to achieve an average GWP of 300) between 2027 and 2030.

Mitigation scenario 2 (Mit-2)

In the more ambitious mitigation scenario, many of the above conversions in the manufacturing sector can be brought forward by a few years in Category 1 countries.

- Countries can also take a more ambitious target of moving to non-HFC-based refrigerants in small AC manufacturing by the year 2028 (80% HC-290 and the rest HFC-32-based). Post

2035, all HFC demand for small AC manufacturing will be based on zero- or near-zero-GWP options.

- Mit-2 also assumes that there will be appropriate standards allowing a higher charge size of HC-290 to ensure even larger systems can move to an alternative mix of 600 by 2035 and 150 GWP by 2040.
- The chiller subsector can move to an average GWP of 300 between 2025 and 2029 as in Mit-1.

The reductions in HFC consumption resulting from these measures will lead to a reduction in servicing demand for the sector starting 2026, which has been modelled under this analysis and is presented in the next section.

4.1.2. Domestic refrigeration

The DR subsector is estimated to consume 29,710 mt of CO_2eq HFC-134a in the year 2020 contributing to nearly 2.6% of the total HFC demand for the manufacturing and servicing sector in Article 5 countries (Table 16).

Table 16: HFC consumption in domestic refrigeration

	Manufacturing	Servicing
Category 1	2.36%	0.12%
Category 2	0.30%	2.72%
Category 3	0.0%	2.1%
Total (pro rata)	2.0%	0.6%

A large segment of the manufacturing of DRs has already been converted to R-600a (isobutene). The use of HFC-134a as a refrigerant for these appliances is limited overall, but still significant in some Article 5 countries. HC-600a is the main energy-efficient and cost-competitive alternative being roughly 5% more energy-efficient compared with similar HFC-134a based systems.

Table 17: Alternative technologies in the domestic refrigeration sector

System	Conventional Refrigerant	Alternative Refrigerants (low-GWP)
Domestic refrigeration	HC-600a, HFC-134a (GWP 1430)	HC-600a

Given that HC-600a technology in DR is already prevalent even in many Article 5 countries, the proposed technology pathway for the DR subsector in both mitigation scenarios is a complete shift to HC-600a in the manufacturing of new appliances between 2024 and 2028. Assuming 15 years lifetime of DR, by 2040–43 the entire servicing demand for existing DR stock based on HFC-134a would cease to exist.

4.1.3. Industrial and commercial refrigeration (ICR)

The ICR sector is estimated to consume nearly 18.32% of total HFC consumption (in mt) in manufacturing, local assembly and servicing in Article 5 countries. However due to the use of high-GWP HFCs, such as HFC-404A and HFC-507A, the share of the ICR sector in CO_2eq emissions is estimated to be higher at 27.6% (Table 18). A large proportion of sector consumption for condensing units and centralized systems is in the local installation and assembly subsector (installation and refrigerant charging on site). As previously mentioned, for the purpose of this study, local installation and assembly are considered to be part of manufacturing and not servicing, as this makes it more feasible to consider options to replace high-GWP HFCs in this sector.

Table 18: HFC consumption in the ICR sector (CO_2eq)

Category	ICR stand-alone		ICR centralized and condensing unit[14]	
	Manufacturing	Servicing	Manufacturing	Servicing
Category 1	4.12%	2.08%	6.28%	14.66%
Category 2	0.81%	6.06%	6.66%	15.55%
Category 3	0.0%	10.0%	7.0%	19.1%
Total (pro rata)	3.5%	2.8%	6.4%	14.9%

Stand-alone systems: there is widespread use of hydrocarbons (HCs) in this market subsector, namely HC-290. HCs are suitable for stand-alone equipment (for example, in ice cream freezers and bottle coolers) and are already in widespread use in a number of Article 5 and non-Article 5 countries. Therefore, this sector, like domestic refrigeration, provides the opportunity for a relatively early conversion to a very low-GWP option.

Condensing units: systems are often too large for the safe use of HCs. R-744 is a possibility and is starting to be used in condensing units in non-Article 5 countries, but cost and efficiency may be a challenge given the size of these systems. Another option is the use of lower flammability alternatives, such as HFC-32, pure HFOs and HFO/HFC blends. Safety standards may need updating for the use of flammable refrigerants in condensing units. For industrial applications, ammonia can be a cost-effective option as could, to a lesser extent, R-744 and HCs.

Centralized systems: increasing use of R-744 in some regions shows that this refrigerant can be used safely and cost effectively in commercial centralized systems. A significant increase in usage can be expected in the next ten years if there are regulations in Article 5 countries promoting the use of low-GWP refrigerants and/or restricting the use of high-GWP refrigerants. There are also a range of medium-GWP HFCs and HFC/HFO blends with GWPs ranging from 150 to 1,400, available for new equipment or retrofits (Table 18), or both. However, as with the air-conditioning sector, the higher-GWP blends would likely not ensure compliance with the Kigali Amendment over the long-

14 To simplify the analysis, both AC chillers and industrial refrigeration chillers have been placed in the same category (large AC). Therefore, the ICR sector in this category does not include industrial refrigeration chillers.

term and would thus require a second conversion. For industrial applications, ammonia can be a cost-effective option as could, to a lesser extent, R-744 and HCs.

Table 19: Alternative technologies in the ICR sector

System	Conventional Refrigerant	Alternative Refrigerants (medium and low-GWP)
Stand-alone systems	R-134a, HFC-404A (GWP 3922)	HC-290
Condensing units, cold rooms	HFC-404A, HFC-507A (GWP 3985), HFC-134a	HC-290, R-744, HC-1270 (not fully market-ready), R-448A (GWP 1273), R-449A (GWP 1397) (available) and ammonia (usually in industrial applications) There are newly developed blends (i.e. R-450A (GWP = 601), R-513A (GWP = 631), R-451A (GWP = 140) and R-451B (GWP = 150)) with thermophysical properties similar to HFC-134a, being considered for medium temperature systems and (R-446A (GWP= 460) and R-447A (GWP= 582)) with properties similar to HFC-404A for condensing units.
Centralized systems	R404A, R507A, HFC134a	Already in use: R-744, R-448A, R-449A. Reduction of HFCs through cascade systems and other innovative designs. Ammonia for industrial applications. Limited use of HC-290

In this sector (condensing and centralized units), units are often installed on site along with refrigerant charging (in other words, local installation and assembly subsector). Conversion in this subsector presents a different challenge than in the traditional manufacturing sector as it involves many contractors who work with end users to design, install and charge systems on site. These contractors usually purchase locally or import different components of the systems from manufacturers but have no control over the types of components that are manufactured. However, the subsector also presents an opportunity for significant reductions in the short term due to the availability of medium- and low-GWP alternatives to the very high-GWP R-404A and R-507A refrigerants.

A possible way for countries to address this subsector is through a strategy bringing together contractors, suppliers of components and end users to gradually shift the current design and installation of new systems to lower-GWP options. This could be supported by demonstration projects for end users, in other words, supermarket chains, as well as policies and regulations that limit the GWP of refrigerants that can be used in new systems. As most emissions occur through leakage during the operation of the equipment and tend to be high (15–30% annually), the strategy could include working with contractors to apply best practices in the design and installations of systems, and assistance to end users and service technicians to apply best practices in maintenance, with a view to minimizing emissions as much as possible. Given the high GWPs of the refrigerants used in this sector, these measures will lead to significant reductions in servicing amounts, which are presented in the following section.

Mit-1:

- For the manufacturing of stand-alone systems, conversion to HC-based refrigerants for all manufacturing between 2026 and 2030.
- For the manufacturing or local assembly of condensing units and centralized systems, a domestic strategy to facilitate a shift towards the design and installation of systems with a GWP below a specified limit. In the first instance, it is assumed that the average GWP of refrigerants for new systems in this subsector can be reduced to 600 between 2028 and 2038 (a mix of R-744, ammonia, HC and HFC/HFO blends) and 300 by 2045.
- For existing systems, a strategy to facilitate emission reductions and retrofits to lower-GWP refrigerants.

Mit-2:

- For the manufacturing of stand-alone systems, conversion to HC-based refrigerants for all manufacturing between 2024 and 2028.
- For the manufacturing or local assembly of condensing units and centralized systems, an average GWP of 600 between 2026 and 2032 and a GWP of 150 by 2038.

4.1.4. Mobile air conditioning (MAC)

HFC-134a is the dominant refrigerant in MAC systems in Article 5 countries and its use is expected to continue increasing as the world economy grows. A total of 138,340 mt CO_2eq of HFC-134a (11.9% of total HFC consumption) was estimated to be consumed during the year 2020. Table 20 shows HFC consumption in the MAC sector (CO_2eq) in three categories of countries defined in the report.

Table 20: HFC consumption in the MAC sector (CO_2eq)

	Manufacturing	Servicing
Category 1	4.48%	6.72%
Category 2	0.30%	14.81%
Category 3	0.0%	17.9%
Total (pro rata)	3.8%	8.2%

In most non-Article 5 countries, HFO-1234yf has now replaced HFC-134a in the manufacture of new MAC units. There is also some manufacturing using R-744 (CO_2) for a few car models but, currently, this does not seem to be the preferred option for most of the automobile industry. In light of the high price of HFO-1234yf due to limited supply and growing demand (NREL, 2020), it appears unlikely that it will be used in Article 5 countries for new vehicles in the near future without a regulated environment. HFC-152a is a lower-GWP refrigerant (GWP 124) that may be pursued in the future. HFC-152a is flammable and is not currently used for this application, but there are indications it can be used safely with proper technology configuration. Therefore, under the present scenario, it is assumed that conversion in the MAC manufacturing sector will not be initiated until 2030, unless a significant push is made to convert earlier (as under Mit-2).

Table 21: Alternative technologies in MAC

System	Conventional Refrigerant	Alternative Refrigerants (low-GWP)
Cars	HFC-134a	HFO-1234yf, CO_2, HFC-152a (GWP 124)

Mit-1: The proposed technology pathway for this subsector involves conversion of MAC manufacturing mainly to HFO-1234yf, with some conversion to CO_2 (the impact on the phase-down does not change whether one or the other refrigerant is selected as neither is controlled under the Kigali Amendment) between 2032 and 2042, by which time the price of HFO-1234yf should be significantly reduced. As with the preceding subsectors, conversion of the manufacturing sector will lead to a gradual reduction and eventual elimination of HFCs for servicing.

Mit-2: In this scenario, air-conditioning systems in all new vehicle types will be converted to non-HFC options between 2028 and 2032.

4.1.5. Transport refrigeration

This market sector includes refrigeration systems used in various modes of transport. Most transport refrigeration systems are used for the carriage of frozen or chilled food and beverages. A total of 32,732 CO_2eq was estimated to be used in this subsector in 2020 contributing to a 2.8% share (in CO_2eq) of total HFC consumption.

There are several alternatives which are being used or trialled in transport refrigeration, including HFO/HFC blends, transcritical CO_2, R-717 (ammonia) and HCs. In Mit-1, a shift to refrigerants with average GWPs 700 range are considered for use during 2028-35 and 150 by the year 2045. In Mit-2, a shift to refrigerants with an average GWP in the 700 range are considered for use during 2027-34 and 150 by the year 2040.

4.1.6. Foams

This study assumes that 1.76% (CO_2eq) of HFC is in the foam sector. This translates into a consumption of 20,374 CO_2eq during 2020 (Table 22).

Table 22: HFC consumption in the foam sector (CO_2eq)

	Production
Category 1	1.97%
Category 2	0.84%
Category 3	0.00%
Total (pro rata)	1.76%

There are several HC, HFOs and other blowing agent alternatives (methylal, methyl format, CO_2), which are used in Article 5 countries, depending on the specific foam application. It is assumed that this sector can shift to non-HFC options quickly resulting in significant climate benefits. In both mitigation scenarios, the foam sector moves to hydrocarbons/HFOs as blowing agents between 2024 and 2029. As there is no servicing required for foam, such a technology shift will eliminate HFCs fully from this sector.

4.1.7. RAC servicing sector

Consumption of HFCs in the refrigeration servicing sector (for AC and refrigeration appliances) should normally reduce gradually in all countries as the different manufacturing sectors are converted to lower-GWP alternatives as outlined above, and with the implementation of the proposed strategies for the local assembly and installation subsector. However, while these reductions should be sufficient to ensure the compliance of large manufacturing countries, at least in the short term, for LVC countries and many non-LVC countries that have a majority of their consumption in the servicing sector, immediate action would need to be taken to address this sector to ensure compliance with all the reductions mandated under the Kigali Amendment.

For countries where all HFCs are consumed in the RAC servicing sector, it is essential to continue capacity-building activities similar to the ones being implemented under HPMPs, as well as to undertake interventions in this area. Capacity-building activities should include training on Good Servicing Practices for installation and servicing, leak detection, recovery and recycling, training on the use of low-GWP and flammable ODS alternatives. In addition, retrofits of smaller refrigeration equipment could be an option where there are safe and cost-effective alternatives available. As with the CFC and HCFC phase-out, these activities should be supported by a robust regulatory environment, including the development of standards where these may be lacking, codes of practice, institutionalization of training and technicians certification and, most of all, development and enforcement of regulations setting strict HFC import quotas that meet or exceed Kigali targets.

Under Mit-1, it is assumed that only modest reductions are made overall in the servicing sector (although the reductions may be significant in individual LVCs), and that most of these reductions result from the conversion of the manufacturing subsectors as outlined in the preceding sections.

Under Mit-2, it is assumed that significant efforts are made to reduce consumption in the refrigeration servicing sector in all countries (not only LVCs) through the above-mentioned activities, resulting in an overall reduction of HFCs for servicing about 20% above what is calculated to be reduced annually through the conversions in the RAC sectors modelled in Mit-2.

Table 23 below summarizes key assumptions used for building mitigation scenarios. These options are in no way a prescription of priorities but a reference of possible practical actions that can be considered based on national circumstances. Again, it should be mentioned that the scenarios presented are not meant to be prescriptive, but are selected simply to illustrate potential HFC reduction pathways. Depending on each country's circumstances, including its specific sectoral distribution, the reduction scenarios could be quite different.

Table 23: Summary of measures in Mit-1 and Mit-2

Subsector	Mit-1	Mit-2
Stationary AC manufacturing	Small ACs: Conversion to HC-290 and HFC-32 between 2026 and 2032 to achieve an average GWP of 170 for the subsector. Post-2045, all HFC demand for small AC manufacturing will be based on zero- or near-zero-GWP options. Large ACs: Conversion to HFC-32 and a mix of lower-GWP HFC/HFO blends between 2029 and 2040 to achieve an average GWP of 600. Chillers: conversion to HFO-1234yz and ammonia in centrifugal chillers (to achieve an average GWP of zero) and a mix of R-450A, R-513A and hydrocarbons in screw chillers (to achieve an average GWP of 300) between 2027 and 2030.	Small ACs: 170 average GWP in small AC manufacturing by year 2028 (80% HC-290 and rest HFC-32-based). Post 2035, all HFC demand for small AC manufacturing will be based on zero- or near-zero-GWP options. Large ACs: the study assumes that there will be appropriate standards allowing a higher charge size of HC-290 to ensure even larger systems can move to an alternative mix of 600 by 2035 and 150 GWP by 2040. Chiller: the subsector can move to an average GWP of 300 between 2025 and 29 and 150 by 2042 onwards.
Domestic refrigeration manufacturing	HC-600a in the manufacturing of new appliances between 2024 and 2028.	
ICR local assembly and manufacturing	Stand-alone systems: conversion to HC-based refrigerants for all manufacturing between 2026 and 2030.	Stand-alone systems: conversion to HC-based refrigerants for all manufacturing between 2024 and 2028.

	Condensing units and centralized systems: the average GWP of refrigerants for new systems in this subsector can be reduced to 600 between 2028 and 2038 (a mix of R-744, ammonia, HC and HFC/HFO blends) and 300 by 2045.	Condensing units and centralized systems: average GWP of 600 between 2026 and 2032 and GWP of 150 by 2038.
MAC manufacturing	Shift to HFO or CO2 between 2032 and 2042.	Shift to HFO or CO2 between 2028 and 2032.
Transport refrigeration manufacturing	Shift to refrigerant mix of GWP 700 between 2028 and 2035, and 150 by 2045.	Shift to refrigerant mix of GWP 700 between 2027 and 2034, and 150 by 2040.
Foam sector	The foam sector moves to hydrocarbons/HFOs as blowing agents between 2025 and 2029.	Phase-out is achieved by the year 2026.
RAC servicing	Servicing demand tapers down over a period of equipment lifetime (10–20 years) due to a decrease in the uptake of low-GWP alternatives and the usual retirement of old RAC equipment.	Additional measures in the RAC servicing sector may decrease servicing demand by an additional 20% compared with Mit-1.

4.2. Impact of the mitigation scenarios on the HFC phase-down and climate benefits

The following section presents the results of the modelling conducted in this study to assess the impact of the two scenarios outlined above in terms of climate benefits as compared to BAU. "Climate benefits" are determined as the reductions in HFC consumption compared to the BAU scenario over 2024-2050 (Table 24).

Table 24: Consumption scenarios and resulting reductions for mitigation efforts (CO2eq)

HFC consumption (kt CO_2eq)	2024	2029	2032	2035	2040	2045	2050
BAU consumption	1,361	1,972	2,367	2,777	3,491	4,108	4,853
Kigali phase-down consumption	1,600	1,440	1,440	1,120	800	320	320
Mit-1 consumption	1,361	1,353	1,307	1,073	786	331	258
Mit-2 consumption	1,355	1,253	872	637	346	171	94
Reductions from BAU (to achieve a Kigali phase-down)[15]		532	928	1,657	2,691	3,788	4,533
Reductions from BAU to achieve Mit-1		619	1,060	1,704	2,705	3,777	4,595
Reductions from BAU to achieve Mit-2		718	1,495	2,140	3,144	3,937	4,759

The Kigali Amendment phase-down schedule delivers reductions of 54,415 MtCO_2eq in cumulative HFC consumption between 2024 and 2050. The mitigation scenarios developed in this study project additional savings of 2,931 MtCO2eq (Mit-1) and 10,733 MtCO2eq (Mit-2) of HFC cumulative consumption during the same time period (Figure 17).

15 For a given year.

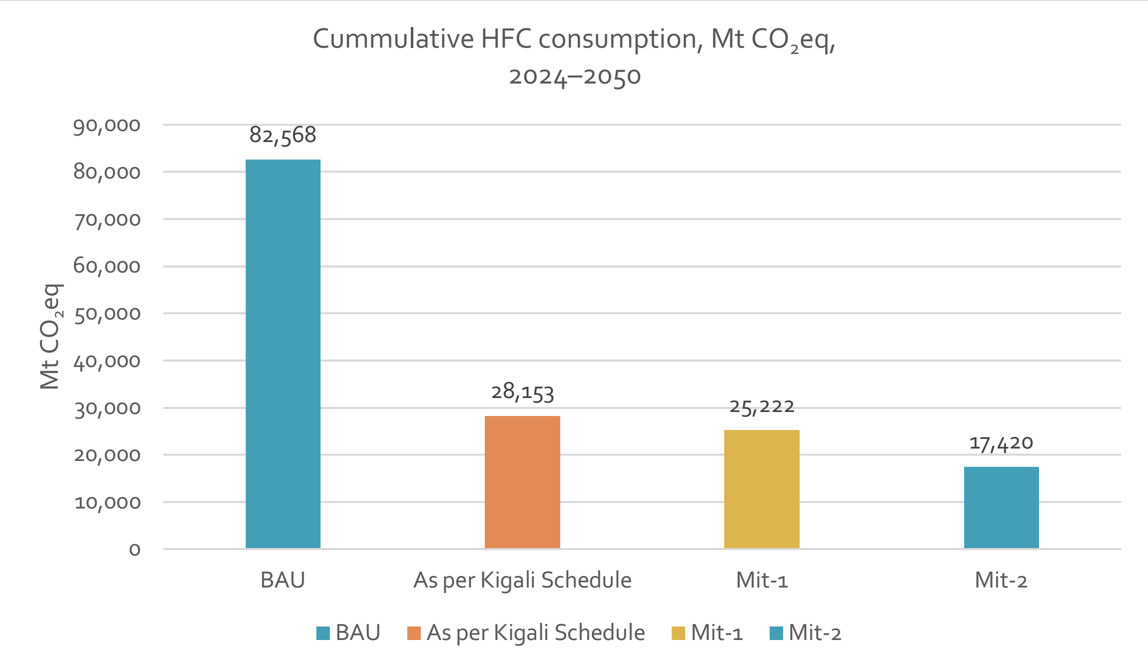


Figure 17: Total HFC consumption, Mt CO_2eq, 2024–2050

As expected, the total cumulative consumption avoided under Mit-1 is similar to the consumption avoided under strict compliance with the Kigali Amendment, since Mit-1 essentially represents the minimum reductions needed per sector for countries to comply with the Kigali phase-down schedule. Mit-1 results in slightly higher reductions than is the case under strict adherence to the Kigali Amendment phase-down schedule because it would be impossible in a scenario to convert specific subsectors by certain dates to achieve the identical reductions mandated by the phase-down schedule.

Under Mit-2, on the other hand, the sectoral reductions scenarios considered collectively end up achieving significantly higher reductions than the Kigali schedule, in the order of 10,733 Mt CO_2eq. It could of course be argued that even more ambitious reductions would be achievable. The aim of this section is simply to illustrate how certain technology pathways and associated reductions in each key sector could achieve a higher climate benefit than the Kigali Amendment. It does not preclude other, more aggressive technology pathways from being implemented.

The following figures show HFC consumption reductions per subsector in Mit-1 (Figure 18) and Mit-2 (Figure 19).

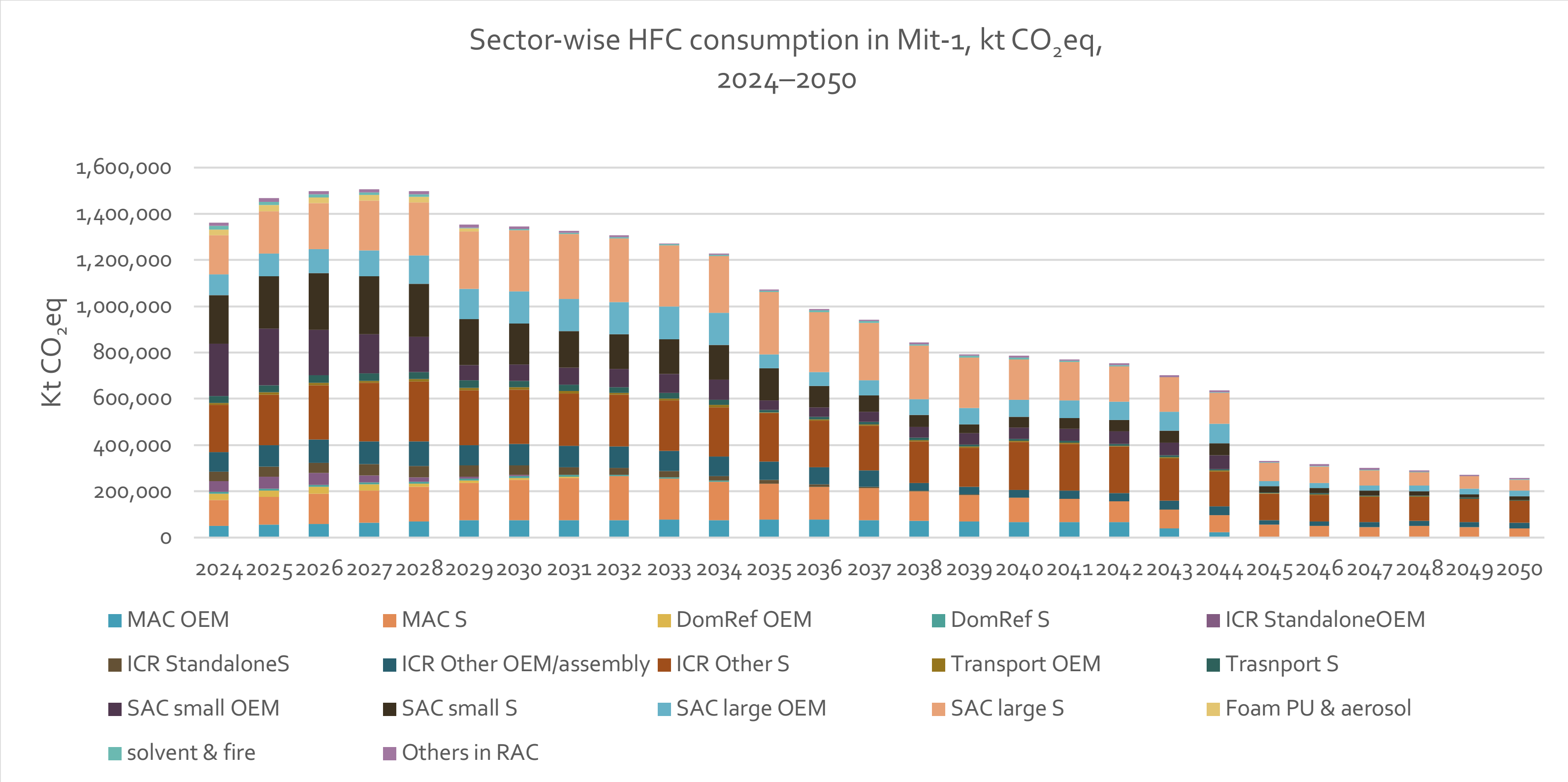


Figure 18: Sector-wise HFC consumption in Mit-1, kt CO_2eq, 2024-2050

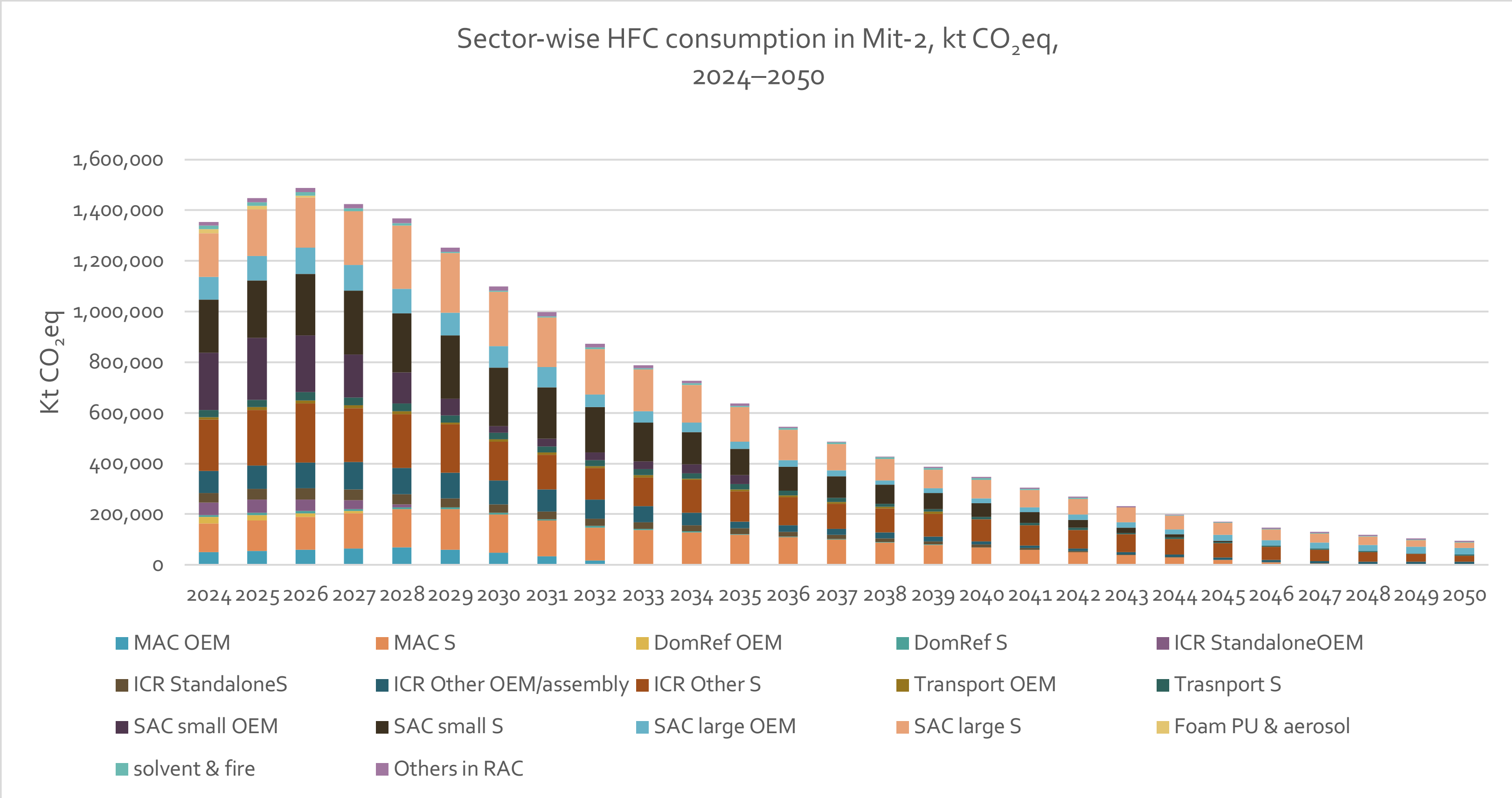


Figure 19: Sector-wise HFC consumption in Mit-2, kt CO_2eq, 2024-2050

Figure 20 shows a comparison of HFC consumption (kt CO_2eq) in BAU, Kigali Amendment phase-down schedule and two mitigation scenarios. The targets in Mit-2 are aggressive but can be considered feasible given that the technology options for the selected subsectors are already available and gaining market share in non-Article 5 and large Article 5 countries.

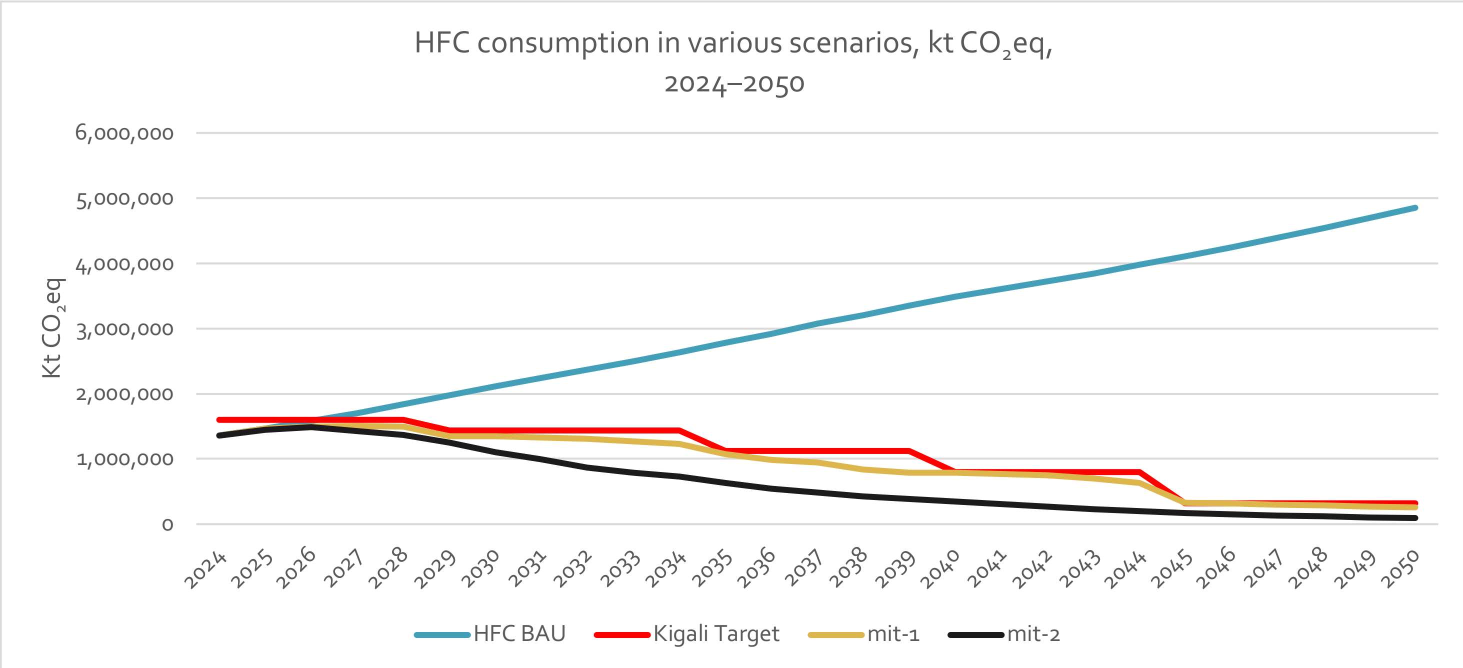


Figure 20: HFC consumption in various scenarios, kt CO_2eq, 2024–2050

Annex 1: Sectoral consumption in three categories of countries

Table 25: Estimated share of subsectoral consumption in Category 1 countries, CO_2eq

HFC	Total	MAC		DR		ICR stand-alone		ICR condensing and centralized		Transport Ref		Air conditioners (small)		Air conditioners (large)		Foam	Other subsectors
		M	S	M	S	M[16]	S	M	S	M	S	M	S	M	S		
HFC-32	3.45%											2.07%	1.38%				0.00%
HFC-134a	24.89%	4.48%	6.72%	2.36%	0.12%	3.83%	1.64%							1.64%	3.83%		0.25%
R-404a	18.17%					0.29%	0.44%	4.42%	10.30%	0.82%	1.91%						0.00%
HFC-407C	4.44%													1.77%	2.66%		0.00%
HFC-410A	38.96%											17.53%	11.69%	3.90%	5.84%		0.00%
HFC-507A	6.23%							1.87%	4.36%								0.00%
HFC-245fa, HFC-365mfc	1.97%															1.97%	0.00%
Fire and solvent, aerosol	1.04%																1.04%
Other substances	0.85%																0.85%
Total	100.00%	4.48%	6.72%	2.36%	0.12%	4.12%	2.08%	6.28%	14.66%	0.82%	1.91%	19.60%	13.07%	7.31%	12.34%	1.97%	2.15%

*M-manufacturing (including local assembly), S-servicing

Table 26: Estimated share of subsectoral consumption in Group 2 countries, CO_2eq

HFC	Total	MAC		DR		ICR stand-alone		ICR condensing and centralized		Transport Ref		Air conditioners (small)		Air conditioners (large)		Foam	Other subsectors
		M	S	M	S	M[17]	S	M	S	M	S	M	S	M	S		
HFC-32	1.96%												2.0%				0.00%
HFC-134a	30.22%	0.3%	14.8%	0.3%	2.7%	0.6%	5.4%							0.9%	5.1%		0.00%

16 For the purpose of this study, local assembly consumption in ICR (condensing and centralized systems) is considered under the manufacturing and not the servicing sector.

17 For the purpose of this study, local assembly consumption in ICR (condensing and centralized systems) is considered under the manufacturing and not the servicing sector.

R-404a	20.67%					0.2%	0.6%	5.0%	11.7%	0.6%	2.5%	0.0%	0.0%	0.0%			0.00%
HFC-407C	3.48%												0.0%	1.7%	1.7%		0.00%
HFC-410A	35.50%											2.8%	25.6%	0.7%	6.4%		0.00%
HFC-507A	5.47%							1.6%	3.8%								0.00%
HFC-245fa, HFC-365mfc	0.84%															0.84%	0.00%
Fire and solvent, aerosol	1.02%																1.02%
Other substances	0.84%																0.84%
Total	100.00%	0.30%	14.81%	0.30%	2.72%	0.81%	6.06%	6.66%	15.55%	0.62%	2.48%	2.84%	27.52%	3.36%	13.27%	0.84%	1.86%

Table 27: Estimated share of subsectoral consumption in Category 3 countries (LVCs), CO_2eq

HFC	Total	MAC		DR		ICR stand-alone		ICR condensing and centralized		Transport Ref		Air conditioners (small)		Air conditioners (large)		Foam	Other subsectors
		M	S	M	S	M[18]	S	M	S	M	S	M	S	M	S		
HFC-32	0.16%												0.16%				0.00%
HFC-134a	34.41%		17.9%		2.1%		6.9%	0.0%	0.0%						7.6%		0.00%
R-404a	31.27%						3.1%	7.0%	16.4%		4.7%						0.00%
HFC-407C	2.23%														2.2%		0.00%
HFC-410A	28.25%												22.6%		5.6%		0.00%
HFC-507A	2.70%								2.7%								0.00%
HFC-245fa, HFC-365mfc	0.00%															0%	0.00%
Fire and solvent, aerosol	0.19%																0.19%
Other substances	0.79%																0.79%
Total	100.00%	0.0%	17.9%	0.0%	2.1%	0.0%	10.0%	7.0%	19.1%	0.0%	4.7%	0.0%	22.8%	0.0%	15.4%	0.0%	0.99%

18 For the purpose of this study, local assembly consumption in ICR (condensing and centralized systems) is considered under the manufacturing and not the servicing sector.

Table 28: BAU Consumption of HFCs in Category 1 countries per sector for selected years between 2020 and 2050, in kt CO_2eq

Subsector	2020	2025	2030	2040	2050
MAC manufacturing	35,729	53,129	76,869	127,942	177,795
MAC servicing	53,594	79,693	115,303	191,913	266,693
DR manufacturing	18,857	28,040	40,570	67,525	93,836
DR servicing	992	1,476	2,135	3,554	4,939
ICR stand-alone manufacturing	32,887	48,902	70,753	117,763	163,651
ICR stand-alone servicing	16,578	24,652	35,667	59,365	82,497
ICR centralized manufacturing	50,117	74,523	107,822	179,461	249,390
ICR centralized servicing	116,939	173,886	251,585	418,743	581,911
Transport manufacturing	6,521	9,696	14,029	23,350	32,448
Transport servicing	15,215	22,624	32,734	54,482	75,712
Small ACs manufacturing	156,330	232,460	336,331	559,797	777,927
Small ACs servicing	104,220	154,973	224,221	373,198	518,618
Large ACs manufacturing	58,331	86,737	125,494	208,874	290,264
Large ACs servicing	98,413	146,339	211,728	352,405	489,722
Foam	15,711	23,362	33,801	56,259	78,181
Solvent, aerosol and fire suppression	8,294	12,333	17,844	29,700	41,273
Others in RAC	8,784	13,061	18,897	31,453	43,709
Total	797,514	1,185,885	1,715,783	2,855,784	3,968,566

Table 29: BAU Consumption of HFCs in Category 2 countries per sector for selected years between 2020 and 2050, in kt CO2eq

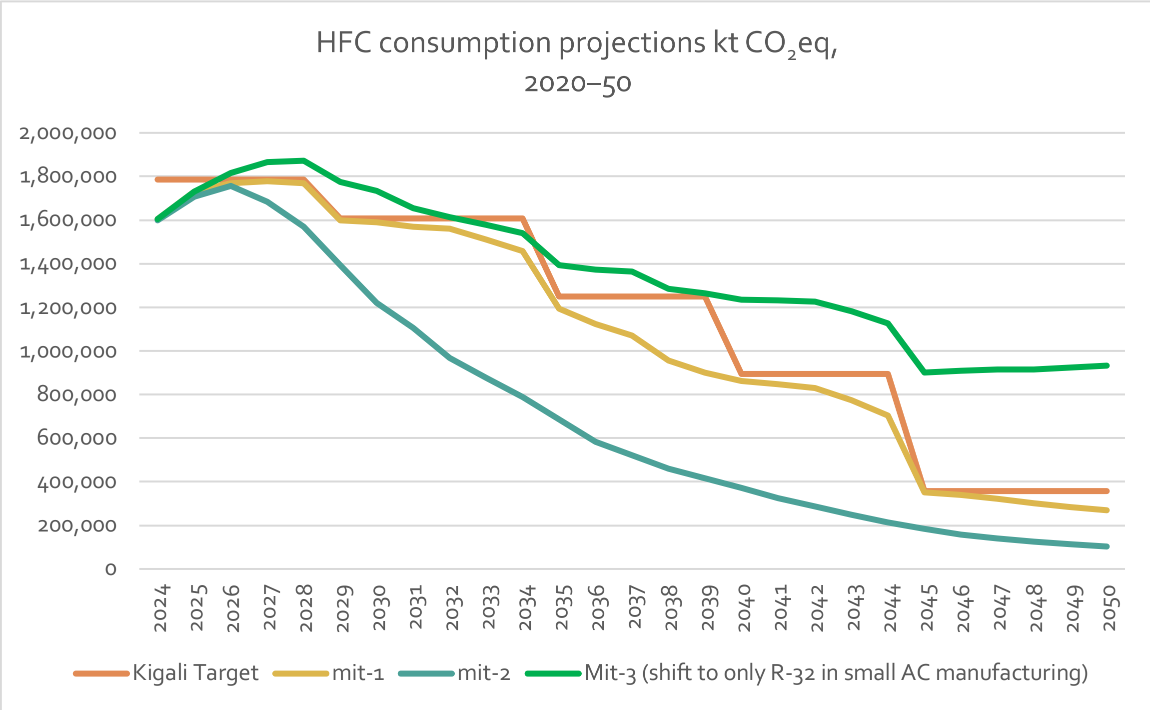
Subsector	2020	2025	2030	2040	2050
MAC manufacturing	516	713	1,009	1,583	2,206
MAC servicing	25,270	34,946	49,425	77,559	108,079
DR manufacturing	516	713	1,009	1,583	2,206
DR servicing	4,641	6,419	9,078	14,246	19,851
ICR stand-alone manufacturing	1,384	1,914	2,707	4,248	5,920
ICR stand-alone servicing	10,341	14,301	20,226	31,739	44,229
ICR centralized manufacturing	11,369	15,723	22,238	34,896	48,627
ICR centralized servicing	26,529	36,687	51,888	81,424	113,464
Transport manufacturing	1,058	1,463	2,070	3,248	4,526
Transport servicing	4,233	5,854	8,279	12,992	18,104
Small ACs manufacturing	4,845	6,701	9,477	14,872	20,724
Small ACs servicing	46,951	64,930	91,832	144,106	200,813
Large ACs manufacturing	5,725	7,917	11,197	17,571	24,486
Large ACs servicing	22,636	31,304	44,274	69,476	96,814
Foam	1,432	1,980	2,801	4,395	6,125
Solvent, aerosol and fire suppression	1,740	2,407	3,404	5,342	7,444
Others in RAC	1,438	1,989	2,813	4,414	6,151
Totals	170,624	235,961	333,727	523,694	729,769

Table 30: BAU Consumption of HFCs in Category 3 countries per sector for selected years between 2020 and 2050, in kt CO_2eq

Subsector	2020	2025	2030	2040	2050
MAC servicing	5,851	8,177	12,040	19,886	27,590
DR servicing	675	944	1,389	2,294	3,183
ICR stand-alone servicing	3,273	4,574	6,735	11,123	15,433
ICR centralized manufacturing	2,301	3,215	4,734	7,819	10,848
ICR centralized servicing	6,250	8,734	12,860	21,240	29,469
Transport servicing	1,534	2,143	3,156	5,213	7,232
Small ACs servicing	7,444	10,402	15,317	25,297	35,098
Large ACs servicing	5,052	7,060	10,395	17,169	23,821
Solvents, aerosol and fire suppression	62	87	128	211	293
Others in RAC	260	364	535	884	1,227
Totals	32,701	45,700	67,291	111,137	154,194

Annex 2: HFC consumption in small AC manufacturing with different GWP refrigerant options

The results from the modelling performed here show that a shift to R-32 in small AC will result in HFC reductions in the short term. However, these reductions would not be sufficient to meet further (future) phase-down targets unless a shift to much lower GWP (or near-zero) options occurs. Figure 21 shows total HFC consumption in small AC manufacturing for Article 5 countries (Mit-3) if R-32 is used as the only alternative refrigerant up to 2050. Mit-3 is an adaptation of Mit-1 in which small AC manufacturing shifts to R-32 only; the rest of the sectors have a similar reduction profile as discussed earlier.



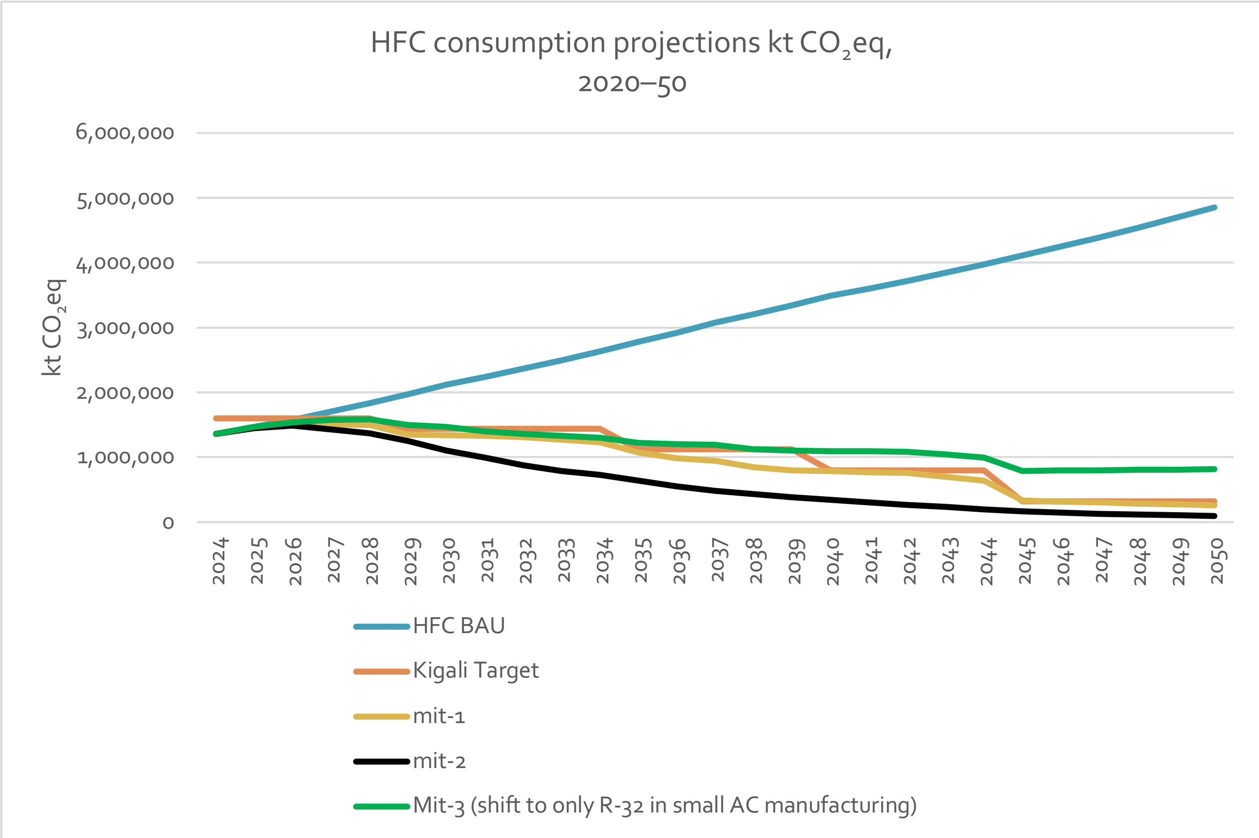


Figure 21: HFC consumption projections (CO2eq), 2020-50

Annex 3: Growth projections for Article 5 countries (not part of the high-priority list)

Table 31: HFC consumption projections for other countries in Group 1 (kt CO2eq) that are not included in high-priority list

Country	LVC/Non-LVC	Total HFC baseline	2024	Consumption 2024/HFC baseline	2025	Consumption 2025/HFC baseline	2026	Consumption 2026/HFC baseline
Tunisia	Non-LVC	2,699	2 365	88%	2 533	94%	2 709	100%
Fiji	LVC	363	313	86%	338	93%	365	100%
Nigeria	Non-LVC	12,491	10 850	87%	11 622	93%	12 428	99%
Philippines	Non-LVC	9,107	7 715	85%	8 344	92%	9 010	99%
Peru	Non-LVC	2,389	2 060	86%	2 208	92%	2 362	99%
Thailand	Cat1	46,341	39 655	86%	42 551	92%	45 578	98%
Myanmar	LVC	258	217	84%	234	91%	253	98%
South Sudan	LVC	262	220	84%	238	91%	256	98%
Lao People's Democratic Republic	LVC	133	110	82%	120	90%	130	98%
Djibouti	LVC	40	33	82%	36	90%	39	98%
Sri Lanka	LVC	759	631	83%	682	90%	737	97%
Democratic Republic of the Congo	LVC	3,847	3,178	83%	3,446	90%	3,731	97%
Eritrea	LVC	63	51	82%	56	89%	61	97%
Nepal	LVC	62	51	81%	55	89%	60	97%
Central African Republic	LVC	693	571	82%	619	89%	670	97%
Cameroon	Non-LVC	4,849	4,062	84%	4,363	90%	4,679	96%
China	Cat1	884,969	728,593	82%	788,019	89%	850,927	96%
Chad	LVC	920	752	82%	813	88%	877	95%
Turkey	Cat1	24,755	20,510	83%	22,019	89%	23,597	95%
Palau	LVC	11	9	82%	9	88%	10	95%
Marshall Islands	LVC	12	10	81%	11	88%	12	95%
Solomon Islands	LVC	112	90	81%	98	88%	106	95%
Bosnia and Herzegovina	LVC	265	215	81%	232	88%	251	95%

Papua New Guinea	LVC	186	150	81%	163	88%	176	95%
Bhutan	LVC	13	10	80%	11	87%	12	94%
Cuba	LVC	848	684	81%	739	87%	797	94%
Georgia	LVC	292	233	80%	253	87%	274	94%
Côte d'Ivoire	Non-LVC	3,689	2,961	80%	3,203	87%	3,459	94%
Egypt	Non-LVC	22,563	18,215	81%	19,629	87%	21,116	94%
Zimbabwe	LVC	1,214	966	80%	1,044	86%	1,127	93%
Dominican Republic	Non-LVC	3,348	2,659	79%	2,874	86%	3,102	93%
South Africa	Non-LVC	14,073	11,307	80%	12,113	86%	12,953	92%
Paraguay	LVC	1,490	1,175	79%	1,270	85%	1,370	92%
Jamaica	LVC	878	692	79%	748	85%	807	92%
Saint Kitts and Nevis	LVC	26	20	77%	22	84%	24	91%
Timor-Leste	LVC	26	20	77%	22	84%	24	91%
Mauritius	LVC	572	443	77%	479	84%	518	91%
Bahamas	LVC	252	195	77%	210	84%	227	90%
Belize	LVC	147	114	77%	123	84%	132	90%
Congo	LVC	531	410	77%	443	84%	478	90%
Lebanon	Non-LVC	2,628	2,059	78%	2,206	84%	2,359	90%
Yemen	Non-LVC	8,780	6,874	78%	7,363	84%	7,874	90%
Algeria	Non-LVC	3,436	2,684	78%	2,875	84%	3,075	89%
Malaysia	Cat1	22,466	17,337	77%	18,683	83%	20,101	89%
Morocco	Non-LVC	2,818	2,191	78%	2,347	83%	2,510	89%
Argentina	Cat1	21,732	16,765	77%	17,960	83%	19,205	88%
Haiti	LVC	172	130	76%	141	82%	152	88%
Togo	Non-LVC	1,072	815	76%	879	82%	946	88%
Uruguay	Non-LVC	1,134	844	74%	904	80%	967	85%
Brunei Darussalam	LVC	508	370	73%	400	79%	432	85%
Syrian Arab Republic	Non-LVC	17,129	12,149	71%	13,014	76%	13,916	81%

Albania	LVC	296	205	69%	222	75%	240	81%
Barbados	LVC	291	199	68%	215	74%	232	80%
Namibia	LVC	687	465	68%	503	73%	542	79%
Samoa	LVC	21	13	64%	14	69%	15	75%
Eswatini	LVC	72	46	64%	50	69%	54	75%
Burkina Faso	LVC	1,173	725	62%	791	67%	862	73%
Saint Lucia	LVC	62	39	62%	42	67%	45	72%
Malawi	LVC	434	259	60%	281	65%	304	70%
Botswana	LVC	425	247	58%	269	63%	291	69%
Liberia	LVC	196	112	57%	121	62%	131	67%
Libya	Non-LVC	4,581	2,609	57%	2,822	62%	3,048	67%
Ethiopia	LVC	245	136	56%	149	61%	162	66%
Jordan	Non-LVC	3,225	1,846	57%	1,978	61%	2,115	66%
Dominica	LVC	8	5	54%	5	59%	5	64%
Democratic Republic of Sao Tome and Principe	LVC	72	38	53%	41	57%	45	62%
Afghanistan	Non-LVC	809	390	48%	417	52%	446	55%
Tonga	LVC	6	3	46%	3	50%	3	53%
Ghana	Non-LVC	1,790	706	39%	764	43%	825	46%
Burundi	LVC	208	74	35%	80	38%	86	41%
Equatorial Guinea	LVC	279	96	35%	104	37%	112	40%
Lesotho	LVC	108	35	32%	37	35%	40	37%
Kenya	Non-LVC	1,571	469	30%	505	32%	543	35%
Democratic People's Republic of Korea	Non-LVC	2,190	655	30%	702	32%	750	34%
Mali	LVC	409	116	28%	126	31%	137	33%
Venezuela (Bolivarian Republic of)	Non-LVC	4,527	1,026	23%	1,099	24%	1,175	26%
Tuvalu	LVC	2	0.4	19%	0.4	20%	0.4	22%
Moldova	LVC	2,942	535	18%	581	20%	629	21%

Niue	LVC	0.4	0.1	16%	0.1	18%	0.1	19%
Cabo Verde	LVC	32	4	13%	5	14%	5	16%

Table 32: HFC consumption projections for countries in Group 2 (kt CO2eq)

Country	LVC/Non-LVC	Total HFC baseline	2028	Consumption 2028/HFC baseline	2029	Consumption 2029/HFC baseline	2030	Consumption 2030/HFC baseline
Bahrain	Non-LVC	3,515	2,942	84%	3,140	89%	3,346	95%
India	Non-LVC	99,588	92,630	93%	99,877	100%	107,565	108%
Iran (Islamic Republic of)	Non-LVC	17,803	11,819	66%	12,611	71%	13,437	75%
Iraq	Non-LVC	6,813	5,612	82%	6,032	89%	6,476	95%
Kuwait	Non-LVC	14,516	6,802	47%	7,258	50%	7,733	53%
Oman	Non-LVC	3,662	3,677	100%	3,923	107%	4,180	114%
Pakistan	Non-LVC	17,183	17,667	103%	18,948	110%	20,295	118%
Qatar	Non-LVC	32,982	38,054	115%	40,605	123%	43,264	131%
Saudi Arabia	Non-LVC	100,170	84,086	84%	89,725	90%	95,600	95%

Annex 4: Compliance forecast for Group 1 countries in 2029 with respect to HFC consumption target

Table 33: Comparison of HFC consumption in 2029 with compliance goal of 10% reduction below baseline level (Group 1 countries)

Country	Consumption in 2029 (kt CO_2eq)	2029 consumption/10% below HFC baseline
Afghanistan	545	75%
Albania	302	113%
Algeria	3,756	121%
Angola	7,954	196%
Antigua and Barbuda	76	188%
Argentina	23,460	120%
Armenia	632	161%
Bahamas	285	126%
Bangladesh	8,189	154%
Barbados	291	111%
Belize	166	126%
Benin	2,400	147%
Bhutan	16	135%
Bolivia	679	151%
Bosnia and Herzegovina	315	132%
Botswana	371	97%
Brazil	90,702	149%
Brunei Darussalam	542	118%
Burkina Faso	1,112	105%
Burundi	108	58%
Cabo Verde	6	22%
Cambodia	1,876	165%
Cameroon	5,764	132%
Central African Republic	849	136%
Chad	1,102	133%
Chile	8,925	161%
China	1,071,608	135%
Colombia	9,132	137%
Comoros	75	198%
Congo	601	126%
Cook Islands	13	229%
Costa Rica	2,304	178%
Côte d’Ivoire	4,356	131%
Cuba	1,000	131%

Democratic People’s Republic of Korea	917	47%
Democratic Republic of the Congo	4,729	137%
Djibouti	51	140%
Dominica	7	89%
Dominican Republic	3,900	129%
Ecuador	3,688	160%
Egypt	26,274	129%
El Salvador	1,900	187%
Equatorial Guinea	141	56%
Eritrea	78	138%
Eswatini	68	104%
Ethiopia	209	95%
Fiji	458	140%
Gabon	3,706	153%
Gambia	562	217%
Georgia	349	133%
Ghana	1,038	64%
Grenada	84	159%
Guatemala	1,727	174%
Guinea	2,626	150%
Guinea Bissau	1,189	192%
Guyana	221	182%
Haiti	191	123%
Honduras	2,396	154%
Indonesia	26,073	142%
Jamaica	1,013	128%
Jordan	2,584	89%
Kenya	674	48%
Kiribati	20	209%
Kyrgyzstan	716	187%
Lao People’s Democratic Republic	168	140%
Lebanon	2,881	122%
Lesotho	51	52%
Liberia	164	93%
Libya	3,838	93%
Madagascar	2,618	153%
Malawi	385	99%
Malaysia	25,020	124%
Maldives	638	176%

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Mali	175	48%
Marshall Islands	15	134%
Mauritania	1,314	191%
Mauritius	654	127%
Mexico	85,739	153%
Micronesia (Federated States of)	17	157%
Moldova	799	30%
Mongolia	171	163%
Montenegro	214	159%
Morocco	3,066	121%
Mozambique	850	155%
Myanmar	318	137%
Namibia	681	110%
Nauru	22	163%
Nepal	78	139%
Nicaragua	964	168%
Niger	1,591	141%
Nigeria	15,179	135%
Niue	0	2%
North Macedonia	664	185%
Palau	13	133%
Panama	3,570	175%
Papua New Guinea	221	132%
Paraguay	1,720	128%
Peru	2,890	134%
Philippines	11,348	138%
Rwanda	587	173%
Saint Kitts and Nevis	31	130%
Saint Lucia	57	101%
Saint Vincent and the Grenadines	49	185%
Samoa	19	104%
Democratic Republic of Sao Tome and Principe	56	87%
Senegal	3,701	150%
Serbia	5,565	202%
Seychelles	451	209%
Sierra Leone	536	193%
Solomon Islands	134	133%
Somalia	1,810	189%
South Africa	15,822	125%

South Sudan	322	137%
Sri Lanka	929	136%
Sudan	2,395	150%
Suriname	496	183%
Syrian Arab Republic	16,996	110%
Thailand	55,957	134%
Timor-Leste	30	129%
Togo	1,180	122%
Tonga	4	75%
Trinidad and Tobago	9,339	172%
Tunisia	3,309	136%
Turkey	29,015	130%
Turkmenistan	1,031	188%
Tuvalu	1	31%
Uganda	92	198%
United Republic of Tanzania	552	197%
Uruguay	1,181	116%
Vanuatu	27	157%
Venezuela (Bolivarian Republic of)	1,435	35%
Viet Nam	19,764	154%
Yemen	9,618	122%
Zambia	590	159%
Zimbabwe	1,414	129%

Annex 5: Compliance forecast for Group 2 countries with respect to 2032 HFC consumption target

Table 34: Comparison of HFC consumption in 2032 with compliance goal of 10% reduction below baseline level (Group 2 countries)

Country	Consumption in 2032 (kt CO_2eq)	2032 consumption/10% below HFC baseline
Bahrain	3,680	116%
India	120,985	135%
Iran (Islamic Republic of)	14,776	92%
Iraq	7,218	118%
Kuwait	8,503	65%
Oman	4,596	139%
Pakistan	22,526	146%
Qatar	47,574	160%
Saudi Arabia	105,124	117%

Annex 6: Commonly used HFCs

Chemical*	Chemical name, Blend	GWP[19]	Sectors				
			RAC	Foam	Aerosols	Solvent	Fire suppression
HFC-23	Trifluoromethane	14,800	X				X
HFC-32	Difluoromethane	675	X				
HFC134a	1,1,1,2-tetrafluoroethanol	1,430	X	X	X		X
HFC-143a	1,1,1-trifluoroethanol	4,470	X				
HFC-152a	1,1-difluoroethanol	124	X	X	X		
R407C	HFC-32/HFC-125/HFC134a (23.0/25.0/52.0)	1,774	X				
R410A	HFC-32/HFC-125 (50.0/50.0)	2,088	X				
R404A	HFC-125/HFC-143a/HFC134a (44.0/52.0/4.0)	3,922	X				
R507A	HFC-125/HFC-143a (50.0/50.0)	2,465					

19 Global warming potential (GWP) values used are based on the 4th Assessment of the Intergovernmental Panel on Climate Change.

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