

Achieving Paris climate goals calls for increasing ambition of the Kigali Amendment

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Brief Communication

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Abstract

We assess that full global compliance with the Kigali Amendment to the Montreal Protocol will not provide emission reductions consistent with the 1.5°C target of the Paris Agreement. Following the Montreal Protocol's start-and-strengthen approach to refrigerant management, fast-tracking hydrofluorocarbon phase-down under the Kigali Amendment would result in additional reductions vital for achieving the Paris climate goals. This would also increase chances of staying below 1.5°C additional warming throughout this century.

Main

Hydrofluorocarbon (HFC) refrigerants are factory-made chemicals produced for use in refrigeration, air conditioning, insulating foams, fire extinguishers, solvents and aerosol propellants. Since their introduction emissions of HFCs have grown rapidly as they are the primary replacement for ozone-depleting substances (ODSs) currently managed under the Montreal Protocol^{1,2,3}. HFCs are not ODSs but powerful greenhouse gases (GHGs) and account for about 1.5% of global anthropogenic GHG emissions². Without any controls, HFC emissions are expected to double by 2030 and nearly quadruple by 2050 over the 2015 level^{3,4}.

Even though HFCs are not ODSs, an international consensus was achieved that HFCs could be most effectively controlled through the phase-down of their production and consumption under the Montreal Protocol⁵, complementary to mitigation under the UN Framework Convention on Climate Change (UNFCCC). The Montreal Protocol has the experience and expertise to ensure a fast, effective, and efficient phase-down of HFCs, which are in the same family of gases, have similar chemical properties and are used in the same sectors as the ODSs that they are replacing. The Montreal Protocol also utilizes a 'start and strengthen' approach wherein controlled substances are phased out in an orderly and transparent schedule which is regularly evaluated and strengthened, through amendments, as markets innovate and adjust (Fig S1). Furthermore, unlike the Paris Agreement to the UNFCCC, the Montreal Protocol and its amendments are legally binding for countries that ratify them.

The Kigali Amendment (KA) to the Montreal Protocol (in force since 1 January 2019) is a global agreement to phase down consumption of HFCs by 80-85% by the late 2040s (See: Table S2). Unlike previous Montreal Protocol amendments, which managed ODSs, the KA is primarily a climate treaty, therefore it is appropriate to evaluate the sufficiency of its ambition based on its consistency with climate mitigation targets. The 2015 Paris Agreement established an ambitious target of limiting global temperature rise this century to well below 2°C preferably to 1.5°C, compared to pre-industrial levels, but did so in the context of broader international goals of sustainable development and poverty eradication. The 1.5°C-consistent scenarios used in *IPCC's Special Report on Global Warming of 1.5°C (SR1.5)* include a 70-80% reduction in HFC emissions by 2050 compared to 2010 levels⁶ along with deep and simultaneous reductions of CO₂ and all non-CO₂ climate-forcing emissions.

A recent IIASA study⁷ use the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model⁸ framework to develop a range of long-term scenarios for HFC emissions under varying degrees of stringency in climate policy and assess co-benefits in the form of electricity savings and associated reductions in GHG and air pollutant emissions. Full compliance with the KA (Fig. 1 (a)) is expected to achieve a 56% reduction in HFC emissions by 2050, compared to 2010 levels^{7,9}. This will not surpass the 70-80% threshold set by 1.5°C consistent scenarios⁶. Full compliance with the KA phase-down schedule is estimated to avoid 0.2 to 0.4°C additional warming by the end of this century^{3,10} which is significant, but insufficient to achieve a 1.5°C-consistent pathway⁶. Despite the widely recognized success of the Montreal Protocol for phasing out ODSs faster¹¹ and at a lower cost than originally assumed, some observers question whether the HFC-reduction process under KA is taking place quickly enough to adequately address the urgency of the climate crisis¹². Considering the role HFC mitigation plays in 1.5°C consistent scenarios⁶, enhancing the ambition of mitigation efforts by all Parties to the Montreal Protocol is called for. In this study, we develop a series of alternative HFC phase-down scenarios (Fig. 1) consistent with the Montreal Protocol's history and experience of a gradual increase in ambition.

The Kigali Amendment defines HFC phase-down schedules for four different Party groups. The first group (Article 5-Group 1) includes 136 primarily developing countries that make up all Article 5 countries with the exception of ten countries characterized by high ambient air temperatures forming a second group (Article 5-Group 2) and allowed less ambitious timing of targets. Non-article 5 countries are primarily developed countries and under KA divided into two groups with 45 countries in a first group (non-Article 5-Earlier start) and five in a second group allowed to start somewhat later (non-Article 5-Later start).

Figure 2 (a) presents the HFC emissions (CO₂eq using GWP₁₀₀ from IPCC/AR5¹³) for all analyzed scenarios. In a pre-KA baseline, HFC emissions increase to about 4.2 Gt CO₂eq by 2050, which is within the range of previous estimates (4.0–5.3 Gt CO₂eq) by Velders et al.¹⁴ With full KA compliance, global HFC emissions drop to 0.32 Gt CO₂eq by 2050, achieving 56% reduction compared to 2010 levels. Technology exists that if deployed globally to a maximum extent could achieve near-complete mitigation of HFC emissions one-decade sooner than the KA phase-down schedule, resulting in a cumulative reduction of approximately 77 Gt CO₂eq HFC emissions until 2050 (Table S2). Such a rapid reduction is however infeasible on practical grounds and also inconsistent with the Montreal Protocol's history of a phased step-wise approach to refrigerant management. Instead, we have analyzed a set of more realistic reduction scenarios.

First, we analyze whether aligning Article 5-Group 2 countries with the higher ambition level of the Article 5-Group 1 (*A5-Groups 1&2-alignment scenario*) would result in achieving the Paris Agreement targets, however found that this would not be the case, as shown in Fig. 2 (b), where the orange box indicates the 70-80% threshold set by 1.5°C consistent scenarios⁶. In a second set of three scenarios, we increased the ambitions of both Article 5 and non-Article 5 parties, resulting in achieving the Paris Agreement targets globally by 2050, however with different cumulative emissions until 2050 due to variations in the timing

of adapted KA targets. If Article 5 and non-Article 5 party groups follow the KA phase-down schedules but step-up ambitions in their final phase-down step (starting in 2036 for non-Article 5 with Article 5 following only in year 2050) to 95% below baseline in 2050 (*95% scenario*), then the resulting cumulative reduction is 61 Gt CO₂eq (Table S2). If the *A5-Groups 1&2-alignment scenario* and *95% scenario* are combined (*Combined scenario*), the resulting cumulative reduction is 63 Gt CO₂eq. Finally, if the combined scenario is accelerated with a more ambitious target timeline (*Accelerated combined scenario*), with non-Article 5 countries achieving 95% reduction already in 2036 and Article 5 countries starting earlier and achieving 95% in 2045, then a cumulative HFC reduction potential of 69 Gt CO₂eq can be achieved. The latter scenario follows the example of the accelerated phaseout of HCFCs under the Montreal Protocol from 2007. In particular for the period 2021-2030, the cumulative emissions are lower in the *Accelerated combined scenario* compared to other scenarios.

The developing countries are less than three years away from the first HFC consumption compliance obligation of the Kigali Amendment applicable to Article 5-Group 1 countries. Much still needs to be done to ensure that all these countries are ready to comply with the 2024 HFC freeze. In countries where HFC consumption is projected to exceed their baselines by 2024, there is an urgent need to implement actions towards a rapid transition to low-GWP refrigerants. In countries where HFC consumption is projected lower than their baselines by the agreed freeze year, there are opportunities for faster implementation of the Kigali Amendment to achieve HFC emission reductions earlier than strictly required under Kigali.

The Kigali Amendment provides an important opportunity and framework to control the production and consumption of HFCs resulting in reductions of both direct and indirect emissions from the cooling sector. Combining benefits from energy efficiency and climate-friendly cooling is vital to developing markets with rising cooling demand. Harnessing such opportunities by ensuring the transition to low-GWP refrigerants is combined with adoption of energy efficient cooling equipment can potentially double the climate benefits of the HFC phase-down³ and save as much as 20% of the expected future global electricity consumption⁷. Lower electricity consumption also offsets the need to build new power plants and increases energy access across emerging economies. For example, transitioning to low-GWP refrigerants with enhanced energy efficiency in room air-conditioners in China could avoid the construction of approximately 300 coal-fired power plants (500 MW each) by 2050¹⁵. Therefore, an early HFC phase-down will foster sustainable growth with energy-efficient, innovative technologies that provide jobs, increase energy access, and reduce air pollution while reducing consumer energy bills.

The Kigali Amendment is a work in progress, but one that needs to be embraced and expanded upon in the global interests of mitigating climate change, just as the original Montreal Protocol has been instrumental in the recovery of the stratospheric ozone layer. An example of progressive legislation could be the HFC reduction steps under the EU F-gas regulation that are more ambitious than what is included in the Kigali Amendment¹⁶. Finally, if parties to the Montreal Protocol do not align early HFC phase-down policies with their economic transformation plans in the post-COVID era, they might not only become

more vulnerable to climate shocks but also miss out on new technologies, investment and market access in a rapidly shifting global economy.

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Methods

In developing the baseline HFC emissions under IIASA study⁷, the historical consumption of HFCs for major sources, i.e., stationary and mobile air-conditioning and domestic refrigerators, have been derived in a consistent manner across countries, starting from a compilation of data on underlying drivers, e.g., the number of vehicles by type, commercial floor space area, cooling degree days, per capita income, average household sizes, current equipment penetration rates, etc. Estimating HFC consumption in commercial, industrial and transport refrigeration, foams and other smaller HFC sources (e. g. aerosols, fire extinguishers, solvents) is more challenging since it varies greatly between countries due to differences in industrial structures and consumption patterns¹⁷. For these sectors, historical HFC consumption, as reported by industrialized countries to the UNFCCC, has been adopted when available. For developing countries, information on HFC consumption in these sectors has been compiled from various published sources, alternatively, derived consistently from underlying activity data using default factors from literature^{7,18}. For the development of the baseline scenarios until 2040 we use the existing model setup in GAINS⁸, which for global scenarios uses drivers consistent with macroeconomic and energy sector projections from the International Energy Agency¹⁹. The extension in demand for cooling services between 2040 and 2100, expressed in tonnes of HFC consumed⁷, is consistent with the growth in population and macroeconomic indicators of the third Shared Socioeconomic Pathway (SSP3)²⁰ and the expected future increase in regional CDDs.

In addition to the Kigali amendment (KA) and Maximum Technically Feasible Reduction (MTFR) scenarios as explained in the IIASA study⁷, we analyze four additional scenarios for HFC phase-down to achieve the Paris Agreement targets by 2050. In the *A5-Groups 1&2-alignment scenario*, we assume that Article 5 Group 2 countries join the Article 5 Group 1 phase-down schedule immediately as shown in Fig. 1 (b). Note that Article 5 Group 2 countries have a later freeze date (Table S1) and delayed phase-down

steps compared with Article 5 Group 1 under the Kigali Amendment. In the *95% scenario*, we assume that all party groups will follow the Kigali Amendment phase-down schedules but in addition, the final phase-down step by 2050 will be 95% of baseline, valid for all party groups, as shown in Fig. 1 (c). In the *Combined scenario*, we assume that Article 5 Group 2 countries join the Article 5 Group 1 phase-down schedule immediately as in the case of the *A5-Groups 1&2-alignment scenario* and in addition, the final phase-down step by 2050 will be 95% of baseline and just like in the case of *95% scenario*, be valid for all party groups, as shown in Fig. 1 (d). Finally, the *Accelerated combined scenario* is designed following the example of the accelerated phaseout of HCFC in 2007 (Fig. S1) as shown in Fig. 1 (e). In the case of the HCFC example, the accelerated phaseout was agreed upon 11 years after the freeze date set for non-Article 5 countries and three years after the first phaseout step, but before the freeze date set for Article 5 countries.

Figures

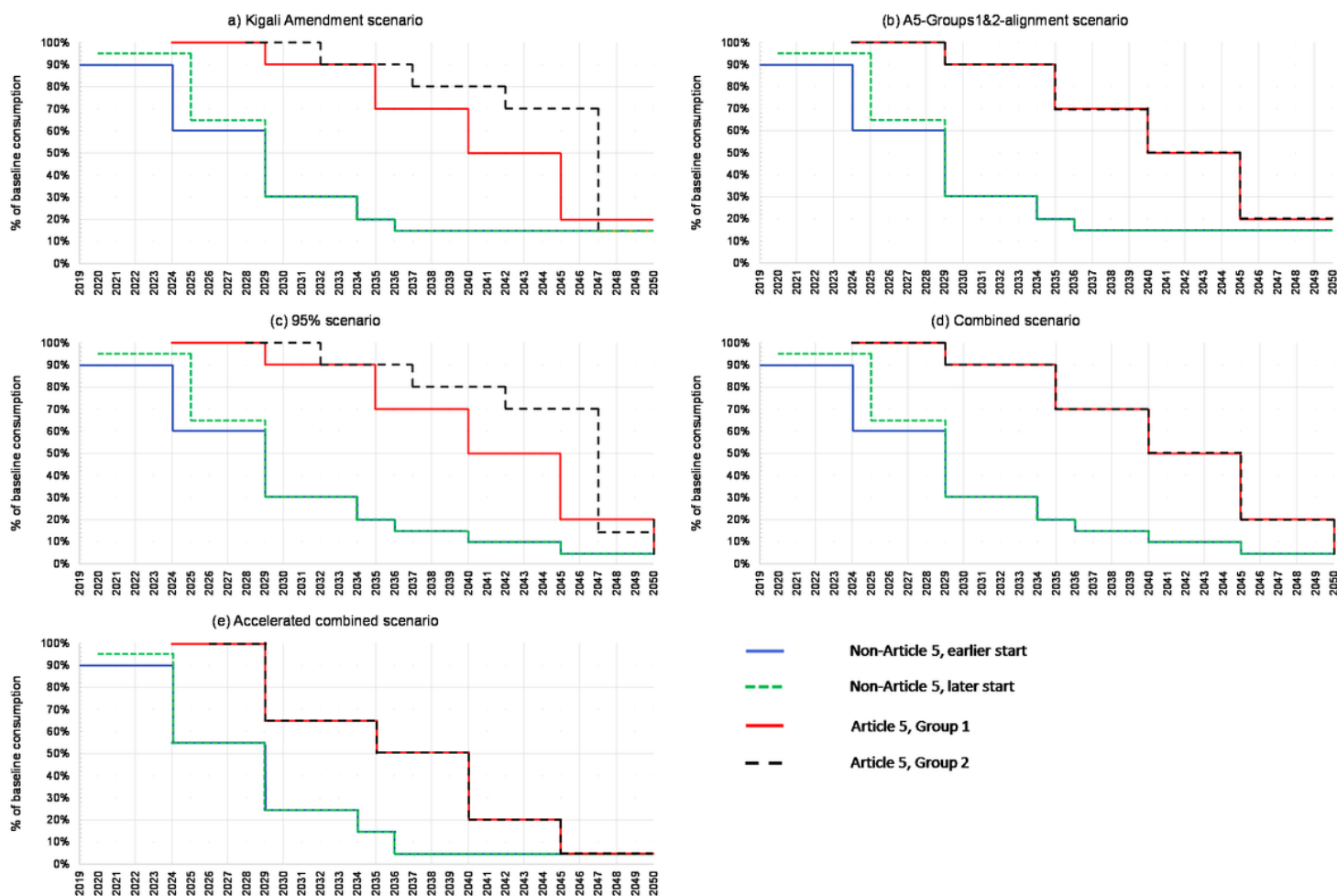


Figure 1

HFC phase-down schedule in Kigali amendment and alternative scenarios

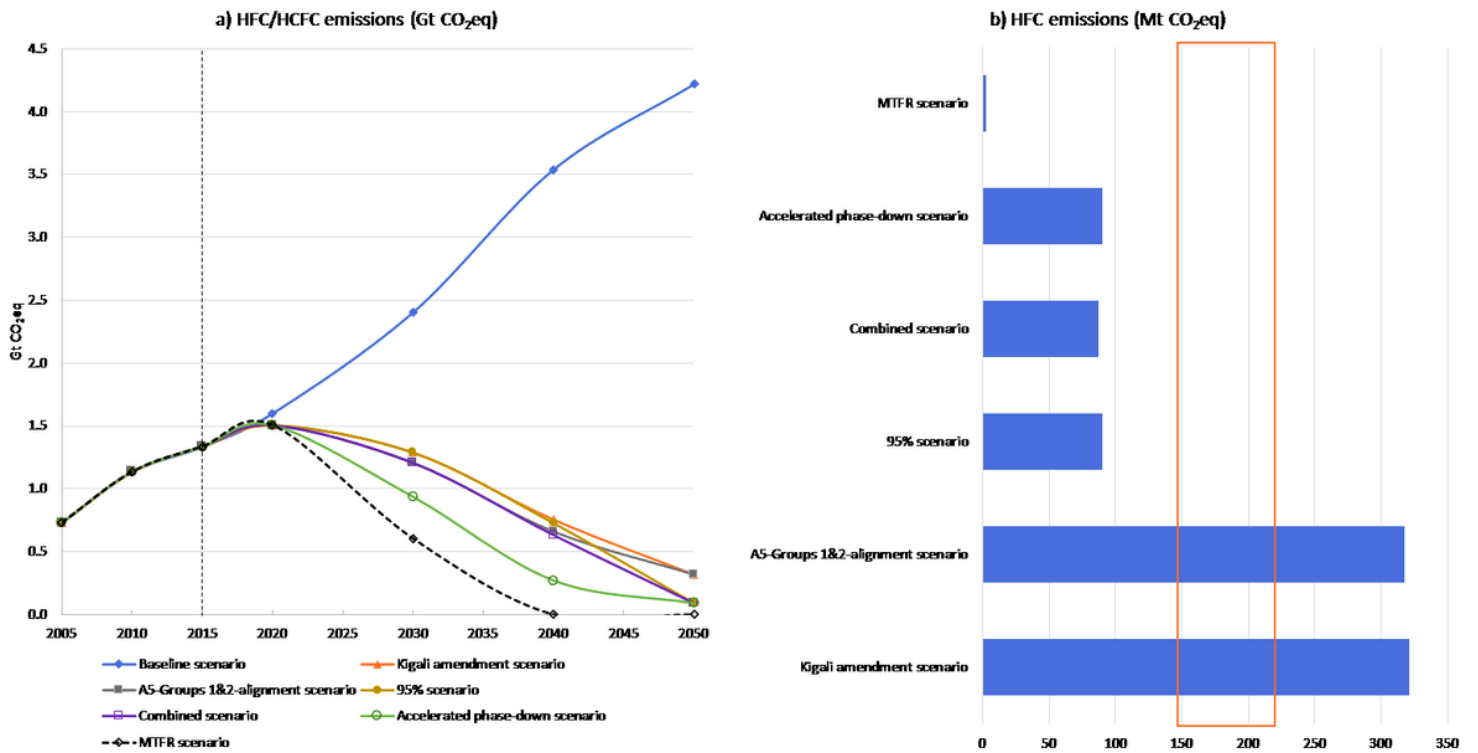


Figure 2

a) HFC emissions (2005-2050) in the baseline and alternative scenarios; b) HFC emissions in 2050 under KA, MTR and additional alternative scenarios; the orange box indicates the estimated range of HFC emissions consistent with the 1.5 oC target⁶.

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