Climate Benefits of a Rapid Global HFC Phase-Out

Assessment of climate benefits of global HFC phase-out scenarios under the Montreal Protocol

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Contents

Abbreviations

A2	Parties operating under Article 2 of the Montreal Protocol
A5	Parties operating under Article 5 of the Montreal Protocol
AR4	Fourth Assessment Report (of the Intergovernmental Panel on Climate Change)
BAU	Business as usual
CFC	Chlorofluorocarbons
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
EPA SNAP Program	Significant New Alternatives Policy of the Environmental Protection Agency
Gt	Gigatonnes
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
Mt	Megatonnes
NRDC	Natural Resources Defense Council
R	Refrigerant
RAC	Refrigeration and air-conditioning
TEAP	Technology and Economic Assessment Panel
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

1 Background

With the adoption of the Kigali Amendment to the Montreal Protocol on 15 October 2016, an essential milestone for climate protection was reached, aiming at significantly reducing emissions from hydrofluorocarbons (HFCs). Once ratified, the Kigali Amendment sets out a legally binding multilateral agreement to govern the production and consumption of HFCs. Hence it will provide a major boost to the prospects for climate-friendly refrigerants and accelerate innovation for sustainable technologies.

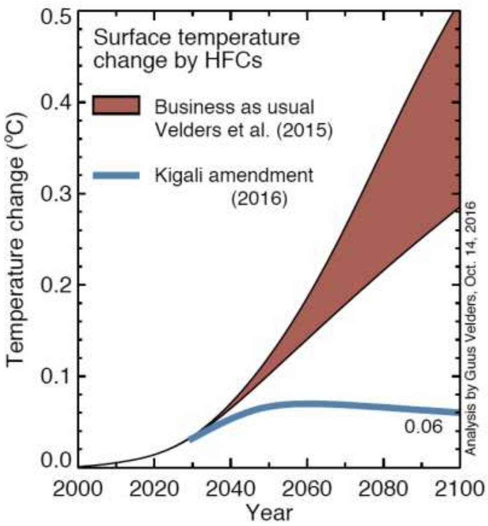
Unlike previous Montreal Protocol amendments, which resulted in a full phase-out of the ozone-depleting substances chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) used in sectors such as refrigeration and air-conditioning (RAC), aerosols, foam blowing, and fire suppression,[1] the Kigali Amendment commits all Parties to phase down HFCs. Over the next few decades, all Parties are expected to reduce HFCs by 80 or 85 % from their respective baselines. Formerly developed and promoted as alternatives to CFCs and HCFCs, HFCs largely contribute to the concentration of greenhouse gases in the atmosphere due to their high global warming potentials (GWP).

By requiring Parties to phase down their HFC emissions from 2019 onwards, this latest amendment to the Montreal Protocol will considerably contribute to the long-term goals of the Paris Agreement to hold the global temperature rise to well below 2° Celsius above pre-industrial levels and to pursue efforts to limit the increase in temperature to 1° Celsius. In addition to the global regulation, there is regulatory action at regional and national level to control HFCs.

Velders et al. (2015) indicate that a successful implementation of the Kigali Agreement is meant to stall global warming from HFC emissions to 0.06° Celsius (see *Figure 1*). In contrast, without any reduction measures, HFC emissions could cause a global temperature increase up to 0.35 to 0.5° Celsius (Velders et al. 2015, Xu et al. 2013). According to IPCC's projections, the global surface temperature increase by the end of the 21st century is likely to exceed 1.5° C relative to the 1850 to 1900 period for most scenarios, and is likely to exceed 2.0° C for many of the considered scenarios presented in the Fifth IPCC Assessment Report (AR5). Hence, the implementation of the Kigali Amendment is considered to contribute to overall greenhouse gas reduction targets, thus providing a crucial opportunity to meet the Paris Agreement's long-term goals. Estimates by the National Resource Defense Council (NRDC) assume the cumulative climate benefits of the HFC phase-down schedules to be about 70 Gt CO_2e from 2015 to 2050.

[1] Both developed and developing countries completed the phase-out of CFCs in 1996 and 2010 and will phase-out HCFCs by 2020 and 2030, respectively.

Figure 1: *Avoided temperature change compared to business-as-usual (Source: Velders 2016)*



However, opinions diverge whether or not the agreed Kigali Agreement is ambitious enough. There are different possibilities to further decrease the contribution of HFCs to the global temperature, e.g. by making the HFC phase-down more stringent, reducing the HCFC percentage in the baseline calculation or even adopting an early total global HFC phase-out. It is assumed that accelerating the HFC phase-down schedules would only have a limited impact. In contrast, a complete global HFC phase-out in the near future could have a significant effect.

As there is urgent need for accelerated short-term action,[2] if the Paris Agreement's goals are to remain achievable, it should be borne in mind that the Montreal Protocol contains a specific provision, which provides an important opportunity to increase ambition over time: Article 2 paragraph 9 allows for quickly adopting future adjustments and thus accelerating existing agreements. Since its adoption in 1987, the Montreal Protocol has been adjusted six times[3] whereby, among other things, a fast-track HCFC phase-out was decided in 2007.

Estimates on climate benefits of HFC phase-down and phase-out scenarios generally depend on a broad range of factors and assumptions. For this report, we established a model based on the consumption of HFCs and HCFCs/CFCs and their respective CO_2e quantities (under the Kigali Amendment, HFCs are to be expressed in CO_2e, not in HFC mass quantities), in order to calculate following different scenarios and to assess their respective climate benefits:

- Global HFC phase-down according to the Kigali Amendment (see Section 3)
- Global HFC phase-out by 2020, 2025 and 2030 (see Section 4)

[2] See the recently published Emissions Gap Report 2017 by UN Environment (UNEP 2017).

[3] The Second, Fourth, Seventh, Ninth, Eleventh and Nineteenth Meetings of the Parties to the Montreal Protocol adopted certain adjustments and reductions of production and consumption of the controlled substances listed in the Annexes of the Protocol. These adjustments entered into force, for all the Parties, in 1991, 1993, 1996, 1998, 2000 and 2008, respectively.

2 Modelling tool

In order to depict the climate benefits of the Kigali Agreement as well as the herewith proposed global HFC phase-out scenarios, a modelling tool has been developed, which allows analysing and assessing the respective climate benefits (expressed in CO_2e). The assessment of the potential contribution of a total global HFC phase-out to limit global temperature increase requires the projection of HFC consumption until the end of this century, i.e. 2100.

As *Table 1* shows, the Kigali Agreement allows for different HFC phase-down schedules for Article 2 or Non-Article 5 countries (developed countries) and Article 5 countries (developing countries), whereby each country group is to be divided into subgroups (Group 1 / Group 2). It is, in fact, the first time subgroups have been established for which different baselines and phase-down schedules apply.

Baselines consist of the average HFC consumption in a specific reference period as well as a certain percentage of HCFCs and CFCs. The reason behind the inclusion of HCFCs in baseline calculations is that HFCs are widely used as substitutes for HCFCs, which still need to be phased out.

Table 1: *HFC phase-down obligations by country groups*

A2 countries / Group 1	A2 countries / Group 2	A5 countries / Group 1	A5 countries / Group 2
	Belarus, Kazakhstan, Russian Federation, Tajikistan, Uzbekistan		Bahrain, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, United Arab Emirates
Baselines			
Average HFC production/ consumption 2011 – 2013	Average HFC production/ consumption 2011 – 2013	Average HFC production/ consumption 2020 – 2022	Average HFC production/ consumption 2024 – 2026
+	+	+	+
15 % HCFC baseline (HCFC consumption 1989 + 2.8 % of CFC consumption 1989)	25 % HCFC baseline (HCFC consumption 1989 + 2.8 % of CFC consumption 1989)	65 % HCFC baseline (HCFC consumption 2009 – 2010)	65 % HCFC baseline (HCFC consumption 2009 – 2010)
Reductions steps			
2019 – 2023 / - 10 %	2020 – 2024 / - 5 %	2024 – 2028 / freeze	2028 – 2031 / freeze
2024 – 2028 / - 40 %	2025 – 2028 / - 35 %	2029 – 2034 / - 10 %	2032 – 2036 / - 10 %
2029 – 2033 / - 70 %	2029 – 2033 / - 70 %	2035 – 2039 / - 30 %	2037 – 2041 / - 20 %
2034 – 2035 / - 80 %	2034 – 2035 / - 80 %	2040 – 2044 / - 50 %	2042 – 2046 / - 30 %
2036 / - 85 %	2036 / - 85 %	2045 / - 80 %	2047 / - 85 %
Art. 2J + Art. 2F (2) of the Montreal Protocol	Art. 2J + Art. 2F (2) of the Montreal Protocol	Art. 5 (8) of the Montreal Protocol	Art. 5 (8) of the Montreal Protocol

Starting point for our calculations was the projection of allowed HFC consumption without the implementation of any global political measures. Data were retrieved from the "business-as-usual" (BAU) projections conducted by the UNEP Ozone Secretariat's Technology and Economic Assessment Panel (TEAP) in its September 2016 TEAP XXVII/4 Task Force Update Report. These BAU projections already imply the impacts of two existing regional HFC reduction measures, the EU F-gas Regulation 517/2014 and regulations in the United States (EPA SNAP Program).

Total HFC demand expressed in CO_2 equivalents for the period from 2010 to 2050 was calculated based on total HFC demand (in metric tonnes), consisting of new manufacturing and servicing HFC demand, and was further differentiated by country groups, i.e. A2 and A5 countries. Substances included in the TEAP HFC consumption data encompass the most common HFCs (HFC-134a) and refrigerant blends (R404A, R507, R410A, and R407C), used in the six RAC sectors (domestic, commercial and industrial refrigeration, transport, stationary and mobile air-conditioning).

Due to the fact that TEAP only provides data in five-year steps from 2010 to 2050, a linear interpolation was performed to approximate the HFC consumption of the missing years. For the second half of the century, i.e. from 2051 to 2100, the quantity of HFCs probably consumed was estimated using a moving trend calculation.

As shown in *Table 1*, baselines are to be calculated from HFCs (A2 and A5 countries) as well as historic HCFC (A5 countries) and HCFC/CFC (A2 countries) consumption. HCFC and CFC baseline data were obtained from the UNEP Data Centre.[4]

HCFCs and CFCs as fluorinated ozone-depleting substances and HFCs are characterised by a long atmospheric lifetime and are therefore assumed to contribute significantly to global warming over their long atmospheric life time. The GWP is commonly used as it, among other things, integrates the radiative forcing of substances over the selected time horizon, relative to that of CO_2. Mostly applied to 100 years, the GWP was adopted as an emission metric to implement a “multi-gas” approach, embedded in the United Nations Framework Convention on Climate Change (UNFCCC) and made operational in the Kyoto Protocol 1997. GWP values are regularly updated by the Intergovernmental Panel on Climate Change (IPCC) and have also been added to the Kigali Agreement’s Annexes. All calculations in this report are based on GWP_{100} values from the IPCC’s Fourth Assessment Report (AR4). As only ODP tonnes can be retrieved from the UNEP Data Centre, HCFC/CFC consumption data had to be converted into CO_2 equivalents.

Due to the differentiation of baselines and phase-down schedules under the Kigali Amendment, it was necessary to apportion the available consumption data for A2 and A5 countries into subgroups. The split of the subgroups was determined based on regional HFC base level amounts published by Velders et al. (2015) and HCFC/CFC baseline data available at UNEP Data Centre.

In order to assess the impact of the HFC emissions on global warming, results from Xu et al. (2013) were used. Xu et al. showed that the replacement of all HFCs with low-GWP substitutes could avoid warming of as much as 0.35 to 0.5° Celsius by 2100. Assuming that the total HFC consumption under the BAU scenario aligns reasonably well with the BAU data of Xu et al., we set our BAU data in relation to the temperature change in Xu et al. and applied this ratio to all HFC data for the different scenarios.

[4] UNEP Data Access Centre (see http://ozone.unep.org/en/data-reporting/data-centre)

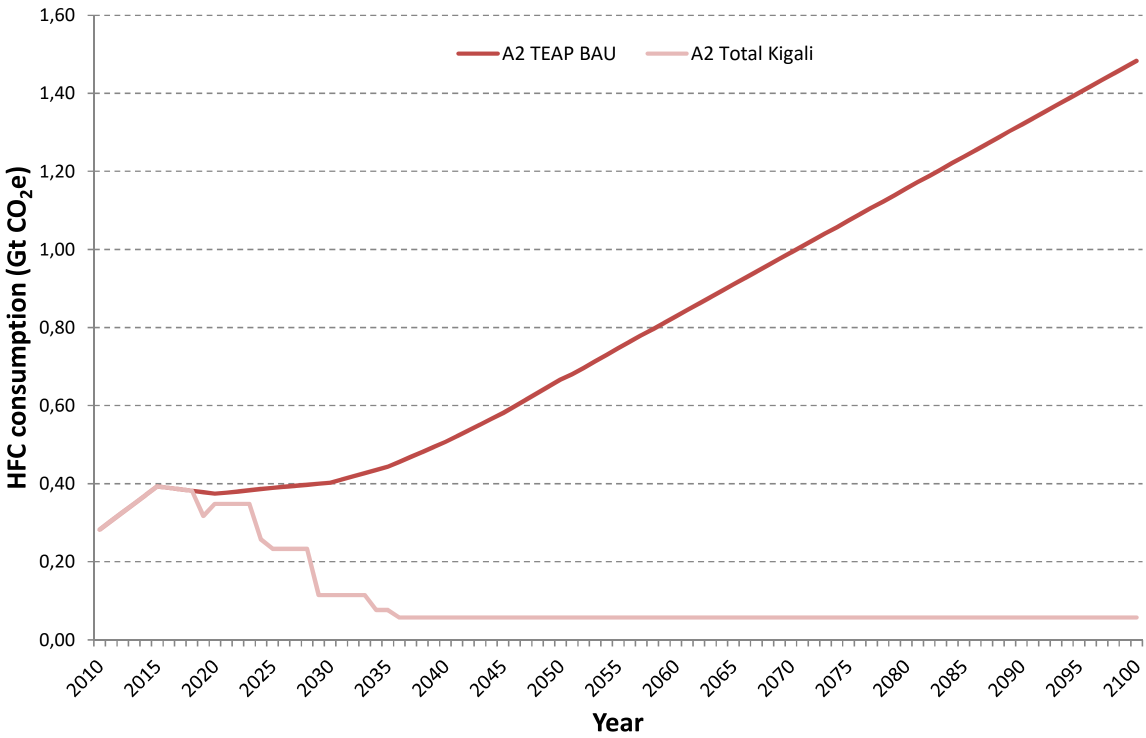
3 Climate benefits of the Kigali Amendment

According to our calculations, the combined HFC consumption of developed (A2) and developing (A5) countries would continue to increase and could reach 5.3 Gt CO_2e in 2050 and 12.5 Gt CO_2e in 2100, without the implementation of the Kigali Amendment (BAU).

In A2 countries, national and regional actions have already been introduced. However, as *Figure 2* shows, HFC BAU consumption would further increase to about 1.5 Gt CO_2e in 2100, in case the Kigali Amendment would not come into force, adding up to a cumulative climate effect of about 71 Gt CO_2e.

While the majority of A2 countries will begin phasing down HFCs from 2019 onwards (Group 1), some A2 countries will start the reduction with slight delay in 2020 (Group 2, see also *Table 1*). For both groups, HFC consumption will reach a plateau of 15 % of the respective baselines in 2036.

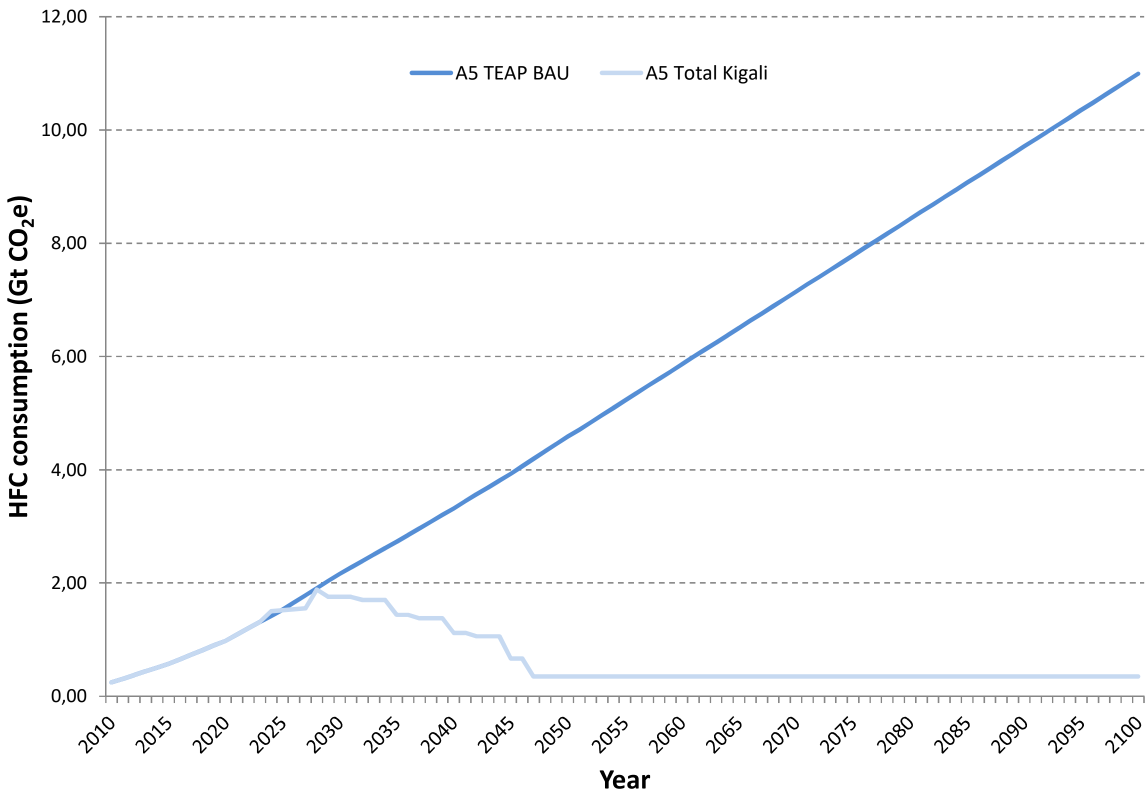
Figure 2: *HFC phase-down for A2 countries*



Unlimited HFC growth in A5 countries (*Figure 3*) would have an enormous climate impact, reaching about 11 Gt CO_2e in 2100 and a cumulative climate effect of 481 Gt CO_2e until the end of this century. The comparison of the HFC consumption (BAU) for A2 and A5 countries reached at the end of this century shows that the climate effect of A5 countries is considerably larger.

Under the Kigali Amendment, most A5 countries will freeze their HFCs from 2024 to 2028 before starting the actual reduction in 2029 (Group 1), while some will take the first reduction step in 2032, after freezing HFC consumption from 2028 to 2031 (Group 2). In 2045 or 2047 A5 countries will reach a plateau of 20 % or 15 %, respectively.

Figure 3: *HFC phase-down for A5 countries*



As a result of the above mentioned HFC phase-down schedules for A2 and A5 countries, a successful implementation of the Kigali Amendment could result in a climate benefit of about 58 Gt CO_2e by 2050. With regard to 2100, the HFC reduction would accumulate to about 484 Gt CO_2e, leaving a remaining HFC quantity (tail consumption) of about 68 Gt CO_2e.

4 Climate benefits of total global HFC phase-out scenarios

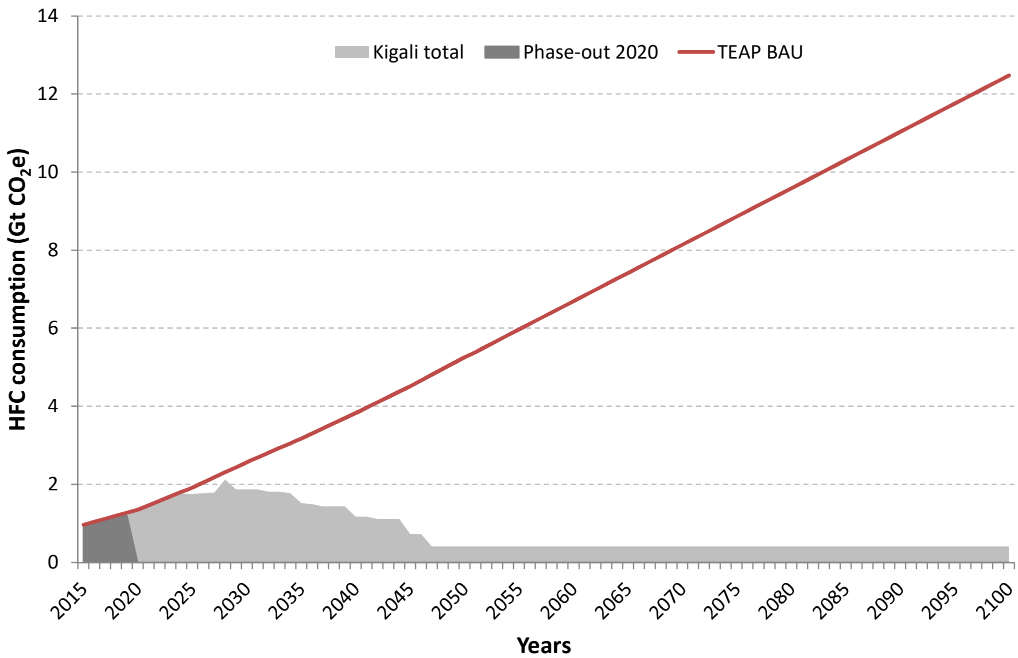
The different HFC phase-down schedules that were adopted under the Kigali Amendment imply that the vast majority of HFCs will be reduced in earlier years, while after the final plateau is reached, the HFC consumption will stay at a low and steady level (0.41 Gt CO_2e per year) for the period from 2047 onwards. Until 2100, this HFC tail consumption adds up to about 22 Gt CO_2e.

Results for three different global HFC phase-out scenarios are presented in the following. All results refer to the time period from 2015 to 2100. Until the HFC phase-out takes effect, it is assumed that the adopted HFC phase-down schedules apply.

Compared to the HFC phase-down to be implemented by the Kigali Amendment, a **total global HFC phase-out**, i.e. a phasing out of HFCs without any transitional provisions,

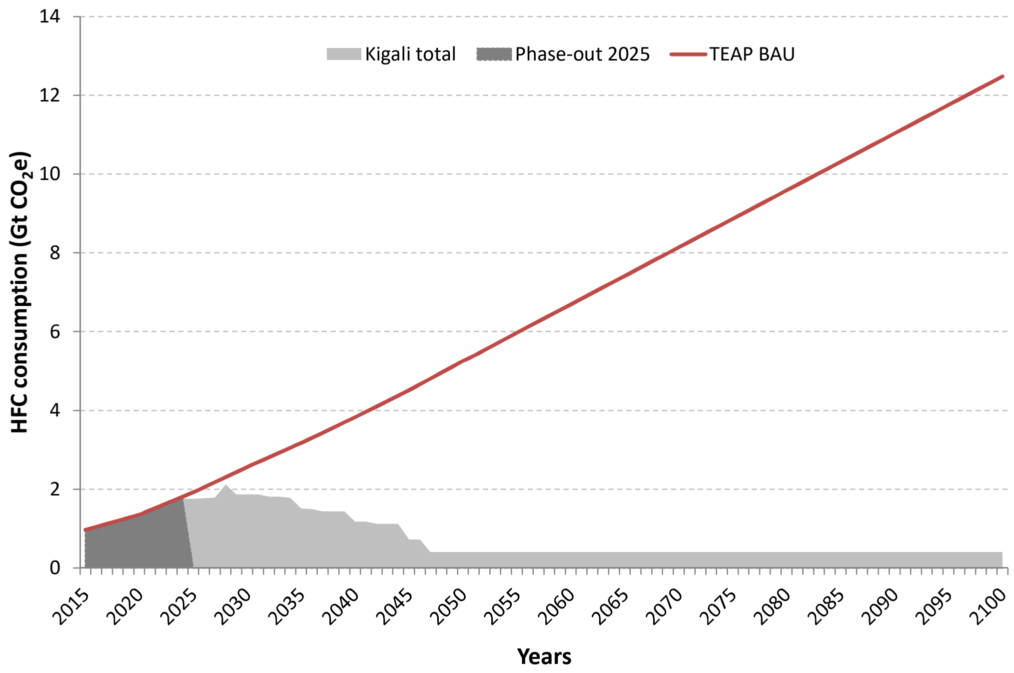
1) **by 2020** could lead to an additional cumulative reduction of HFC consumption of about 62 Gt CO_2e, illustrated as light grey shaded area in *Figure 4.* The dark grey shaded area shows that the remaining share of HFC consumption will be about 6 Gt CO_2e.

Figure 4: *Climate benefits of a total global HFC phase-out by 2020*



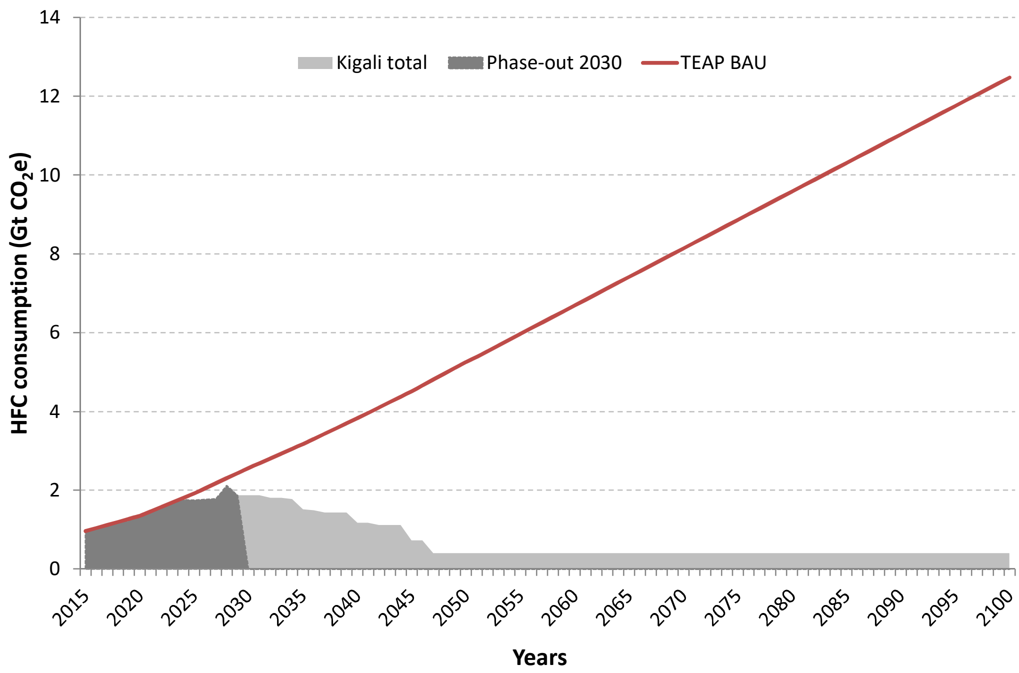
2) **by 2025** could lead to an additional cumulative reduction of HFC consumption of about 55 Gt CO_2e, illustrated as light grey shaded area in *Figure 5*. The dark grey shaded area shows that the remaining share of HFC consumption will be about 13 Gt CO_2e.

Figure 5: *Climate benefits of a total global HFC phase-out by 2025*



3) **by 2030** could lead to an additional cumulative reduction of HFC consumption of about 45 Gt CO_2e, illustrated as light grey shaded area in *Figure 6.* The dark grey shaded area shows that the remaining share of HFC consumption will be about 23 Gt CO_2e.

Figure 6: *Climate benefits of a total global HFC phase-out by 2030*



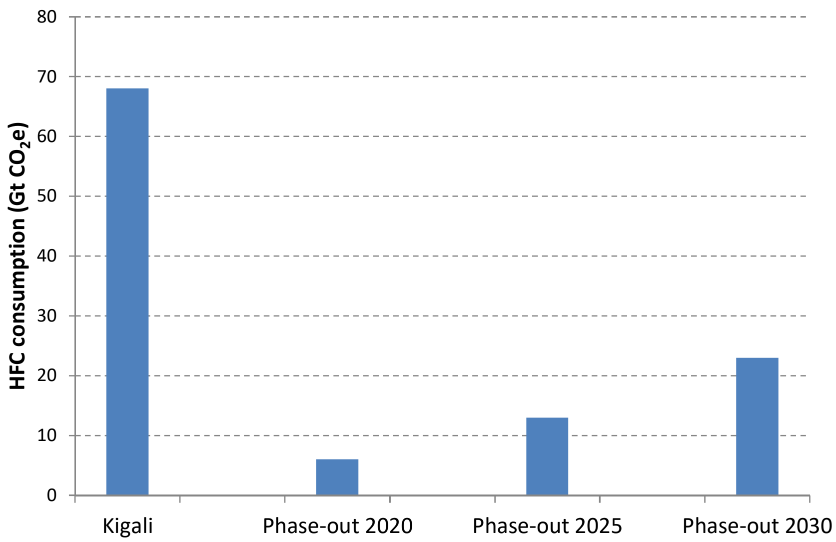
The following *Table 2* summarises the above mentioned calculation results.

Table 2: *Projected impact of the HFC phase-down and HFC phase-out scenarios from 2015 to 2100*

	Kigali HFC phase-down	HFC phase-out 2020	HFC phase-out 2025	HFC phase-out 2030
Reduction compared to TEAP BAU	484 Gt CO_2e	546 Gt CO_2e	539 Gt CO_2e	529 Gt CO_2e
Reduction compared to Kigali HFC phase-down		62 Gt CO_2e	55 Gt CO_2e	45 Gt CO_2e
Remaining HFC consumption	68 Gt CO_2e	6 Gt CO_2e	13 Gt CO_2e	23 Gt CO_2e

Figure 7 provides an overview of the climate benefit from the reduction scenarios. It clearly shows that a total global HFC phase-out will have an increasing impact on CO_2e reduction, the earlier it is implemented.

Figure 7: *Remaining HFC consumption*



5 Conclusions: Avoided temperature increase

Xu et al. (2013) stated that the replacement of all HFCs with low-GWP substitutes could avoid warming of as much as 0.35 to 0.5° Celsius by 2100.

According to our calculations, the Kigali Amendment will result in a limitation of global temperature rise (*Table 3*), avoiding 0.31 to 0.44° Celsius by 2100. This would imply that, since the Kigali Amendment will implement a HFC phase-down, the remaining HFC quantities will likely still cause warming of up to 0.06° Celsius by 2100.[5]

As *Table 3* shows, all phase-out scenarios will further increase the climate benefit compared to the HFC phase-down. In general, the scale of improvement depends on the date on which the HFC phase-

[5] Similarly, Velders recently stated that the remaining contribution of HFCs still allowed under the Kigali Amendment will amount to 0.06° Celsius to global warming by 2100. (http://www.sciencemag.org/news/2016/10/how-key-number-new-deal-curb-refrigerating-chemicals-was-born).

out would be introduced. What all HFC phase-out scenarios have in common is that they avoid an unlimited consumption of HFCs at a low and steady level (tail consumption).

Table 3: *Climate benefit (avoided temperature increase) of the HFC phase-down and HFC phase-out scenarios on global warming by 2100*

	Kigali HFC phase-down	**HFC phase-out 2030**	**HFC phase-out 2025**	**HFC phase-out 2020**
Climate benefit by 2100	0.31 - 0.44° C	0.34 - 0.48° C	0.34 - 0.49° C	0.35 - 0.49° C

The largest climate benefit results from the implementation of a HFC phase-out in 2020, which allows for avoiding warming of as much as 0.34 to 0.48° Celsius by 2100. The climate benefit of a 2020 phase-out is likely to be up to approximately 0.05° Celsius larger compared to the HFC phase-down agreed under the Kigali Amendment. Looking at a HFC phase-out in 2025 or 2030, climate benefits are slightly lower, i.e. the additional climate benefit resulting from a phase-out only slightly differs among the proposed phase-out scenarios. In conclusion, a HFC phase-out could strengthen international efforts to reach the long-term goals of the Paris Agreement.

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