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ADB Working Paper Series

**INTERNATIONAL AGREEMENTS
AND GLOBAL INITIATIVES FOR
LOW-CARBON COOLING**

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Abstract

Since the mid-1980s, the international community has controlled refrigerants that may damage the ozone layer and cause climate change based on several international agreements. In particular, the Montreal Protocol contributed to not only solving the ozone layer depletion problem but also limiting global warming. Given that the global demand for cooling would triple by 2050 and this rise would increase global greenhouse gas emissions significantly, the Montreal Protocol has expanded its regulatory scope to decarbonize the cooling sector through the adoption of the Kigali Amendment. Also, increasing interest in low-carbon cooling has driven the launch of various global initiatives to complement the international agreements and accelerate low-carbon cooling in developing countries. The experience of implementing the Montreal Protocol and its Amendments suggests some lessons and insights for making the Kigali Amendment work well. First, each country should develop and enforce national policies aligned with international agreements. Second, financial and technical support mechanisms should be strengthened to facilitate developing countries' compliance with the Kigali Amendment. Third, along with the improving energy efficiency of cooling, the substances that neither harm the ozone layer nor exacerbate climate change should be used as substitutes for hydrofluorocarbons. Lastly, the monitoring, reporting, and verification of controlled substances need to be strengthened.

Keywords: global warming potential, international environmental agreement, Kigali Amendment, low-carbon cooling, Montreal Protocol

JEL Classification: F53, Q01, Q53, Q54

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1. INTRODUCTION

The development of cooling technologies, including air conditioning and refrigeration, has improved the quality of life, but at the same time has generated serious global environmental problems. Traditional cooling systems use vapor compression refrigeration in which the liquid refrigerant is circulated to absorb heat. However, substances used as refrigerants have contributed to ozone depletion and global warming. International efforts have been made to solve these problems under several multilateral environmental agreements. Until the mid-2010s, the regulation of refrigerants was primarily aimed at protecting the ozone layer. However, the recent international agreements, such as the Paris Agreement and the Kigali Amendment to the Montreal Protocol, emphasize the linkages between cooling and climate change and suggest that refrigerant regulation should contribute to both preventing ozone depletion and tackling climate change (Campbell, Kalanki, and Sachar 2018; SEforALL 2018).

During the 1970s and 1980s, scientists discovered that halogenated gases and chlorofluorocarbons (CFCs), which had been commonly used as refrigerants, were the culprit in depleting the ozone layer over Antarctica. Hence, the international community adopted a series of agreements, including the 1985 Vienna Convention for the Protection of the Ozone Layer, the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, and several amendments to the Montreal Protocol, in order to protect the ozone layer by controlling the ozone-depleting substances (ODSs). In consequence, ozone-depleting refrigerants have been replaced by noncontrolled substances having much lower ozone-depleting potential (ODP) for the last 35 years. For instance, hydrochlorofluorocarbons (HCFCs) replaced CFCs and hydrofluorocarbons (HFCs) replaced HCFCs.

Meanwhile, as HFCs became the dominant refrigerants, emissions from them have sharply increased by 10%–15% annually during the last two decades (UNEP 2011). Even though HFCs do not harm the ozone layer, they arouse other environmental concerns due to their fairly high global warming potential (GWP), which is thousands of times higher than that of carbon dioxide (CO₂). Increasing HFC emissions are expected to heighten global temperature by up to 0.5°C by 2100 if there is no relevant regulation (Xu et al. 2013). Listed as one of the six major greenhouse gases (GHGs) covered by the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), HFCs were originally controlled within the global climate change regime. However, as the Kigali Amendment specified HFCs in the controlled substance list in 2016, the HFC emissions began being regulated within both the global climate change and ozone regimes. This confirms that decarbonizing refrigerants beyond reducing their ODP emerged as a new objective of the cooling sector.

International agreements can stimulate national low-carbon cooling policies by setting targets that each party has to meet and by offering financial and technical support to developing countries. On this account, the successful execution of international agreements will eventually contribute to achieving the global climate goals. In fact, since most of the controlled ODSs in the Montreal Protocol are potent GHGs, regulating these substances had a positive impact on GHG emissions reduction even before the adoption of the Kigali Amendment (Velders et al. 2007). Furthermore, phasing down HFCs under the Kigali Amendment would prevent GHG emissions equivalent to approximately 100 billion tons of CO₂ (tCO₂e) by 2050 (Zaelke et al. 2013). Given that the global demand for space cooling could triple and subsequently could lead an increase in the direct and indirect GHG emissions from cooling by up to

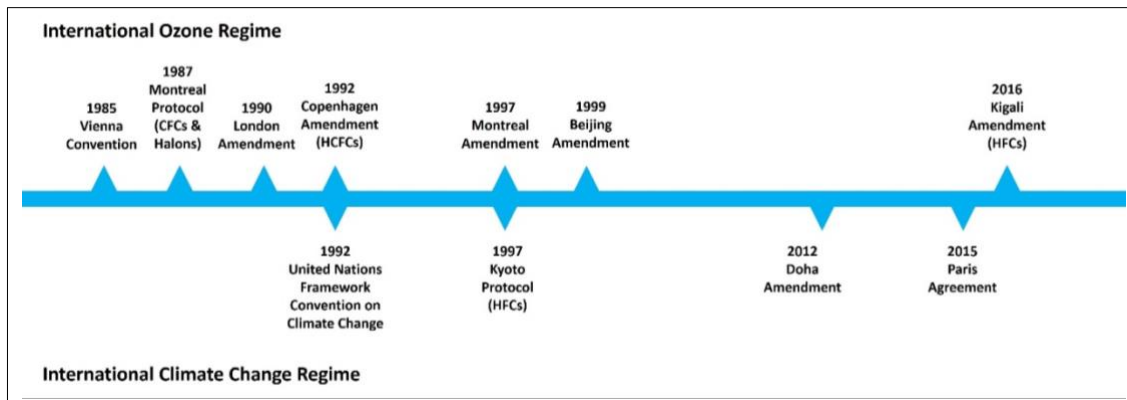
90% by 2050 (UNEP and IEA, 2020), international efforts for low-carbon cooling should be continued and strengthened.

Against this background, this paper examines the evolution of the global regulatory framework of refrigerants to decarbonize the cooling sector. This study contributes to the current understanding of global efforts to achieve low-carbon cooling by providing a comprehensive overview of relevant international agreements and global initiatives based on the latest information. The remainder of this paper comprises the following sections: Section 2 describes international agreements related to low-carbon cooling and critical changes in controlled substances and measures over time, and Section 3 summarizes the impacts of those international agreements on ozone layer protection and climate change. Section 4 introduces global initiatives to support low-carbon cooling in developing countries. Finally, Section 5 provides policy recommendations to make the international agreements work well and accelerate the decarbonization of the cooling sector.

2. INTERNATIONAL AGREEMENTS FOR LOW-CARBON COOLING

There is no international agreement whose primary objective is achieving low-carbon cooling. Instead, several international agreements that control refrigerants as air pollutants and GHGs have been made since the mid-1980s within the global ozone and climate regimes (Figure 1).

Figure 1: Key International Agreements to Regulate Refrigerants



Source: Author’s illustration.

2.1 Vienna Convention for the Protection of the Ozone Layer

Production of CFCs increased significantly between the 1960s and 1980s as CFC refrigerants were widely used in the industrial process and daily life, including refrigeration, air conditioning, packaging, and cleaning electrical components. CFCs were initially believed to be safe for the environment and the human body, but scientists began to warn against their potential harm to the stratospheric ozone layer in the early 1970s (Morrisette 1989; Handwerk 2010). International organizations, notably the United Nations Environmental Programme (UNEP), have spearheaded international efforts to deal with this issue. The UNEP Governing Council adopted the World Plan of Action on the Ozone Layer in 1977, calling for research and monitoring

of the ozone layer at the international level. It also organized an ad hoc Working Group of Legal and Technical Experts in 1981 to prepare a draft of a framework convention for ozone layer protection (Morrisette 1989; Caron 1991).

Accordingly, the Vienna Convention for the Protection of the Ozone Layer was adopted in March 1985 and entered into force in September 1988. In 2009, it became the first multilateral environmental agreement ratified by all parties involved. One of the main objectives of this convention is “to protect human health and the environment against adverse effects resulting or likely to result from human activities which modify or are likely to modify the ozone layer (Article 2.1) (UNEP Ozone Secretariat 2019: 3)”. As a framework convention, it did not include binding commitments but set common principles for preventing ozone depletion. The parties agreed on cooperating on research, monitoring, and observations of the ozone layer modification, adopting appropriate protection measures for the ozone layer, and formulating agreed measures, procedures, and standards to support implementing this Convention (Article 2.2) (UNEP Ozone Secretariat 2019: 3). Also, the Vienna Convention listed, in the Annex, chemical substances that are thought to have the potential to modify the ozone layer. Those substances were categorized into five groups: i) carbon substances including carbon monoxide (CO), carbon dioxide (CO₂) and methane (CH₄); ii) nitrogen substances including nitrous oxide (N₂O) and nitrogen oxides (NO_x); iii) chlorine substances including CFCs; iv) bromine substances; and v) hydrogen substances.

2.2 Montreal Protocol on Substances that Deplete the Ozone Layer and Its Amendments

In May 1985, right after adopting the Vienna Convention, several British researchers reported that they had discovered a recurring huge hole in the ozone layer over Antarctica. It captured considerable scientific and public attention globally on the causality between ozone depletion and refrigerants including CFCs (Caron 1991; Handwerk 2010). The widespread concern about the ozone hole led the states to agree on reducing the use of ODSs. In September 1987, the Montreal Protocol on Substances that Deplete the Ozone Layer, which regulates the production, consumption, and trade of ODSs, was adopted under the Vienna Convention. The controlled substances include five CFCs (CFCl₃ (CFC-11), CF₂Cl₂ (CFC-12), C₂F₃Cl₃ (CFC-113), C₂F₄Cl₂ (CFC-114), C₂F₅Cl (CFC-115)) and three halons (CF₂BrCl (halon-1211), CF₃Br (halon-1301), and C₂F₄Br₂ (halon-2402)) (UNEP Ozone Secretariat 2020: 865). This Protocol came into effect in January 1989.

The Montreal Protocol required gradual reductions in production and consumption of the eight controlled substances from all parties. However, it allowed different phase-out timing for developed countries and Article 5 countries based on the principle of common but differentiated responsibilities. Article 5 countries refer to developing countries and countries whose annual per capita CFC consumption is less than 0.3 kg. For developed countries, the annual production and consumption levels of halons had to be maintained at the levels in 1986, and those of controlled CFCs had to be reduced to 80% of the 1986 levels by June 1994 and 50% by June 1999. The annual production and consumption levels of controlled CFCs and halons in Article 5 countries were limited to a maximum 10% increase based on the 1986 levels by June 1994 and a 15% increase by June 1999 (Article 2.1–2.4). Also, a 10-year grace period was granted to Article 5 countries. During the grace period, those countries could delay their compliance with the control measures (Article 5.1). Such phase-out schedules have been tightened through several adjustments. Furthermore, the Protocol imposed prohibition and restrictions on the trade of controlled substances with non-parties

(Article 4). In addition, each party was obliged to disclose annual data related to the controlled substances including the production, imports and exports (Article 7) (UNEP Ozone Secretariat 2020: 857–861).

Besides these obligations, the Protocol established flexible and supportive mechanisms to promote compliance of the parties. The controlled substances and control measures can be adjusted based on the scientific, technical, environmental, and economic assessment and review (Article 2.9–2.10), and financial and technical support are provided to promote the implementation of the Protocol (Article 10) (UNEP Ozone Secretariat 2020: 858–862). Moreover, the Protocol made the reporting requirements work as a compliance monitoring mechanism instead of creating a punishing mechanism for noncompliance (Birmpili 2018). With a shift in the position of the American chemical industry from opposition to support due to the possibility of CFC substitutes, these advantageous provisions helped countries participate in the Montreal Protocol (Heath 2017; Whitesides 2020). Eventually, the Montreal Protocol achieved universal ratification in 2009.

As the Montreal Protocol controlled CFCs and halons, many companies began to use other substances, including HCFCs, as alternative refrigerants to CFCs (Ciconkov 2018). Such substitutes were not included in the original Montreal Protocol because their ODPs are much lower than CFCs and halons. Whereas the ODPs of initially controlled eight CFCs and halons range from 0.6 to 10.0, the ODPs of most substitutes are less than 1.0. Since these substances still have negative effects on the ozone layer, the world has gradually extended controlled substances and enhanced control measures and support mechanisms to raise the effectiveness of the regime through six adjustments and five amendments. Table 1 summarizes the expansion of controlled substances in the respective amendment, and Table 2 presents the latest phase-out schedule of controlled substances. Except for the Kigali Amendment, which is the latest amendment to the Montreal Protocol, the four Amendments—the London, Copenhagen, Montreal, and Beijing Amendments—have been ratified by 197 parties out of 198 parties as of July 2022.

The London Amendment was adopted in June 1990 and took effect in August 1992. In this Amendment, ten additional CFCs, carbon tetrachloride (CCl_4), and methyl chloroform ($\text{C}_2\text{H}_2\text{Cl}_3$) were added as controlled substances, and 34 HCFCs were considered transitional substances (Annex B and C). The parties did not have phase-out requirements for the transitional substances, but had reporting requirements on the production, imports, and exports data (Article 7.2). The phase-out requirements for the controlled CFCs and halons were strengthened: from 50% reduction by June 1999 to 100% reduction by January 2000. One of the critical revisions of the London Amendment is establishing the Multilateral Fund financed by developed countries, which is a financial and technical cooperation mechanism for developing countries (Article 10) (UNEP Ozone Secretariat 2020: 884–896). The financial support facilitated the engagement of large developing countries that had refused to join the Protocol, including Argentina, Brazil, the People's Republic of China (PRC), and India (Downie 2012). Up to June 2021, the Multilateral Fund contributions have reached US\$4.3 billion and US\$3.97 billion have been allocated to technical assistance for industrial conversion and capacity building and training programs through various international organizations (UNEP 2021).

Table 1: Expansion of Controlled Substances under the Montreal Protocol

	Montreal Protocol (1987)	London Amendment (1990)	Copenhagen Amendment (1992)	Montreal Amendment (1997)	Beijing Amendment (1999)	Kigali Amendment (2016)
Existing	•	<ul style="list-style-type: none"> • 5 CFCs • 3 Halons 	<ul style="list-style-type: none"> • 5 CFCs • 3 Halons • 10 fully halogenated CFCs • CCl4 • C2H3Cl3 	<ul style="list-style-type: none"> • 5 CFCs • 3 Halons • 10 fully halogenated CFCs • CCl4 • C2H3Cl3 • 40 HCFCs • 34 HBFCs • CH3Br 	<ul style="list-style-type: none"> • 5 CFCs • 3 Halons • 10 fully halogenated CFCs • CCl4 • C2H3Cl3 • 40 HCFCs • 34 HBFCs • CH3Br 	<ul style="list-style-type: none"> • 5 CFCs • 3 Halons • 10 fully halogenated CFCs • CCl4 • C2H3Cl3 • 40 HCFCs • 34 HBFCs • CH2BrCl • CH3Br
New	<ul style="list-style-type: none"> • 5 CFCs • 3 Halons 	<ul style="list-style-type: none"> • 10 fully halogenated CFCs • Carbon tetrachloride (CCl4) • Methyl chloroform (C2H3Cl3) • Transitional substances: 34 HCFCs 	<ul style="list-style-type: none"> • 40 HCFCs • 34 HBFCs • Methyl bromide (CH3Br) 		<ul style="list-style-type: none"> • Bromochloromethane (CH2BrCl) 	<ul style="list-style-type: none"> • 18 HFCs
Total	8	20	95	95	96	114

CFC = chlorofluorocarbon, HBFC = hydrobromofluorocarbon, HCFC = hydrochlorofluorocarbon, HFC = hydrofluorocarbon.

Source: Authors' summary based on UNEP Ozone Secretariat (2020), pp. 31–35; pp. 856–926.

Table 2: Latest Phase-out Schedule of Controlled Substances

	Non-Article 5 Countries (Developed Countries)	Article 5 Countries (Developing Countries)
Annex A, Group I (CFCs)	<ul style="list-style-type: none"> • Baseline: 1986 level • JUL 1, 1989: Freeze • JAN 1, 1994: 75% reduction • JAN 1, 1996: 100% reduction 	<ul style="list-style-type: none"> • Baseline: Average of 1995–1997 • JUL 1, 1999: Freeze • JAN 1, 2005: 50% reduction • JAN 1, 2007: 85% reduction • JAN 1, 2010: 100% reduction
Annex A, Group II (Halons)	<ul style="list-style-type: none"> • Baseline: 1986 level • JAN 1, 1992: Freeze • JAN 1, 1994: 100% reduction 	<ul style="list-style-type: none"> • Baseline: Average of 1995–1997 • JAN 1, 2002: Freeze • JAN 1, 2005: 50% reduction • JAN 1, 2010: 100% reduction
Annex B, Group I (Other fully halogenated CFCs)	<ul style="list-style-type: none"> • Baseline: 1989 level • JAN 1, 1993: 20% reduction • JAN 1, 1994: 75% reduction • JAN 1, 1996: 100% reduction 	<ul style="list-style-type: none"> • Baseline: Average of 1998–2000 • JAN 1, 2003: 20% reduction • JAN 1, 2007: 85% reduction • JAN 1, 2010: 100% reduction
Annex B, Group II (Carbon tetrachloride)	<ul style="list-style-type: none"> • Baseline: 1989 level • JAN 1, 1995: 85% reduction • JAN 1, 1996: 100% reduction 	<ul style="list-style-type: none"> • Baseline: Average of 1998–2000 • JAN 1, 2005: 85% reduction • JAN 1, 2010: 100% reduction
Annex B, Group III (Methyl chloroform)	<ul style="list-style-type: none"> • Baseline: 1989 level • JAN 1, 1993: Freeze • JAN 1, 1994: 50% reduction • JAN 1, 1996: 100% reduction 	<ul style="list-style-type: none"> • Baseline: Average of 1998–2000 • JAN 1, 2003: Freeze • JAN 1, 2005: 30% reduction • JAN 1, 2010: 75% reduction • JAN 1, 2015: 100% reduction

continued on next page

Table 2 continued

	Non-Article 5 Countries (Developed Countries)	Article 5 Countries (Developing Countries)
Annex C, Group I (HCFCs)	<p>Consumption</p> <ul style="list-style-type: none"> • Baseline: 1989 HCFC consumption + 2.8% of 1989 CFC consumption • JAN 1, 1996: Freeze • JAN 1, 2004: 35% reduction • JAN 1, 2010: 75% reduction • JAN 1, 2015: 90% reduction • JAN 1, 2020: 100% reduction <p>Production</p> <ul style="list-style-type: none"> • Baseline: Average of 1989 HCFC production + 2.8% of 1989 CFC consumption and 1989 HCFC consumption + 2.8% of 1989 CFC consumption • JAN 1, 2004: Freeze • JAN 1, 2010: 75% reduction • JAN 1, 2015: 90% reduction • JAN 1, 2020: 100% reduction 	<ul style="list-style-type: none"> • Baseline: Average of 2009–2010 • JAN 1, 2013: Freeze • JAN 1, 2015: 10% reduction • JAN 1, 2020: 35% reduction • JAN 1, 2025: 67.5% reduction • JAN 1, 2030: 100% reduction
Annex C, Group II (HBFCs)	<ul style="list-style-type: none"> • JAN 1, 1996: 100% reduction 	<ul style="list-style-type: none"> • JAN 1, 1996: 100% reduction
Annex C, Group III (Bromochloromethane)	<ul style="list-style-type: none"> • JAN 1, 2002: 100% reduction 	<ul style="list-style-type: none"> • JAN 1, 2002: 100% reduction
Annex E, Group I (Methyl bromide)	<ul style="list-style-type: none"> • Baseline: 1991 level • JAN 1, 1995: Freeze • JAN 1, 1999: 25% reduction • JAN 1, 2001: 50% reduction • JAN 1, 2003: 70% reduction • JAN 1, 2005: 100% reduction 	<ul style="list-style-type: none"> • Baseline: Average of 1995–1998 • JAN 1, 2002: Freeze • JAN 1, 2005: 20% reduction • JAN 1, 2015: 100% reduction
Annex F (HFCs)	<p>Belarus, Kazakhstan, Russian Federation, Tajikistan, and Uzbekistan</p> <ul style="list-style-type: none"> • Baseline: Average HFC for 2011–2013 + 25% of HCFC baseline • JAN 1, 2020: 5% reduction • JAN 1, 2025: 35% reduction • JAN 1, 2029: 70% reduction • JAN 1, 2034: 80% reduction • JAN 1, 2036: 85% reduction <p>Other non-Article 5 countries</p> <ul style="list-style-type: none"> • Baseline: Average HFC for 2011–2013 + 15% of HCFC baseline • JAN 1, 2019: 10% reduction • JAN 1, 2024: 40% reduction • JAN 1, 2029: 70% reduction • JAN 1, 2034: 80% reduction • JAN 1, 2036: 85% reduction 	<p>Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and UAE</p> <ul style="list-style-type: none"> • Baseline: Average HFC for 2024–2026 + 65% of HCFC baseline • JAN 1, 2028: Freeze • JAN 1, 2032: 10% reduction • JAN 1, 2037: 20% reduction • JAN 1, 2042: 30% reduction • JAN 1, 2047: 85% reduction <p>Other non-Article 5 countries</p> <ul style="list-style-type: none"> • Baseline: Average HFC for 2020–2022 + 65% of HCFC baseline • JAN 1, 2024: Freeze • JAN 1, 2029: 10% reduction • JAN 1, 2035: 30% reduction • JAN 1, 2040: 50% reduction • JAN 1, 2045: 80% reduction

Source: UNEP Ozone Secretariat (2020), pp. 36–45.

The Copenhagen Amendment was adopted in November 1992 and came into effect in June 1994. The transitional substances designated in the London Amendment became controlled substances with six additional HCFCs, 34 hydrobromofluorocarbons (HBFCs), and methyl bromide (CH₃Br). Phase-out schedules for the existing controlled substances were tightened again. The Amendment put 100% reduction timing for CFCs and halons forward from January 2000 to January 1996 and January 1994, respectively. Also, it required parties to make their HCFC consumption levels zero by January 2030 (Article 2F). However, HCFCs and methyl bromide were exempted from the trade ban (Article 4).

In the Montreal Amendment, adopted in September 1997 and taking effect in November 1999, a new provision about licensing was added. Each party should implement a licensing system for importing and exporting new, used, recycled, and reclaimed controlled substances (Article 4B). Additionally, the Amendment prohibited the trade of methyl bromide with non-parties (Article 4.2) (UNEP Ozone Secretariat 2020: 908–909). The Beijing Amendment was adopted in December 1999 and entered into force in February 2002. This Amendment added bromochloromethane (CH₂BrCl) as a controlled substance (Annex C, Group III) and stipulated bans on trading HCFCs and bromochloromethane (Article 4.1–4.2) (UNEP Ozone Secretariat 2020: 911–914).

The panels for scientific, technical, environmental, and economic assessments, reviewing the scientific evidence, technological developments, and economic issues on an ongoing basis, were one of the mechanisms that enabled such flexible adjustments of the Montreal Protocol. The parties have been able to strengthen the provisions and clearly define the controlled substances, reduction targets, and schedules based on the panels' reports and information (Birmpili 2018; Gonzalez, Toddonio, and Sherman 2015). In consequence of the continuous adjustments and amendments, 96 ODSs were listed as controlled substances in the Montreal Protocol before the Kigali Amendment (Table 1). The Montreal Protocol effectively regulated the ODSs by sending the industry a signal that investing in developing alternative substances would be inevitable (Birmpili 2018).

2.3 Kigali Amendment to the Montreal Protocol

As the production and consumption of CFCs and HCFCs have been cut down, HFCs have become one of the most popular refrigerants due to their negligible effect on ozone depletion and high compatibility with CFC production (Ciconkov 2018). HFC emissions increased by 10%–15% annually during the last two decades (UNEP 2011), particularly by 23% from 2012 to 2016 (WMO 2018). However, given that HFCs are very strong GHGs with 100-year GWPs ranging from 53 to 14,800 (UNEP Ozone Secretariat 2020: 35), heavy use and leakage of HFCs will not be desirable for the global environment in terms of climate change. Although HFC emissions currently represent less than 3% of total global GHG emissions (EEA 2021), they are projected to increase sharply because of the growing cooling demand, particularly in developing countries. Increasing HFC emissions are expected to raise the global temperature up to 0.5 °C by 2100 if there is no regulation for these substances (Xu et al. 2013). Hence, proposals for including HFCs under the Montreal Protocol have been submitted annually since 2009. However, many countries have been reluctant to agree on these proposals and argued that HFCs should be covered by the UNFCCC (Michaelowa et al. 2019).

It may not look sensible to include HFCs as controlled substances in the Kigali Amendment, since the Montreal Protocol had focused on regulating ODSs rather than global warming substances. However, separating ozone protection and climate change is unreasonable because many ODSs emitted into the atmosphere during the last eight decades have contributed to global warming (Ciconkov 2018; Whitesides 2020). For example, the GWPs of CFC-12 and HCFC-22, the most widely used refrigerant before HFCs, are 10,300 and 1,780, respectively, and have a long lifetime (Ciconkov 2018). Furthermore, it is not true that the scopes of the Vienna Convention and the Montreal Protocol are limited to protecting the ozone layer only. The Vienna Convention defines adverse effects resulting from human activities modifying the ozone layer as “changes in the physical environment or biota, including changes in climate, which have significant deleterious effects on human health or on the composition, resilience and

productivity of natural and managed ecosystems, or on materials useful to mankind (Article 1.2) (UNEP Ozone Secretariat 2019: 2)". Moreover, it specifies that "modification of the vertical distribution of ozone, which could change the temperature structure of the atmosphere and the potential consequences for weather and climate (Annex I: 1(b)) (UNEP Ozone Secretariat 2019: 12)" is one of the major scientific issues for future research and observations. The parties also declared their consciousness of the potential effects of ODSs on global climate in the preamble of the Montreal Protocol (UNEP Ozone Secretariat 2020: 3). In this context, it is legitimate that the Montreal Protocol can regulate new refrigerants with high GWP, including HFCs, to tackle climate change (UNEP Ozone Secretariat 2016).

Hence, after seven years of discussions and negotiations, the Kigali Amendment, adding 18 HFCs under the regulation of the Montreal Protocol, was finally adopted in October 2016 and took effect in January 2019. As of July 2022, 137 out of 198 parties have ratified the Kigali Amendment. According to the phase-out schedules stated in the Kigali Amendment, the production and consumption of HFCs in developed countries will be reduced by 85% from the baseline values by January 2036, and those in Article 5 countries will decrease by 80%–85% from the baseline values by 2047 (Article 2J and 5.8). Along with the phase-out measures, the trade of HFCs is banned upon entry into force of this Amendment (Article 4.1–4.2) (UNEP Ozone Secretariat 2020: 14–23).

The Kigali Amendment also includes more specific phase-out schedules for the respective group of controlled substances. The different baselines, phase-out schedules and targets for developed countries and Article 5 countries are summarized in Table 2. Another notable revision is that the list of controlled substances contains the 100-year GWPs of selected controlled substances: 5 CFCs, 8 HCFCs, and 18 HFCs. The Kigali Amendment also requires the parties to report their HCFC and HFC production and consumption levels in CO₂ equivalent tons instead of metric tons (Article 3.2) (UNEP Ozone Secretariat 2020: 15; 31–35). This provision will encourage the parties to put a priority on reducing HCFCs and HFCs having higher GWPs (Michaelowa et al. 2019).

The Kigali Amendment provides another important opportunity to mitigate GHG emissions in the cooling sector by promoting energy efficiency improvement (SEforALL 2018). Although the provisions about energy efficiency are not explicit in the Amendment, the parties have extensively developed discussions about energy efficiency in the cooling sector, including air-conditioning, refrigeration and heat-pump, at several meetings of the parties (MOPs) to the Montreal Protocol since the adoption of the Kigali Amendment. At the 28th MOP in 2016, the parties requested the Technology and Economic Assessment Panel to examine opportunities to increase energy efficiency in the cooling sector and bring about a transition toward climate-friendly alternatives (UNEP Ozone Secretariat 2020: 247–248). At the 29th MOP in 2017, the parties recognized that maintaining and enhancing cooling efficiency could have significant climate benefits. Thus, they requested the Technology and Economic Assessment Panel for an overview of other institutions' funding and practices to enhance the efficiency of cooling (UNEP Ozone Secretariat 2020: 249–250). The parties also requested the Executive Committee of the Multilateral Fund to identify and support energy efficiency improvement of Article 5 countries at the 30th MOP in 2018 (UNEP Ozone Secretariat 2020: 252).

In short, the objectives and provisions of the Kigali Amendment are aligned with the goals of the Paris Agreement under the UNFCCC (Michaelowa et al. 2019). Thus, the Kigali Amendment could be understood as a climate agreement linking the global ozone regime and climate change regime (Heath 2017; Sharadin 2018).

2.4 Kyoto Protocol to the United Nations Framework Convention on Climate Change and Paris Agreement

The UNFCCC calls for the parties' commitments to manage GHGs that have been excluded from the Montreal Protocol's regulation (Article 4.1) (UN 1992). The Kyoto Protocol, adopted under the UNFCCC in December 1997 and taking effect in February 2005, is the first international agreement that set binding restrictions on GHG emissions. The Kyoto Protocol listed six GHG categories: CO₂, methane (CH₄), nitrous oxide (N₂O), HFCs, perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆) (Article 3.1). The collective target under the Kyoto Protocol was to reduce emissions of these GHGs by at least 5% below 1990 levels during the first commitment period (2008–2012) (Article 3.1) (UN 1998). In the same manner as the Montreal Protocol, the principle of common but differentiated responsibilities applied to the Kyoto Protocol's GHG mitigation target setting for Annex I countries and economies (developed countries and economies) and developing countries. Thus, the Protocol set the mandatory reduction targets for 37 individual developed countries and the European Economic Community in Annex I but did not impose binding obligations to non-Annex I developing countries. While domestic measures were primarily encouraged for the parties to meet their reduction targets, the Protocol also allowed three flexible market-based mechanisms, namely clean development mechanism, joint implementation, and emission trading, to supplement domestic actions (UNFCCC 2011).

In December 2012, the Doha Amendment to the Kyoto Protocol was adopted for the second commitment period of the Kyoto Protocol. It added Nitrogen trifluoride (NF₃) to the GHGs list and set a new target, reducing GHG emissions by at least 18% below 1990 levels during the second commitment period (2013–2020) (Article 3.1) (UN 2012). This Amendment entered into force in December 2020.

At the 21st Conference of the Parties (COP21) to the UNFCCC in December 2015, the Paris Agreement was adopted. The parties agreed on the global climate target of limiting the increase in global temperature well below 2°C by 2100, preferably to 1.5°C, compared to pre-industrial levels (Article 2.1(a)). Unlike the Montreal Protocol and the Kyoto Protocol, following the top-down approach, the Paris Agreement takes the bottom-up approach to achieve the goal. While the mitigation obligations were given to only Annex I countries under the UNFCCC and the Kyoto Protocol, all parties communicate their nationally determined contributions (NDCs), conveying the national climate targets and commitments, every five years under the Paris Agreement (Article 4) (UN 2015). This Agreement entered into force in November 2016 and has been ratified by 193 parties, as of July 2022.

The Paris Agreement does not include a list of GHGs. However, since the NDCs incorporate economy-wide emission reduction targets, the cooling sector should be included in the NDCs. Furthermore, given that the Paris Agreement requires that successive NDCs should represent a progression and reflect the parties' highest possible ambition (Article 4.3), the reduction of emissions from refrigerants having high GWPs, such as HFCs, will play a significant role in formulating the NDCs and achieving the climate targets. Lastly, the Kigali Amendment states that it does not intend for CFCs to be excluded from the scope of the UNFCCC and the Kyoto Protocol (Article III) (UNEP Ozone Secretariat 2020: 925). Thus, HFCs will remain as GHGs covered, monitored, and mitigated under the UNFCCC (Michaelowa et al. 2019).

3. IMPACTS OF THE INTERNATIONAL AGREEMENTS

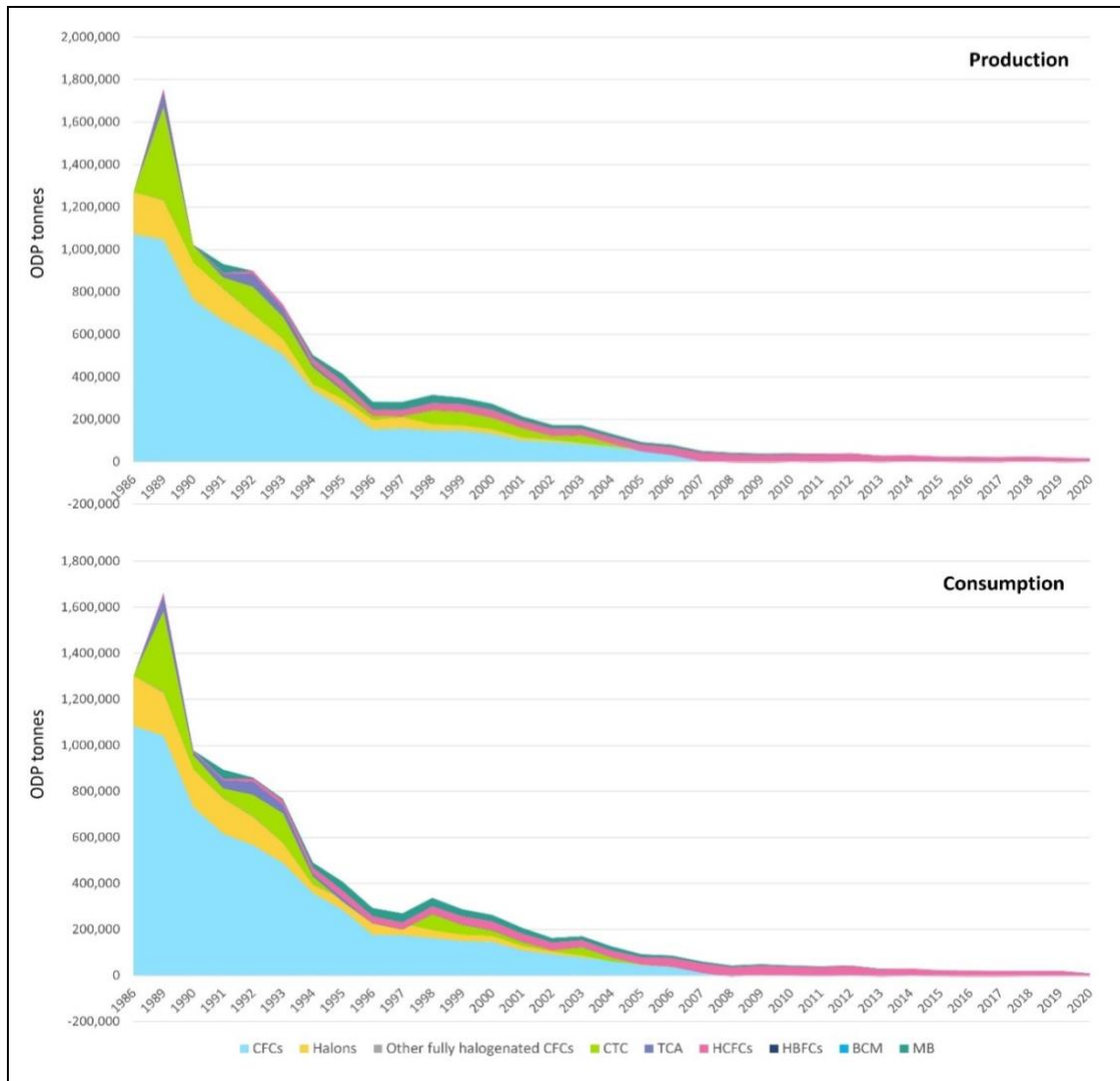
The Montreal Protocol is evaluated as the most successful international environmental agreement (Gonzalez et al. 2015; Heath 2017; UNEP and IEA 2020). Under the Montreal Protocol's regulatory framework, industries have changed their manufacturing processes and patterns, and developed countries have achieved their targets of complete phase-down of CFCs and HCFCs (DeSombre 2000). The Montreal Protocol not only contributed to solving the ozone layer depletion problem but also played the most significant role in reducing the climate threat, compared to other agreements, because many controlled substances have both high ODPs and GWPs (UNEP and IEA 2020). This section summarizes the impacts of the international agreements described in the former section.

3.1 Trends of Production and Consumption of Refrigerants

Implementation of the Montreal Protocol changed the production and consumption patterns of the controlled ODSs. Except for HFCs, nearly 99% of the total 96 controlled substances have been phased out during the last three decades since the time that the Montreal Protocol came into effect in January 1989. Notably, in 1996 by which time developed countries were supposed to achieve zero production and consumption of the substances listed in the Montreal Protocol's Annex A and Annex B, such as CFCs, halons, carbon tetrachloride and methyl chloroform, the world had already achieved almost 80% reductions in controlled substances compared to the 1986 levels. In 2020, the global production and consumption of controlled substances were 15,768 tons and 9,328 tons, respectively. They represent only 1.2% and 0.7% of the 1986 levels, which were 1.27 million tons and 1.3 million tons. Remarkably, CFC achieved the most dramatic reduction within a relatively short time period (Figure 2).

Figure 3 shows more detailed reduction trends of CFCs, halons, and HCFCs, which had been most widely used as refrigerants. All three refrigerants have been successfully phased out in compliance with the Montreal Protocol's phase-out schedules. Developed countries were obliged to make 100% reductions in CFCs by January 1996 and in halons by 1994. They reached zero production and consumption of CFCs and halons in 2008 and in 2001, respectively. Article 5 countries were required to reduce CFCs and halons by January 2010 and met the targets in 2013 for CFCs and in 2010 for halons. Even though the specific phase-out timing for each group has been slightly delayed, the global levels of CFCs and halons became zero in 2010. Developed countries also met their target to phase out HCFCs by January 2020. Article 5 countries' requirements for HCFC reductions are to maintain their 2009–2010 average production and consumption levels by 2013 and reduce the levels to 90% by 2015, to 65% by 2020, to 32.5% by 2025 and zero by 2030. The countries have sharply reduced HCFCs since 2012. In 2020, the collective levels of HCFC production and consumption of Article 5 countries were 17,843 tons and 17,396 tons, respectively. This means they overachieved with almost 50% reductions of HCFCs from the baseline values.

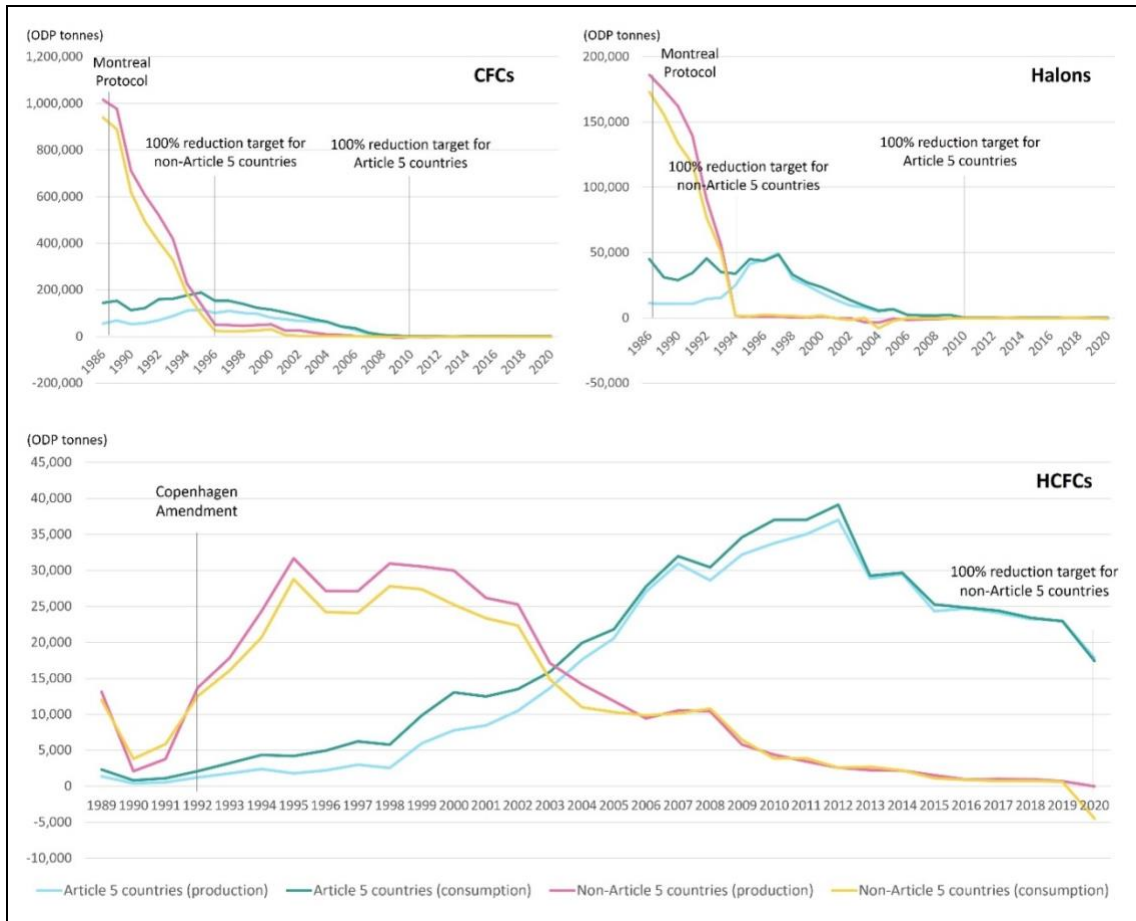
Figure 2: Global Production and Consumption of Controlled Substances (Except HFCs)



Source: Authors' illustration based on data from the UNEP Ozone Secretariat.

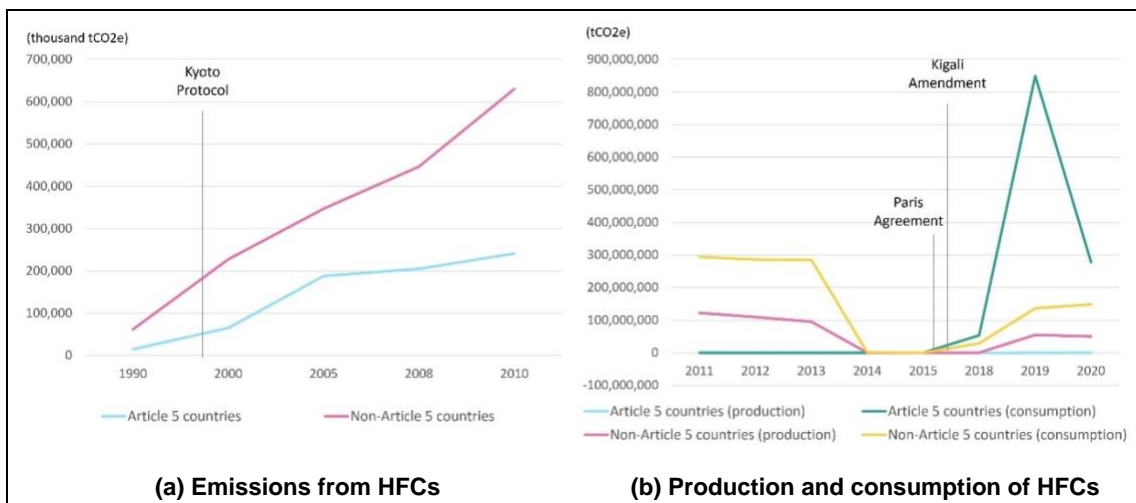
Due to the incomplete and insufficient data, it is difficult to examine the production and consumption trends of HFCs. However, according to the available data, HFC emissions have continually increased even after the adoption of the Kyoto Protocol (Figure 4(a)), and consumption of HFCs also showed an increasing trend after the adoption of the Paris Agreement and Kigali Amendment (Figure 4(b)). This observation suggests that more active global efforts should be made to reduce HFCs.

Figure 3: Production and Consumption of Selected Controlled Substances



Source: Authors' illustration based on data from the UNEP Ozone Secretariat.

Figure 4: Production and Consumption of HFCs



(a) Emissions from HFCs

(b) Production and consumption of HFCs

Source: Authors' illustration based on data from the World Bank and UNEP Ozone Secretariat.

3.2 Benefits for the Ozone Layer and Climate

As a result of the successful reductions of ODSs controlled by the Montreal Protocol, a slow recovery of the ozone layer has been reported in the last two decades. Scientists estimated the ozone hole in the stratosphere would have been 1.4 times larger by 2013 without the Montreal Protocol (UNEP Ozone Secretariat n.d.). However, owing to the successful execution of the Montreal Protocol, the ozone layer is healing and will likely recover the 1980 benchmark levels by around 2050 (WMO 2014; Birmpili 2018).

In addition to such an intended positive impact on the ozone layer, the implementation of the Montreal Protocol also brought significant benefits to limiting global warming because most of the controlled substances were not only solid ODSs but also strong GHGs. The phase-down of ODSs between 1990 and 2010 prevented 135 billion tCO₂e of emissions. It was estimated that the annual GHGs mitigation from the Montreal Protocol by 2010 was approximately 15 billion tCO₂e, which was five times greater than the annual emissions reduction target under the first commitment period of the Kyoto Protocol (Birmpili 2018; Solomon, Alcamo, and Ravishankara 2020). Some studies indicate that global average temperatures would have risen over 2°C by 2070 and the intensity of tropical cyclones would have been three times greater if the international community had not adopted the Montreal Protocol (UNEP Ozone Secretariat n.d.).

Many researchers predicted that implementing the Kigali Amendment would contribute considerably to meeting the global climate targets set under the Paris Agreement. Full compliance with the Kigali Amendment is expected to remove about 39 billion tCO₂e of HFCs between 2018 and 2050 (Höglund-Isaksson et al. 2017), and prevent approximately 100 billion tCO₂e of GHG emissions by 2050 (Zaelke et al. 2013). Consequently, such reductions in HFCs and other GHGs may avoid up to a 0.5°C increase by 2100 (UNEP 2017; WMO 2018). Moreover, if the efficiency of cooling equipment is improved, the benefits of the Kigali Amendment for the global climate will likely be more than double (UNEP and IEA 2020).

However, there exists a concern about the control measures for HFCs under the Kigali Amendment. The baseline for the developed countries is the sum of average HFC levels between 2011 and 2013 and 15%–25% of the HCFC baselines, and the baseline for Article 5 countries is the sum of average HFC levels between 2020 and 2022 or between 2024 and 2026, and 65% of the HCFC baseline. That is, while the baseline for the developed countries is calculated based on the past average, Article 5 countries' baseline depends on the future average. If the production and consumption levels of HFCs in Article 5 countries significantly increase over the next few years, the positive impacts of Kigali Amendment on climate change mitigation may be smaller than expected.

4. OTHER RELEVANT GLOBAL INITIATIVES

In spite of widespread cooling technologies and solutions, more than one billion people still endure inconvenience from the lack of access to cooling. Moreover, 90% of medical facilities in developing countries have limited access to modern cold chain equipment. Also, heat stress may threaten job security. In this regard, the necessity and demand for cooling are growing substantially in developing countries. In particular, the expansion of low-carbon cooling will improve quality of life by playing a vital role in achieving the UN Sustainable Development Goals (SDGs) (SEforALL 2018; UK Parliament 2021). Besides helping global climate change efforts (SDG13), low-carbon cooling may particularly contribute to reducing poverty and hunger (SDG1 and 2),

ensuring good health and well-being (SDG3), accessing affordable and clean energy (SDG7), building sustainable cities and communities (SDG 11), and promoting responsible consumption and production (SDG12) (UNEP and IEA 2020). Based on such recognition of the importance of low-carbon cooling and increasing interest, several global frameworks and initiatives have been launched, in addition to the international agreements (Table 3).

Table 3: Global Initiatives for Low-carbon Cooling

Initiative	Activity
Cool Coalition	<ul style="list-style-type: none"> • Networking various stakeholders • Helping knowledge sharing, advocacy and joint action for low-carbon cooling • Supporting policy development, technology pilots, innovative products and cooling solutions, and district cooling
Clean Cooling Collaborative (Formerly, Kigali Cooling Efficiency Program)	<ul style="list-style-type: none"> • Focusing on increasing access to climate-friendly cooling • Advancing policies, financing and technologies, strengthening institutions, and creating enabling environment for efficient and climate-friendly cooling • Launched a new fund, Fair Cooling Fund, in 2020 to boost sustainable and affordable cooling solutions for low-income households and communities
Climate & Clean Air Coalition	<ul style="list-style-type: none"> • Launched the Efficient Cooling Initiative in 2019 • Building political support and catalyzing actions related to energy efficiency in cooling and life-cycle management of HFCs
Green Cooling Initiative	<ul style="list-style-type: none"> • Forming a global network for green cooling • Promoting natural refrigerants and energy-efficient appliances • Policy advice, technology transfer, and capacity building
World Bank Group's programs	<ul style="list-style-type: none"> • Efficient and Clean Cooling Program: providing cross-sectoral technical support with affordable and efficient clean cooling solutions • Sustainable Cooling Innovation Program: supporting sustainable cooling solutions and business models for companies in developing countries • Sustainable Cooling Initiative: providing technical assistance and mobilizing further financing

Source: Authors' summary.

At the international organization level, the World Bank Group launched some programs to accelerate the uptake of sustainable cooling in developing countries. The World Bank's Energy Sector Management Assistance Program (ESMAP) and the Montreal Protocol Unit have established the Efficient and Clean Cooling Program to provide client countries with technical assistance in developing and applying affordable and efficient clean cooling solutions (UNEP and IEA 2020). Moreover, the International Finance Corporation (IFC) has established a Sustainable Cooling Innovation Program that supports the adoption of innovative sustainable cooling solutions and business models of companies in developing countries (UNEP and IEA 2020). The World Bank also launched the Sustainable Cooling Initiative in 2021 to provide technical assistance and mobilize further financing. To this end, this initiative will assist countries in advancing the necessary financing mechanisms and market infrastructure, and designing relevant policies and regulations for low-carbon cooling. The focus areas include air conditioning, refrigeration, cold chain, cool surfaces, and mitigation of urban heat island effects (Vender 2021).

UNEP has formed the Climate & Clean Air Coalition and the Cool Coalition to create global networks for low-carbon cooling and supported their activities. The Climate & Clean Air Coalition is a voluntary partnership to improve air quality and protect the climate. It was initiated in 2012 by the UNEP and six national governments, namely Bangladesh, Canada, Ghana, Mexico, Sweden, and the United States. It currently includes 76 state partners, 78 nongovernment organizations (NGOs) and international organizations, and about 200 actors around the world. The Climate & Clean Air Coalition launched the Efficient Cooling Initiative in 2019 as one of its key sectors. Through this initiative, the coalition partners and actors have made efforts to build political support and awareness and catalyze actions related to energy efficiency improvement in cooling and life-cycle management of HFCs. For example, they organized high-level ministerial roundtables to discuss the acceleration of lower ODP and lower GWP cooling and developed the Fluorocarbon Life Cycle Management initiative with the Ministry of Environment in Japan (Climate & Clean Air Coalition n.d.).

The Cool Coalition was formed at the First Global Conference on Synergies between the 2030 Agenda and Paris Agreement held in April 2019 in Copenhagen, to bring a unified effort of various stakeholders. It connects more than 100 partners from different sectors, including international organizations, national governments, municipalities, NGOs, industries, financial institutions, and academia worldwide. It helps their knowledge sharing, advocacy and joint action for low-carbon cooling. Starting from identifying the specific cooling needs of stakeholders, the Cool Coalition supports policy development, including National Cooling Plans (NCPs), Minimum Energy Performance Standards (MEPS) and labels, innovative cooling products and solutions, technology pilot projects, cooling audits, and scaling up of finance (UNEP and IEA 2020). It has supported three pilot projects: i) the passive cooling project in Cambodia that raises awareness of passive cooling and demonstrates passive cooling applications in buildings; ii) the demonstration of cold chain services for the agricultural and vaccine supply chain in India; and iii) the capacity building project in Vietnam that establishes National Cooling Fund and supports urban cooling strategies.

Another global network, the Green Cooling Initiative, was established by the German government. Funded by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) and the Federal Ministry for Economic Cooperation and Development (BMZ), it has implemented more than 240 cooling projects in around 40 emerging and developing countries since 1995. It has promoted natural refrigerants and energy-efficient appliances through policy advice, technology transfer in the refrigeration and air-conditioning and foam sector, and capacity building for technicians and political decision-makers (Breitfeld and Schabel 2020).

The ClimateWorks Foundation launched the Clean Cooling Collaborative focusing on increasing access to climate-friendly cooling in 2021. This initiative originated from the Kigali Cooling Efficiency Program (K-CEP), established in 2017 by 17 foundations and philanthropists with US\$51 million to facilitate Article 5 countries' compliance with the Kigali Amendment. The program aims at advancing policies, financing, and technologies for efficient and climate-friendly cooling for all. In this regard, it primarily supports efficient cooling appliances and refrigeration, natural refrigerants having low GWP, and space and passive cooling. To this end, approximately US\$60 million of K-CEP grants have been allocated to various policies and projects of governments, international organizations and the private sector to strengthen institutions and create an enabling environment for efficient low-carbon cooling (UNEP and IEA 2020). The supported activities include developing NCPs in 27 countries, including Chile, the PRC, Ghana, Lebanon, and Sri Lanka, MEPS and efficiency labeling in 26 countries,

upgrading cooling appliance manufacturing lines, building the capacity of the financial sector, and increasing access to cooling (Clean Cooling Collaborative 2021). In 2020, the Clean Cooling Collaborative launched a new Fair Cooling Fund with ClimateWorks Foundation and Ashden. It aims to increase access to cooling by boosting sustainable and affordable cooling solutions for low-income households and communities. This fund is supporting seven organizations' projects in five countries, namely Colombia, Egypt, Ghana, India, and Rwanda. The specific solutions include portable solar-powered cold storage units and freezers for low-income farmers, milk producers and fishermen, upgrades of slum houses to tackle high indoor temperatures, and promotion of urban greening.

5. CONCLUSION AND POLICY RECOMMENDATIONS IN THE ASIAN CONTEXT

International agreements usually initiate or accelerate regional and national action for a common problem. The Montreal Protocol required and encouraged each party to join the global efforts for ozone layer protection, by setting the international objectives, including the controlled substances, reduction targets, and phase-out schedules, and establishing financial and technical support mechanisms and scientific assessment and review mechanisms. The Protocol worked effectively, and the successful experience of ozone layer protection led the international ozone regime to extend its attention to climate change.

The adoption of the Kigali Amendment is a critical step towards meeting the global climate targets by decarbonizing the cooling sector. Each country is required to comply with this international agreement so that it can accomplish its decarbonization purpose. In particular, Asia is expected to take a central part in executing the Kigali Amendment since the PRC is the world's largest HFC producer and consumer and rapidly industrializing economies and enormously large population in this region will significantly increase the demand for cooling. Thus, it needs to consider how to make the Kigali Amendment work effectively with the countries' full compliance. Due to its unique, irreplicable success factors, the Montreal Protocol's success does not guarantee that the Kigali Amendment will follow the same path. Nevertheless, the experience of the Montreal Protocol and its Amendments still suggests some lessons and insights for the successful implementation of the Kigali Amendment.

First, national-level policies should be aligned with international agreements. Given that the international environmental agreements have limitations of weak penalties for noncompliance and difficulties in regulating and monitoring respective producers and consumers, they will be ineffective if the national governments choose not to participate in the agreement or do not enact specific policies to fulfill their obligations stated in the international agreement. To accelerate the low-carbon cooling, on the one hand, the ratification of the Kigali Amendment should be encouraged. While 198 parties have ratified the Montreal Protocol, the Kigali Amendment has been ratified by 137 parties, as of July 2022. In Asia, over 20 countries have not ratified the Kigali Amendment yet. In order to raise the effectiveness of global efforts for low-carbon cooling, those countries are encouraged to participate in the Kigali Amendment.

On the other hand, each country should develop effective policies to reduce HFCs and improve cooling efficiency. The early experience of the Montreal Protocol compliance in Asian developing countries showed that the countries having quantitative restrictions on CFCs supply, such as Hong Kong, China; Singapore; and Taipei, China, have significantly reduced CFCs by sending a clear signal of preventing CFCs consumption

to companies producing and using CFCs (O'Connor 1991). Furthermore, an extensive policy mix of stringent regulations and market-based instruments has fueled successful ODS reductions and meeting scheduled phase-out targets of large ODS-producing and -consuming countries, such as the PRC and India. The implemented policies include legislation regulating and licensing production, sale, consumption and trade of ODSs, customs and excise duty exemption, capacity building for local governments and stakeholders, and public awareness campaign (Zhao 2005; Government of India 2007). In this regard, active national support and policies to mitigate HFCs will help spur low-carbon cooling and meet the national and global targets of the Kigali Amendment.

Second, financial and technical assistance should be strengthened to facilitate developing countries' compliance with the Kigali Amendment. Considering that most Asian countries are developing countries, this is particularly important for motivating Asian countries to engage in low-carbon cooling. Developing countries' decarbonization efforts may be marginal to the global mitigation of global warming in the short term due to their small contribution to the global GHG emissions. However, given their potential for a sharp increase in GHG emissions based on rapid industrialization, their commitment to low-carbon cooling is essential to successfully implementing the Kigali Amendment and achieving the global climate goal in the long term. Lack of finance, advanced technology, and institutional capacity are typical constraints that developing countries often face when they try to comply with international agreements. Hence, developing countries have argued that financial and technical support is required for them to set ambitious targets for environmental protection and achieve the targets.

The Montreal Protocol also experienced the developing countries' reluctance to join in the absence of financial support mechanisms. A 10-year grace period and a trade incentive given to Article 5 countries were insufficient to bring developing countries into the international regulation. Before the adoption of the London Amendment in 1990, when the establishment of the Multilateral Fund for developing countries was stated, only three countries (Mexico, Nigeria, and Venezuela) among the major CFC-using developing countries had joined the Montreal Protocol (DeSombre 2000). However, the financial support through the Multilateral Fund led to the participation of large developing countries that had refused to join the Protocol, including Argentina, Brazil, the PRC, and India (Downie 2012), and ultimately enabled the universal ratification of the Montreal Protocol. In fact, the Multilateral Fund has supported the development of national ODS mitigation strategies and relevant technologies in developing countries. For instance, in the PRC, the Multilateral Fund provided financial assistance for the companies' technology shift and enhancement of the institutional and administrative capacity of Chinese government agencies (Zhao 2005). Therefore, the roles of the Multilateral Fund will remain important for the success of the Kigali Amendment.

As the demand for cooling in developing countries rapidly increases, it may become difficult for the Multilateral Fund to meet all the needs of these countries. Hence, the roles of global initiatives of international organizations and NGOs for low-carbon cooling will grow. As stated in the previous section, they have been supporting various low-carbon cooling policies and projects. Therefore, those global initiatives may function as additional funding sources that complement the Multilateral Fund and a channel for technology transfer and information sharing by supporting NCP development, policy implementation related to low-carbon cooling, energy efficiency improvement, demonstration of small-scale cooling solutions, and capacity building (Michaelowa et al. 2019; UK Parliament 2021).

Third, along with the improving energy efficiency of cooling, the substances that neither harm the ozone layer nor exacerbate climate change should be used as substitutes for HFCs. The history of the Montreal Protocol shows that the regulation of certain refrigerants will inevitably bring other refrigerants not controlled under the Protocol. It should be noted that the ultimate objective of the international agreement is not to phase out HFCs but to meet the global climate goal. In this context, alternative refrigerants may become an essential factor that determines the success of the Kigali Amendment and the Paris Agreement. Currently, natural refrigerants and foam blowing agents, such as hydrocarbons and ammonia that have much smaller GWPs than HFCs, are expected to replace the HFCs (UNEP 2017). Governments should support the research and development of national laboratories and academic institutions to find and commercialize other alternative refrigerants beyond currently available substitutes.

In addition to government and academic efforts, industries are also expected to play an essential role in such refrigerant transition. One of the success factors of adopting and implementing the Montreal Protocol was the industries' shift in position about the CFCs regulation from the strong objection to conditional acceptance and involvement with CFCs mitigation. As the scientific evidence on the adverse effects of CFCs had increased and the expectation of the adoption of the international agreement regulating CFCs had been heightened, large ODS-producing companies, such as DuPont, developed alternative substances to CFCs to avoid future regulations (Morrisette 1989). They initially complained about the difficulty in finding substitutes and the rise in production costs, but finally found the available substitutes and made them affordable (Pfluger 2010). HFC control will directly impact the profit of HFC-producing companies. To deal with this challenge, industries need to take the lead in developing new refrigerants and innovative cooling solutions as they did in phasing down CFCs.

Lastly, the monitoring, reporting, and verification (MRV) need to be strengthened. The Montreal Protocol's basic approach for the parties' compliance is self-reporting based on their own monitoring systems without a strong enforcement system (Solomon, Alcamo, and Ravishankara 2020). Such an institutional setting enabled many parties to participate in the agreement, but at the same time, caused some challenges to global monitoring and assessment. Observational studies of ODSs have been mostly conducted by scientists and individual governments, and the data on newly controlled substances, such as HFCs, have been missing in many countries. Incomplete data sets and the different monitoring and verification systems may hinder the accurate assessment of the performance under the Kigali Amendment. Furthermore, the increasing number of controlled substances, recent changes in data reporting requirements, and more complex control measures may make it difficult for the parties, particularly developing countries, to track the actual progress, compile the relevant information, and make self-assessments. Therefore, it is expected that clear guidance for MRV and a robust enforcement system would help enhance the credibility of data, assure parties' compliance, and ensure the success of the Kigali Amendment.

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