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Report

Impacts of the Kigali Amendment to phase-down hydrofluorocarbons (HFCs) in Asia

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Table of Contents

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1. Introduction

The Montreal Protocol (UNEP, 2007) has successfully worked to phase out the use of ozone depleting substances (ODSs) primarily by substituting the use of chlorofluorocarbons (CFCs) and hydrochloroflourocarbons (HCFCs) with hydrofluorocarbons (HFCs) in various sectors such as refrigeration, air-conditioning, aerosols, fire extinguishers and foam blowing. As well, HFC-23 is generated as a by-product of HCFC-22 production for feedstock and emissive use. The high Global Warming Potentials (GWP) of HFCs replacing ODSs is a climate concern and the reason behind the Kigali Amendment of the Montreal Protocol adopted during the 28th Meeting of the Parties 8-14 October 2016 in Kigali, Rwanda (UNEP, 2016a) to phase-down the use of HFCs globally by 2050. HFC emissions have increased significantly in recent years and can without a targeted HFC phase-down be expected to rise further in response to increased demand for cooling services and the phase-out of ODSs. The focus of this study is to analyze the implications on emissions and co-benefits like electricity savings of meeting the HFC phase-down targets in Asian countries set out in the Kigali Amendment to the Montreal Protocol. We develop baseline and alternative policy scenarios for Asian countries using the HFC module of the Greenhouse gas and Air pollution Interactions and Synergies (GAINS) model (http://gains.iiasa.ac.at) framework developed by the International Institute for Applied Systems Analysis and described in Purohit and Höglund-Isaksson (2017).

The report is structured as follows: Section 2 briefly explains different policy scenarios analyzed in this study. Section 3 highlights key control measures adopted by Asian countries. Section 4 presents estimated HFC emissions in different policy scenarios along with mitigation potentials and discusses possible co-benefits associated with mitigation. Section 5 concludes key findings and policy recommendations.

2. HFC emission scenarios

In this study, we have used an updated version of Purohit and Höglund-Isaksson (2017) consistent with the findings presented in Höglund-Isaksson et al. (2017) to specifically analyze HFC emissions and mitigation potentials in Asian[1] countries over the period 2018 to 2050 under different policy scenarios. Key drivers at the sectoral level, source-specific emission factors, and assumptions about the implementation of control policies in the baseline scenario are presented in detail in the supplementary section of Purohit and Höglund-Isaksson (2017) with updated assumptions about electricity savings at the technology level presented in Table S1 of the supplement of Höglund-Isaksson et al. (2017). Assumptions about future economic growth and energy consumption are consistent with those of the Medium cost scenario of the IEA's report Energy Technology Perspectives 2012 (IEA, 2012). We apply

1 Including Afghanistan, Bangladesh, Bhutan, Brunei, Cambodia, China, India, Indonesia, Iran, Japan, Laos, Malaysia, Mongolia, Myanmar, Nepal, North Korea, Pakistan, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand and Vietnam.

IPCC AR5 global warming potentials (GWPs) over 100 years with climate–carbon feedback effects (IPCC, 2013).

The following policy scenario have been analyzed in this study:

1) The 2005 freeze scenario describes the expected future emission path had the emission control situation of year 2005 been preserved into the future (i.e., no further regulations adopted after 2005 to reduce CFC, HCFC, and HFC emissions). It should however be noted that prior to 2005 substitutes with low global warming potential like hydrocarbons and ammonia were already employed to varying extents in some sectors and regions.

2) The pre-Kigali baseline scenario reflects emissions taking into account the effects of control legislation adopted by 2015. This includes effects of F-gas legislations adopted in the EU, US, Japan, Canada, Australia and Intended Nationally Determined Contribution (INDC) pledges of China for an effective control of HFC-23 by 2020.

3) The post-Kigali scenario is developed to analyze the implications of achieving the HFC phase-down targets set out in the Kigali Amendment. The post-Kigali scenario assumes that all countries meet the targets set out in the Kigali Amendment.

4) The maximum technically feasible reduction (MFR) scenario is developed to assess the maximum technically viable reduction of HFCs at the sectoral and regional levels. The abatement potential in the MFR scenario encompasses reductions in emissions through the application of technologies that are currently commercially available and already tested and implemented, at least to a limited extent.

The Kigali Amendment sets targets for the phase-down of HFCs consumption for four different Party groups. The first group primarily includes 136 developing countries that make up all Article 5 countries as specified under the Montreal Protocol with the exception of Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates (UAE). These ten countries are characterized by high ambient air temperatures and make up a second and separate group of Article 5 countries. Countries specified as non-Article 5 countries under the Montreal Protocol are primarily developed countries and under the Kigali Amendment divided into two separate groups with 45 countries in a first group and with the five countries Belarus, the Russian Federation, Kazakhstan, Tajikistan and Uzbekistan forming a separate second group. Table 1 presents the baseline years and HFC phase-down schedule of Article 5 and non-Article 5 Parties. We will hereafter refer to these four Party groups as Article 5 Group I, Article 5 Group II, non-Article 5 Group I, and non-Article 5 Group II.

Table 1. Baseline and HFC phasedown schedule of Article-5 and non- Article-5 Parties

	Article 5 Parties: Group I		Article 5 Parties: Group II	
Baseline Years	2020, 2021 & 2022		2024, 2025 & 2026	
Baseline Calculation	Average production /consumption of HFCs in 2020, 2021, and 2022 *plus* 65% of HCFC baseline production/consumption		Average production /consumption of HFCs in 2024, 2025, and 2026 *plus* 65% of HCFC baseline production/consumption	
Reduction steps Freeze	2024		2028	
Step 1	2029	10%	2032	10%
Step 2	2035	30%	2037	20%
Step 3	2040	50%	2042	30%
Step 4	2045	80%	2047	85%
	Non-Article 5: Group I		**Non-Article 5: Group II**	
Baseline Years	2011, 2012 & 2013		2011, 2012 & 2013	
Baseline Calculation	Average production /consumption of **HFCs** in 2011, 2012 & 2013 *plus* **15%** of **HCFC** baseline production/consumption		Average production /consumption of **HFCs** in 2011, 2012 & 2013 *plus* **25%** of **HCFC** baseline production/consumption	
Reduction steps Step 1	2019	10%	2020	5%
Step 2	2024	40%	2025	35%
Step 3	2029	70%	2029	70%
Step 4	2034	80%	2034	80%
Step 5	2036	85%	2036	85%

Source: UNEP (2016a)

3. HFC control measures in Asian countries

To estimate HFC emissions in the pre-Kigali baseline scenario, we take into account the effects on emissions from implementation of existing legislation to control HFC emissions at the regional or national level. For developing countries, several studies discuss the impact of the Clean Development Mechanism (CDM) projects on HFC-23 emissions from HCFC-22 production for emissive and feedstock applications (Wara, 2007; Miller et al., 2010; Montzka et al., 2010; Miller and Kuijpers, 2011; Schneider, 2011). HFC-23 emissions from HCFC-22 production are assumed to be controlled in most developing countries due to CDM (Fenhann, 2014), except China where 36% of HCFC-22 production is controlled (Feng et al., 2012).

The Chinese production capacity of HCFC-22 accounts for 78% of the global HCFC production (UNEP, 2014). HCFC-22 is a major source of HFC-23 emissions, which is a strong greenhouse gas with GWP_{100} of 12,400 times that of CO_2 (IPCC, 2013). In its Intended Nationally Determined Contribution (INDC) submitted in June 2015, China reiterated its commitment under the Montreal Protocol to achieve effective control on emissions of HFC-23 by 2020. In 2015, the Chinese National Development and Reform Commission (NDRC) announced that it plans to achieve abatement of all HFC-23 emissions by 2019 (Sachweh and Zhu, 2015). This would imply installing destruction technology in all plants currently not covered by CDM and ensuring that the destruction technology on plants covered under CDM is being operated and maintained. In line with this information, we assume in recent updates of the GAINS model that all HCFC-22 production facilities in China will be fully controlled from 2020 onwards. It is observed that except for China other Asian countries do not make HFC specific emission reduction commitments in the INDCs (UNFCCC, 2016).

In the 28th Meeting of the Parties to the Montreal Protocol in October 2016 in Kigali, the Indian government presented a domestic legislation that mandates control of trifluoromethane (HFC-23) emissions. At present, all HCFC-22 production facilities in India are fully controlled under the Clean Development Mechnism (CDM) and we assume the control on all Indian facilities stays operational and maintained in the future.

In Japan, the Fluorocarbons Recovery and Destruction Law was amended and became effective on 1st April 2015 as the *Act on Rational Use and Proper Management of Fluorocarbons* (Fluorocarbon Emission Control Law) (METI, 2015). Among other requirements, the Act requires entities manufacturing and importing air conditioning and refrigeration units to transition to either fluorocarbon-free refrigerants or to low global warming fluorocarbons by certain target years.

4. Results and Discussion

4.1 HFC emissions in Asian countries

HFC emissions in Asia in the pre-Kigali baseline scenario are presented in Figure 1 by source sector. For historical years 2005 and 2010, the contribution from HFC emissions to global warming are estimated at 0.15 and 0.22 Gt CO_2eq, respectively. Future emissions in the pre-Kigali baseline scenario are estimated to increase by a factor of 11 between 2005 and 2050. The growth is mainly driven by a large increase in demand for refrigeration and air-conditioning services, which in turn is driven by an expected increase in per capita wealth in developing countries combined with the effect of replacing CFCs and HCFCs with HFCs in accordance with the 2007 revision of the Montreal Protocol (UNEP, 2007). Figure 1 also presents the expected HFC emissions in Asia under alternative policy scenarios. If the level of control present in 2005 would have been preserved into the future, HFC emissions would have been expected to increase by a factor of 14 reaching annual emissions of 2.13 Gt CO_2eq in 2050 (upper dashed line in Figure 1). This is almost exclusively due to the control of HFC-23 emissions from HCFC-22 production implemented after 2005. In the post-Kigali scenario (middle dashed line in Figure 1) HFC emissions in Asia decline gradually over the analyzed period reaching 95% removal of pre-Kigali baseline emissions on an annual basis in 2050. The MFR scenario (lower dashed line) shows that it is considered technically feasible for Asian countries to move earlier in terms of emission reductions and to remove more than 99% of annual emissions in the period 2035 to 2050.

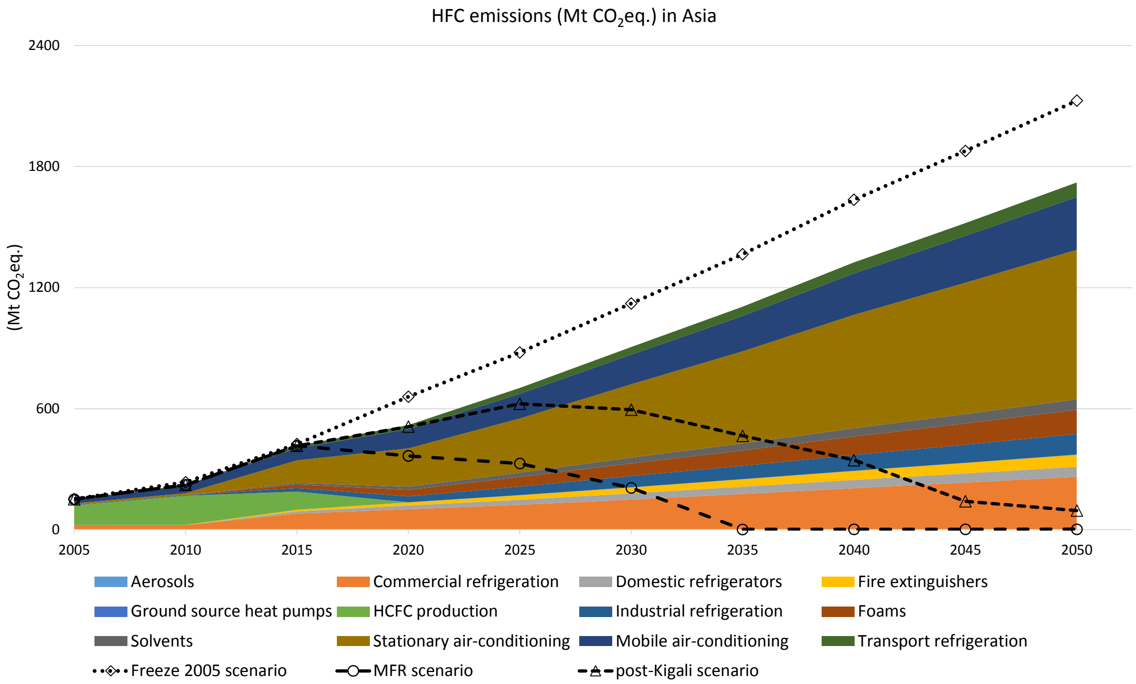
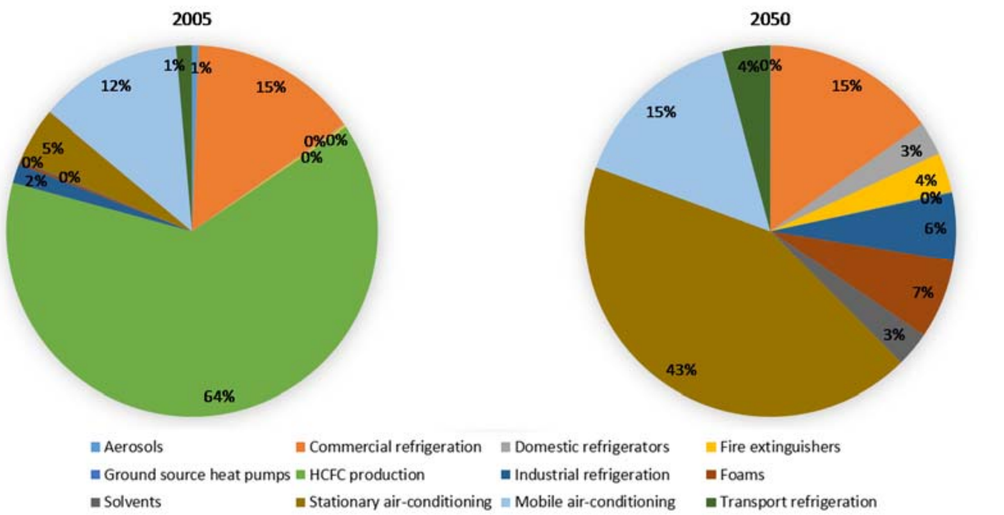


Figure 1. HFC emissions in Asia under 2005 freeze, pre-Kigali baseline, MFR and post-Kigali scenarios.

Figure 2 presents HFC emissions in Asia by sector. In 2005, 64% of HFC emissions are released from HCFC-22 production for emissive and feedstock use, 15% from commercial refrigeration sector, 13% from mobile air-conditioners, 5% from stationary air-conditioners, 3% from domestic refrigerators, industrial refrigeration and refrigerated transport sector, and the remaining 1% as HFCs from use in aerosols, foams, solvents and fire-extinguishers (Figure 2a). In contrast by 2050, 43% HFC emissions are expected to be released from stationary air-conditioners, 15% from mobile air-conditioners, 15% from commercial refrigeration, 7% from foams, 6% from industrial refrigeration, 6% from refrigerated transport, and the remaining 8% from aerosols, domestic refrigerators, solvents, and fire-extinguishers (Figure 2b). HFC-23 emissions from HCFC-22 production for feedstock applications are assumed fully controlled from 2020 in Asian countries in the pre-Kigali baseline scenario as already discussed in Section 3.

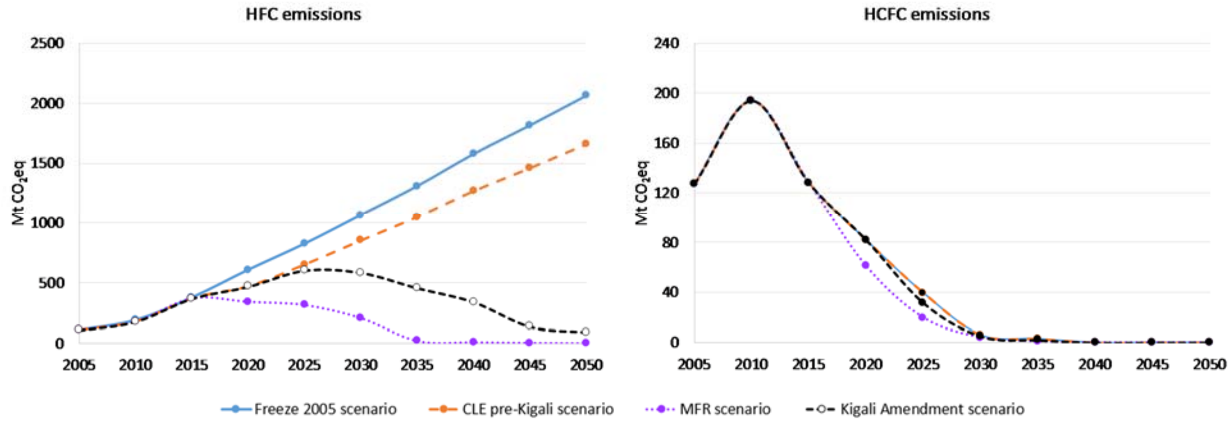


(2a) HFC emissions by sector in 2005 (2b) HFC emissions by sector in 2050

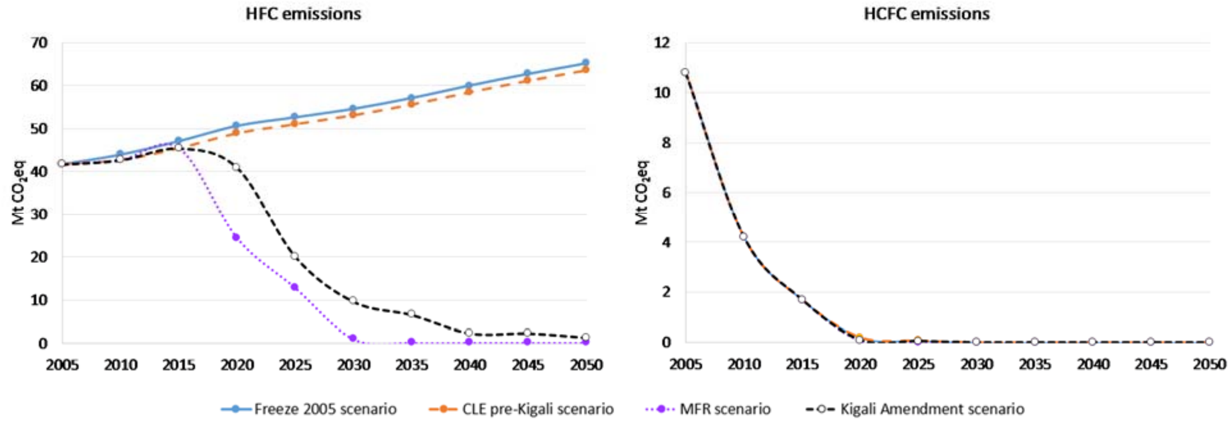
Figure 2. HFC emissions by sector in Asian countries for GAINS model domain in the pre-Kigali baseline scenario.

To account for the full global warming effect of the combined use of HFCs and hydrochlorofluorocarbons (HCFCs) as coolants, and considering that they are close substitutes with equally strong GWPs, we keep track of and display baseline HCFC emissions in parallel to HFC emissions, even though HCFCs are not a target for future abatement efforts since they are addressed as ozone depleting substances (ODSs) that are subject to phase-out under the Montreal Protocol (UNEP, 2007). Figure 3 presents HFC/HCFC emissions in different policy scenarios for 3a) Article 5 countries of Asia, 3b) Japan (non-Article 5), and 3c) non-Asian countries.

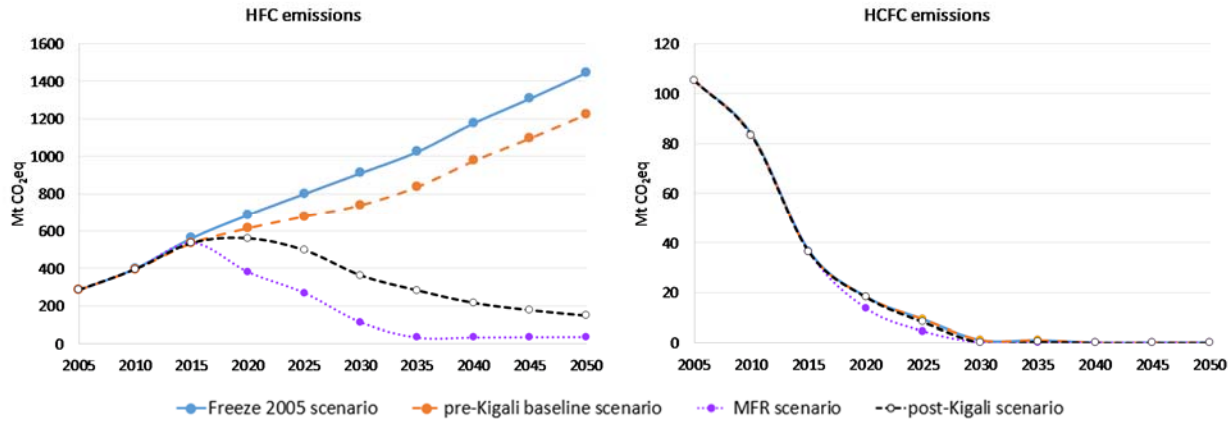
The results from the GAINS model suggest that in the 2005 freeze scenario, HFC emissions in Asian Article 5 countries are expected to grow by a factor of 11 between 2010 and 2050 (i.e., from 191 to 2061 Mt CO_2eq). In the pre-Kigali baseline scenario, HFC emissions in Asian countries are expected to grow by a factor of nine between 2010 and 2050 (i. e., from 179 to 1657 Mt CO_2eq). In Japan, HFC emissions are expected to increase by 50 percent in the pre-Kigali baseline scenario with growth in emissions contained somewhat by the revised F-gas law in Japan from 2015. In particular, a sharp increase in demand for air-conditioning and refrigeration services in Asian countries contributes to increased emissions. Major uncertainties affecting the above results are uncertainty in the emission factors and activity pathways, as well as in the future penetration of mitigation technology, e.g., the use of low-GWP substances in mobile and stationary air conditioners and refrigerators. There is also a general lack of data on reported emissions at the country level to verify model emission estimates.



(a) Article 5 countries of Asia



(b) Japan



(c) Non-Asia

Figure 3. HFC/HCFC emissions in different policy scenarios for a) Article 5 countries of Asia, b) Japan, and c) non-Asian countries.

Table 2 presents cumulative emissions over the entire period 2018 to 2050 in the different scenarios. At the global level, cumulative HFC emissions are estimated at 78.5 Gt CO_2eq in the 2005 freeze scenario had HFC control measures put into effect after 2005 not been implemented. In the pre-Kigali baseline scenario cumulative HFC emissions from 2018 to 2050 are estimated at approximately 65 Gt CO_2eq. Hence, the estimated effect on global HFC emissions from control of HFC-23 emissions from

HCFC22 production for feedstock use in industry in Asian countries and control policies implemented at regional/national levels in the EU, Japan, Australia and the United States after 2005 is 14 Gt CO_2eq or an 18% emission reduction. Stringent implementation of the Kigali Amendment is expected to reduce HFC emissions by 61% (39 Gt CO_2eq) below the pre-Kigali baseline scenario over the entire period 2018 to 2050. In the MFR scenario, we estimate it technically feasible to limit the cumulative release of global HFC emissions to 10 Gt CO_2eq between 2018 and 2050, which corresponds to an 85% reduction in emissions below the pre-Kigali baseline scenario. For Asian Article 5 countries, we estimate that full implementation of the Kigali amendment (post-Kigali scenario) will remove 60% of emissions in the pre-Kigali baseline scenario between 2018 and 2050, with a technical possibility to remove as much as 86% with maximum feasible implementation of mitigation technology (MFR scenario).

Table 2. Cumulative emissions over the entire period 2018 to 2050

Scenarios	Unit	Article 5 Asia	Japan	Sum Asia	Non-Asia	Global
2005 Freeze scenario	Gt CO_2eq	42.6	1.83	44.5	33.9	78.5
pre-Kigali baseline scenario	Gt CO_2eq	34.2	1.78	36.1	28.5	64.6
MFR scenario	Gt CO_2eq	4.8	0.2	5.0	4.6	9.6
post-Kigali scenario	Gt CO_2eq	13.7	0.4	14.1	11.0	25.2

4.2 Co-benefits of HFC phase-down in Asia

In addition to the direct climate benefits from HFC mitigation, transitioning away from HFCs can catalyze additional climate benefits through improvements in the energy efficiency of the refrigerators, air conditioners, freezers, and other products and equipment that currently use HFC refrigerants. The resulting energy-related emissions can be reduced with lowered cooling demands, efficient equipment, and operating strategies that maximize system performance (Calm, 2006). Based on their operating profiles, even small efficiency improvements translate into significant reductions in GHG emissions (Phadke et al., 2014). In addition, less electricity consumption can translate into lower air pollution with associated health benefits, however in relation to the contribution to air pollution from other sources the health benefits from reduced electricity use in various cooling services are likely to be negligibly small. Under this task we express estimated electricity-savings from compliance with the Kigali Amendment in terms of CO_2 reductions and quantify the expected health benefits in terms of lower exposure to particulate matter ($PM_{2.5}$), as this is the air pollutant likely to have the largest impact on health from electricity production.

From surveying the literature on the current state of technology, we conclude that replacement of HFCs with ammonia or hydrocarbons like propane or isobutene (Chang et al., 2009; Kita et al., 2011; Rasti et al., 2013), or switches to CO_2-based technologies (Karampour and Sawalha, 2017; Sawalha et al. 2017; Tsamos et al., 2017), could be accompanied by reduced electricity consumption in the sectors listed in Table 3 (Cox, 2003; Mani and Selladurai, 2008; Schwartz et al., 2011; Wang et al., 2014; Elbel and Hrnjak, 2016; UNEP, 2016b; Gullo et al., 2017; Mota-Babiloni et al., 2017; Purohit et al., 2017; Shaik and Babu, 2017). Particularly well documented through wide-spread implementation are electricity savings in industrial refrigeration when switching away from HFCs to ammonia (EIA, 2012). It may be noted that energy efficiency benefits could not be achieved by one action alone, such as choosing a different refrigerant, but are the result of integrated solutions involving equipment, process, maintenance as well as refrigerant alterations. The efficiency in refrigeration and air-conditioning depends on the thermodynamic properties of the refrigerant adjusted for the loss from the mixing of any lubricant in the fluid (Conde, 1996), efficiency of heat transfer, the thermal sink for the heat removed from the cooled space, and the design, materials, and controls of the mechanical equipment (Domanski et al., 2017; Sanukrishna et al., 2017). There can be additional efficiency losses in transferring the conditioned air to the location where it is needed. Each of these contributing factors are the focus of technical innovation. Refrigerants and refrigerant blends are designed to have as close to ideal thermodynamic properties as possible; machines are designed with ceramic or magnetic bearings to avoid the degradation of efficiency by lubricants; cold ocean, lake, and ground heat sinks are used rather than less efficient air-to-air and cooling towers; and equipment is designed to be as efficient in heat transfer as possible (Dreyfus et al., 2017). Hybrid designs include, for example, those used in supermarkets in cold climates that use the heat rejected from refrigeration to warm the grocery store itself (Woolley, 2016). For other sectors, full realization of the listed electricity-savings across all applications in a sector is less certain due to limited current implementation, however on the basis of the available literature we also believe the listed savings to be technically feasible given careful installation and maintenance of the technology.

Table 3. Specifications of sectors and options assumed to come with possible electricity savings.

Sector	Control measure/low-GWP option	Electricity saving
Refrigerated transport	Carbon dioxide (CO_2)	2.0%
	Propane (HC-290)	4.0%
Industrial refrigeration	Ammonia (NH_3)	15.0%
Residential air-conditioners	Propane (HC-290)	6.0%
Commercial refrigeration	Carbon dioxide (CO_2)	4.5%
	Propane (HC-290)	4.5%
Domestic refrigeration	Iso-butane (HC-600a)	1.6%

Source: Höglund-Isaksson et al. (2017)

Table 4 presents expected operational electricity savings by sector and type of HFC substitute for Asian countries in 2030 and 2050 when meeting the Kigali Amendment and assuming the electricity savings presented in Table 3 to be fully realized in practice. Total estimated electricity savings amount to 66 TWh in 2030 and 178 TWh in 2050. The largest electricity-savings are expected to come from the use of hydrocarbons in various sector applications, followed by a complete switch to ammonia in industrial refrigeration and to CO_2-based technology in larger commercial refrigeration installations for which hydrocarbon-based technology is not considered feasible due to flammability concerns. Cumulative electricity savings over the period 2018 to 2050 from full implementation of the Kigali Amendment in Asia are estimated at about 3000 TWh, which is about 0.5% of the expected cumulative electricity consumption of Asia over the same period.

Table 4. Estimates of electricity savings from HFC phase-down following full implementation of the Kigali Amendment in Asia, presented by key sectors and technology in 2030 and 2050.

Sector	Electricity savings in 2030 (TWh)			Electricity savings in 2050 (TWh)		
	Switch to CO_2-based technology	Switch to ammonia	Switch to hydrocarbons (propane, isobutane, etc.)	Switch to CO_2-based technology	Switch to ammonia	Switch to hydrocarbons (propane, isobutane, etc.)
Commercial refrigeration	7.7	0.0	5.3	44.2	0.0	11.1
Domestic refrigerators	0.0	0.0	0.2	0.0	0.0	1.1
Industrial refrigerators	0.0	25.3	0.0	0.0	58.4	0.0
Transport refrigeration	0.0	0.0	6.4	0.0	0.0	15.3
Stationary air-conditioning	0.0	0.0	21.2	0.0	0.0	48.2
Sum by technology type	7.7	25.3	33.1	44.2	58.4	75.7
Sum by year	66			178		

The electricity-savings presented in Table 4 can be converted to approximate reductions in CO_2 emissions from electricity generation if we combine them with weighted average CO_2 emission factors for electricity generation in each country. For this purpose we employ country specific emission factors (CO_2 emissions per kWh of electricity consumed) from Brander et al. (2011) that in addition to direct combustion emissions also take into account the country specific electricity transmission and distribution losses. Table 5 presents estimated CO_2eq reductions corresponding to the electricity savings estimated for Asian countries in 2030 when meeting the Kigali Amendment commitments and under maximum technically feasible reduction.

Table 5. Co-benefits of HFC phase-down in the post-Kigali and MFR scenarios in 2030

Montreal Protocol party groups	Electricity savings (TWh)		CO_2 mitigation potential through electricity saving in Mt CO_2eq (and as % of total CO_2eq mitigation following HFC replacement)		Population weighted $PM_{2.5}$ exposure in µg/m^3 (and as % of total expected exposure)	
	Post-Kigali	MFR	Post-Kigali	MFR	Post-Kigali	MFR
Article 5 Asia	51.2	67.9	55.1 (21%)	72.2 (11%)	0.007 (0.014%)	0.017 (0.02%)
Japan	14.9	15.3	7.0 (16%)	7.1 (13%)	0.004 (0.023%)	0.004 (0.024%)
Sum Asia	66.1	83.3	62.1 (20%)	79.3 (11%)	0.007 (0.02%)	0.009 (0.02%)

Figure 4 presents corresponding estimates for the period 2020 to 2050. In both scenarios, estimated annual CO_2 reductions due to electricity-savings are about 75 Mt CO_2 in 2030 and approaching 200 Mt CO_2 in 2050. Cumulatively over the period 2018 to 2050, CO_2 reductions in Asia due to electricity-savings sum to 3 Gt CO_2 in the post-Kigali scenario and to 3.5 Gt in the MFR scenario when comparing with the pre-Kigali baseline scenario. If we add these to the direct cumulative reductions in CO_2eq emissions of 22 Gt in the post-Kigali scenario and 31 Gt CO_2eq in the MFR scenario (see Table 2), we find that the total reduction in greenhouse gas emissions over 2018 to 2050 from implementing HFC phase down technology is 25 Gt CO_2eq when meeting the Kigali Amendment commitments with a reduction of 34.5 Gt CO_2eq considered technically feasible with maximum technology adoption. Hence, the CO_2 reductions achieved through electricity savings corresponds to about 10 to 12% of the total cumulative greenhouse gas reduction expected to follow from a phase-out of HFCs under the post-Kigali and MFR scenarios.

The associated health impacts are expressed in terms of population weighted $PM_{2.5}$ exposure and are presented in Table 5. As expected, co-benefits in terms of reduced $PM_{2.5}$ exposure due to electricity savings in air-conditioning and refrigeration equipment is a very tiny fraction of overall $PM_{2.5}$ exposure. In terms of reduction in population weighted $PM_{2.5}$ concentration, the effects are negligible as the $PM_{2.5}$ concentration level is ≥40 μg/m^3 in most of the developing and emerging economies of Asia (WHO, 2016).

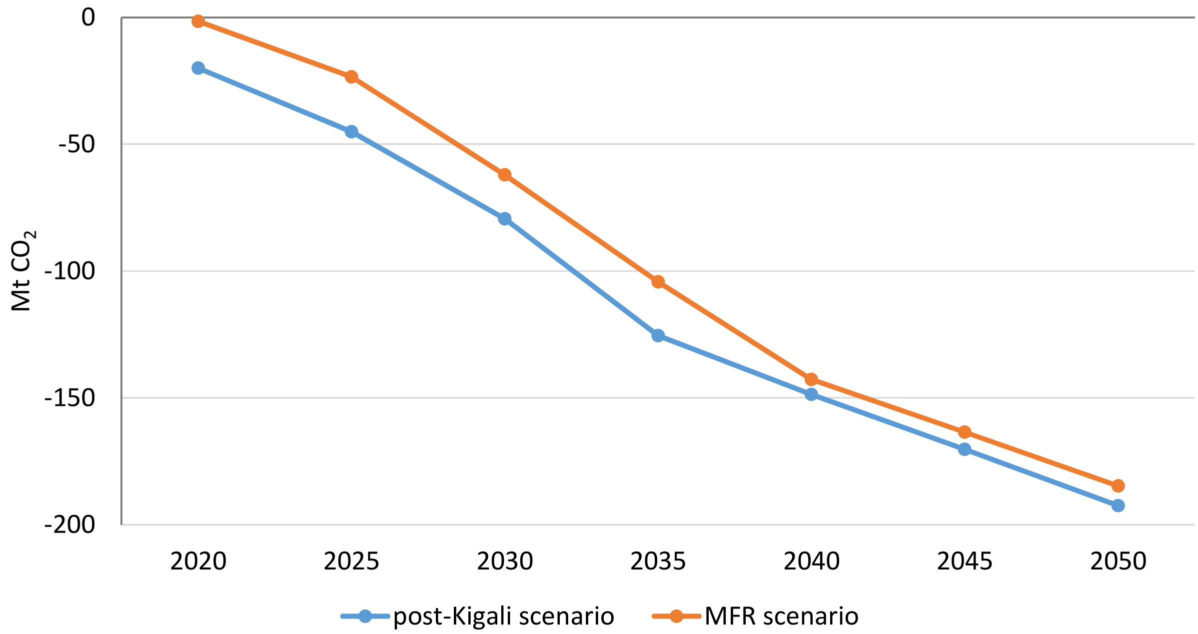


Figure 4. Estimated carbon dioxide mitigation potential due to electricity savings following adoption of HFC replacement technology in Asia under the post-Kigali and MFR scenarios.

5. Conclusions and Policy recommendations

- Prior to the commitments made by Asian countries under the Kigali Amendment to the Montreal Protocol in October 2016, pre-Kigali baseline emissions of HFCs in Asia are expected to increase from 0.26 to 1.7 Gt CO_2eq between 2010 and 2050. The growth is mainly driven by a twenty fold increase in demand for refrigeration and air conditioning services, which in turn is driven by an expected increase in per capita wealth in developing countries (primarily China and India) combined with the effect of replacing CFCs and HCFCs with HFCs in accordance with the 2007 revision of the Montreal Protocol. The expected future growth in emissions corresponds to cumulative emissions estimated at 36 Gt CO_2eq released over the entire period 2018 to 2050, whereof 34.2 Gt are released in Asian Article 5 countries and 1.8 Gt in Japan.
- With a freeze of technology in year 2005 cumulative future HFC emissions in Asia are expected at 23% higher than in the pre-Kigali baseline scenario, almost exclusively due to control implemented after 2005 on HFC-23 emissions from HCFC-22 production for feedstock use in industry.

- With full future compliance with the commitments made in Kigali, the Asian countries are expected to reduce cumulative HFC emissions by 22 Gt CO_2eq over the period 2018 to 2050, which is 61% lower than in the pre-Kigali baseline emission scenario.
- With maximum technically feasible implementation of existing control technology and without the delays in implementation built into the Kigali Amendment, we estimate it technically feasible for Asian countries to remove 31 Gt CO_2eq over the period 2018 to 2050, which is 86% lower than in the pre-Kigali baseline scenario.
- Phase-down of HFCs is likely to come with electricity-savings for several sector applications. Full compliance with the Kigali Amendment is estimated to save about 3000 TWh of electricity in Asian countries over the period 2018 to 2050. This corresponds to an estimated 0.5% of expected cumulative electricity consumption in Asia over the same period.
- Employing average country-specific CO_2 emission factors for electricity generation, the estimated electricity savings can be converted to corresponding CO_2 emissions. We find that the cumulative reduction in CO_2 emissions due to electricity savings corresponds to between 10 and 12% of the total reduction in greenhouse gas emissions (i.e., the sum of the CO_2eq reduction in HFCs and the CO_2 reduction due to electricity-savings) attained when phasing down HFCs over the period 2018 to 2050. We find potential health benefits from reduced $PM_{2.5}$ exposure due to reduced electricity consumption to be negligible due to the tiny contribution from these sources to overall $PM_{2.5}$ exposure.
- A key policy finding of this analysis is that speeding up implementation of the HFC phase down schedule under the Kigali Amendment in Asia could extend the cumulative mitigation potential over the period 2018 to 2050 from 61% to 86% below a pre-Kigali baseline emission level.
- Another key policy finding is the importance of paying careful attention to the electricity-savings that can be reaped when the refrigeration/air-conditioning equipment that use alternative technologies to HFCs are properly installed and maintained as the CO_2 reductions of these electricity-savings correspond to about 10 to 12% of total greenhouse gas emission reductions from a HFC phase-down.

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