MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

SEPTEMBER 2016 REPORT
VOLUME II

DECISION EX.III/1 WORKING GROUP REPORT:
ON THE CLIMATE BENEFITS AND COSTS OF REDUCING HYDROFLUOROCARBONS UNDER THE DUBAI PATHWAY

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Montreal Protocol
On Substances that Deplete the Ozone Layer

UNEP Technology and Economic Assessment Panel

Decision Ex.III/1 Working Group Report:
On the climate benefits and costs of reducing hydrofluorocarbons
under the Dubai pathway

September 2016

The text of this report is composed in Times New Roman.

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Foreword

The September 2016 TEAP Report consists of four volumes:

Volume I. TEAP Decision XXVII/4 Update Task Force Report: Additional Information on Alternatives to Ozone-depleting Substances

Volume II. TEAP Decision Ex. III/1 Working Group Report: Climate Benefits and Costs of Reducing Hydrofluorocarbons under the Dubai Pathway

Volume III. TEAP Evaluation of 2016 Critical Use Nominations for Methyl Bromide and Related Matters: Final Report

Volume IV. TEAP-SAP Decision XXVII/7 Report: Investigation of Carbon Tetrachloride Discrepancies

This is Volume II.

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ACKNOWLEDGEMENT

The UNEP Technology and Economic Assessment Panel and the Ex.III/1 Working Group co-chairs and members wish to express thanks to all who contributed from governments, both Article 5 and non-Article 5, furthermore in particular to the Ozone Secretariat and the Multilateral Fund Secretariat, as well as to a large number of individuals involved in Protocol issues, without whose involvement this Ex.III/1 report would not have been possible.

The opinions expressed are those of the Panel and its Ex.III/1 Working Group and do not necessarily reflect the reviews of any sponsoring or supporting organisation.

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Executive Summary

1. Decision Ex.III/1 requests the Technology and Economic Assessment Panel (TEAP) to "*prepare a report for consideration by the twenty-eighth Meeting of the Parties containing an assessment of the climate benefits, and the financial implications for the Multilateral Fund, of the schedules for phasing down the use of hydrofluorocarbons (HFCs) contained in the amendment proposals as discussed by the Parties at the thirty-eighth meeting of the Open-ended Working Group and the Third Extraordinary Meeting of the Parties.*" In preparing its report responding to this decision, TEAP considered it important to define key terms of this decision, as used within the context of this report, as follows:

   a. Although the term "climate benefit" can be defined in a number of different ways, in the context of this report, "climate benefit" is understood as a reduction in HFC consumption below that of a business-as-usual (BAU) scenario integrated over a specified period; this is a simplified climate impact metrics method, based on HFC consumption reductions. It is also consistent with the approach taken by TEAP on mitigation scenarios for high-GWP alternatives in previous reports to parties. It is understood to mean achieved reductions in units of t CO_2-eq from the HFC BAU consumption for both non-Article 5 and Article 5 parties as a result of the future implementation of mitigation measures, i.e., the schedules for phasing down HFCs as contained in the amendment proposals. This report considers the major, specific HFCs only (as opposed to blends in conjunction with ongoing HCFC phase-out) currently produced and used in various sectors in non-Article 5 and Article 5 parties. The reductions in HFC consumption from BAU are calculated over the period from the year the control schedule starts up to and including the year 2050[1];

   b. The term "financial implications for the Multilateral Fund" is understood to mean costs to the Multilateral Fund (MLF) for Article 5 implementation of control schedules following the schedules for HFC phase-down in amendment proposals (HFC reductions only). The costs are calculated based on the current MLF guidelines for costs including the HCFC Phase-out Management Plans (HPMPs) stage II. They do not contain "administrative" elements such as Institutional Strengthening; neither have parameter studies been done varying the criteria for investment and operational costs which remain under discussion by parties.

   c. The term "amendment proposals as discussed by parties" can have a number of meanings given the extensive discussion of parties during the 38th Open-Ended Working Group Meeting (OEWG-38) in the Contact Group on the feasibility and ways of managing HFCs (HFC Contact Group). There are the four amendment proposals originally submitted by parties in 2015. There were also other proposals discussed in the contact group including one that also provided both non-Article 5 and Article 5 schedules with phase-down or consumption reduction steps, and additional proposals providing only baseline and freeze dates. In order to provide an analysis of climate benefits and financial implications of schedules for phasing down HFCs, this report only considered the four amendment proposals formally submitted in 2015, which actually provided HFC phase-down schedules (step reductions) for both non-Article 5 and Article 5 parties (important for calculating the costs to the MLF to achieve HFC consumption reductions), as follows:

[1] [1] There are more comprehensive methods of calculating "climate benefits" on the basis of emissions, supported by atmospheric measurements (Velders, 2015)).

i. The amendment proposal on HFCs submitted in 2015 by Canada, Mexico and the United States of America (with additional text submitted in 2016) (hereafter referred to as "North America");
ii. The amendment proposal on HFCs submitted in 2015 by India;
iii. The amendment proposal on HFCs submitted in 2015 by the European Union and its member States (hereafter referred to as "EU");
iv. The amendment proposal on HFCs submitted in 2015 by Kiribati, the Marshall Islands, Mauritius, the Federated States of Micronesia, Palau, the Philippines, Samoa and Solomon Islands (hereafter referred to as "Islands"); and

For the further consideration of Parties, this report also considers and provides limited analysis of the additional suggestions contained in a table that came out of the Contact Group discussions related to preliminary proposals for baselines and freeze dates.

2. This report only considers the BAU relevant phase-down schedules for pure HFCs (as listed in many of the amendment proposals) and these pure HFCs if applied in mixtures. It does not consider the possible use of alternative mixtures (for example, those including HFCs and other non-HFC chemicals).

3. This report updates the latest estimates for the global production of the four main HFCs (HFC-32, HFC-125, HFC-134a and HFC-143a) plus other HFCs for the year 2015. There is close agreement between current estimates of HFC production and consumption in R/AC (manufacturing and servicing), foam, MDIs, non-MDI aerosols and fire protection sectors. The report provides projections on HFC consumption under a BAU scenario from 2015 until 2050.

Estimates for non-Article 5, Article 5 and global HFC production in 2015 (ktonnes)

HFCs	Estimate for non-A5 production (2015)	Estimate for A5 production (2015)	Estimate global 2015 production
HFC-32	23.0	71.0	94.0
HFC-125	31.5	98.5	130.0
HFC-134a	97.0	176.0	273.0
HFC-143a	11.0	17.0	28.0
Sub-total			*525*
Other HFCs (HFC-152a, -245fa, -365mfc, -227ea, -236fa)*, **			140.0
Total			665.0

* A substantial part is related to non-feedstock HFC-152a production, global estimate at slightly higher than 60 ktonnes; of this, only 5-10 ktonnes relate to use in foam production
** Estimated global production of HFC-236fa is estimated as small (300-500 tonnes); HFC-236fa is produced in one Article 5 country (Kuijpers, 2016)

4. In 2015, the R/AC sector was estimated to account for almost 75% of the total global consumption of the four main HFCs used in this sector (HFC-32, HFC-125, HFC-134a, and HFC-143a), and for more than 80% of these HFCs in Article 5 parties.

Estimates for non-Article 5, Article 5 and global HFC consumption in 2015 (ktonnes)

Sector	Estimate for non-A5 consumption (2015)	Estimate from various sources A5 consumption (2015)	Estimate global consumption 2015 (*)
R/AC manufacture	106.6	185.8	292.4
R/AC service	94.2	87.0	181.2
Foams	71.0	12.6	83.6
MDIs	10.1	3.9	14.0
Aerosols	50.0	9.0	59.0
Fire protection, others	5.5	9.5	15.0
Total	**334.4**	**305.8**	**645.2**

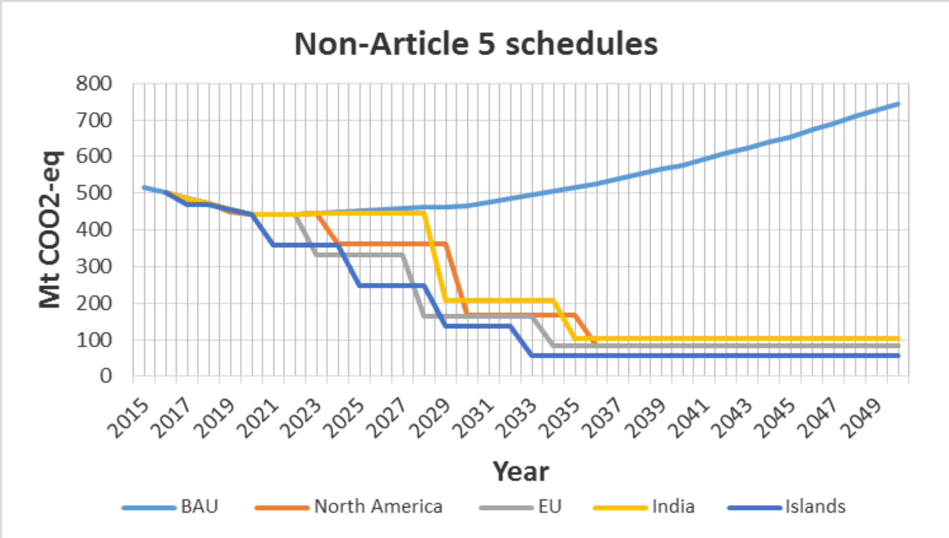
5. Based on the definitions of baselines contained in the four HFC amendment proposals considered in this report, the amounts as given below are calculated for the baselines for the proposed non-Article 5 and Article 5 control schedules.

Non-Article 5 parties proposal	**Non-Article 5 parties baseline (MtCO_2-eq.)**		
	HFC part	**HCFC part**	**Total**
North America	488.4	68.5	556.9
EU	448.2	102.4	550.6
India	524.7	162.7	687.4
Islands	488.4	65.1	553.5

Article 5 parties proposal	**Article 5 parties baseline (MtCO_2-eq.)**		
	HFC part	**HCFC part**	**Total**
North America	418.4	417.2	835.6
EU	671.9	700.0	1371.9
India	2134.1	283.3	2417.4
Islands	710.9	566.6	1277.5

6. **Non-Article 5 parties:** The **climate benefits** calculated for non-Article 5 parties are given in the table below. For the period up to 2050, the four amendment proposals considered in this report yield an integrated total reduction in HFC consumption in the range of 10-12,500 Mt CO_2-eq., compared to BAU, with little differences between proposals.

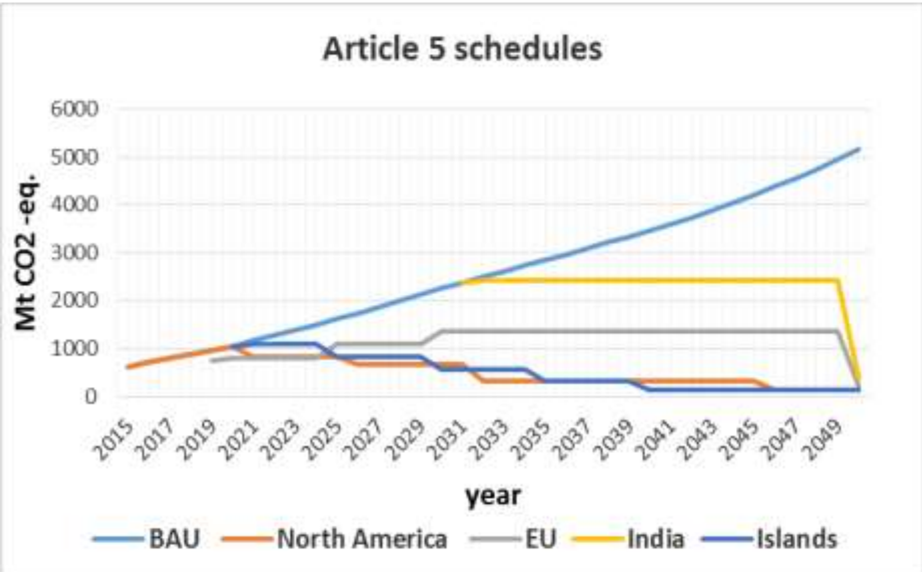
Proposals for non-Article 5 parties	**North America**	**EU**	**India**	**Island states**
Freeze date	n/a	n/a	2016	n/a
Remaining consumption after last reduction step	15%	15%	15%	10%
Climate benefit (Mt CO2-eq.)	**10,690**	**11,500**	**10,000**	**12,470**



7. **Article 5 Parties**: The **climate benefits** calculated for Article 5 parties based on the four amendment proposals are summarized in the table below, however, these may not all be directly comparable and would need to be considered based on the merits of each proposal. Generally, earlier freeze dates combined with adequate lower baseline values provide larger climate benefits (with little difference observed between the two proposals with intermediate reduction steps defined, i.e., North America and Island states).

Proposal for Article 5 parties	**North America**	**EU***	**India****	**Island states**
Freeze date	2021	2019	2031	2020
Remaining consumption after last reduction step	15%	15%	15%	10%
Climate benefit (MtCO_2-eq.)	**75,850**	**53,260**	**26,130**	**74,980**

* The calculation for the EU proposal is conservative (leading to “minimum” climate benefits), with no intermediate HFC reductions assumed until a final 85% reduction in 2050. Intermediate reductions should be negotiated. It takes into account the HCFC consumption until 2030 to be considered in a “combined” freeze, leading to a small increase in HFC consumption during the period 2019-2030).
** The calculation for the Indian proposal is of the same type (leading to “minimum” climate benefits), with no intermediate HFC reductions assumed until a final 85% reduction in 2050. Reductions should be negotiated.



8. **Estimating costs to the MLF based upon the various proposals.** Costs have been estimated on the basis of the installed manufacturing capacity in the year the freeze commences (at a specific baseline value). Costs have been estimated in such a way that a virtually complete conversion of manufacturing capacity in many sectors can be achieved, which will be required to achieve the 85-90% reduction in consumption in a given year (in most amendment proposals between 2040 and 2050). This report estimates the total costs for manufacturing conversion, for servicing and for HFC production phase-down. The analysis does not address costs for other activities, including those for preparatory surveys, development of management plans, institutional strengthening, capacity building, and training programmes.

9. **Cost-Effectiveness**: The following cost effectiveness factors were taken into account for the various sectors and sub-sectors. Because potential related costs to an HFC phasedown are currently an ongoing discussion by parties, for the purposes of this report, the factors used are consistent with current MLF cost guidelines and comparable to the factors applied in HCFC HPMPs stage II.

Sector	**US$/kg**
R/AC domestic	7-9
R/AC based on 134a	8-10
R/AC commercial	10-15
R/AC transport/industrial	10-15
R/AC servicing	6-8
Stationary air conditioning (SAC)	11-15
Mobile air conditioning (MAC)	4-6
Foams	7-9
Fire protection	3-5
Aerosols	4-6
MDIs (no conversion assumed)	None
Production	1.5-3.5

10. **Servicing and production phase-down costs:** For the phase-down of HFC consumption in servicing, moving to lower GWP substitutes may need to take account issues such as addressing flammability, which will increase costs. Therefore, TEAP has utilised a cost effectiveness range of US$ 6-8/kg. This is higher than the value of US$ 4.8 per kg used in HPMP stage II plans for HCFC servicing transition. For the closure of HFC production, TEAP has taken into account that conversion of production to low-GWP refrigerants will involve a number of additional issues that could add to cost effectiveness values, including possible intellectual property rights (IPR), and used a range of US$ 1.5-3.5/kg.

11. **Total Costs**: The total estimated costs to the MLF for phase-down following the four HFC amendment proposals, as considered in this report, are given in the table below. In general, although costs are dependent on the baseline levels selected, they are lower the earlier the freeze date sets in.

Proposal	**Freeze date**	**Lower value of the cost range (US$ million)**	**Higher value of the cost range (US$ million)**
North America	2021	3440	5250
**EU*, ** **	2019	5580	8540
India*	2031	9300	14220
Island states	2020	4550	6950

* In the case of the EU and Indian proposal, estimated costs are relatively high because HFC consumption reductions are to be negotiated after the freeze.

** The amount for calculating manufacturing conversions is the baseline amount used after 2040, leading to relatively high amounts. This amount is also sensitive to the HCFC 2015-2016 consumption in the baseline.

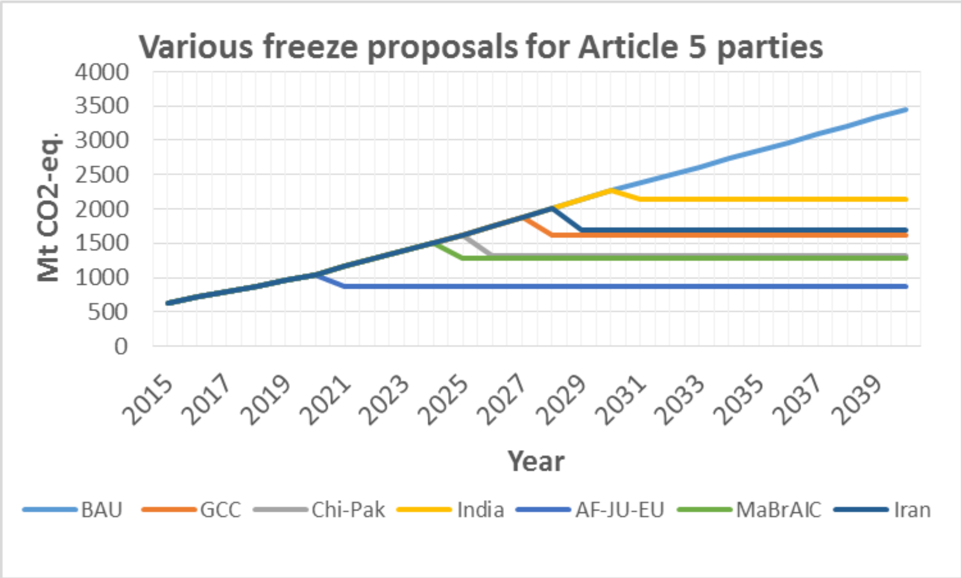
12. **Baseline and freeze date suggestions from the HFC Contact Group:** During the OEWG-38 and ExMOP-3 meetings in Vienna, July 2016, a number of suggestions were discussed in the HFC Contact Group that contained a baseline consisting of an average HFC consumption (averaged over a certain period) and a freeze date, as in the table below. No indication was yet provided for an HCFC baseline component, neither do these suggestions contain reduction percentages for the HFC consumption after the freeze date. Six suggested proposals for baseline and freeze dates for Article 5 parties and two for non-Article 5 parties were presented.

Suggested Article 5 baselines and freeze dates		
Proponents	**Baseline, i.e., HFC component of baseline (average value)**	**Freeze date**
GCC	2024-2026	2028
China, Pakistan	2019-2025	2025-2026
India	2028-2030	2031
African Group, Pacific Island Countries, Latin America like-minded*, EU and JUSSCANNZ	2017-2019	2021
Malaysia, Indonesia, Brazil, Argentina**, English-speaking Caribbean, Cuba	2021-2023	2025
Iran	2024-2027	2029
Suggested non-Article 5 baselines and freeze dates, first reduction step		
EU and JUSSCANNZ	2011-2013	90% of baseline in 2019
Belarus and Russian Federation	2009-2013**	100% of baseline in 2020

**Nicaragua, El Salvador, Guatemala, Venezuela, Chile, Colombia, Honduras, Costa Rica, Mexico, Dominican Republic, Haiti, Panama, Peru, Paraguay (as a basis)*
*** Subject to confirmation by Government*

The above suggestions do not contain any reduction percentages after the freeze, as was the case for the amendment proposals considered in sections 3-2 and 3-3 in this report. Nevertheless, TEAP considered that it may be helpful to parties to conduct a limited analysis (see Annex II), for the six proposals for Article 5 parties, of the potential for theoretical climate benefits, defined as the difference between the BAU scenario and the freeze value, which is assumed to remain constant as an HFC consumption limit until 2050. Values for the climate benefit calculated in this way are as given in the table and figure below (n.b., they should not be directly compared to the values given in the climate benefit tables for the four amendment proposals with HFC phasedown schedules as in the sections above and the tables in chapter 3).

Suggestion (assuming constant through 2050)	**Gulf Cooperation Countries**	**China and Pakistan**	**India**	**African group, Pacific Islands, Latin America , JUSSCANZ/ EU**	**Malaysia, Brazil, Argentina, Indonesia, Caribbean, Cuba**	**Iran**
Freeze date	2028	2025-26	2031	2021	2025	2029
Benefit (Mt CO_2-eq.)	**41,510**	**50,440**	**29,660**	**63,150**	**50,890**	**39,720**



Various freeze proposals for Article 5 parties
Mt CO2-eq.
4000
3500
3000
2500
2000
1500
1000
500
0
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
Year
BAU
GCC
Chi-Pak
India
AF-JU-EU
MaBrAIC
Iran

1 Introduction, decision and definitions

1.1 Background to Decision Ex.III/1

In paragraph 1 of its decision XXVII/1, “Dubai pathway on hydrofluorocarbons (HFCs)”, the Twenty-Seventh Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer (MOP-27) decided “*to work within the Montreal Protocol to* an HFC *amendment in 2016 by first resolving challenges by generating solutions in the contact group on the feasibility and ways of managing HFCs during Montreal Protocol meetings*”. To that end, the Meeting of the Parties agreed in paragraph 4 of the same decision to hold in 2016 a series of Open-ended Working Group meetings and other meetings, including an extraordinary meeting of the parties.

The thirty-seventh meeting of the Open-ended Working Group (OEWG-37), held in Geneva 4-8 April 2016, was the first of those meetings and was focused solely on the discussions on HFCs contemplated by decision XXVII/1. The Working Group agreed to convene the contact group on the feasibility and ways of managing HFCs that had been established at MOP-27. At the final session of the meeting, it was reported that the contact group had concluded a first review of all the challenges listed in its mandate and had made progress in generating proposed solutions, including the text proposal with agreed concepts and elements with regard to an exemption for high ambient temperature countries and proposed solutions to some aspects of challenges related to funding and flexibility in implementation.

A resumed thirty-seventh meeting of the Open-ended Working Group was held in Vienna on 15 and 16 July 2016. The Open-ended Working Group again decided that it would conduct the bulk of its discussions in the HFC contact groups, with informal discussions also taking place as needed, and that the discussions would be taken up where they had been suspended at OEWG-37. The meetings of the contact group and informal discussions were mainly closed to non-party participants. At the final plenary session, it was reported that the contact group had reached agreement on solutions to the challenges set out in the Dubai Pathway, including agreement that proposed solutions to some of the challenges would be discussed during the negotiation of the HFC amendment proposals and would be concluded prior to the adoption of any such amendment.

The thirty-eighth meeting of the Open-ended Working Group (OEWG-38) was held in Vienna from 18 to 21 July 2016. The Working Group decided that the HFC contact group would continue to work on the proposals to amend the Montreal Protocol with respect to HFCs. Contact group meetings and informal discussions were held, mainly again closed to non-party participants. At the final session of OEWG-38, it was reported that the contact group had actively discussed issues relating to the proposed amendments to the Protocol with respect to HFCs, including the calculation of baselines, the year in which a freeze could commence and possible reduction steps, including the estimation of amounts and timing of the peak year for production and consumption, for both Article 5 and non-Article 5 parties. The contact group had not reached agreement on any issue, however, needing additional time to continue its discussions. The Open-ended Working Group accordingly decided to suspend its thirty-eighth meeting to allow the contact group, including through informal consultations, to continue its discussions in the margins of the Third Extraordinary Meeting of the Parties and to report on the outcome of its discussions to the Third Extraordinary Meeting of the Parties in plenary.

In accordance with Decision XXVII/1 of MOP-27 on the Dubai pathway on HFCs, the Third Extraordinary Meeting of the Parties to the Montreal Protocol (ExMOP-3) was held in Vienna on 22 and 23 July 2016. The contact group on the feasibility and ways of managing HFCs continued its discussions on the baselines, freeze years, phase-down schedule; it also considered four conference room papers (CRPs). As with previous meetings, the contact group meetings and informal discussions remained closed to non-party participants. While the contact group did not complete its consideration of three of the CRPs, these were forwarded to ExMOP-3 for consideration. A fourth CRP was revised by the contact group and forwarded to ExMOP-3 for consideration and adoption. Parties adopted that CRP as the current Decision Ex.III/1.

1.2 TEAP Working Group and approach

To respond to Decision Ex.III/1, the Technology and Economic Assessment Panel (TEAP) constituted a TEAP Working Group with the following composition:

Co-chairs *Lambert Kuijpers, member RTOC and senior expert TEAP*
Bella Maranion, co-chair TEAP
Members *Suely Carvalho, senior expert TEAP*
Roberto Peixoto, co-chair RTOC and member TEAP
Helen Tope, co-chair MCTOC, member TEAP
Dan Verdonik, co-chair HTOC, member TEAP
Ashley Woodcock, co-chair TEAP and chair FTOC
Shiqiu Zhang, senior expert TEAP.

This report is the result of efforts carried out by the Working Group, conducted primarily electronically.

The response to Decision Ex.III/1 was carefully considered by TEAP prior to the development of this report. The factors considered include:

- That certain meetings of the contact group on the feasibility and ways of managing HFCs and the additional informal discussions on key challenges such as funding issues, baselines, and freeze years were closed meetings. This proved challenging to TEAP, since first-hand knowledge and insights of the status of the parties' current discussions was lacking;
- That TEAP has ensured as far as possible that it has an understanding of the correct context in order to develop an appropriate response to this decision, so that it met the intent of parties and would be useful in furthering the discussions. To that end, TEAP had informal discussions in the margins of the meetings focused on better understanding the key terms of the decision and, as much as possible, where agreement had been reached on key issues that would be relevant to the decision; and
- That delivery of a report for this new decision was in addition to the completion of other TEAP reports in response to previous decisions, within a very short timeframe of early September for submission of all documents for the consideration of parties prior to MOP-28.

1.3 Key Terms under Decision Ex.III/1

The Third Extraordinary Meeting of the Parties decides:

Decision Ex.III/1: Report by the Technology and Economic Assessment Panel on the climate benefits and costs of reducing hydrofluorocarbons under the Dubai pathway

> To request that the Technology and Economic Assessment Panel prepare a report for consideration by the twenty-eighth Meeting of the Parties containing an assessment of the climate benefits, and the financial implications for the Multilateral Fund, of the schedules for phasing down the use of hydrofluorocarbons (HFCs) contained in the amendment proposals as discussed by the Parties at the thirty-eighth meeting of the Open-ended Working Group and the Third Extraordinary Meeting of the Parties.

a. Although the term "climate benefit" can be defined a number of different ways, in the context of this report, "climate benefit" is understood as a reduction in HFC consumption below that of a business-as-usual (BAU) scenario integrated over a specified period; this is a direct, simplified climate impact metrics method based on HFC consumption reductions and consistent with the approach taken by TEAP on mitigation scenarios for high-GWP alternatives in its previous reports to parties. There are more comprehensive methods of calculating "climate benefits" more broadly on the basis of emissions, supported by atmospheric measurements (as in (Velders, 2015)). These calculations give the direct impact on global temperatures via the radiative forcing in a given year[2]. In the approach taken by TEAP in this report, achieved reductions are in units of t CO_2-eq from the HFC business-as-usual (BAU) consumption for both non-Article 5 and Article 5 parties as a result of the future implementation of mitigation measures, i.e., the schedules for phasing down HFCs contained in the amendment proposals. This report considers the major, specific HFCs (only as opposed to blends or in conjunction with ongoing HCFC phase-out) currently produced and used in various sectors in non-Article 5 and Article 5 parties. The reductions in HFC consumption from BAU are calculated over the period from the year the control schedule starts up to and including the year 2050;

b. The term "financial implications for the Multilateral Fund" is understood to mean costs to the Multilateral Fund (MLF) for Article 5 implementation of control schedules following the schedules for HFC phase-down in amendment proposals (HFC reductions only). The costs are calculated based on the current MLF guidelines for costs including the HCFC Phase-out Management Plans (HPMPs) stage II. They do not contain "administrative" elements such as Institutional Strengthening; neither have parameter studies been done varying the criteria for investment and operational costs.

c. The term "amendment proposals as discussed by parties" can have a number of meanings given the extensive discussion of parties during the 38th Open-Ended Working Group Meeting (OEWG-38) in the Contact Group on the feasibility and ways of managing HFCs (HFC Contact Group). There are the four amendment proposals originally submitted by parties in 2015. There were also other proposals discussed in the contact group including one that also provided both non-Article 5 and Article 5 schedules with phase-down or consumption reduction steps, and additional proposals providing only baseline and freeze dates. In order to provide an analysis of climate benefits and financial implications of schedules for phasing down HFCs, this report considered the four amendment proposals formally submitted in 2015, which actually provided HFC phase-down schedules (step reductions) for both non-Article 5 and Article 5 parties (important for calculating the costs to the MLF to achieve HFC consumption reductions), as follows:

   i. The amendment proposal on HFCs submitted in 2015 by Canada, Mexico and the United States of America (with additional text submitted in 2016) (hereafter referred to as "North America");
   ii. The amendment proposal on HFCs submitted in 2015 by India;
   iii. The amendment proposal on HFCs submitted in 2015 by the European Union and its member States (hereafter referred to as "EU");
   iv. The amendment proposal on HFCs submitted in 2015 by Kiribati, the Marshall Islands, Mauritius, the Federated States of Micronesia, Palau, the Philippines, Samoa and Solomon Islands (hereafter referred to as "Islands"); and

1.4 Structure of the report

The structure of the report is as follows:

[2] Climate benefits of avoided HFC consumption in this more comprehensive methodology would be expressed by converting consumption values to emissions, emissions to changes in radiative forcing, and radiative forcing determinations to changes in global temperature.

Chapter 1: Introduction on definitions; it presents the working modalities as have been decided via a TEAP working group.

Chapter 2: Presents information on how HFC BAU for non-Article 5 and Article 5 parties have been constructed, with all of the separate elements considered.

Chapter 3: Presents information on how the “climate benefits” for this report were derived, and gives estimated “climate benefit” values for the various amendment proposals up to 2050.

Chapter 4: Presents information on how costs were derived that might apply for the various amendment proposals and gives the estimated cost values applying to Article 5 parties for the period up to 2050.

Annexes: (1) Additional information on calculations in this report,
(2) Limited analysis of “climate benefit” of HFC Contact Group table with proposed HFC baselines and freeze dates; and
(3) Spreadsheets for HFC total consumption (2010-2015) and for HFC BAU consumption calculations by sectors and totals for non-Article 5 and Article 5 parties.

2 HFC 2015 production estimates and consumption in a Business as Usual (BAU) scenario

2.1 HFC consumption and production data

With the main purpose of emissions reporting, developed countries (classified as Annex I parties under the UNFCCC) also report HFC consumption and production data to the UNFCCC. From these data, certain trends can be seen, but it is impossible to precisely derive where all production has taken place from published UNFCCC data. Developing countries do not report to the UNFCCC, and trends in production (and consumption) of HFCs remain unclear. As a valuable check on HFC consumption estimates, latest global HFC production estimates for 2015 are provided below.

Estimates can be made for global production of the relevant HFC chemicals for 2012-2015 by combining UNFCCC data, manufacturer's estimates of production quantities, and some global emission data. First estimates were already given in the TEAP Decision XXVI/9 Task Force report (UNEP, 2015). Estimates for HFC production in that report are from various sources including:

- estimates by non-Article 5 chemical manufacturers of the production in Article 5 parties, (Kuijpers, 2015);
- Chinese HFC (and HCFC) production data up to the year 2013 (Kaixiang, 2015);
- additional specific Chinese manufacturer information (Kuijpers, 2015).

The HFCs considered here are HFC-32, HFC-125, HFC-134a and HFC-143a, as well as HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa and HFC-365mfc. The latter four chemicals were also considered for the first time in the June 2016 TEAP XXVII/4 Task Force report (UNEP, 2016).

Table 2-1 shows global production of these main HFCs in 2015 is estimated at 665 ktonnes, equivalent to about 1220 Mt CO_2-eq. The *four* main HFCs (namely HFC-32, HFC-125, HFC-134a and HFC-143a), are mainly used in the R/AC sector, except for HFC-134a, which is also applied in several other sectors (such as foams, aerosols, MDIs). For these four HFCs, a total (global) HFC production of about 525 ktonnes is estimated for the year 2015.

Global production quantities for other HFCs (HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa and HFC-365mfc) are estimated at around 140 ktonnes (160-170 Mt CO_2-eq.), of which a substantial part in tonnes (but not in Mt CO_2-eq.) consists of HFC-152a production (Kaixiang, 2015, Kuijpers, 2016).

Estimates for non-Article 5, Article 5 and global HFC production in 2015 (ktonnes)

HFCs	Estimate for non-A5 production (2015)	Estimate for A5 production (2015)	Estimate global 2015 production
HFC-32	23.0	71.0	94.0
HFC-125	31.5	98.5	130.0
HFC-134a	97.0	176.0	273.0
HFC-143a	11.0	17.0	28.0
Sub-total			*525*
Other HFCs (HFC-152a, -245fa, -365mfc, -227ea, -236fa)*, **			140.0
Total			665.0

* A substantial part is related to non-feedstock HFC-152a production, global estimate at slightly higher than 60 ktonnes; of this, only 5-10 ktonnes relate to use in foam production

** Estimated global production of HFC-236fa is estimated as small (300-500 tonnes); HFC-236fa is produced in one Article 5 country (Kuijpers, 2016)

The consumption values calculated and estimated for all sectors and chemicals are given below, in Table 2-2. In considering both tables, good agreement was obtained for 2015 between estimated production and consumption of the HFCs in R/AC (manufacturing and servicing), foam, MDIs, non-MDI aerosols and fire protection sectors.

Table 2-2 Estimates for non-Article 5, Article 5 and global HFC consumption in 2015 (ktonnes)

Sector	Estimate for non-A5 consumption (2015)	Estimate from various sources A5 consumption (2015)	Estimate global consumption 2015 (*)
R/AC manufacture	106.6	185.8	292.4
R/AC service	94.2	87.0	181.2
Foams	71.0	12.6	83.6
MDIs	10.1	3.9	14.0
Aerosols	50.0	9.0	59.0
Fire protection, others	5.5	9.5	15.0
Total	**334.4**	**305.8**	**645.2**

For the R/AC sector (manufacture and service), the total 2015 consumption (determined via bottom-up calculations) is estimated at 473.7 ktonnes (200.8 ktonnes for non-Article 5 parties and 272.9 ktonnes for Article 5 parties (see also the June 2016 XXVII/4 Task Force report, Table 6-1). Taking the 525 ktonnes estimate for production of the four main HFCs (Table 2-1 above), TEAP estimates that about 50-55 ktonnes of these HFCs (mainly HFC-134a) are used globally in sectors other than R/AC, i.e., mainly in the foams, MDIs and aerosols sectors.

2.2 Method used for calculation

The HFC Business As Usual (BAU) scenarios for non-Article 5 and Article 5 parties are calculated in this report taking into account the R/AC, foams, MDIs and aerosols, and fire protection sectors. The HFCs considered here are HFC-32, HFC-125, HFC-134a and HFC-143a, as well as HFC-152a, HFC-227ea, HFC-245fa and HFC-365mfc. The HFC BAU for non-Article 5 parties takes into account two final regulations that impact certain sectors. The F-gas regulation in the European Union (EU), and regulations in the United States (US) that make certain HFCs unacceptable for certain sub-sectors by specific dates, will impact the R/AC sectors and sub-sectors, and other industry sectors (foam blowing, aerosols).

In this final report, the HFC BAU scenario for non-Article 5 parties takes into account available, reported HFC consumption up to 2014 by non-Article 5 parties or regions (USEPA, 2015; EEA, 2015) to estimate total (global) HFC consumption. It needs to be noted that the annual reporting of consumption or supply may also take into account stockpiling. The value of these reports is to provide some indication of short-term trends, but analysis of BAU demand is needed for the longer term. The reported supply or consumption values for the period 2010-2014 for these regions (integrated) and adjusted for total (global demand) are approximately 10% lower than previously calculated total non-Article 5 BAU demand (in the *advance copy* of this report). The BAU non-Article 5 scenario has therefore been corrected upwards for the period 2010-2014 and 2015-2019 (by 10% for the demand during 2010-2014, then gradually decreasing to the BAU demand as calculated for the year 2019). The above procedure leads to differences (from the *advance copy*) in the BAU HFC values, which are used to calculate the baselines for the four amendment proposals, which then also have a certain influence on climate benefits calculated for the period 2015-2050 (see also Annex III).

The HFC BAU scenario for Article 5 parties is calculated without accounting for any HFC regulations as the impacts for these parties are not clear. The BAU scenario specifically takes into account economic growth factors expected for the period 2015-2050, as already presented for R/AC in the June 2016 XXVII/4 Task Force report (UNEP, 2016).

2.3 Construction of an R/AC BAU following the approach in XXVII/4 (and XXVI/9)

Construction of the HFC BAU for the R/AC sector includes a manufacturing and servicing component (see Table 2-3). The total HFC manufacturing demand is determined by the amount of equipment that is manufactured in the conversion from HCFCs (this only applies to Article 5 parties), and by continuing growth of HFC equipment. For Article 5 parties, this results in steady growth in the HFC demand for the four major HFCs used in R/AC (see above). In the case of the HFC BAU for non-Article 5 parties, the demand for HFCs is reduced through the impact of existing regulations. However, certain sub-sectors and certain countries are not subject to such regulations, from which it can be concluded that there will be a certain level of growth in HFC BAU demand.

The HFC servicing demand is the total HFC amount that is required to guarantee good operation of the equipment bank in the R/AC sector. The servicing component (see Table 2-3) is complex, and of equal or greater importance than the manufacturing component in the construction of an HFC BAU scenario. Considerations include leakage, loss in case of accidents, recovery and recycling, all considered alongside the lifetime of equipment in the various sub-sectors. With 12-20 year R/AC equipment lifetimes, the R/AC servicing amounts will be the same or larger than the amount needed for manufacturing.

It needs to be re-emphasized here that for the construction of any BAU scenario, the main HFCs have been included, not considering alternative, low GWP pure compounds or low GWP mixtures. This is different from the approach taken in the XXVII/4 Task Force June 2016 report where the impact of the replacement by low GWP mixtures has been taken into consideration in the mitigation scenarios. It should be noted that major use of these mixtures in the R/AC sector may well lead to difficulties in achieving a 75% HFC consumption reduction or more in future, assuming that these mixtures remain in use (this relates to the proposals discussed in chapter 3).

Table 2-3 BAU demand for R/AC manufacturing and servicing in non-Article 5 and Article 5 parties in Mt CO2-eq. (2015-2050)[3]

HFC BAU demand in Mt CO_2-eq. (year)	**2015#**	**2020#**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Non-Article 5								
Manufacturing	209.1	185.2	207.7	238.5	280.5	319.9	370.3	429.3
Servicing	184.8	192.8	183.8	165.1	167.5	187.5	210.4	237.2
Total R/AC demand*	**393.9**	**378.0**	**391.5**	**403.6**	**448.0**	**507.4**	**580.7**	**666.5**
Total BAU (comparison)**	517	444	451	467	515	578	655	745
Article 5								
Manufacturing	388.2	592.7	847.2	1113.1	1281.5	1483.6	1728.7	2025.9
Servicing	181.9	384.0	677.6	1043.9	1441.0	1825.8	2318.8	2952.4
Total R/AC demand*	**570.1**	**976.7**	**1524.8**	**2157.0**	**2722.5**	**3309.4**	**4047.6**	**4978.3**
Total BAU (comparison)**	627	1047	1615	2264	2847	3451	4207	5157

* Note the difference and increase in order of magnitude between non-Article 5 and Article 5 parties

** See Annex III for all BAU total HFC consumption values for the separate years

\# The values highlighted in yellow have been corrected to be consistent with the corresponding values in Annex III.

[3] Data for R/AC are already contained in the XXVII/4 TF report. For comparison reasons, total BAU values have also been given, i.e., including all other sectors next to R/AC.

2.5 BAU scenarios for foams, MDIs and non-MDI aerosols, fire protection

A BAU scenario approach for foams for non-Article 5 parties has been elaborated in the TEAP Decision XXV/5 Task Force report (UNEP, 2014); in that approach the phase-down of HFCs for foam blowing following the EU F-gas regulation was already taken into account.

This approach has been expanded for this report, taking into account all information from regulations for the US, EU and other countries. For the BAU scenario for HFC foam blowing agents in Article 5 parties, no regulations were considered; the scenario is simply based on growth expectations up to 2030, assuming that production will keep pace with demand, with a simple extrapolation towards the year 2050. See Tables 2-4 and 2-5.

Table 2-4 BAU demand for foams in non-Article 5 parties (2015-2030) (kt CO2-eq. per year taken from recent calculations for the Decision XXVII/4 Task Force Update Report September 2016)

HFC demand (kt CO2-eq./year)	**2015**	**2020**	**2025**	**2030**
HFC-245fa	32,960	5,150	0	0
HFC-365mfc w/HFC-227ea	9,260	4,970	0	0
HFC-134a/HFC-152a	20,280	1,960	1,820	1,960
Total	**62,500**	**12,080**	**1,820**	**1,960**

Table 2-5 BAU demand for foams in Article 5 parties (2015-2030) (kt CO2-eq. per year taken from recent calculations for the Decision XXVII/4 Task Force Final Report September 2016)

HFC demand in kt CO2-eq. (year)	**2015**	**2020**	**2025**	**2030**
HFC-245fa	2,210	3,920	5,090	5,620
HFC-365mfc w/HFC-227ea	1,790	3,490	4,630	5,110
HFC-134a/HFC-152a	9,460	13,630	23,700	30,910
Total	**13,460**	**21,040**	**33,420**	**41,640**

For MDIs, BAU scenario approaches have been developed for the global demand for HFC-134a and HFC-227ea, as well as for the separate Article 5 and non-Article 5 demand, both up to the year 2050.It is worthwhile noting that accuracy is likely to decline beyond about 2020. This approach does not allow, other than in the flattening of the HFC-227ea demand due to the European Union F-gas regulations, for any other regulatory impact.

For non-medical aerosols, an annual growth rate for global HFC demand is assumed, with a gradual shift of production moving from non-Article 5 to Article 5 parties. The BAU approximates the introduction of SNAP rules by removing HFC-134a consumption for certain aerosols intended for the North American market in 2017, and converting them to HFC-152a, as a possible worst case scenario.

This was applied across all regions proportionally, noting that the SNAP rule also applies to imported products. EU F-gas requirements for aerosols have been in effect from 2008 onwards. EU industry has already been moving away from HFCs voluntarily since 2002. F-gas requirements allow the continued production of HFC aerosols for export. The BAU scenario assumes no specific additional change as a result of EU F-gas to HFC volumes (starting in 2015, and assuming major step change has already taken place) as a possible worse case.

Table 2-6 BAU demand for MDIs and non-MDI aerosols in non-Article 5 and Article 5 parties in kt CO2-eq. ((2015-2030) taken from recent calculations for the Decision XXVII/4 Task Force Update Report September 2016

HFC demand in kt CO2-eq. (year)	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Non-Article 5								
MDIs								
HFC-134a	8,330	10,220	10,720	10,860	10,930	10,960	10,970	10,970
HFC-227ea	1,760	2,280	2,670	2,960	3,050	3,090	3,100	3,110
Non MDI aerosols								
HFC-134a	15,320	6,780	7,170	7,570	7,970	8,370	8,760	9,150
HFC-152a	6320	9700	10,250	10,810	11,390	11,960	12,530	13,090
Article 5								
MDIs								
HFC-134a	5,310	9,790	12,080	13,910	14,730	15,090	15,240	15,310
HFC-227ea	690	930	1,020	1,100	1,140	1,160	1,180	1,200
Non MDI aerosols								
HFC-134a	6,560	3,320	3,980	4,750	5,630	6,650	7,820	9,150
HFC-152a	1,110	1,460	1,900	2,490	3,260	4,250	5,560	7,270

For fire protection in non-Article 5 parties, the 2015 HFC demand (consumption) is assumed to be about 5,500 tonnes (HFC-227ea). This would include the HFC-227ea import from Article 5 parties (1,500 tonnes). In the BAU scenarios for non-Article 5 and Article 5 parties, TEAP has assumed annual growth percentages of 1.5% for non-Article 5 and 2.5% for Article 5 parties.

Total production of HFC-227ea takes place in both non-Article 5 and Article 5 parties. Production of HFC-227ea occurs in one Article 5 party and is currently (2015) in the order of 11,000 tonnes, of which 9,500 tonnes are reported to be used in various Article 5 parties (mostly in fire protection), the remainder is exported to non-Article 5 parties. Total HFC-227ea consumption in non-Article 5 parties is assumed to be about 5,500-6,000 tonnes annually (2015), assuming HFC-227ea for MDIs would be included (Kuijpers, 2016). Data are given in Table 2-6.

For this report, HFC-227ea demand in fire protection is simply assumed to grow through the year 2050. However, taking into account the production for MDIs, one has to say that MDI based HFC-227ea growth takes into account the impact of F-gas regulations, and is expected to flatten to almost zero growth by 2050.

2.6 Non-Article 5 and Article 5 BAU for HFCs

The non-Article 5 and Article 5 BAU scenarios for HFCs have been built up from the various sectoral contributions, as given in sections 2.3-2.5. This applies to R/AC manufacture, R/AC servicing, foams, MDIs, non-medical aerosols, fire protection, as mentioned above. Annex III contains the spreadsheets for BAU consumption determination by sectors and total for non-Article 5 and Article 5 parties.

Figure 2-1 shows the trends for non-Article 5 and Article 5 parties (shown up to the year 2040 only to maintain reasonable vertical axis values). BAU consumption for non-Article 5 parties decreases, and then increases slightly, whereas in Article 5 parties, the BAU consumption increases continuously. Total values are given in Figure 2-1 as well as the values for the R/AC sector in both non-Article 5 and Article 5 parties, showing similar trends.

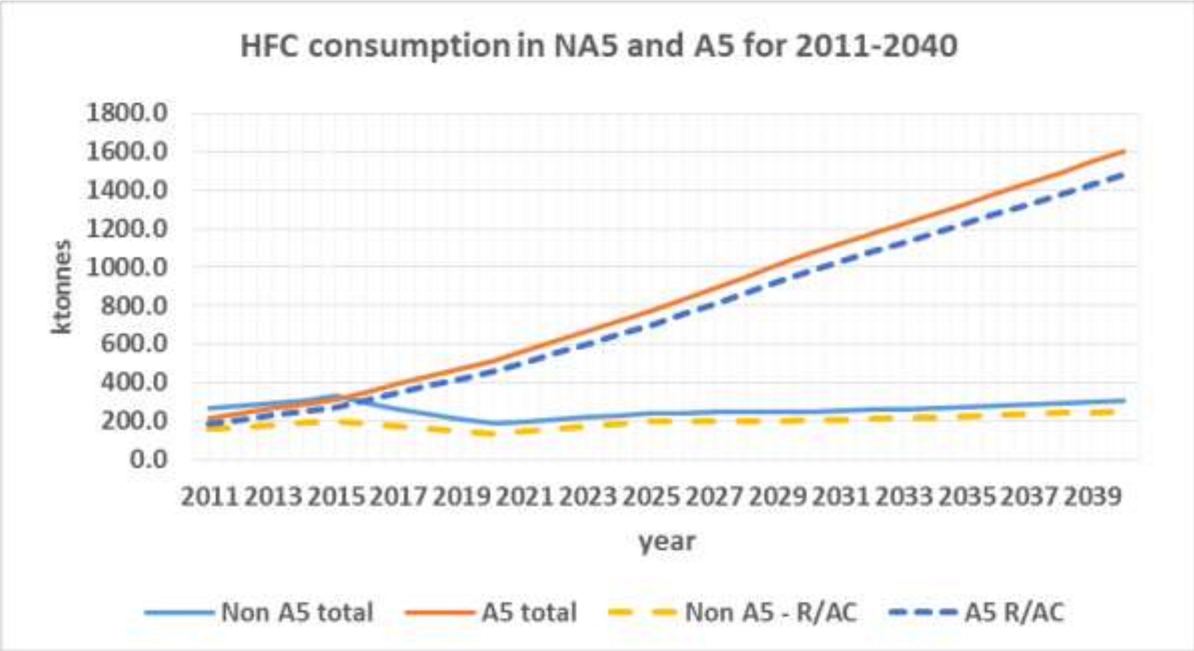


Fig. 2-1 HFC consumption (total and R/AC consumption) for Non-Article 5 and Article 5 parties for the period 2011-2040 (n.b., in ktonnes).

3 Calculating climate benefits of proposals

3.1 Summary of ways to calculate climate benefits

TEAP has considered "climate benefit" as a reduction in HFC consumption below that of a business-as-usual (BAU) scenario integrated from the present to 2050; this is a simplified climate impact metrics method based on HFC consumption reductions and consistent with the approach taken by TEAP on mitigation scenarios for high-GWP alternatives in its previous reports to parties. There are more comprehensive methods of calculating "climate benefits" on the basis of emissions, supported by atmospheric measurements (Velders, 2015). These calculations give the direct impact on global temperatures via the radiative forcing in a given year[4].

For this report, TEAP has considered "climate benefit" as the integrated difference between the BAU and the controlled HFC consumption (applying amendment proposal reduction schedules) for the period between the year the control schedule starts to work and the year 2050. The year 2050 has been chosen because this is consistent with the end-year as requested by parties for the scenarios in the TEAP Decision XXVII/4 Task Force report. HFC GWP values are taken from the IPCC AR4 report as these are the values proposed in the amendment proposals. Figure 3-1 is an illustration of the term as used in this report.

Choice of a different end year would lead to different climate benefits. The further into the future the end-year would be chosen, the smaller the difference in climate benefits for different control schedules, because the BAU consumption becomes more and more dominant. This has not been further investigated in this study, but forms useful background knowledge for judging climate benefit values for all kind of HFC phase-down and freeze proposals.

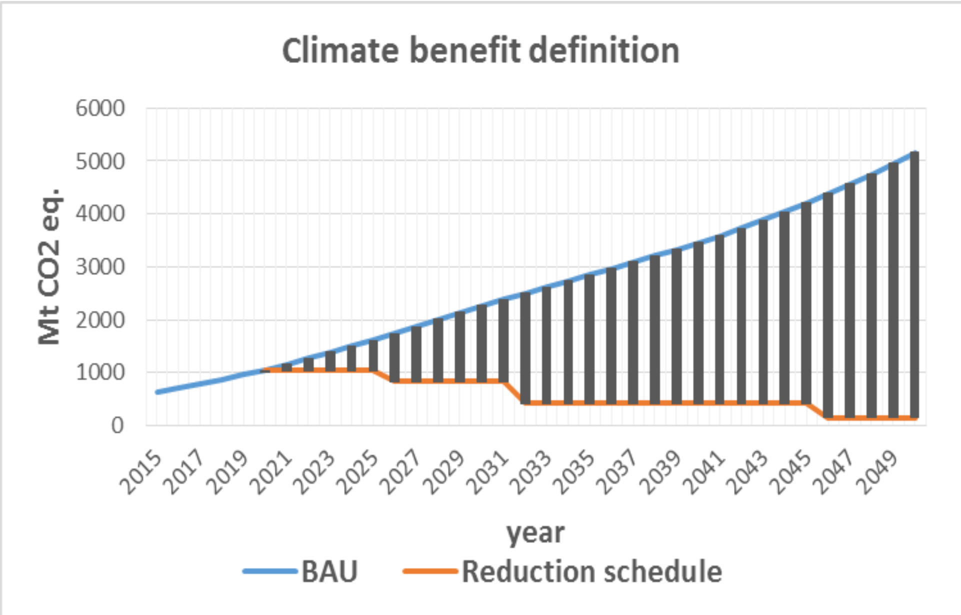


Fig 3-1 BAU compared with a (phase-down) reduction schedule starting in 2021 (freeze), until 2050 (the integrated "climate benefit" value is given by the shaded area for the relevant period)

4 Climate benefits of avoided HFC consumption in this more comprehensive methodology would be expressed by converting consumption values to emissions, emissions to impact on radiative forcing, and radiative forcing determinations to changes in global temperature

Calculations for the HCFC/HFC baselines and BAU consumption used the following approach:

- Historic values available for HCFC consumption (or HCFC baselines) are used (as prescribed) in the calculation of HFC baselines for proposals (expressed in climate terms of t CO_2-eq.);
- If future HCFC consumption is referred to in baseline formulas, a best estimate on the consumption trend for Article 5 parties can be made;
- HFC BAU consumption until 2014 is determined on the basis of available consumption data or best estimates for the various HFC consuming sectors; combining the data from sectors then yields historical trends (all expressed in climate terms of t CO_2-eq.);
- HFC consumption for 2015 is checked against best estimates for HFC production data, to have the best calibration for 2015, as a starting point for future estimates;
- HFC BAU consumption for the period 2015-2050 is calculated on the basis of either specific assumptions for manufacturing and servicing in the R/AC sector, taking into account economic growth and other parameters in both non-Article 5 and Article 5 regions, or taking a best estimate for trends in HFC consumption estimated for other sectors (following the method for calculation as described and used in the previous TEAP Decision XXVII/4 report (UNEP, 2016));
- Since baseline values can been calculated for certain years (as prescribed in amendment proposals), comparing control schedules based on these baselines against BAU becomes an easy arithmetic and this then yields the climate benefit values (expressed in Mt CO_2-eq. consumption difference) as explained above.

3.2 Amendment proposals for non-Article 5 parties

Four amendment proposals for freeze and subsequent reductions in HFC consumption for non-Article 5 parties have been submitted to the meeting of the parties in 2016: 1) North America, 2) EU, 3) India and 4) Island states. The amendment proposal details are given in Table 3-1 below.

Table 3-1 Details of the various amendment proposals for non-Article 5 parties

Non-Article 5 parties						
Proposal	**Baseline**	**Reduction steps**				
North America	Average HFC consumption plus 75% of average HCFC consumption in 2011–2013	90% 2019	65% 2024	30% 2030	15% 2036	
EU	Average HFC consumption in 2009–2012 plus 45% of average HCFC consumption allowed** under the Protocol in 2009-2012	85% 2019	60% 2023	30% 2028	15% 2034	
India	Average HFC consumption in 2013–2015 plus 25% of the HCFC baseline* consumption	100% 2016	90% 2018	65% 2023	30% 2029	15% 2035
Island States	Average HFC consumption in 2011-2013 plus 10% of the HCFC baseline* consumption	85% 2017	65% 2021	45% 2025	25% 2029	10% 2033

* HCFC baseline is the 1989 HCFC baseline (1989 HCFC consumption plus 2.8% of 1989 CFC consumption) in climate terms
** Allowed HCFC consumption is consumption following the Protocol reduction schedule

3.2.1 Baselines

The various baselines, consisting of an HFC and an HCFC component, are given in Table 3-2 below.

Table 3-2 HFC and HCFC parts of the non-Article 5 baselines, as well as the total amounts for those baselines (in Mt CO_2-eq.)

Proposal	Baseline	HFC part	HCFC part	Total
North America	Average HFC consumption plus 75% of average HCFC consumption in 2011–2013	488.4	68.5	556.9
EU	Average HFC consumption in 2009–2012 plus 45% of average HCFC consumption allowed under the Protocol in 2009-12	448.2	102.4	550.6
India	Average HFC consumption in 2013–2015 plus 25% of the HCFC baseline consumption	524.7	162.7	687.4
Islands	Average HFC consumption in 2011-2013 plus 10% of the HCFC baseline consumption	488.4	65.1	553.5

With all different methods used in the above proposals, using certain HFC and HCFC components, the baseline values are in the range of 550-700 Mt CO_2-eq. While the baselines are +/- 15% different, the combination with freeze and reduction percentages in certain years (as percentages of the baseline) does not yield major differences in the overall climate benefits calculated (see below, Table 3-3).

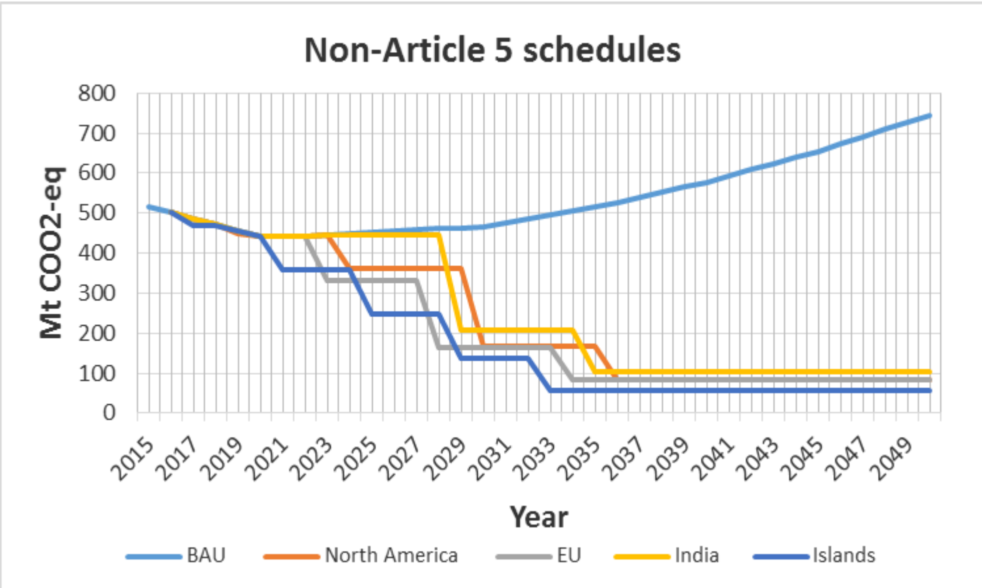


Fig. 3-2 The BAU scenario compared to the various reduction schedules in amendment proposals for non-Article 5 parties (Mt CO_2-eq.)

3.2.2 Climate benefits for non-Article 5 parties proposals

Climate benefits have been calculated using the approach described in section 3.1 above (defining climate benefit as the difference between the BAU and the relevant phase-down scenario until 2050).

This has first been done for the amendment proposals for non-Article 5 parties. The phase-down scenario is assumed to be equal to the BAU scenario until the freeze date (there may be small differences, e.g., in case the baseline consumption is higher than BAU consumption in freeze years).

The climate benefits for the various amendment proposals for non-Article 5 parties are given in Table 3-3. As mentioned above, climate benefits are not much different for the various proposals. For the period up to 2050, the four amendment proposals yield an integrated total reduction in HFC consumption in the range of 10-12,000 Mt CO2-eq. compared to BAU, with little differences between proposals.

Table 3-3 Climate benefits for various proposals for non-Article 5 parties until 2050 (Mt CO_2-eq.)

Proposal	**North America**	**EU**	**India**	**Island states**
Freeze date	n/a	n/a	2016	n/a
Final reduction step	15%	(15%)	15%	10%
Climate benefit (Mt CO_2-eq.)	**10,690**	**11,500**	**10,000**	**12,470**

3.3 Amendment proposals for Article 5 parties

The four amendment proposals for freeze and subsequent reductions in HFC consumption for Article 5 parties have been considered here. It needs to be mentioned that, in the case of the EU proposal, the set-up is a bit different from the other proposals; it has no reduction steps after a freeze date (these steps are proposed to be negotiated in the near future). This EU proposal will be further elaborated upon below. The details for the four various Article 5 proposals are given in Table 3-4 below.

Table 3-4 Details of the various amendment proposals for Article 5 parties

Developing (Article 5) countries						
Proposal	**Baseline**	**Red 1**	**Red 2**	**Red 3**	**Red 4**	**Red 5**
North America	Average HFC consumption plus 50% of average HCFC consumption in 2011–2013	100% 2021	80% 2026	40% 2032	15% 2046	
EU*	Average HCFC and HFC 2015-2016 consumption	100% 2019				
India	Average HFC consumption in 2028–2030 plus 32.5% of the HCFC baseline** consumption	100% 2031	---	---	15% 2050	
Islands	Average HFC 2015-2017 consumption plus 65% of the HCFC baseline consumption	85% 2020	65% 2025	45% 2030	25% 2035	10% 2040

* The EU proposal has a freeze in 2019 at the average HCFC-HFC consumption of 2015-2016, a freeze for combined HCFC and HGFC consumption, no reduction steps (to be negotiated); values for HCFC and HFC consumption in 2015 and 2016 are not yet accurately known

** The HCFC baseline is the average 2009-2010 HCFC consumption in climate terms

3.3.1 Baselines

The various Article 5 party baselines, consisting of separate HFC and HCFC components, are given in Table 3-5 below.

All the different proposals for the calculation of baselines (consisting of both HFC and HCFC components) are in the range of 840-1370 Mt CO_2-eq., with the exception of the Indian proposal baseline, which is about two times greater, at a level of 2400 Mt CO_2-eq. The highest is the EU proposal, where an average of 700 Mt CO_2-eq. was selected for the HCFC 2015-2016 consumption, based on reported values up to 2014 (714.6 Mt CO_2-eq.). It is likely that this value will be lower once reported under Article 7 (in the range of 660-690 Mt CO_2-eq.), but for this report, the 700 Mt CO_2-eq. value is considered the best (conservative) estimate for the average HCFC 2015-2016 consumption.

Table 3-5 Totals, as well as HFC and HCFC components of the Article 5 baselines (Mt CO_2-eq.)

Proposal	Baseline	HFC part	HCFC part	Total
North America	Average HFC consumption plus 50% of average HCFC consumption in 2011–2013	418.4	417.2	835.6
EU	Average HCFC and HFC 2015-2016 consumption	671.9	700.0	1371.9
India	Average HFC consumption in 2028–2030 plus 32.5% of the HCFC baseline consumption	2134.1	283.3	2417.4
Islands	Average HFC consumption in 2015–2017 plus 65% of the HCFC baseline consumption	710.9	566.6	1277.5

The freeze date is the major determinant of this difference between the Indian proposal and the remainder. See for further clarification also Fig. 3-3. In the case of the EU schedule, the freeze at the baseline value of 1371.9 MtCO_2-eq is meant for both HCFCs and HFCs. This implies that in the period 2019-2029, some increase in the HFC consumption will be allowed (with reductions assumed for the HCFC consumption of 35% of baseline in 2020, 67.5% in 2025 and 97.5% in 2030), see Fig. 3-3.

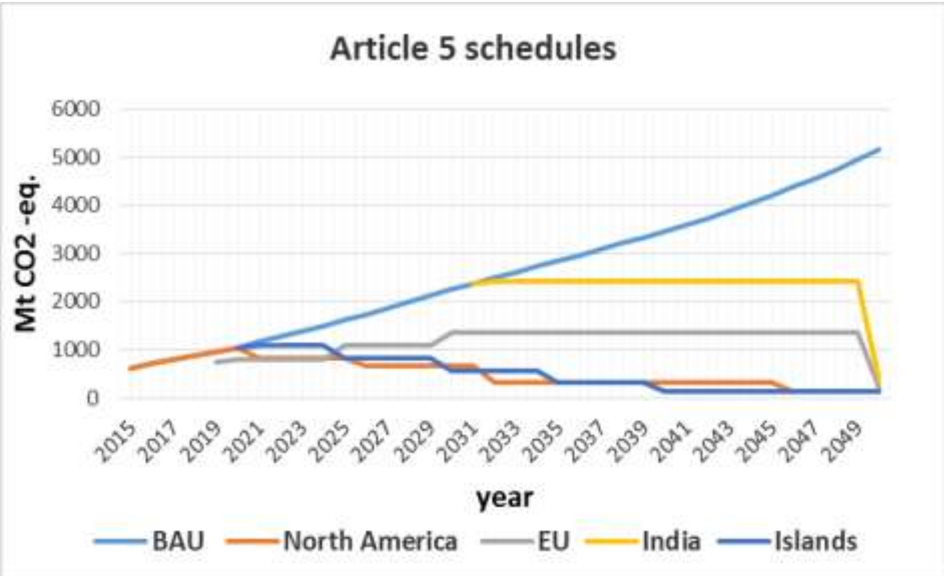


Fig. 3-3 The BAU scenario compared to the various reduction schedules in amendment proposals for Article 5 parties (Mt CO_2-eq.) (for the India proposal no intermediate reduction step has been assumed)[5]

4.3.2 Climate benefits for Article 5 parties phase-down proposals

Climate benefits have been calculated using the approach described in section 3.1 above (defining climate benefit as the difference between the BAU and the relevant phase-down scenario until 2050). In this section, results are given for the amendment proposals for Article 5 parties. The phase-down scenario is assumed to be equal to the BAU scenario until the freeze date (there may be small differences, e.g., in case the baseline consumption is higher than the BAU consumption in the freeze year). The climate benefits calculated for Article 5 parties based on the four amendment proposals are summarized in Table 3.6 below. However, these may not all be directly comparable and would need to

[5] Note the differences in scale between Figs. 3-2 and 3-3.

be considered based on the merits of each proposal. Generally, earlier freeze dates combined with adequate lower baseline values provide larger climate benefits (with little difference observed between the two proposals with intermediate reduction steps defined, i.e., North America and Island states).

Table 3-6 Climate benefits for various proposals for Article 5 parties until 2050 (Mt CO_2-eq.)

Proposal	**North America**	**EU***	**India***	**Island states**
Freeze date	2021	2019	2031	2020
Remaining consumption after last reduction step	15%	15%	15%	10%
Climate benefit (Mt CO_2-eq.)	**75,850**	**53,260**	**26,130**	**74,980**

* The calculation for the EU proposal is conservative (minimum climate benefits), with no intermediate HFC reductions assumed until a final 85% reduction in 2050; it takes into account HCFC consumption until 2030 to be considered in a freeze, leading to a small increase in HFC consumption during 2019-2030. The EU proposal assumes the baseline consumption for HFCs between 2040 and 2049

** Since the Indian proposal proposes to negotiate intermediate steps, an extra calculation has also been made assuming a 50% reduction halfway between the freeze and the 15% 2050 reduction step, resulting in a climate benefit of 38,220 Mt CO2-eq.

4 Calculating financial implications to the MLF from proposals

4.1 Summary of financial implications (for Article 5 implementation of HFC proposals)

Costs have been estimated on the basis of the installed manufacturing capacity in the year the freeze commences (at a certain baseline value). Costs are estimated in such a way that a virtually complete conversion of manufacturing capacity in many sectors can be achieved, which will be required to achieve the 85-90% reduction in consumption in a specific year (in most amendment proposals between 2040 and 2050). This report estimates the total costs for both manufacturing conversion, for servicing and for HFC production phase-down. The analysis does not address costs for other activities, including those for preparatory surveys, development of management plans, institutional strengthening, capacity building, and training programmes.

The following cost effectiveness factors in Table 4-1 were taken into account for the various sectors and sub-sectors. Because potential related costs to an HFC phasedown are currently an ongoing discussion by parties, for the purposes of this report, the factors used are consistent with current MLF cost guidelines and these are comparable to the factors applied in HCFC HPMPs stage II. For those sectors or sub-sectors where no guidance was available, assumptions about the costs per kg (US$ per kg) to be phased out in manufacturing have been made by the Task Force. It should be noted that, so far, there is no cost effectiveness threshold for the stationary air conditioning sector - SAC.

Table 4-1 Cost effectiveness ranges applied for the varies sectors and sub-sectors for phasing down HFCs

Sector	**US$/kg**
R/AC domestic	7-9
R/AC based on HFC-134a	8-10
R/AC commercial	10-15
R/AC transport/industrial	10-15
R/AC servicing	6-8
Stationary AC	11-15
Mobile AC	4-6
Foams	7-9
Fire protection	3-5
Aerosols	4-6
MDIs	None
Production closure	1.5-3.5

4.2 Production closure

Phasing down HFCs will have the consequence that HFC production plants will have to be shut down in Article 5 parties during the phase-down period. Projects for closure of HCFC production plants have been given cost effectiveness ranges of US$ 1.5-2.5/kg in the most recent TEAP replenishment reports as issued in 2011 and 2014. For the closure of HFC production plants a range of US$1.5 to 3.5/kg has been utilised in this report, taking into account that conversion of production to low-GWP refrigerants may involve a number of additional issues that could add to cost effectiveness values, including IPR. Due to the large production volumes involved, the estimated costs associated with production closure will be sensitive to the accuracy of the cost effectiveness value.

4.3 Servicing aspects

For servicing, an amount of US$ 4.8/kg has been used in HPMP stage II plans for servicing cost effectiveness in the phase out of HCFCs (reference ExCom). For the phase-down of HFC consumption in servicing, moving to low-GWP HFCs might need to take account of issues of flammability, etc., and so a higher cost effectiveness range of US$ 6-8/kg has been assumed.

4.4 Costs to the MLF of the various proposals

Costs to the Multilateral Fund have been calculated using the following approach (taking into account relevant information in chapter 3):

- Current MLF guidelines (for HCFC conversion) are used;
- Manufacturing (including production shutdown) and servicing costs are taken into account. Costs for project preparation, planning surveys, development of management plans, institutional strengthening, capacity building, and training programs, among other costs, have not been included;
- Schedule for disbursement to the year 2050 is not discussed in this report, only the total costs (funding value) over the period have been calculated;
- After a calculation of the baseline, the schedule starts with the value in the freeze year; if this freeze year value is higher than the BAU value in a given year, the BAU value is taken, until the BAU value is higher than the baseline value. This implies that the funding of conversion of manufacturing starts as soon as the reduction schedule is lower than BAU. This implies that, in spite of small differences in baselines and freeze dates in various amendment proposals, a very similar amount will have to be addressed for the start of the manufacturing conversion (note: three amendment proposals will therefore have more or less the same cost ranges);
- Even when the remaining level after the final reduction is 15% or 10% of baseline (dependent on the amendment proposal), it has been assumed that during the period until 2030-2040, all manufacturing in R/AC, foams, fire protection, aerosols etc. will have been addressed (for funding);
- One simplifying assumption is conversion of all manufacturing, then consumption in manufacturing can be assumed not to be part of the remaining HFC consumption (at the level of 10-15% of the baseline level). The remaining 10-15% is assumed to be used for MDIs, for servicing (of that portion of equipment that is still in operation when the 10-15% step comes in), and for certain critical uses that will not have been phased out at that moment.

Table 4-2 Costs that would apply to the MLF for various amendment proposals for the entire phase-down period

Proposal	Freeze date	Lower value of the cost range (US$ million)	Higher value of the cost range (US$ million)
North America	2021	3440	5250
EU*, **	2019	5580	8540
India*	2031	9300	14220
Island states	2020	4550	6950

* In the case of the EU and Indian proposal, estimated costs are relatively high because HFC consumption reductions are to be negotiated after the freeze.

** The amount for calculating manufacturing conversions is the baseline amount used after 2040, leading to relatively high amounts. This amount is also sensitive to the HCFC 2015-2016 consumption in the baseline.

The proportions of the costs of the various sectors and subsectors in the total costs have been determined. This has been done for the proposals that consider the years 2020-2021 as the start of the HFC consumption reduction (freeze value). The upper and the lower value of the range calculated are given in Table 4-4.

Table 4-4 Percentage of costs for the various subsectors and sectors of the total costs for a typical amendment proposal starting around 2021

Subsector/ Sector	**Lower value of the range**	**Higher value of the range**
R/AC domestic	2.2%	1.9%
R/AC -134a commercial/transport/industrial	1.9%	1.5%
R/AC -134a in AC	0.5%	0.4%
Mobile AC	3.6%	3.5%
R/AC R-404A commercial	7.4%	7.2%
R/AC R-404A transport/industrial	0.9%	0.8%
R/AC R-407C Stationary AC	10.1%	9.9%
R/AC R-410A Stationary AC	32.9%	29.4%
R/AC Servicing	21.5%	18.8%
Foams	3.5%	3.0%
MDIs	-	-
Aerosols HFC-134a	<0.2%	<0.2%
Aerosols HFC-152a	<0.3%	<0.2%
Fire protection	0.7%	0.8%
Production	14.9%	22.7%
TOTAL	100%	100%

5 References

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IPCC, 2013	AR5, IPCC Fifth Assessment Report, Working Group I, The Physical Science Basis, 2013
Kaixian, 2015	Kaixian, W., Presentation at OORG meeting World Bank, "HCFCs and HFCs Production in China", May 2015
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RTOC, 2010	UNEP, Refrigeration, AC and Heat Pumps Technical Options Committee, 2010 Assessment Report, ISBN 978-9966-20-002-0
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USEPA, 2012	see: https://www3.epa.gov/climatechange/Downloads/EPAactivities/Appendices_Global_NonCO2_Projections_Dec2012.pdf.
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Velders, 2015	Velders, G.J.M. et al. Future atmospheric abundances and climate forcings from scenarios of global and regional hydrofluorocarbon (HFC) emissions. Atmospheric Environment, 123 (2015), 200-209 http://www.sciencedirect.com/science/article/pii/S135223101530488X

Annex I – Additional information on calculations

Calculating HFC consumption implies that values for chemicals in ktonnes have to be multiplied by a GWP, with some differences based on the use of 2007 IPCC AR4 (IPCC, 2007) values or 2013 IPCC AR5 (IPCC, 2013) values. Most of the current HFC amendment proposals propose IPCC AR4 GWP values but not all of them.

This implies that for all CFC, HCFC and HFC chemicals the relevant GWPs (whether AR4 or AR5 based) have to be listed for further calculations related to baselines, HFC BAU and control schedules. CFC values are needed to calculate the baseline for HCFCs for non-Article 5 parties (see below).

In this report, aggregated values (in tonnes) for all the HCFC chemicals have been determined on the basis of UNEP Article 7 reporting. Where the calculation of the Article 5 HCFC baseline (the average of the 2009-2010 HCFC consumption in ODP tonnes, or recalculated to tonnes) is relatively easy, a calculation of the non-Article 5 1989 HCFC baseline is far more difficult, because it is based on the 1989 HCFC consumption (in ODP tonnes) plus 2.8% of the 1989 CFC consumption in ODP tonnes. Assuming that this exercise can also be done in the same way as for ODP tonnes, HCFC baselines for both non-Article 5 and Article 5 groups can be calculated in t CO_2-eq.

Where it concerns HFCs, based on whether AR4 or AR5 GWP values are used, estimates of consumption depend on either the reporting (by developed countries, Annex I parties under the UNFCCC) or best estimates from various sources (consisting of all the various HFC types, separately. From these sources, total quantities can be determined in units of t CO_2-eq.

Once an HFC BAU scenario for non-Article 5 and Article 5 parties (with or without impact of regulations, in case these exist) has been determined, average HFC consumption levels expressed in t CO_2-eq. can be determined and be used in the determination of baselines as proposed in the HFC amendment proposals.

For determining the HFC BAU scenarios, a large part of the HFC consumption comes from the R/AC sector. For determining the demand or consumption in this sector, a bottom-up model has been used (called “RIEP” in the past), that has been considered in various RTOC Assessment and TEAP Task Force reports. An elaborate description was given in (RTOC, 2010), where it concerns equipment lifetimes, leakages etc. Some specific descriptions have also been given in the TEAP XXVI/9 (UNEP, 2015) and XXVII/4 Task Force (UNEP, 2016) reports. This kind of model can be compared to the so called “vintaging” model that the US uses (USEPA, 2012) for calculating specific issues for the R/AC sector on consumption. In the case of the use of this type of models for making global estimates, much depends on the knowledge of many parameters for the various regions. The model used here considers many countries and regions (with their specific parameters), which are then combined into estimates for the two regions, non-Article 5 and Article 5. A similar approach is followed in the US “vintaging” model.

The way of determining HCFC baselines for non-Article 5 and Article 5 parties, using very specific (HCFC) chemical information from Montreal Protocol Article 7 reporting, is given in the sheets that have been reproduced below. It is expected that this gives a good impression of which calculations are required to determine the HCFC baselines. It should be mentioned that determining an average “climate” baseline for HCFCs (as the average of 2009-2010 consumption in Mt CO_2-eq.) is different from determining an average “ozone” baseline (as the average consumption in ODP tonnes). This is because the ODP numbers that apply are totally different from GWP numbers used.

Non Article 5 parties

HCFCs	1989	2009	2010	2011	2012	2013	CFCs	1989	2.8%
Tonnes									
HCFC-123	600	1215	732	1255	1454	1382	CFC-11	333128	9328
HCFC-124	1	1228	251	1369	694	147	CFC-12	430440	12052
HCFC-141b	1007	7289	1911	3633	2083	2508	CFC-13	827	23
HCFC-142b	16191	4829	539	376	243	116	CFC-112	2318	65
HCFC-22	216168	95974	64817	61302	41336	42823	CFC-113	237491	6650
HCFC-all other	0	995	1517	1388	1303	1608	CFC-114	14382	403
Total	**233967**	**111529**	**69767**	**69322**	**47113**	**48584**	CFC-115	14454	405
							Total	**1033040**	**28925**
ODP tonnes									
HCFC-123	12	24	15	25	29	28	CFC-11	333128	9328
HCFC-124	0	25	5	27	14	3	CFC-12	430440	12052
HCFC-141b	111	802	210	400	229	276	CFC-13	827	23
HCFC-142b	1052	314	35	24	16	8	CFC-112	2318	65
HCFC-22	11889	5279	3565	3372	2274	2355	CFC-113	189993	5320
HCFC-other	0	35	53	49	46	56	CFC-114	14382	403
Total	**13064**	**6478**	**3883**	**3897**	**2607**	**2726**	CFC-115	8672	243
							Total	**979760**	**27433**
GWP weighted (kt CO_2-eq.)									
HCFC-123	46	94	56	97	112	106	CFC-11	1582358	44306
HCFC-124	1	748	153	834	423	90	CFC-12	4691796	131370
HCFC-141b	730	5285	1386	2634	1510	1818	CFC-13	11909	333
HCFC-142b	37401	11154	1246	868	561	268	CFC-112	13908	389
HCFC-22	391264	173713	117318	110956	74819	77510	CFC-113	1455820	40763
HCFC-all other	0	348	531	486	456	563	CFC-114	143820	4027
Total	**429442**	**191341**	**120690**	**115874**	**77881**	**80355**	CFC-115	105659	2958
							Total	**7899611**	**221189**
HCFC base 1989 (MtCO2-eq)	**650,63**								

GWP	AR4	GWP	AR4
CFC-11	4750	HCFC-123	77
CFC-12	10900	HCFC-124	609
CFC-13	14400	HCFC-141b	725
CFC-112	6000	HCFC-142b	2310
CFC-113	6130	HCFC-22	1810
CFC-114	10000	HCFC-other	350
CFC-115	7310		

Article 5

HCFCs	Baseline	2009	2010	2011	2012	2013	2014	2015	2020
Tonnes									
HCFC-123		2164	2556	2607	3345	2919	3389	**estimate**	
HCFC-124		1498	1044	897	543	301	391		
HCFC-141b		103860	113288	124148	123678	90904	89578		
HCFC-142b		33783	32457	30236	24830	16120	15385		
HCFC-22	395250	381517	408982	390124	434734	330677	338986	355725	256912
HCFC-all other		169	112	142	140	109	145		
Total		522990	558439	548154	587270	441030	447874		
ODP tonnes									
HCFC-123		43	51	52	67	58	68		
HCFC-124		30	21	18	11	6	8		
HCFC-141b	11944	11425	12462	13656	13605	9999	9854		
HCFC-142b	2153	2196	2110	1965	1614	1048	1000		
HCFC-22	21739	20983	22494	21457	23910	18187	18644		
HCFC-other		5	3	4	4	3	4		
Total	35882	34686	37143	37154	39207	29302	29578	32293	23323
GWP weighted (kt CO_2-eq.)									
HCFC-123	182	167	197	201	258	225	261		
HCFC-124	774	912	636	546	331	183	238		
HCFC-141b	78716	75299	82134	90007	89667	65905	64944		
HCFC-142b	76507	78039	74976	69845	57357	37238	35540		
HCFC-22	715402	690546	740257	706124	786869	598525	613564		
HCFC-all other	49	59	39	50	49	38	51		
Total	**871630**	**845021**	**898239**	**866774**	**934530**	**702115**	**714597**		
HCFC base (MtCO2-eq) (years 2009-2010)	**871,63**								

Annex II – Baselines and freeze dates for suggested approaches

This report considered the four amendment proposals originally submitted by parties in 2015 and another proposal discussed in the HFC Contact Group at OEWG-38; all provided both non-Article 5 and Article 5 schedules with phase-down or consumption reduction steps (important for calculating the costs to the MLF to achieve HFC consumption reductions). During the OEWG-38 and ExMOP-3 meetings in Vienna, a number of suggestions were discussed in the HFC Contact Group that contained a baseline consisting of an average HFC consumption (over a certain period) and a freeze date. These suggestions do not (yet) contain an HCFC baseline component in the total (HFC) baseline, neither do they contain reduction percentages for the HFC consumption after the freeze date. Six proposals relate to Article 5 parties and two proposals relate to non-Article 5 parties; they are presented in the Table AII-1 below.

Table AII-1 Details of the various suggestions for baselines and freeze dates, as launched by several party groups at the meetings in Vienna, July 2016

Suggested Article 5 baselines and freeze dates		
Proponents	**Baseline, i.e., HFC component of baseline (average value)**	**Freeze date**
GCC	2024-2026	2028
China, Pakistan	2019-2025	2025-2026
India	2028-2030	2031
African Group, Pacific Island Countries, Latin America like-minded*, EU and JUSSCANNZ	2017-2019	2021
Malaysia, Indonesia, Brazil, Argentina**, English-speaking Caribbean, Cuba	2021-2023	2025
Iran	2024-2027	2029
Suggested non-Article 5 baselines and freeze dates, first reduction step		
EU and JUSSCANNZ	2011-2013	90% of baseline in 2019
Belarus and Russian Federation	2009-2013**	100% of baseline in 2020

**Nicaragua, El Salvador, Guatemala, Venezuela, Chile, Colombia, Honduras, Costa Rica, Mexico, Dominican Republic, Haiti, Panama, Peru, Paraguay (as a basis)*

** *Subject to confirmation by Government*

Since these suggestions do not contain any reduction percentages after the freeze, a calculation of the climate benefit in principle cannot be made, as was done for the amendment proposals in sections 3-2 and 3-3. For the further consideration of Parties, this report also considered and provides limited analysis as below of these additional suggestions contained in the table. Below, these can be compared according to their relative merits by calculating a climate benefit that is defined as the difference between the BAU scenario and the freeze value, which is assumed to be the HFC consumption limit until 2050. Values for the climate benefit calculated in this way, as given in the table AII-2, should not be directly compared to the values given in Tables 3-3 and 3-6, the modelling is only indicative.

Table AII-2 Modeling the impact of different freeze proposals (Table 3-7) assuming a constant consumption at freeze level until 2050). Climate benefits from the various suggestions by and for Article 5 parties until 2050 (Mt CO_2-eq.)

Suggestion (assuming constant through 2050)	**Gulf Cooperation Countries**	**China and Pakistan**	**India**	**African group, PIC, Latin America, JUSSCANZ /EU**	**Malaysia, Brazil, Argentina, Indonesia Caribbean Cuba**	**Iran**
Freeze date	2028	2025-26	2031	2021	2025	2029
Benefit (Mt CO_2-eq.)	**41,510**	**50,440**	**29,660**	**63,150**	**50,890**	**39,720**

* For the China Pakistan suggestion of the baseline, the average of 2019-2025 has been taken, for Brazil Indonesia etc. the average of 2021-2023 (both are not much different)

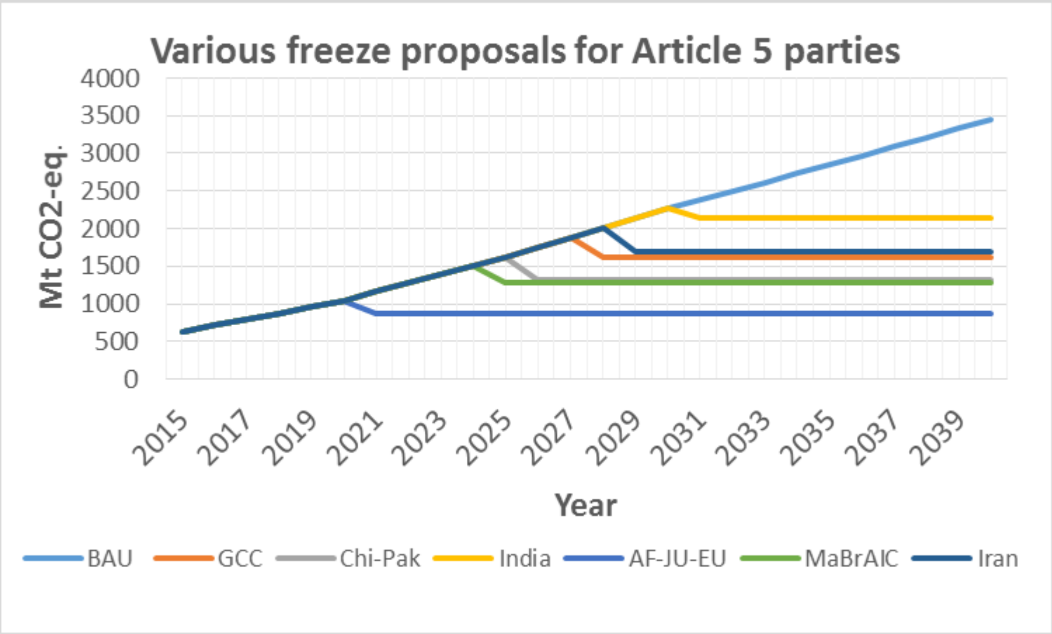

Fig. 3-5 Modelling the impact of different freeze proposals (Table 3-7) assuming a constant consumption at freeze level until 2050. Climate benefits from the various suggestions by and for Article 5 parties (GCC (Gulf Cooperation); China and Pakistan; India; various including African, JUSSCANZZ/EU; Malaysia, Brazil, Argentina, Indonesia, Caribbean, Cuba; and Iran, until 2040 (Mt CO_2-eq.)

The timing of freeze and baseline impacts the projections because of the interaction with HPMP stage II plans for HCFCs, especially if the freeze date is chosen early in the 2020-2030 decade. It will then be important to model in an HCFC component, since HPMP stage II plans have a scheduled reduction in HCFC consumption of 67.5% by 2025. However, if a later date in that decade is chosen, HCFC consumption will have less impact because most of the HPMP stage II plans will have been implemented.

Annex III – Spreadsheets for BAU consumption determination by sectors and total for non-Article 5 and Article 5 parties

Four sheets are presented covering the period 2015-2025 (as examples), in which the consumption

- takes into account available, reported HFC consumption up to 2014 (i.e., US and EU); otherwise,
- for the various R/AC sectors has been calculated using the bottom-up model for all subsectors
- for the foams sector has been determined from manufacturer information for the various subsectors (explained above)
- for the MDI and non-medical aerosols sector has been determined (explained above)
- for the fire protection sector has been derived on the basis of the 2015 estimate for consumption, extrapolated towards 2050

1. Non-Article HFC BAU demand calculated and estimated (in ktonnes)
2. Non-Article HFC BAU demand calculated and estimated (in Mt CO_2-eq.)
3. Article HFC BAU demand calculated and estimated (in ktonnes)
4. Article HFC BAU demand calculated and estimated (in Mt CO_2-eq.)

One fifth sheet gives the HFC total consumption for the period 2009(2010)-2015 and for the total BAU HFC consumption for the period 2015-2050, for both non-Article 5 and Article 5 parties.

Non-Article 5 HFC BAU demand calculated and estimated (in ktonnes)												
YEAR		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
R/AC manufacture												
HFC-134a	domestic	1,4	1,4	1,3	1,2	1,1	1,0	1,0	1,0	1,0	1,0	1,0
	comm, tra and ind	2,2	2,0	1,8	1,6	1,4	1,2	1,3	1,3	1,3	1,3	1,4
	air conditioning	3,1	3,1	3,1	3,1	3,1	3,1	2,8	2,4	2,1	1,7	1,4
	MACs	17,6	15,0	12,4	9,8	7,2	4,6	4,7	4,9	5,1	5,3	5,4
R-404A	commercial	3,0	2,9	2,7	2,6	2,4	2,3	2,2	2,1	2,0	1,9	1,8
	trans and ind	1,2	1,0	0,8	0,6	0,4	0,2	0,2	0,2	0,2	0,2	0,2
R-407C	air conditioning	16,3	14,5	15,0	13,2	11,5	10,8	11,1	11,4	11,7	12,0	12,4
R-410A	air conditioning	61,8	62,0	64,5	65,2	66,0	68,1	70,3	72,4	74,6	76,8	78,9
R/AC service												
HFC-134a	domestic	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	comm, tra and ind	1,5	1,7	1,9	2,2	2,4	2,6	2,6	2,6	2,6	2,6	2,6
	air conditioning	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4
	MACs	50,7	49,4	48,0	46,6	45,2	43,9	41,6	39,4	37,2	34,9	32,7
R-404A	commercial	13,1	12,4	11,7	11,0	10,3	9,6	8,9	8,1	7,3	6,5	5,7
	trans and ind	1,5	1,4	1,4	1,3	1,2	1,2	1,1	1,1	1,1	1,0	1,0
R-407C	air conditioning	10,5	11,5	12,8	13,8	14,2	15,4	15,9	16,4	17,0	17,5	18,0
R-410A	air conditioning	15,6	17,7	21,0	23,1	25,2	26,1	27,9	29,7	31,5	33,3	35,1
Foams												
mix of 245, 365, 134a, 152a		67,0	58,4	49,8	41,1	32,5	23,9	21,7	19,5	17,3	15,2	13,0
MDIs												
HFC-134a (and some 227) only		10,1	10,6	11,4	12,0	12,3	12,5	12,8	13,0	13,2	13,3	13,4
Tech aerosols												
HFC-134a		15,3	15,5	6,6	6,6	6,7	6,8	6,9	6,9	7,0	7,1	7,2
Tech aerosols												
HFC-152a		51,0	52,0	53,1	54,1	55,2	56,3	57,4	58,6	59,8	60,9	62,2
Fire protection and others												
HFC-227ea		5,5	5,6	5,7	5,8	5,8	5,9	6,0	6,1	6,2	6,3	6,4
SUM (ktonnes)		350	339	326	316	306	297	298	299	299	300	301
Refrigeration manufacture		106,6	101,8	101,6	97,2	93,1	91,2	93,5	95,7	98,0	100,2	102,4
Refrigeration servicing		94,2	95,4	98,1	99,3	100,0	100,2	99,5	98,7	97,9	97,2	96,4
TOTAL	(ktonnes)	200,8	197,2	199,7	196,6	193,1	191,5	192,9	194,4	195,9	197,4	198,9
YEAR		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

Non-Article 5 HFC BAU demand calculated and estimated (in ktCO2-eq.)												
YEAR		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
R/AC manufacture												
HFC-134a	**domestic**	2072	1931	1790	1648	1507	1366	1365	1365	1364	1363	1363
	comm, tra and ind	3137	2860	2583	2306	2029	1752	1793	1834	1874	1915	1956
	air conditioning	4433	4433	4433	4433	4433	4433	3947	3461	2974	2488	2002
	MACs	25199	21467	17735	14003	10271	6539	6784	7030	7275	7520	7765
R-404A	**commercial**	11876	11275	10674	10073	9472	8872	8499	8126	7754	7381	7009
	trans and ind	4542	3823	3105	2386	1668	949	938	927	916	905	894
R-407C	**air conditioning**	28939	25723	26610	23417	20401	19143	19696	20250	20803	21356	21909
R-410A	**air conditioning**	128944	129456	134676	136138	137808	142159	146687	151215	155744	160272	164800
R/AC service												
HFC-134a	**domestic**	0	0	0	0	0	0	0	0	0	0	0
	comm, tra and ind	2082	2415	2748	3081	3414	3747	3734	3721	3709	3696	3684
	air conditioning	1931	1951	1971	1991	2011	2031	2025	2019	2013	2008	2002
	MACs	72554	70585	68616	66647	64677	62708	59515	56323	53130	49937	46744
R-404A	**commercial**	51241	48558	45876	43193	40510	37828	34726	31625	28523	25422	22320
	trans and ind	5793	5549	5305	5061	4817	4573	4430	4286	4142	3999	3855
R-407C	**air conditioning**	18606	20342	22707	24443	25191	27286	28215	29144	30072	31001	31930
R-410A	**air conditioning**	32571	36975	43848	48252	52657	54593	58321	62050	65778	69506	73235
Foams												
mix of 245, 365, 134a, 152a		62499	52414,4	42329,8	32245,2	22160,6	12076	7070	2060	1980	1900	1820
MDIs												
HFC-134a (and some 227) only		14415,48	15220,87	16328,57	17098,7	17551,2	17878,07	18270,05	18633,8	18822,55	18979,99	19138,17
Tech aerosols												
HFC-134a		21900,88	22156,54	9375,65	9483,801	9592,527	9701,809	9811,625	9921,953	10032,77	10144,05	10255,77
Tech aerosols												
HFC-152a		6324	6450,48	6579,49	6711,079	6845,301	6982,207	7121,851	7264,288	7409,574	7557,765	7708,921
Fire protection and others												
HFC-227ea		17710	17975,65	18245,28	18518,96	18796,75	19078,7	19364,88	19655,35	19950,18	20249,44	20553,18
SUM	(in MtCO2-eq.)	**517**	**502**	**486**	**471**	**456**	**444**	**442**	**441**	**444**	**448**	**451**
Refrigeration manufacture		209,1	201,0	201,6	194,4	187,6	185,2	189,7	194,2	198,7	203,2	207,7
Refrigeration servicing		184,8	186,4	191,1	192,7	193,3	192,8	191,0	189,2	187,4	185,6	183,8
TOTAL	**(in MtCO2-eq.)**	**393,9**	**387,3**	**392,7**	**387,1**	**380,9**	**378,0**	**380,7**	**383,4**	**386,1**	**388,8**	**391,5**
YEAR		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**

Article 5 HFC demand calculated and estimated (BAU) (in ktonnes)

		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
R/AC manufacture												
HFC-134a	domestic	12,8	13,2	13,5	13,9	14,3	14,6	15,2	15,7	16,2	16,8	17,3
	comm, tra and ind	6,0	6,9	7,9	8,8	9,8	10,7	11,3	11,8	12,4	12,9	13,5
	air conditioning	1,6	1,9	2,1	2,4	2,7	2,9	3,0	3,0	3,0	3,0	3,1
	MACs	32,6	34,2	35,9	37,5	39,2	40,8	43,1	45,3	47,6	49,8	52,1
R-404A	commercial	20,8	22,8	24,9	26,9	29,0	31,0	35,3	39,6	43,9	48,1	52,4
	trans and ind	2,9	3,0	3,2	3,4	3,5	3,7	4,1	4,5	4,8	5,2	5,6
R-407C	air conditioning	26,6	29,9	33,2	36,5	39,8	43,1	48,5	53,8	59,1	64,5	69,8
R-410A	air conditioning	82,6	93,0	103,4	113,9	124,3	134,7	143,5	152,2	161,0	169,8	178,5
R/AC service												
HFC-134a	domestic	0,5	0,6	0,6	0,6	0,7	0,7	0,8	0,8	0,8	0,9	0,9
	comm, tra and ind	1,5	1,8	2,1	2,3	2,6	2,9	3,3	3,6	4,0	4,4	4,7
	air conditioning	0,7	0,9	1,1	1,3	1,5	1,6	1,9	2,1	2,3	2,5	2,8
	MACs	18,8	20,2	21,6	23,0	24,5	25,9	27,3	28,6	30,0	31,4	32,8
R-404A	commercial	10,6	13,4	16,1	18,9	21,7	24,5	28,7	32,8	37,0	41,2	45,4
	trans and ind	2,2	2,7	3,2	3,7	4,2	4,8	5,5	6,2	7,0	7,7	8,5
R-407C	air conditioning	28,6	34,6	40,5	46,5	52,4	58,4	67,6	76,9	86,1	95,4	104,6
R-410A	air conditioning	24,1	30,9	37,7	44,5	51,3	58,1	67,7	77,3	86,9	96,5	106,1
Foams												
mix of 245, 365, 134a		10,6	12,2	13,8	15,4	17,0	18,6	21,3	24,0	26,7	29,4	32,1
MDIs												
HFC-134a only		3,9	4,5	5,2	6,0	6,7	7,1	7,5	7,8	8,1	8,4	8,8
Tech aerosols												
HFC-134a		4,6	4,8	2,1	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8
Tech aerosols												
HFC-152a		9,0	9,5	10,0	10,6	11,1	11,8	12,4	13,1	13,8	14,6	15,4
Fire protection and others												
HFC-227ea		9,5	9,7	10,0	10,2	10,5	10,7	11,0	11,3	11,6	11,9	12,2
(some MDI included)												
SUM (ktonnes)		**310**	**350**	**390**	**431**	**471**	**511**	**563**	**615**	**667**	**719**	**769**
R/AC	manufacture	185,8	205,0	224,1	243,3	262,5	281,6	303,8	325,9	348,1	370,2	392,4
R/AC	servicing	87,0	105,0	122,9	140,9	158,8	176,8	202,6	228,4	254,3	280,1	305,9
	total	**272,9**	**310,0**	**347,1**	**384,2**	**421,3**	**458,4**	**506,4**	**554,4**	**602,3**	**650,3**	**698,3**
YEAR		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**

Article 5 HFC demand calculated and estimated (BAU) (in kt CO2-eq.)												
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
R/AC manufacture												
HFC-134a	**domestic**	18318	18833	19348	19863	20378	20892	21668	22444	23220	23996	24772
	comm, tra and ind	8551	9905	11259	12613	13967	15321	16118	16915	17712	18509	19306
	air conditioning	2269	2652	3034	3416	3798	4180	4223	4265	4308	4350	4393
	MACs	46585	48943	51301	53659	56017	58375	61601	64826	68052	71277	74503
R-404A	**commercial**	81593	89615	97636	105657	113678	121700	138472	155244	172016	188788	205560
	trans and ind	11193	11849	12505	13161	13816	14472	15988	17505	19021	20537	22053
R-407C	**air conditioning**	47268	53116	58965	64813	70661	76509	85976	95443	104909	114376	123843
R-410A	**air conditioning**	172421	194188	215956	237723	259490	281258	299565	317871	336178	354485	372792
R/AC service												
HFC-134a	**domestic**	739	798	857	916	975	1034	1090	1146	1202	1258	1314
	comm, tra and ind	2151	2544	2937	3330	3724	4117	4651	5185	5720	6254	6788
	air conditioning	1041	1300	1559	1818	2076	2335	2662	2990	3317	3644	3971
	MACs	26911	28924	30937	32951	34964	36977	38970	40964	42957	44951	46944
R-404A	**commercial**	41522	52416	63310	74203	85097	95991	112413	128835	145258	161680	178102
	trans and ind	8468	10514	12561	14607	16654	18700	21606	24511	27416	30322	33227
R-407C	**air conditioning**	50795	61352	71909	82466	93023	103580	119984	136389	152793	169197	185601
R-410A	**air conditioning**	50287	64479	78671	92863	107054	121246	141322	161397	181473	201549	221624
Foams												
mix of 245, 365, 134a		13314,42	14975,25	16539,6	18007,47	19548,85	20839,84	23221,36	25441,06	27498,94	29395	32092
MDIs												
HFC-134a only		5609,165	6500,969	7482,869	8601,586	9514,238	10201,57	10714,23	11194,6	11632,7	12075,19	12530,19
Tech aerosols												
HFC-134a		6563,7	6822,497	2965,342	3080,147	3198,358	3320,066	3445,362	3574,342	3707,104	3843,745	3984,37
Tech aerosols												
HFC-152a		1116	1177,38	1242,136	1310,453	1382,528	1458,567	1538,789	1623,422	1712,71	1806,909	1906,289
Fire protection and others												
HFC-227ea		30590	31354,75	32138,62	32942,08	33765,64	34609,78	35475,02	36361,9	37270,94	38202,72	39157,79
(some MDI included)												
SUM (in Mt CO2-eq.)		**627**	**712**	**793**	**878**	**963**	**1047**	**1161**	**1274**	**1387**	**1500**	**1614**
(in MtCO2-eq.)												
R/AC	manufacture	388,2	429,1	470,0	510,9	551,8	592,7	643,6	694,5	745,4	796,3	847,2
R/AC	servicing	181,9	222,3	262,7	303,2	343,6	384,0	442,7	501,4	560,1	618,9	677,6
	total	**570,1**	**651,4**	**732,7**	**814,1**	**895,4**	**976,7**	**1086,3**	**1195,9**	**1305,6**	**1415,2**	**1524,8**
YEAR		**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**

HFC total consumption (2009-2015 and BAU 2015-2050) for non-Article 5 Partes

Year	2009	2010	2011	2012	2013	2014	2015
Consumption ($Mt\ CO_2$-eq.)	408,9	434,8	461,6	488,4	515,2	542,1	516,8

BAU

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Consumption ($Mt\ CO_2$-eq.)	516,8	501,6	486,4	471,3	456,1	443,7	442,3	440,9	444,3	447,6	450,9	454,2

BAU

Year	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Consumption ($Mt\ CO_2$-eq.)	457,4	460,5	463,7	466,8	476,4	486,0	495,6	505,2	514,8	527,4	540,0	552,6

BAU

Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Consumption ($Mt\ CO_2$-eq.)	565,2	577,8	593,2	608,6	624,0	639,5	654,9	672,8	690,8	708,8	726,8	744,8

HFC total consumption (2010-2015 and BAU 2015-2050) for Article 5 Partes

Year	2009	2010	2011	2012	2013	2014	2015
Consumption ($Mt\ CO_2$-eq.)		335,5	373,1	415,6	463,0	542,2	627,3

BAU

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Consumption ($Mt\ CO_2$-eq.)	627,3	712,2	793,4	878,3	963,0	1047,4	1160,9	1274,3	1387,6	1500,7	1614,6	1744,5

BAU

Year	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Consumption ($Mt\ CO_2$-eq.)	1874,4	2004,2	2134,1	2263,9	2380,6	2497,2	2613,9	2730,6	2847,3	2968,0	3088,8	3209,5

BAU

Year	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Consumption ($Mt\ CO_2$-eq.)	3330,3	3451,2	3589,0	3733,2	3884,0	4041,9	4207,0	4379,9	4560,9	4750,4	4948,8	5156,7