HFC Phasedown Under the Kigali Amendment to the Montreal Protocol Is Less Costly if Fast Than if Slow

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Abstract

This paper makes the case that faster phasedown of hydrofluorocarbons (HFCs) to help avert near-term climate tipping points will be less costly than the existing schedule for both non-Article 5 and Article 5 Parties. In particular, the paper demonstrates that a faster HFC phasedown is less costly for: 1) non-Article 5 donors to the Multilateral Fund for the Implementation of the Montreal Protocol (MLF); 2) new owners of cooling equipment who will benefit from lower cooling and service costs that offset the slightly higher purchase price for which the cost difference can be minimized by a bulk procurement or buyer's club; 3) neighbourhoods and cities that will experience reduced pollution from fossil fuel power plants, leading to lower health care costs and increased productivity; 4) families and communities who will benefit from electricity savings spent locally on goods and services that support quality of life and prosperity and circulate through the economy; and 5) national governments that will incur lower compliance costs for stratospheric ozone and climate treaty obligations and will fiscally benefit from an improved balance of payments and lower interest rates on borrowing for renewable energy and other public investments. The paper also makes the case that accelerating the HFC phasedown can be less costly to manufacturers of HFC replacement technology through enhancements to brand reputation; environmental, social, and governance (ESG) ranking; and fulfilment of public pledges. Additionally, the paper finds that lifecycle refrigerant management (LRM) supports the case for a faster phasedown of HFCs, which avoids unnecessary sales of cooling equipment with obsolete HFC refrigerants that requires servicing, and prevents perverse incentives that unintentionally prolong the use of high-global warming potential (GWP) HFCs.

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1. Findings

This paper finds that grace periods, which prolong the use of obsolete high-global warming potential (GWP) hydrofluorocarbons (HFCs) by Article 5 Parties (A5 Parties),[1] are economically and environmentally counterproductive. Furthermore, it finds that a faster phasedown of HFCs is less costly to public and private interests—except for fluorocarbon manufacturers that will lose market share and profits to companies with not-in-kind (NIK) replacements, while improved lifecycle refrigerant management (LRM) practices reduce demand for newly manufactured HFCs.

In the Chinese market, and universally, companies choose to market highly efficient cooling equipment using refrigerants that do not break down into trifluoroacetic acid (TFA), which under some definitions is considered a per- and poly-alkyl substance (PFAS)—an "everywhere and forever" chemical.[2] Instead, refrigerant R-32 (difluoromethane) now dominates as the replacement for obsolete R-410A in the room air conditioning (RAC) sector, with R-32 adoption far exceeding the A5 Party timelines set forth in the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol).

The primary reason for this rapid transition is that R-32 is cost-effective, and manufacturers prioritize refrigerant selection based on economic considerations. R-32 is more energy-efficient at high ambient temperatures than the obsolete R-410A, which is a 50%/50% blend of R-32 and R-125 (pentafluoroethane); and R-32 also costs less to manufacture and during operation than the blended refrigerants recently patented and promoted by the fluorocarbon industry. Therefore, the refrigerant transition is a crucial factor for manufacturers because it directly influences their decision-making and long-term strategy.

Another refrigerant to replace R-410A in RACs is R-290 (propane). R-290 requires additional considerations for deployment, as it is a highly flammable, natural, hydrocarbon-based refrigerant now overwhelmingly sourced from natural gas processing and crude oil refining (EIA 2025). R-290 is suitable for equipment where the refrigerant charge is small enough not to reach the lower flammability limit if the refrigerant were to leak into the occupied cooled space. R-290 has no TFA or PFAS atmospheric degradation products but is a volatile organic compound (VOC) that requires leak-tight systems with recovery, recycling, or destruction for emissions mitigation. Notably, "responsibly sourced" propane is under development and can be produced from feedstocks such as vegetable oils, natural fats, and various types of grease (AFDC 2025; UVM 2025).

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[1] Article 5 or A5 Parties refers to countries officially designated as developing by the United Nations under Article 5, paragraph 1 of the 1987 Montreal Protocol. This designation provided a 10-year delay in compliance with the original controlled substances (just a portion of CFCs and halons).

"Any Party that is a developing country and whose annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol for it, or any time thereafter until 1 January 1999, shall, in order to meet its basic domestic needs, be entitled to delay for ten years its compliance with the control measures set out in Articles 2A to 2E, …" (UNEP Ozone Secretariat 2020).

The London Amendment (1990) added fully halogenated CFCs, carbon tetrachloride, and methyl chloroform to the list of controlled substances and established the MLF to pay the agreed incremental costs of compliance by A5 Parties. Subsequent Amendments added additional controlled substances; Adjustments accelerated the phaseout, and Decisions guided the success of ozone layer and climate protection. Thus, the Parties adapted the original definition of A5 Parties and the privileges to the evolving Protocol.

[2] HFC-152a and HFC-32 have the conspicuous advantage of not degrading to TFA or other worrisome chemical substances.

2. Introduction to Stratospheric Ozone and the Montreal Protocol

Stratospheric ozone shields Earth from the harmful effects of ultraviolet (UV) radiation originating from the sun. UV radiation increases the incidence of skin cancer and cataracts, suppresses the human immune system, damages agricultural and natural ecosystems, degrades aquatic and terrestrial carbon sinks, and deteriorates the built environment (Young et al. 2021; EEAP 2022; Andersen and Gonzalez 2023). For elaboration of how science persuaded manufacturers to phase out ozone-depleting substances (ODSs), see Appendix A. For a description of governance under the Montreal Protocol, see Appendix B.

a. The Inspired Economics of the Montreal Protocol

The Montreal Protocol community has distinguished itself by early recognition that stratospheric ozone depletion would harm every person on Earth through unique and unequal combinations of financial, health, nutrition, comfort, and convenience impacts. Diplomats realized that the environmental and technical benefits to each citizen put at risk by ozone depletion were far greater than the costs of a fast, fair, and efficient transition to ozone- and climate-safe technology.

The most cost-effective solution turned out to be a combination of stringent control measures to phase out production and consumption of several groups of ODSs, with each ODS numerically weighted by ozone-depletion potential (ODP). Phasedown and phaseout implementations are based on each country's status as a consumer and producer of ODSs and its basic domestic needs (UNEP Ozone Secretariat 2020). Prior to the Kigali Amendment, about 85% of alternatives and substitutes to ODSs were NIK (non-fluorocarbon) replacements, with about 15% in-kind HFC, and hydrofluoroolefin (HFO) replacements mostly for refrigerants now scheduled for phasedown under the Kigali Amendment to the Montreal Protocol (Andersen, Sarma, and Taddonio 2007; Seidel et al. 2016; Andersen and Gonzalez 2023).

In response to Molina and Rowland's 1974 warning, aerosol products such as spray deodorants, hairspray, and household pesticides had been boycotted and then banned in the United States (US), and then in Canada, Denmark, Japan, Norway, and Sweden, and other jurisdictions. Analysis by the countries that had banned chlorofluorocarbon (CFC) aerosol products documented that the replacements were lower cost, often were produced by the same companies and employees, and had fully satisfied consumers. The first Montreal Protocol Technology and Economic Assessment Panel (TEAP) pragmatically recommended an "easy first, hard last" approach, with detailed advice on exactly how to safely and efficiently transition from CFCs to hydrocarbon aerosol propellants and other NIK replacements. With money to be saved and citizens satisfied by protecting the ozone layer, developing countries transitioned far faster than required by their control measures, which were set with schedules ten years slower than for developed countries (Andersen and Sarma 2002; Andersen, Sarma, and Taddonio 2007; Andersen and Gonzalez 2023).

b. The Multilateral Fund for the Implementation of the Montreal Protocol

The Parties to the Montreal Protocol crafted the pathbreaking Multilateral Fund for the Implementation of the Montreal Protocol (MLF) to be democratic, with an equal number of Executive Committee members from A5 Parties and non-A5 Parties. The MLF Executive Committee defined exactly the agreed incremental costs paid to A5 Parties for transitioning to alternatives and substitutes for ODSs. These incremental costs are the actual cost of atmospheric protection rather than the value of damages avoided (such as through chlorine or carbon trading). A5 Parties then expanded their ambition to phase out ODSs as fast as technically and financially feasible.

The first Chief Officer of the MLF, Dr. Omar El-Arini, was an activist UN executive who anticipated and pragmatically solved issues as they emerged, including using flexibility in financing measures to safely implement the replacements and to capture environmental side benefits. The Montreal Protocol's "start-and-strengthen" approach encouraged the development of easy and available replacements while aggressively pursuing solutions in more challenging applications. Furthermore, savings from corporate and military leadership made it possible to accomplish far more and faster than what had been anticipated from the available MLF replenishment. Additional savings from "non-investment" spending for programs at the United Nations Environment Programme (UNEP) OzonAction built capacity, promoted best available technology, and avoided replication of inferior technical choices. In some cases, companies in A5 Parties paid their own cost of transition out of concern for the ozone layer and to avoid delay in offering their customers replacement technology with superior economic, environmental, and technical performance (Andersen and Sarma 2002; Andersen, Sarma, and Taddonio 2007; Andersen and Gonzalez 2023). In other cases, companies in non-A5 Parties paid their A5 suppliers to transition to reduced or ODS-free components and subassemblies so the final product was ozone-safe and avoided "made with or containing ODS" labels required by environmental authorities in some jurisdictions.

The significant cost savings of paying the agreed increment costs under the Montreal Protocol MLF finance mechanism contrast with carbon trading under climate agreements, which pays for the damage avoided. The Montreal Protocol spent billions of dollars to avoid trillions of dollars in damage. One measure of the success of the phaseout of controlled ODSs,[3] which is now 99% complete, is that most people never experienced a noticeable increase in product ownership cost despite dramatic increases in product durability, technical performance, and reliability.

3. Fairness through Government, Corporate, and Military Leadership

Developed countries have captured the profits from the commercialization of ODS and have enjoyed most of the benefits through high per capita use, while developing countries have captured very little of the benefits of commercialization and use but have suffered equal or greater per capita impacts on health and prosperity. Developing countries also have had less ability to mitigate damage.[4]

> For example, nearly 90% of the 95 million people who are blind live in low-income countries (WEF 2021). The leading cause is cataracts, accounting for 50% of all blindness in low- and

[3] Ninety-nine percent of substances controlled under the Montreal Protocol are phased out from production and consumption (WMO 2023). However, nitrous oxide, an ozone-depleting-substance and greenhouse gas, is not a Montreal Protocol controlled substance. ODS and HFC feedstocks are controlled substances under the Montreal Protocol but are subjected to limited exemptions under the Montreal Protocol, including an exemption from calculation of controlled substances produced and consumed (Andersen et al. 2021).

[4] Fair-skinned humans having less melanin are significantly more susceptible to the damaging effects of UV radiation, including skin cancer, but darker skin offers no natural protection against cataracts. Furthermore, citizens in developed countries with income and access to health care can mitigate the quality-of-life consequences of both skin cancer and cataracts (American Cancer Society 2025).

middle-income countries compared to 5% of blindness in higher-income countries (WEF 2021). Cataracts are not difficult or expensive to cure, but they debilitate households without access to affordable eye care. Thus, the economic impact of increased UV radiation from stratospheric ozone depletion caused by wealthy global citizens would justify the cost of developing country phaseout and compensation for damage from historic ODS emissions.

Furthermore, it would have been cost-effective for the citizens of developed countries to pay the entire cost of replacing ODSs worldwide to capture the benefits to themselves of avoiding skin cancer, cataracts, suppression of the immune systems; and damage to agricultural and natural ecosystems, aquatic and terrestrial carbon sinks, and the built environment.

The health of farmers, fishers, and others dependent on natural capital and working outdoors in the sun are harmed more by ozone depletion than workers employed in indoor manufacturing and other sectors with little workplace sun exposure.

Any higher cost of goods and services made with and containing replacements for ODS and greenhouse gas (GHG) fluorocarbons disproportionally harms poor people relative to wealthy people.

People living in countries that share the wealth of national prosperity are less harmed than people living in countries without economic and environmental justice.

The costs of global compliance with the Montreal Protocol might have been paid by the fluorocarbon manufacturers, at least to the extent that they profited from sales of ODS-replacing HFCs and HFOs and their accumulated corporate assets.

Regardless, the solution agreed under the Montreal Protocol provided benefits—including climate protection—to all humanity and to the natural environment at costs voluntarily paid by suppliers and customers of products previously made with or containing ODSs. Smarter still, the Montreal Protocol encouraged and recognized the public leadership of enterprises sharing intellectual property and knowledge.

Simultaneous to the leadership provided by governments in developing and developed countries under the Montreal Protocol, responsible corporations and military organizations offered free access to critical technology and know-how (Andersen, Taddonio, and Sarma 2007). For example, multinational electronics companies pledged to phase out ODSs in overseas operations within one year of phaseout pledges in their home countries. And to accomplish their home country phaseout, these companies required overseas suppliers to certify components as ODS-free. Furthermore, multinational electronics companies in the Industry Cooperative for Ozone Layer Protection (ICOLP) disclosed the know-how and allowed free use of patented technology to accomplish ODS-free manufacturing, and in some cases, financed the transition cost for their suppliers in A5 Parties (ICOLP 1995; Andersen, Sarma, and Taddonio 2007).

4. Grace Period Advantage in the 1990s Is Now Counterproductive to A5 Interests and Climate

In 1987, when the Montreal Protocol was signed, developed countries (non-A5 Parties) dominated the manufacture and use of ODSs, with a large portion used for the manufacture of products sold in developed countries. Developed countries also owned and controlled engineering centres of excellence that could invent ODS chemical replacements. They also had almost unlimited access to the finances necessary to reduce ODS emissions and invent, approve, and implement new technology.

The grace period for developing country compliance with control measures agreed in the Montreal Protocol was consistent with the "common but differentiated responsibilities" principle, promoted at the 1992 Earth Summit in Rio de Janeiro (UN 1993). UNEP Ozone Secretariat Executive Director Mostafa K. Tolba's justification was the fact that developing countries were responsible for a relatively small portion of historic global use and emissions of ODSs. In addition, the cost of replacement would be less for the developing countries once alternatives and substitutes were commercialized in developed countries and had achieved affordable costs from economies of scale.

But today, the tables are completely turned for the following reasons:

1) Industrialized A5 Parties supply about 90% of global cooling equipment, with about 80% from China alone (ChinaIOL n.d.; UN Comtrade Database 2025), with Chinese companies already shifting to low-GWP replacements for non-A5 export markets such as the European Union (EU), which has stringent refrigerant GWP caps.
2) Manufacturers in industrialized non-A5 Parties supply a majority of efficient cooling equipment to their domestic and export markets that demand efficiency.
3) Low-GWP replacement technology is more efficient and has lower life cycle ownership costs than the obsolete technology, which is no longer upgraded with new engineering.
4) A5 Parties are demanding access to the best available cooling technology and an end to dumping in their markets of inefficient cooling appliances using "obsolete" refrigerants.
5) The EU Regulation on fluorinated GHGs includes prohibitions on the export of certain cooling equipment not qualified for sale in domestic markets, providing a powerful model for non-A5 industrialized Parties and global enterprises to follow.
6) Scientists warn that near-term climate tipping points will be exceeded unless the emissions of HFCs and other short-lived climate pollutants (SLCPs) are drastically curtailed by national regulations or by LRM and the acceleration of the control schedules of the Kigali Amendment to the Montreal Protocol.

5. Montreal Protocol Replacing Environmental Dumping with Sales of Earth-Friendly Products

Environmental Dumping is legally defined as:

> *[T]he practice of exporting products to another country or territory that: 1) contain hazardous substances, 2) have environmental performance lower than is in the interest of consumers or that is contrary to the interests of the local and global commons, or 3) can*

undermine the ability of the importing country to fulfil international environmental treaty commitments (Andersen et al. 2018).

Ghana, on behalf of all of Africa, spotlighted at the meetings of the Parties to the Montreal Protocol the dumping in developing countries of newly manufactured but inefficient cooling equipment with obsolete ozone-depleting and climate-forcing refrigerants. This equipment and refrigerants are hazardous to life on Earth and contribute to poverty and environmental injustice (CLASP and IGSD 2020; Agyarko et al. 2022; Andersen and Gonzalez 2023; CLASP and IGSD 2023; CLASP and IGSD 2025).

The response to an abrupt realization of the dumping of inefficient cooling equipment with obsolete refrigerants is often for stakeholders to go through five stages of change: *denial*, *anger*, *bargaining*, *depression*, and *acceptance* (Kübler-Ross 2014).[5] These stages were experienced in the response to the original ozone and climate warnings of Crutzen, Molina and Rowland, and Ramanathan, and to the many other stages in the strengthening of the Montreal Protocol, when new hazardous ODSs and GHGs chemicals were added to the lists of controlled substances to be phased out or phased down (Benedick 1998; Andersen and Sarma 2002; Parson 2003; Andersen and Gonzalez 2023; Miller 2025).

The proof that certain Parties and companies were exporting and marketing ("dumping") new but inefficient cooling equipment with obsolete refrigerants that deplete stratospheric ozone and force climate change was initially met with *denial*, *anger*, and *questioning* of the evidence concerning such claims.

When the evidence of dumping was validated, some cooling equipment manufacturers responsibly expanded the availability of R-32 and R-290 in the A5 markets that were most vocal in wanting the lowest life cycle ownership and carbon footprint. Other cooling equipment manufacturers expressed concern for the environmental injustice but argued that the Montreal Protocol had no responsibility to influence what is sold or not sold so long as the ODS phaseout and HFC phasedown schedules were satisfied.

Another reaction from some manufacturers and marketers of new inefficient and obsolete cooling equipment was to try shifting the burden for resolving dumping to governments and citizens of developing countries, in essence "blaming the victims" for not demanding minimum energy efficiency and not prohibiting obsolete refrigerants, despite evidence that cooling equipment manufacturers often intervene in developing countries to discourage stringent minimum energy performance standards (MEPS) and other standards that encourage purchase of products in the private and public interest (Agyarko et al. 2022.)

Fortunately, the Montreal Protocol's start-and-strengthen experience shows that inequities such as the dumping in vulnerable A5 Parties of inefficient cooling equipment using obsolete refrigerants can be overcome. In the early years of the Montreal Protocol, many companies—including those based in developing countries—who had marketed products made with or containing ODS substances leapfrogged the shame of being associated with ODS use and emissions and became

[5] The Kübler-Ross Change Curve® has evolved from the original five stages to stages that can include any combination and sequence of Anger, Shock, Denial, Frustration, Bargaining, Experiment, and Integration, with or without Depression.

known and appreciated for environmental leadership in protecting Earth (ICOLP 1995; Andersen and Sarma 2002; Andersen, Sarma, and Taddonio 2007; Andersen et al. 2018; Wu and We 2020; Andersen and Gonzalez 2023).

Possibly the best evidence of companies successfully leapfrogging this shame is reflected in the hundreds of awards presented to individuals and organizations for going beyond the call of duty. These companies phased out ODSs far faster than required for compliance, and some shared patents and know-how worldwide to speed recovery of the stratospheric ozone layer and help avoid climate change. An appendix in Andersen and Gonzalez (2023) contains a comprehensive list of awards earned from 1990 to 2023. Figure 1 presents two widely distributed advertisements praising companies and military organizations taking fast action under the Montreal Protocol.

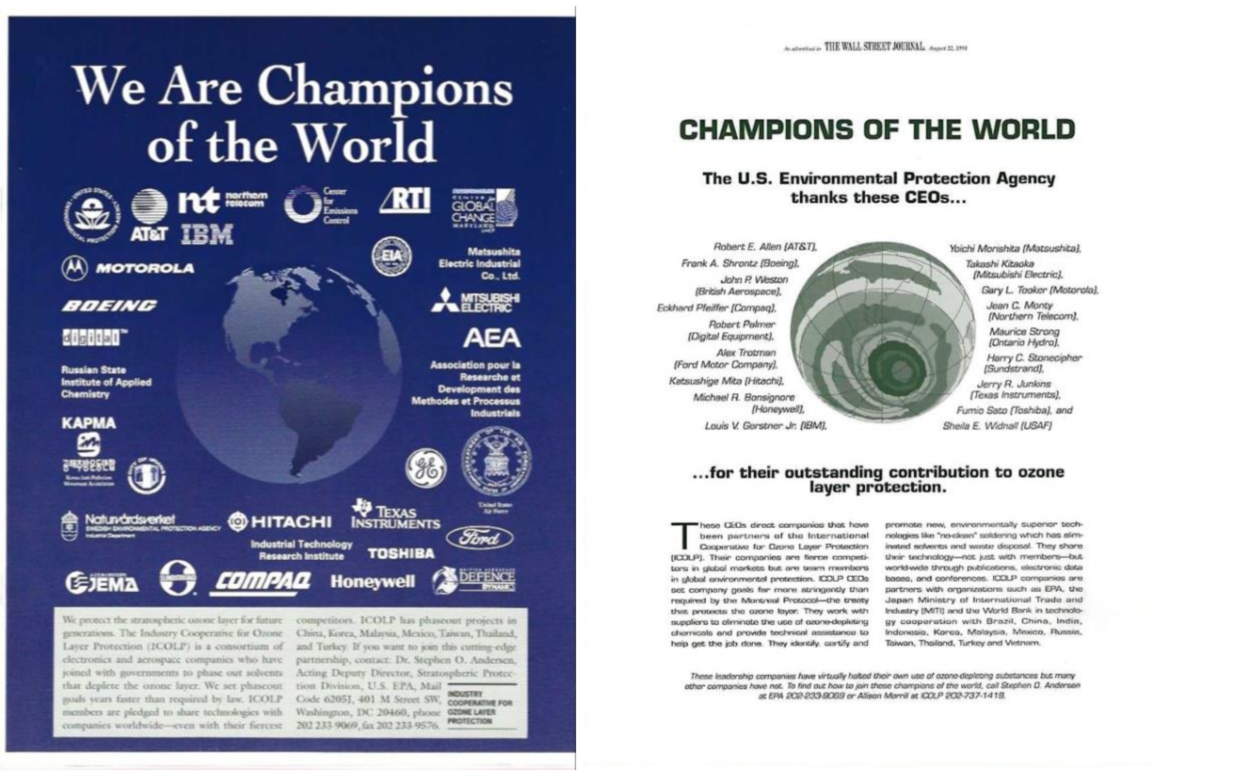

Figure 1. Two Examples of Companies Leapfrogging Shame with ODS Phaseout Leadership
Source: Andersen and Gonzalez 2023

6. Economics of Global Warming and Extreme Heat

Total GHG emissions from the refrigeration and air conditioning sector are projected to reach approximately 4.4 billion tons of carbon dioxide equivalent (t CO_2-eq) in 2020 (GCI 2023), accounting for over 10% of global GHG emissions (Dong, Coleman, and Miller 2023). The atmospheric abundance and emissions of hydrofluorocarbons (HFCs) used as refrigerants are also rapidly increasing (WMO 2023).

Consider two scenarios:

Scenario 1: RAC buyers may consider only narrow self-interest and purchase inefficient air conditioners with obsolete refrigerants which are hazardous to the climate and less expensive if only considering the initial purchase price (i.e. "first cost"). Climate change creates local and global negative impacts to personal and public health, jobs, incomes, purchasing power (inflation), and profits, as well as risking life and property from storms and wildfires, including the damage or destruction of irreplaceable social and cultural assets.

Table 1. Scenario 1: Inefficient RAC impacts

Owner	**Local**	**National**	**Global**	**Ecosystem**
Lower first cost but lower quality and features; higher operating cost and lower resale value	Money spent on electricity only benefits power plant and fossil fuel investors; pollution and impacts from more fossil fuel and biomass combustion harm communities	Less prosperity and tax revenue; higher trade imbalance and interest rates for public investment	Everyone and all economies harmed by resource scarcity, emissions from fossil fuel power plants supplying electricity to cooling appliances, and climate change	Severe damage to already diminished habitat, much of which is the natural capital that supports prosperity and quality of life; for many people, ethical and religious implications for destroying the Earth

Scenario 2: RAC buyers go beyond narrow self-interest and purchase efficient air conditioners with climate-friendly refrigerants, insist on proper installation and service for lowest life cycle carbon footprint, and take satisfaction in investing for maximum global benefits that will be paid back in electricity savings over the lifecycle of the appliance and from reciprocal benefits of others, making an investment for this and future generations.

Table 2. Scenario 2: Efficient RAC benefits

Owner	**Local**	**National**	**Global**	**Ecosystem**
Higher first cost offset by electricity savings or mitigated through bulk purchase or buyer's club; higher quality, with more features; lower operating costs and higher resale value	Money saved on electricity spent locally for goods and services that build community wealth and prosperity; cleaner air for healthy neighbours paying less for health care	Local spending circulates for national prosperity and tax revenue; trade balance supports lower interest costs for public investment	Lessened resource scarcity and inflation; shared benefits of cleaner air, less pollution, and sustainable climate	Recovery and resilience of agricultural and natural ecosystems, including natural capital that supports prosperity and quality of life for all levels of wealth and income; comfort in Earth safer for this and future generations

The ownership cost of cooling equipment depends on the local purchase price of the equipment (including shipping and import tax, if any), the labour cost of proper installation, the operating cost of electricity, the labour cost of service, and the ambient temperature and humidity during the cooling season. Air conditioning equipment owners in developing countries with long, hot, and humid cooling seasons and high electricity cost per kilowatt hour (kWh) save more per year than owners in more temperate climates, where the cost of electricity is lower and greater annual savings in electricity costs justify a higher price for the most energy-efficient cooling equipment.

Table 3. Developed and Developing Country Markets

	Advantages	**Disadvantages**
Developed Country Markets	Local production, competitive pricing, online discount access, easy financing, certified technical performance	High labour costs of local delivery, installation and service; high rent for sales and warehousing; labour less experienced in fabrication forces delay from parts shortages
Developing Country Markets	Low labour costs of installation and service; high experience in fabricating parts, when necessary; MLF finance of agreed incremental cost and energy efficiency speed market transition	Marketing of inefficient cooling equipment with obsolete refrigerants at low purchase price that looks the same as an environmentally superior product tricks buyers into unaffordable cost of electricity

The implication is that cooling equipment designed for temperate European, Japanese, and North American cooling seasons is less efficient than required for climates with longer, hotter, and more humid cooling seasons. The MEPS justified for temperate climates is lower than the MEPS justified for hotter and more humid climates (Holuj et al. 2019). Therefore, the new regulations prohibiting the export of cooling not allowed for sale in the EU and the US are in the self-interest of RAC buyers in export markets with longer, hotter, and more humid cooling seasons. Such regulations are also in the self-interest of citizens worldwide living in the most vulnerable locations with the least financial capacity to mitigate risk. These locations are typically in Parties with coastal and river basin lowlands prone to flooding in storms, which are exacerbated by climate change. In a vicious circle, fossil fuel and biomass emissions from power plants that supply the RACs partially drive climate change. The poorest citizens are not only unable to afford the cost of the RACs but are often living in the most vulnerable locations in the lowlands.

Japan strengthened their domestic MEPS with the “Top Runner” enhancement established in 1999, which continuously improves energy efficiency by requiring manufacturers to meet or exceed the energy efficiency of the top-performing products on the market, effectively pushing innovation and technological advancement (METI n.d.; IEA 2024a; IEA 2024b; UN 2025c). The EU takes a comprehensive approach that considers benefits to the community, nation, and global environment (Zondag et al. 2021).

Consider also that the potential savings from reduced air conditioning needs justify investments like energy-efficient architecture, naturally cool communities, and district cooling. Energy-efficient architecture includes shaded windows and sun shutters, natural ventilation and wind-catching orientation, and reflective glass and roofs. Naturally cool communities include landscaping, water features, wind corridors, and coordinated placement of outside heat-pump units. District cooling uses economies of scale and otherwise wasted energy to reduce the electricity used for space conditioning and other electrical appliances. An example is the use of waste heat from air conditioners and refrigeration condensers to heat water. Another example is chilling or freezing water at the time of day when power generation is at the lowest carbon intensity and using that stored coldness at the time of day when electricity is most carbon intense.

Finally, consider the new opportunities to reduce energy use in air conditioning with smart controls that continuously optimize equipment parameters, such as compressor motor speed, refrigerant charge, cooling fan velocity, and air filtration. The newest innovations include occupancy sensors that turn off cooling in unoccupied spaces and that use a "magic infrared eye" or data from a wearable health monitoring watch to supply cooling only to the occupied portion of the cooled space and set the temperature and humidity to provide the greatest comfort at the least carbon cost.

One useful economic approach is to compare the cost of mitigation to the combined effects of: 1) moving from refrigerants with high GWP to lower GWP; 2) simultaneously increasing energy efficiency of the equipment; 3) properly installing and maintaining the equipment for life cycle energy efficiency; and 4) upgrading the building design, thermal envelope, landscaping, and orientation to require less cooling. Wei and Shaw (2019) estimated that the potential for synergistic emission reductions and cost-effective savings from split air conditioning equipment was highest at an investment cost of just US$ 1 million.

7. The Benefits to Manufacturers of Replacement Equipment of Fast HFC Phasedown

Manufacturers of replacement technologies play a significant role in the transition away from HFCs and can benefit from faster HFC phasedown. Note these findings from the ODS phaseout now being repeated for the HFC phasedown:

> The first companies in A5 Parties that qualify for MLF funding often enjoy more attention and price discounts for new, specialized manufacturing equipment than companies that transition later and are inconspicuous (Andersen, Sarma, and Taddonio 2007).
>
> Safety and labelling regulations are more likely to be tailored for the first companies introducing cooling products with flammable refrigerants such as R-32, R-152a, R-290, R-600, R-1234yf, or for the first countries introducing cooling products with refrigerants with toxic properties, such as ammonia and CO_2.

In the Chinese market, R-32 dominates the RAC sector, with its adoption far exceeding the timeline set by the Kigali Amendment. The primary reasons for this rapid transition are that R-32 has the smallest carbon footprint in climates with long, hot, and humid cooling seasons and is cost-effective for owners, and that manufacturers prioritize refrigerant selection based on economic considerations. Therefore, the refrigerant transition is a crucial factor for manufacturers as it directly influences their decision-making and long-term strategy.

One business case advantage is that companies can enhance their environmental, social, and governance (ESG) ratings by accelerating the transition, improving their market reputation, and appealing to advanced-technology and sustainability-conscious investors.

Moreover, A5 Parties are driven by demand from non-A5 Party markets, making a faster transition necessary. EU and other key markets are tightening restrictions on high-GWP refrigerant equipment; A5 manufacturers risk facing market access barriers if they do not accelerate the shift to low-GWP alternatives because this could weaken their export competitiveness and reduce their global market share. By proactively adapting to international market changes and leading in low-carbon cooling technologies, manufacturers can secure a stronger position in the global supply chain.

8. A Few Seriously Compromised Outcomes Under the Montreal Protocol

Fortunately, the choice of replacements under the Montreal Protocol was generally superior in every environmental respect and often at an unnoticeably small incremental cost, or even savings, and often with significant co-benefits as listed in **Error! Reference source not found.** (Andersen and Sarma 2002); Andersen, Sarma, and Taddonio 2007; Andersen and Gonzalez 2023).

Table 4. Ozone-safe replacements for ODSs: Indicative Examples of Rapidly Identified and Implemented Replacement (with exceptions noted)

Replacement	GWP/Lifecycle Climate Performance (LCCP)	TFA/PFAS/VOC/TOX	Cost to Consumer	Co-benefit
Hydrocarbons replacing CFC-12 in cosmetic, convenience, and household pesticide aerosol products	GWP <1, superior LCCP	Unavoidable VOC emissions, but a small part of total VOC emissions	Far less expensive	Lower sales of household pesticide products in aerosol cans with inhalation and surface contact risk
Roll-on, sticks, sprays, and creams replacing CFC-12 in cosmetic, convenience, and household pesticide aerosol products	No GWP, superior LCCP	No propellent VOCs, far lower inhalation of toxic active ingredients such as pesticides!		High co-benefit of avoiding airborne and surface residues of pesticides, particularly for vulnerable children, elderly, and pets
No-clean replacing CFC-113 solvent	Better LCCP	Less toxic solder waste; no TFA, PFAS, or VOCs	Lower	Higher electronics reliability in lifesaving and life-protecting products
Hydrochlorofluorocarbon (HCFC) blend replacing CFC-12 in ethylene oxide (EtO) sterilization	Lower GWP and LCCP, more effective sterilization	Less toxic with smaller sterilant mix dose; TFA in some blends	Unnoticed	More effective: less toxic EtO per batch, superior sterilization of resistant pathogens, faster sterilization
R-600 hydrocarbon refrigerant replacing R-12 chlorofluorocarbon refrigerant in refrigerators and other stand-alone refrigerated cases	<1 GWP; more energy-efficient = better LCCP	VOC emissions can be minimized with LRM measures in manufacture and at end-of-life (EOL)	Lower purchase price plus lifetime energy savings	Quieter operation is an added benefit in small spaces and if sleeping nearby
Hydrocarbons, water, and methyl formate replacing CFCs and HCFCs as thermal foam blowing agents	Low-GWP and superior LCCP	VOCs for hydrocarbons and methyl formate, but water has none		Better foam expansion into corners of refrigerators and display cases

Note: TOX = toxic

Source: Andersen and Sarma 2002; Andersen, Sarma, and Taddonio 2007; Andersen and Gonzalez 2023.

To make the most of the fast phasedown of HFCs at lower private and public costs, policymakers will want the trusted advice of the Montreal Protocol Assessment Panels and particularly the TEAP. Investigations could include when to sequentially adapt incrementally superior replacements that reduce carbon footprint but not to sustainable levels, and when to wait for a "moonshot." In this situation, policymakers may ask themselves, "Should we accept some risks during the transition to PFAS-free technology to avoid irreversible and catastrophic climate tipping points?"

In hindsight, some natural refrigerants and other NIK replacements should have been implemented faster and with full market penetration:

> With proper LRM, natural hydrocarbon refrigerant R-600a is safe, superior, and sustainable in household refrigerators and freezers and in other stand-alone display cases with a small refrigerant charge. No TFA or PFAS, but R-600a is a VOC.
>
> Natural carbon dioxide refrigerant (R-744) is safe, superior, and sustainable in household heat pumps, water heaters, and supermarket refrigeration. No TFA or PFAS and not a VOC.
>
> Natural hydrocarbon refrigerant (R-290/propane) is superior and sustainable in small RACs installed to cool spaces within the efficient range of cooling capacity, and it is safe if the room is large enough in the event of refrigerant leakage into the occupied space. No TFA or PFAS, but it is a VOC. It is also safe, superior, and sustainable in heat pumps for all-electric vehicles using a secondary-loop system design that isolates the refrigerant from the occupied space. No TFA or PFAS, but is a VOC. It is not safe in direct-expansion system design where the refrigerant charge is unsafe if leaked by accident, equipment failure, or careless service procedures into occupied spaces.

Also, the fast and sequential market penetration of R-134a as a replacement for R-12 and then R-1234yf replacing R-134a in automobile air conditioning was the right choice to rapidly put stratospheric ozone on the path to recovery and to avoid climate tipping points. That sequential replacement should have been implemented faster and with full market penetration in A5 Parties. However, it is now clear that more attention should have been given to the degradation of some fluorocarbon refrigerants to TFA.[6] R-744 (carbon dioxide) for automobile air conditioning was a US$ 2 billion distraction, with only a small portion of the investment being useful to sectors where R-744 has proven superior.

Willi et al. (2021) calculate the atmospheric protection that could have been achieved if a rapid phaseout with technologies already globally available in the mid-1970s had started immediately after the warnings of Molina and Rowland and Ramanathan. These actions are consistent with the "Precautionary Principle" and would have reduced global ozone layer depletion, advanced the dates for ozone layer recovery, and aided in avoiding climate tipping points (see Figure 2).

[6] Full disclosure: Andersen (Papasavva et al. 2009; Luecken et al. 2009) and Hu (Wang et al. 2018), authors of this paper, are among the scientists who spotlighted the issue of R-134a and R-1234yf used in automotive air conditioning and elsewhere degrading to TFA as first warned by Nielsen et al. 2007.

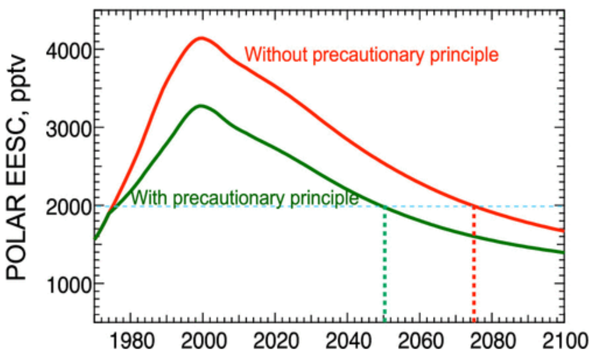

Figure 2. Benefits of earlier CFC substitution
Source: Willi et al. 2021

9. Smarter Lifecycle Refrigerant Management (LRM) through Faster HFC Phasedown

An additional, underexplored rationale for accelerating the HFC phasedown lies in its alignment with more effective LRM. In principle, LRM aims to prevent refrigerant emissions across the entire lifecycle of cooling equipment through leakage prevention, recovery, recycling, reclamation, and destruction. Globally, LRM is gaining traction for its clear environmental benefits (Kato and San Valentin 2022; Theodoridi et al. 2022; UNEP TEAP 2024; Purohit et al. 2025). Yet, critical questions remain: What should be done with the recovered refrigerants? Should they be reclaimed for reuse as refrigerants, repurposed for uses such as feedstocks, or directly destroyed?

Currently, reclamation is often viewed as the preferred strategy. It offers environmental gains by displacing virgin production, conserves valuable resources, and generates profits through resale (Jovell et al. 2022; Yasaka et al. 2023; Muralidharan et al. 2024). However, this approach becomes more contentious when reclaimed substances are high-GWP HFCs that atmospherically degrade to TFA. Furthermore, if a well-functioning, profitable reclamation system is established around obsolete refrigerants, it risks becoming a perverse incentive to prolong use of HFCs instead of accelerating their retirement (Chao et al., 2024).

Perverse incentives are especially damaging to the climate, given that the primary justification for reclaiming HFCs is to support continued use of legacy cooling equipment, which is typically less energy-efficient and more prone to leakage (Stratus Consulting Inc. 2010; Wan, Hwang, and Andersen 2023; Brodribb and McCann 2024). Without destruction, all reclaimed HFCs will eventually be emitted—it is only a matter of time.

A faster phasedown significantly reduces dependence on reclaimed HFCs by accelerating the turnover of legacy systems and shortening the period when reuse is considered necessary and desirable (CCAC 2022). Faster phasedown simplifies refrigerant management, enables clearer pathways to destruction or repurposing of recovered substances, and avoids locking in infrastructure centred around obsolete hazardous refrigerants.

Fast HFC phasedown allows LRM to support the transition rather than hinder it and reduces the long-term environmental and economic costs of maintaining a parallel system for recirculating high-GWP refrigerants. Crucially, this transition must be informed by robust research into the projected servicing demand of legacy equipment across different sectors and regions (UNEP 2024).

A clearer understanding of future demand can help allocate resources to the most efficient mix of reclamation, destruction, and replacement, while avoiding unnecessary build-out of obsolete cooling equipment and infrastructure.

The challenge is to build a robust ODS and HFC recovery infrastructure with adequate reclamation and destruction pathways to accommodate the market transition to the lowest life cycle carbon footprint while avoiding unnecessary investment in infrastructure. During this transition period, industry stakeholders should develop and implement future-oriented, flexible reclamation technologies and systems appropriate to obsolete refrigerants but adaptable to next-generation refrigerants. This will ensure long-term circularity and sustainability of the cooling sector at an affordable cost.

Accelerating the HFC phasedown is not only compatible with effective LRM, but it also enables LRM to deliver its full environmental potential.

a. Scientific Market Drivers

The 1974 Molina and Rowland ozone warning and 1975 Ravishankara climate-change warning prompted consumer boycotts in North America and Scandinavia, as well as bans or boycotts in other jurisdictions. These bans and boycotts, along with subsequent regulations, resulted in a reduction of about a third of total ODS emissions. The 1985 emergence of the Antarctic Ozone Hole motivated agreement on the 1987 Montreal Protocol and fostered fast commercialization and market penetration of already known replacements and rapidly invented ones. NIK replacements that were available within the first five years of the Montreal Protocol are still the best available technology today for over 85% of original ODS uses. The remaining 15% for which there are currently no NIK replacements for HFC refrigerants. Examples include applications where flammable and toxic natural refrigerants are inefficient, aerosol propellants for medical and technical aerosol products, fire extinguishing chemicals in specialty applications, and some forms of pest control. Today, approximately 99% of ODS production and consumption has been phased out (WMO 2023).

In 2007 and 2009, the Velders et al. warnings prompted the 2007 Adjustment accelerating the HCFC phaseout to better protect stratospheric ozone and climate and the 2016 Kigali Amendment and Kigali Decision to phase down HFCs and simultaneously increase energy efficiency of cooling equipment and thermal insulating foam (Velders et al. 2007; Velders et al. 2009; Molina et al., 2009; Sarma, Andersen, and Taddonio 2009; Andersen et al. 2022).

b. Corporate and Military Leadership Market Drivers

In 1985, the Farman Antarctic Ozone Hole warning and the 1987 agreement on the Montreal Protocol prompted aerospace, air conditioning, automotive, electronics, fire protection, pharmaceutical, and refrigeration companies to announce the ambition to phase out and replace ODSs with ozone-safe and otherwise environmentally superior technology. Simultaneously, US military organizations pledged to end all but "mission-critical essential applications" and supply the maximum portion of any ODS use for recovery and recycling from uses phased out (US EPA 1997). Quickly, military organizations from Australia, Canada, Germany, India, the Netherlands, Norway, Saudi Arabia, Sweden, the Union of Soviet Socialist Republics, the United Kingdom, the

US, and the North Atlantic Treaty Organization joined forces for a fast ODS phaseout in both weapons systems and conventional applications.

10. Brazil Case Study: Profit and Loss Market Driver

a. Background

The Government of Brazil ratified the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol on Substances that Deplete the Ozone Layer on 19 March 1990, with entry into force for Brazil on the same day. The Kigali Amendment of the Montreal Protocol was adopted at the 28th Meeting of Parties to the Montreal Protocol in Rwanda in 2016 to phase down the production and consumption of HFCs. Parties also agreed to develop cost guidance for maintaining or enhancing the energy efficiency of low- or zero-GWP replacement technologies and equipment when phasing down HFCs. Brazil ratified the Kigali Amendment on 19 October 2022, with entry into force the same day.

As early as July 2016, just before the Kigali Amendment was agreed, an IGSD-sponsored[7] Side Event during the Open-ended Working Group (OEWG) of the Montreal in Vienna (July 2016) featured a study showing that residential ACs with the highest energy-efficiency rate were certified for sale in Brazil but were not available for purchase (Carvalho, Ribeiro, and Andersen 2016; Andersen et al. 2016). This finding began a global investigation into why inefficient RACs with obsolete ozone-depleting and high-GWP GHGs were being “dumped” in developing countries. The findings also spurred an investigation into the business challenges of the RAC sector in Brazil and ways to resolve them. The ambition was to be able to market and make available for purchase at an affordable cost super-efficient RACs, with sustainable refrigerants, manufactured in Brazil for domestic markets and export.

By 2016, the progressive increase in air conditioning use in all sectors in Brazil had already impacted the country's electricity generation and distribution system. On the other hand, there was also significant potential for higher energy efficiency in all sectors, including the RAC sector, with benefits not only for the electricity system but also for consumers and the environment. In other words, increased energy efficiency in air conditioning could significantly contribute to national and local prosperity.

The starting point for transforming the Brazilian market lay in improving public energy efficiency policies, notably MEPS, the mandatory Brazilian Labelling Program (Program Brasileiro de Etiquetagem, PBE), and the voluntary Programa Nacional de Conservação de Energia Elétrica Label (PROCEL)[8]. The Brazilian PBE energy efficiency label includes the manufacturer's name, trademark, product model, electricity consumption, and product characteristics. In addition, the label has the signatures of the National Institute of Metrology, Standardization and Industrial Quality (INMETRO) and PROCEL.

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[7] IGSD Institute for Governance & Sustainable Development. https://www.igsd.org

[8] PROCEL is a program with Brazil’s National Electric Energy Conservation Program, Ministry of Mines and Energy (MME). PROCEL's actions have contributed to increasing the efficiency of goods and services and to fostering habits and knowledge about efficient energy consumption.

In addition, the emphasis in the Montreal Protocol Parties' Kigali Amendment-related Decisions on improving energy efficiency while phasing down HFCs—with added consideration of the climate emergency—were key to the transformation of the residential AC market in Brazil. The transition from the refrigerant R-22 (an ODS to be phased out) to high-GWP R-410A would present a challenge for future RAC installations, and as result, compliance with the Kigali Amendment. Therefore, getting the market ready for a smooth transition towards an available lower-GWP solution was critical. And energy efficiency led the way.

b. Introduction to the Brazil Kigali Project

In anticipation of ratification by Brazil of the Kigali Amendment to the Montreal Protocol, the Kigali Cooling Efficiency Programme (K-CEP)[9] approved the Kigali Project for Brazil in 2017. The Project was implemented by the Instituto Clima e Sociedade (iCS)[10]and received funding for several actions, including technical support from CLASP[11] to evaluate the Brazilian labelling programs (PBE 2022) relative to international best practices (CLASP, iCS, and K-CEP 2019). One point in the comparative analysis was the existence, in other programs, of clear rules determining when to review efficiency classes. This is the case in the EU, where this review must occur whenever energy-efficiency level A already accounts for 30% of the market, or energy-efficiency levels A and B together account for more than 50% of the market. The Kigali Project for Brazil showed it was time for Brazil to revise its mandatory labelling programme and to investigate potential improvements in the PROCEL voluntary label.

In consultations with the Project team, several manufacturers of the most efficient RACs in Brazil warned that the energy efficiency test method used by the Brazilian Labelling Program did not capture the efficiency benefits of inverter units that allow control of compressor revolutions-per-minute (RPM) to match cooling demand. CLASP reached the same conclusion in its evaluation of the PBE, which analytically proved that inverter RACs outperformed identically labelled fixed-speed RACs. CLASP urged that labelling programmes rapidly transition to a seasonal performance metric to properly promote the cost savings and lower carbon footprint of inverter RACs.

To support the update of the test system in Brazil, the Project team worked with Lawrence Berkeley National Laboratory (LBNL)[12] and INMETRO[13] to foster a technical discussion involving all stakeholders, which was the first step to establish a new seasonal metric. With the new testing method, the government would be able to revise the PBE and the PROCEL voluntary label. This process could include not only rescaling efficiency classes but also introducing clear and transparent criteria for future revisions and effective mechanisms for collecting market data from manufacturers.

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[9] The Kigali Cooling Efficiency Program (now Clean Cooling Collaborative) focuses on cooling sector transformation to make efficient, climate-friendly cooling accessible worldwide.

[10] The Institute for Climate and Society (iCS) "is a philanthropic organization that supports the fight against climate change. It focuses on Brazil through a wide range of approaches and tools that range from institutional and financial support to non-profit organizations."

[11] CLASP is an international nonprofit organization which provides technical and policy support to governments worldwide and works to implement energy efficiency standards and labels (S&L) for appliances, lighting, and equipment.

[12] Lawrence Berkeley National Laboratory (LBNL), U.S. Department of Energy (DOE), University of California (USA). LBNL partner team: Virginie E. Letschert, Nihan Karali, Won Young Park and Nihar Shah.

[13] INMETRO: Instituto Nacional de Metrologia Qualidade e Tecnologia, Ministry of Economy, Brazil.

The K-CEP project also funded a study to support the update of existing MEPS while adopting new methodology for calculating the energy efficiency index based on the Cooling Seasonal Performance Factor (CSPF: Índice de Eficiência Energética Sazonal - IDRS) metric, which captures the efficiency benefits of inverter air conditioners (Letschert et al. 2019). The study assessed the technical requirements, manufacturer economics, and broader benefits of strengthening Brazil's MEPS policies and resulted in positive interactions and technical exchanges with partner government officials and industry associations in the RAC sector. A regulatory impact study, developed with LBNL, was critical for developing a technical basis to revise the MEPS for RACs, which were set at a modest level when compared with international standards, and initiating a discussion on MEPS revision, which represented a major energy savings opportunity.

c. Energy Efficiency Policy as Market Driver

Labelling

With the new testing method established, the federal government revised the PBE.[14] The announcement of the switch to a seasonal metric led to an increase in market share of inverter RACs, even before the seasonal metric became mandatory, as manufacturers changed their production plans to take advantage of the new metric. The new label was appealing to RAC manufacturers with inverter technology, which wanted to have their more efficient products differentiated from the inefficient ones. The revision of the PBE for RACs also introduced in the new label the name of the refrigerant fluid used in the AC equipment. A logical next step would be to rate the refrigerant for GWP and identify refrigerants that atmospherically degrade to TFA, which is considered under some definitions as a PFAS "everywhere and forever chemical."

It has been over five years since the establishment of the ordinance by INMETRO. A new revision is recommended as early as 2026, as suggested in the CLASP study (CLASP 2019).

PROCEL also established the Gold Label (voluntary), which is granted to the cooling equipment with an efficiency equal to or greater than 7.6 CSPF in 2021, and 8.2 in 2023. The most significant change was the entry of a criterion on refrigerant fluid in consideration of a better classification for RACs with lower GWP.[15]

MEPS

In 2022, the Ministry of Mines and Energy (MME) published Resolution number 1/2022[16], which approved new MEPS for RACs. The regulation also established deadlines for manufacturing, importing, and marketing RACs in Brazil. The Resolution adopted a new methodology for

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[14] INMETRO-Ordinance No. 234, of June 29, 2020, Ministry of Economy National Institute of Metrology, Quality, and Technology-INMETRO. Partial improvement of the Conformity Assessment Requirements for Air Conditioners, establishing the Seasonal Cooling Performance Index, the reclassification of energy efficiency categories, and determining other measures to make these products available on the national market. "[S]tarting December 31, 2025, domestic manufacturers and importers must manufacture or import, for the domestic market, only split-type air conditioners that comply with the energy efficiency classes established in Table IV of Annex IV of the RAC for Air Conditioners" … and "starting June 30, 2026, manufacturers and importers must sell, in the domestic market, only split-type air conditioners that comply with the energy efficiency classes established in Table IV of Annex IV" and "starting June 30, 2027, establishments engaged in distribution or trade activities must sell, in the national market, only split-type air conditioners that comply with the energy efficiency classes established in Table IV of Annex IV".

[15] PROCEL Gold Label Implementation, 2022.

[16] https://in.gov.br/en/web/dou/-/resolucao-n-1-de-29-de-abril-de-2022-396910853.

calculating the energy efficiency index, based on ISO 16358-1 standards. This was the first mandatory MEPS in Brazil to be based on the CSPF metric, which captures the efficiency benefits of inverter air conditioners. These stricter requirements are aimed at eliminating most fixed-speed RAC units from the market by 2026 and are key to avoiding the commercialization of new R-22-based equipment, a refrigerant to be phased out. By requiring that all window and split-unit RAC systems operate at a higher efficiency, the models that use outdated and inefficient technology will fade into obsolescence by 2026. The regulation considered that "electricity consumption by air conditioners in the residential sector has increased by approximately 237% over the last 12 years, reaching 18.7 TWh in 2017, impacting peak loads in the national electricity system," according to Empresa de Pesquisa Energética (EPE) analyses (EPE 2018).

According to the MME Energy Efficiency Indicators and Levels Management Committee (CGIEE), the adoption of the new minimum performance standards could generate savings of 67 TWh worth 12 billion Brazilian Reais (~US $2.2 billion[17]) in avoided spending for electricity generation by 2040. This energy would be enough to power approximately 1.9 million homes annually by 2040. Furthermore, 40 million tons of CO_2 would be avoided at average carbon intensity of Brazilian electricity and far more if calculated based on avoiding generation from the most carbon intense sources typically used only during peak grid demand.

d. Impact of Energy Efficiency Measures in the RAC Sector

In the RAC sector, Brazil depended on R-410A to replace R-22, a refrigerant to be phased out under the Montreal Protocol by 2030. With the Kigali Amendment control measures for the phasedown of HFCs, Brazil published quotas for imports of HFCs used in several sectors. The Kigali implementation plan (KIP) is under preparation.

In 2018, as a pioneering move, Daikin-Brazil introduced in the Brazilian market one model of RAC with R-32, a refrigerant fluid with a GWP_{100yr} of 675, lower than the R-410A it replaced (GWP = 2,088), and needing up to 40% less charge to provide the same cooling capacity. Furthermore, an optimized R-32 RAC has significantly higher energy efficiency than an R-410A RAC at high ambient temperature and humidity. With the Kigali Amendment in mind, and with the change in testing method that captured the efficiency benefits of inverter units, Daikin-Brazil switched its production to R-32 exclusively in 2021. It wasn't until 2024, with the MEPS revision in place, that other RAC manufacturers in Brazil began adopting R-32 in their residential product lines. Daikin was one of the Japanese companies that cooperated on the global commercialization of R-32 RACs and donated essential patents for global use without license or payment (Carvalho, Andersen, and Gonzalez 2023).

The impact of the new MEPS with 40 million tons of CO_2 avoided is clear, and so are the results of the labelling programme that benefits more efficient products. For manufacturers that had already invested in more energy-efficient models, there was no need to adapt to the new MEPS, as their products were already exceeding the proposed MEPS values. And when the Labelling Regulation changed the "A rating" to CSPF 5.0, the top-runner models had already exceeded that rating.

[17] At the prevailing exchange rate on 27 July 2025.

Furthermore, Brazil has one compressor manufacturing plant that supplies the domestic manufacturing plants in accordance with the domestic content rule. Per a consultation with a RAC manufacturer by one of this paper's authors, the use of a mandatory quota of lower-efficiency, nationally produced compressors (domestic content requirement in the PPB[18]) resulted in a decrease of the CSPF from 8.6 to 8.0 for the products in those manufacturing lines.[19]

In 2014, Brazil produced and imported a total of 5.1 million residential ACs. Despite the COVID pandemic, at the end of 2020, Brazil had installed over 5.9 million units (residential splits and window units).[20]

Brazil has 14 RAC manufacturing plants in the free-trade zone (ZFM)[21] of Manaus, Brazil. In 2024, with more frequent heatwaves, six million AC units were produced in the Manaus "zona franca" and commercialized in Brazil, a rise from the average of 4.5 million units per year in the last 15 years.[22]

In 2017, inverter models were 30% of total split RACs in the Brazilian market. Inverters were 57% of total split RACs in January 2025[23].

Only three companies in Brazil qualify for MLF assistance, with eligible A5 ownership as per the MLF rule. These companies have converted their RAC production lines from R-22 to R-410A at their own cost. Imports of R-410A account for a large portion of total Brazilian HFC consumption and are second only to R-134a, which is used in mobile air conditioning and refrigeration and some AC equipment.

This case study demonstrates the importance of maintaining a robust regulatory framework—these actions help Brazil fulfil its Montreal Protocol obligations, reduce energy demand on the grid, and save on the energy bill for consumers.

Public-Private Partnerships in the Building Sector

Close collaboration with NGOs (such as, CLASP, International Energy Initiative-Brazil (IEI), ICS, IGSD, Green Building Council (GBC)) and industry associations (such as, Associação Brasileira de Refrigeração, Ar Condicionado, Ventilação e Aquecimento (ABRAVA) and Eletros) has proven of utmost importance as previously described for the residential air conditioning sector. This partnership has been extended to the building sector, and in response, new regulations require that new buildings comply with stricter energy efficiency standards to reduce electricity consumption . It is significant that the NGOs and industry supported those discussions and provided technical information and insights regarding options for equipment selection and refrigerant transition. The measure, coordinated by the Energy Efficiency Indexes and Levels Management Committee

[18] Basic Production Process (PPB, Processo Produtivo Básico).
[19] Personal communication, July 2025.
[20] Eletros, 2021. https://eletros.org.br/wp-content/uploads/2021/06/AC-Split-abr-21.pdf, and https://eletros.org.br/wp-content/uploads/2021/06/AC-Janela-abri-21.pdf
[21] The Zona Franca de Manaus, ZFM, is a free trade zone located in Manaus, Amazon state, offering tax and customs incentives to attract investment and productive activities. SUFRAMA (Superintendência da Zona Franca de Manaus), as the ZFM manager, grants these benefits to companies that establish themselves in the region.
[22] SUFRAMA. Personal information shared by ZFM RAC manufacturing industry with access to database, July 2025.
[23] Eletros, 2025 - Associação Nacional de Fabricantes de Produtos Eletrodomésticos (Dados Suframa).

(CGIEE), aims to align the country with international standards, reduce energy consumption, and ensure greater thermal comfort in buildings. "Energy efficiency labeling, previously voluntary [for buildings], will be required for new public and private projects starting in 2027, with a staggered schedule through 2040 (Diário Oficial da União – DOU 2025)."

This was simply accomplished by making mandatory minimum levels on the National Energy Conservation Label (ENCE), which classifies buildings from "A" (most efficient) to "E" (least efficient). Starting in 2027, federal public buildings must achieve level "A", and the requirement will be extended to state and municipal buildings in stages through 2040. For residential, commercial, and affordable housing, compliance with level "C" will be required starting in 2030—as a prerequisite for the issuance of a building permit and occupancy permit.

The next ambition is to use CCAC approved funding to work with Minister of Energy and UNDP to develop new MEPs for the large cooling equipment, such as the ones that are required in buildings.

11. China Case Study: Ready to Supply Energy-Efficient Low-GWP RACs to All Markets

China approved the Montreal Protocol by Accession on 14 June 1991 with entry into force the same day (UN 2025a) and approved the Kigali Amendment by Acceptance on 17 June 2021 (UN 2025b).

Against the backdrop of seven increases in MEPS for RACs over the past 30 years, China's RAC production has continued to grow, accounting for 80% of global output (ChinaIOL n.d.; UN Comtrade Database 2025). The MEPS issued in 2019 (GB 21455-2019), which came into effect in July 2020, rank among the most stringent in the world (Hillbrand and Horowitz 2020; CLASP 2023; CLASP 2025). Notably, it introduced a unified Annual Performance Factor (APF) evaluation system for both variable-speed and fixed-speed RACs, replacing the previous separate criteria, thus setting the bar for minimum efficiency requirements across the board.

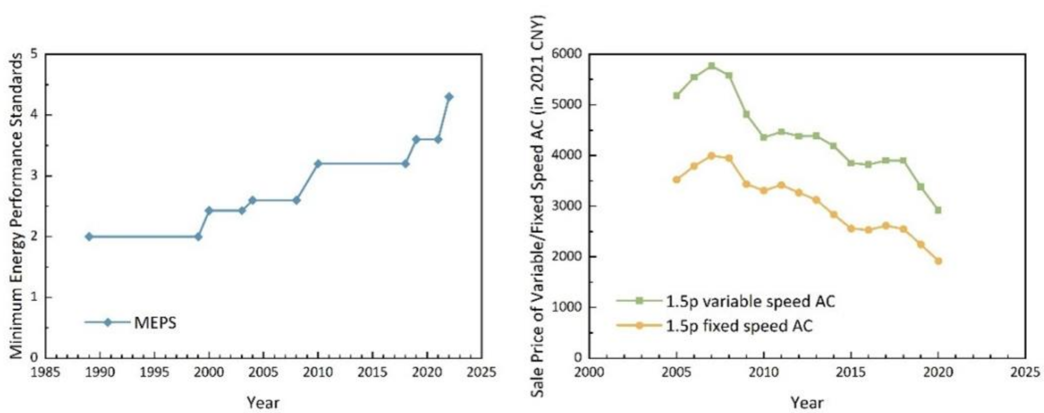

Figure 3. Historical Changes in RAC MEPS and Selling Prices in China

Source: *White Paper for Energy Efficiency Standards and Labelling Program* (CNIS 2023)

Even more encouraging is the fact that the price of RACs with the same cooling capacity has continued to decline as MEPS have increased. In parallel, the share of obsolete R-22 and R-410A RACs produced in China has declined from 93% of production in 2015 to 21% in 2024, while the share of environmentally superior R-32 and R-290 RACs has increased from 7% to 79%. These changes illustrate the combined impact of stricter regulatory standards, technological innovation, and the growing adoption of low-GWP refrigerants, underscoring the synergies between energy efficiency policies and climate mitigation.

The global production of RACs and the trade flow results of major producing countries in 2019 are presented in **Error! Reference source not found.**.

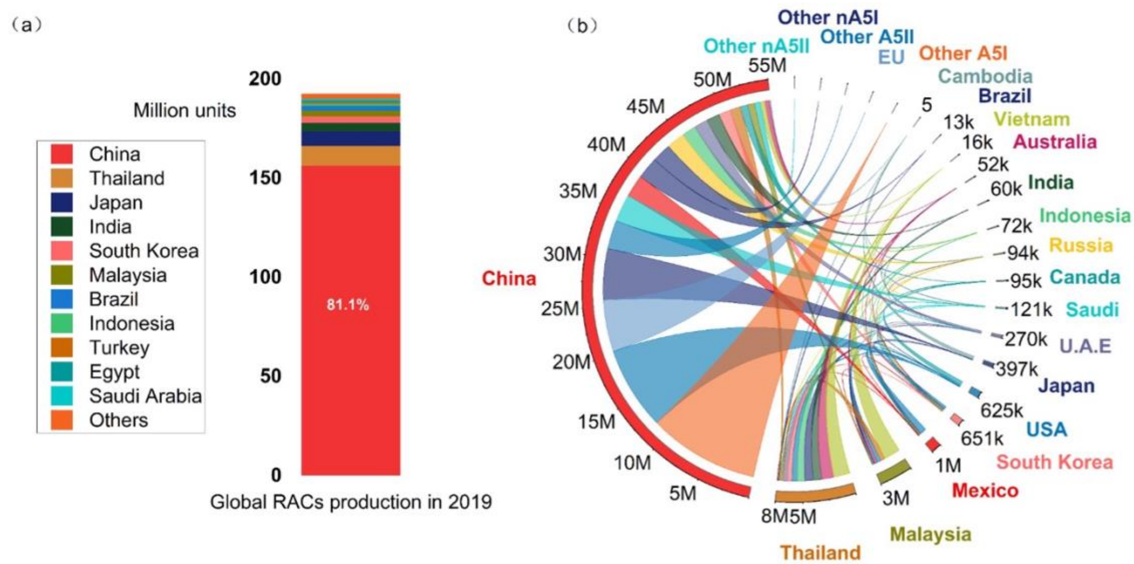

Figure 4. RAC Producing Countries and Trade Flows
Source: Jiang et al. 2024

The data in Jiang et al. (2024) supports the case for: 1) offering to export markets the cooling technology proven in the interest of buyers and citizens in Chinese domestic markets; 2) making good on China's Belt and Road Initiative (BRI) and other ambitions as a respected partner for developing countries that seek environmentally sustainable prosperity; and 3) rationalizing the phasedown of obsolete refrigerants controlled by the Montreal Protocol (Sun et al. 2021).

The sophisticated economic study in Jiang et al. (2024) confirmed cumulative emission reductions in China's RAC manufacturing of up to 17.2 gigatonnes of CO_2-equivalent (Gt CO_2-eq), with average savings of up to US \$68.8/tonne (t) CO_2-eq. Cumulative average abatement costs are around US\$ 18 and US\$ 4/t CO_2-eq globally, which is also offset by the synergistic co-benefits of cleaner air, climate protection, and other social benefits beyond private ownership savings. These cost-effectiveness findings are consistent with those of other studies, which show that sometimes going fast in market transition is less expensive than going slow.

Indeed, the Chinese government has issued national regulations and plans to promote the development of green and high-quality appliances by the cooling industry. For example, China's amended Regulation on the Administration of Ozone Depleting Substances that went into effect 1 March 2024 establishes a comprehensive national regulatory framework for China's HFC phase down (PRC SC 2023). The framework includes provisions on production and consumption allowance; import and export licensing for substances in the List of Controlled ODSs for Import and Export in China; data monitoring and management; leak reduction; and end-of-life recycling, reclamation, and destruction. On 9 April 2025, China issued the National Plan on the Implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer (2025–2030) (PRC MoEE et al. 2025). This National Plan lays out key goals and timelines related to HFC phasedown in China and describes implementation measures that span the full lifecycle of ODSs and HFCs, encompassing upstream source emissions control, operational process management, end-of-life treatment, and transboundary trade controls.

Furthermore, promoting accessibility of energy-efficient and climate-friendly cooling technology for export markets aligns with China's policy efforts to advance the green development of the BRI, including the BRI Green Cooling Initiative (PRC NDRC et al. 2019). It is noteworthy that China's National Development and Reform Commission, Ministry of Foreign Affairs, Ministry of Ecology and Environment, and Ministry of Commerce in March 2022 jointly released their Opinions on Promoting the Green Development of the BRI (PRC NDRC et al. 2022). According to the Opinions, Chinese enterprises are encouraged to comply with prevailing international standards or China's standards, where the BRI country's environmental standards are lower than the prevailing international standards or China's own standards.

> *"Countries should … facilitate the free flow of quality green technologies and products, so that they can be accessible, affordable and beneficial for all countries, especially the developing ones. China will vigorously deepen South-South cooperation and continue to provide help for fellow developing countries to the best of its capability."*
>
> President Xi Jinping at the Leaders Meeting on Climate and the Just Transition (23 April 2025).

12. Ghana Case Study: Unable to Avoid R-410 in R-22 Phaseout but Determined to Replace R-410 as Fast as Possible!

Many studies have determined that energy-efficient RACs with climate-friendly refrigerants: 1) have lower ownership costs now and increasing economic advantage in a hotter future; 2) increase the owner's standard of living with savings in electricity spent locally on education, health care, nutrition, and other goods and services; 3) improve neighbourhood prosperity through savings in electricity circulating as spending through the economy; 4) improve the balance of trade and lower government borrowing rates; 5) reduce the frequency and duration of power outages impacting local business and citizens; and 6) help avoid or delay climate tipping points that threaten wealth, quality of life, and prospect of future generations (Andersen et al. 2020; Miller, et al., 2021).

a. Take Home Message

Experts have determined that new, environmentally and economically superior, next-generation cooling technology has lower ownership costs than the new, inefficient cooling equipment with obsolete refrigerants being dumped in Ghana. And the continued sales of inefficient cooling equipment with obsolete refrigerants increases the cost to the MLF (and matching funds from the government of Ghana for management of the larger inventory of this inefficient RAC equipment). Furthermore, investment in inefficient cooling equipment increases the avoidable demand for electricity, which forces brownouts and blackouts and wasted investment in new electricity generation. The solution to this situation is: Stop Dumping, Access Best Technology, and Save Money and Earth.

b. Elaboration of Why Phase Out HFCs in Ghana as Fast as Possible

The government of Ghana ratified the Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer on 24 July 1989, with the Montreal Protocol entry into force for Ghana on 22 October 1989 (UN 2025a). Ghana ratified the Kigali Amendment to the Montreal Protocol on 2 August 2019, with entry into force the same day (UN 2025b). These actions demonstrate Ghana's commitment to fast global action for atmospheric sustainability.

The Ghana Energy Commission has proven time and time again, year after year, that efficiency costs everyone less than the costs of new electricity supply, particularly when climate and clean air benefits are considered. But just as important as cost savings is how those savings are used. For example, the superior energy efficiency of new equipment sold in Ghana between 2005 and 2016 allowed an increase in electricity access from 55% to 80% of households, with no new generating capacity added. A record increase in annual access of 7.6% in 2014 is mainly attributed to the savings of 400 gigawatt hours (GWh) from Ghana's energy-efficient refrigerating appliances project. Comparable energy savings are available in other cooling sectors in Ghana (Opoku, Edwin, and Agyarko 2019).

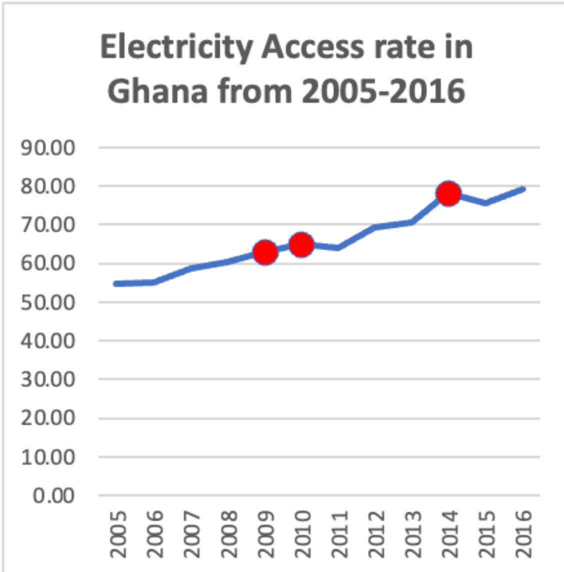

Figure 5. Electricity Access rate in Ghana from 2005–2016
Data source: Opoku, Edwin, and Agyarko 2019

> "*Since 2013–2022, the [Ghana Energy Commission's] efforts to improve energy use efficiency has resulted in a total savings of 7,955 Gigawatt hours, which is about 54% of the total thermal generation in 2022*" (UNDP 2024).

> "*The Standard and Labeling program is designed to empower consumers by educating them on energy efficiency labels, which indicates key parameters like energy consumption and star ratings, ultimately informing their purchasing decisions. As a regulator, the Energy Commission is committed to serving as a referee between manufacturers, importers, and consumers, guaranteeing that only high-grade electrical appliances that meet Ghana's standards enter the market."* Hubert Nsoh Zan, Ghana Energy Commission (UNDP 2024).

Additionally, the benefits of electricity access are transformative in improving the quality of life and productivity in homes, farms, and all enterprises. Electric clothes washing, communication, cooking, lighting, refrigeration, water pumping, and other priority rural uses all contribute to higher incomes, a better standard of living, and improved civil society (White et al. 2006; Agyarko 2016; Agyarko 2018). Savings on electricity from energy efficiency are spent locally on education, healthcare, housing, nutrition, and other goods and services important to the quality of life and local prosperity (Andersen et al. 2019; Andersen et al. 2020; Sebti, Mouline, and Andersen 2021). For example, the US$ 80 savings each year on electricity from efficient new refrigerators is enough to put a child in school (Agyarko 2018).

In the RAC sector, Ghana depended on R-410A for the R-22 HCFC phaseout, which was completed in 2023—seven years faster than the 2030 phaseout deadline. Ghana is now phasing out hazardous and obsolete R-410A with a vengeance in favour of R-32 and R-290.

Ghana is proud to have been a champion, officially on behalf of all of Africa and informally on behalf of all A5 Parties to the Montreal Protocol, in stopping the dumping in developing countries of inefficient cooling equipment using obsolete ODSs and HFC GHGs (Agyarko et al. 2022).

The Africa Stop Dumping Campaign was a significant motivation for the 2024 EU Fluorinated Greenhouse Gas (F-gas) regulation that prohibits the export of certain HFC-using cooling equipment not qualified for sale as delineated in paragraph 25 of the Preamble to the Regulation (European Parliament and Council 2024).[24] Parties to the Montreal Protocol welcome implementation of the Kigali Amendment with similar legislation in the spirit of doing unto export markets what they do unto domestic markets—out of respect for Earth and citizens and in response to government authorities.

In addition, it is the ambition of Ghana to prohibit the unnecessary stockpiling and hoarding of HFCs beyond the amounts required for service of new equipment dumped on Ghana before inefficient cooling equipment with obsolete refrigerants is banished.

[24] Paragraph 25 of the Preamble to the 2024 EU f-Gas Regulation 2024/573: "Following the Kigali Amendment, the export of HFCs from states that are parties to the Protocol to non-party states is prohibited. Such a prohibition is an important step towards the phasing down of HFCs. Nevertheless, several parties to the Protocol consider the prohibition to be insufficient to tackle the environmental concerns linked to the export of HFCs. Several developing countries that are parties to the Protocol have raised the problem of the export from other parties of inefficient refrigeration and air-conditioning appliances, using obsolete refrigerants and refrigerants with high GWP, to their markets, thus increasing service needs. Such a situation is particularly problematic in developing countries with limited resources and capacity for containment and recovery, as well as for used equipment with short remaining expected lifetimes and new equipment during use but at end of life. In the framework of the Union's global efforts to mitigate climate change, in order to support the achievement of the objectives of the Protocol, and in accordance with what is already provided under Regulation (EC) No 1005/2009 of the European Parliament and of the Council (12), it is appropriate to prohibit the export of certain used and new equipment containing, or whose functioning relies upon, fluorinated greenhouse gases with a high GWP. That export prohibition should apply only in cases where the equipment is subject to a prohibition under Annex IV and at the same time meets the requirements set out in Article 22(3)."

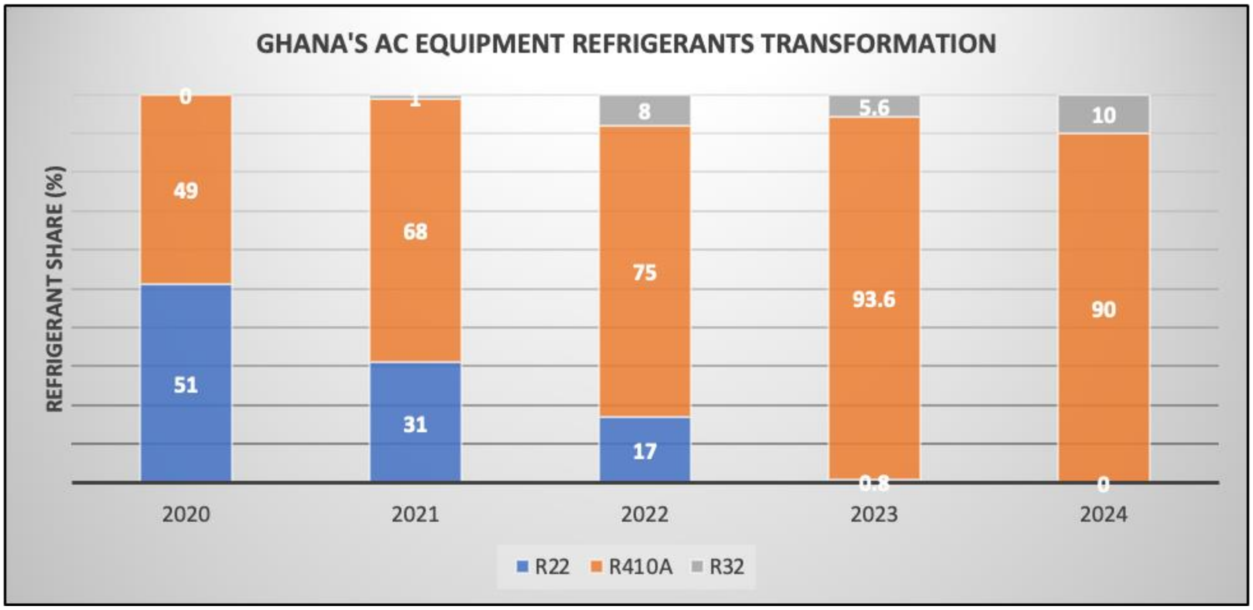

Figure 6. Ghana's AC Equipment Refrigerants Transformation
Source: Ghana Energy Commission 2025

Ghana, like many A5 Parties, has little domestic manufacture or assembly of cooling equipment, which allows for rapid HFC phasedown by demanding from its foreign suppliers the best available cooling technology at an affordable cost. That momentum is well underway with the informal ambition to halt imports of HFCs in new room air conditioners by 2027 (the 40th Anniversary of the Montreal Protocol) and in all new cooling equipment by 2030. Already, at least five global RAC manufacturers are offering highly efficient RACs with R-32 or R-290 refrigerants (CEESD 2020; Agyarko and Zan 2025). This ambition is remarkable because the Kigali Amendment only requires Ghana to reduce HFC consumption by 80% by 2045.

Ghana will achieve its HFC phaseout through MEPS, Ministerial directives, and GHG caps, as well as product labelling, public education, and economic incentives such as programs that finance super-efficiency, which are repaid through accumulated energy savings.

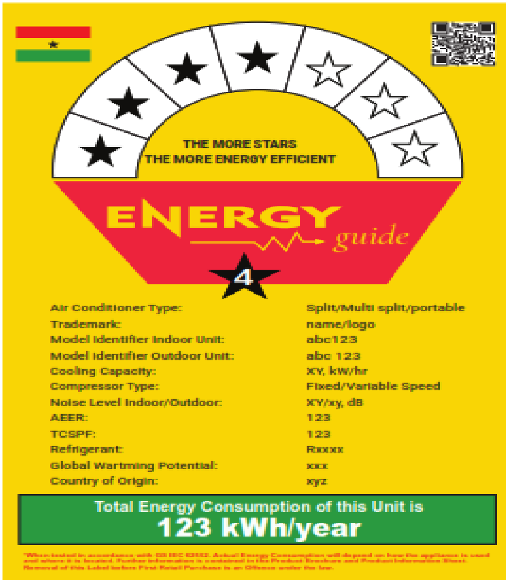

Figure 7. New Energy Label for Air Conditioners
Source: Ghana Energy Commission 2022

Table 5. Star Rating to Total Cooling Season Performance Factor correlation

Star Rating	**Total Cooling Season Performance Factor (TCSPF)**		
7	11.5 ≤	TCSPF	
6	10.0 ≤	TCSPF	< 11.5
5	8.5 ≤	TCSPF	< 10.0
4	7.0 ≤	TSPF	< 8.5
3	5.5≤	TCSPF	< 7.0
2	4.0 ≤	TCSPF	< 5.5
1	2.6 ≤	TCSPF	< 4.0

13. The Power of High-level Orders, Decrees, and Similar Announcements

A lesson from the CLASP/IGSD investigations is that dumping in Africa, Southeast Asia, and Latin America and the Caribbean of energy inefficient cooling equipment with obsolete refrigerants is a crisis in climate, clean air, and an affordable quality of life and community prosperity.

A lesson from Ghana's All of Africa Campaign is that environmental injustice in Article 5 Parties might be ignored by developed nations—even under the watchful eyes of the Montreal Protocol with its Assessment Panels, Multilateral Fund, Implementing Agencies, Regional Networks and National Ozone Units, and commercial and professional cooling associations.

A lesson from the Ghana Case Study is that traditional procedures in Article 5 Parties for strengthening MEPs or restricting sales of obsolete refrigerants are slow, expensive, and vulnerable to influence from multinational enterprises that profit from dumping.

A lesson from the Brazil Case Study is that an Article 5 Parties that manufactures energy efficient RACs with next generation refrigerants like R-32 and R-290 are less vulnerable to dumping from foreign suppliers and that domestic government, NGOs, and industry stake holders can put emphasis on the importance of review and update of MEPs and Labelling for the market transformation towards availability of efficient products without obsolete refrigerants.

A lesson of hope is that the shared responsibility embraced in Decisions by the Parties to the Montreal Protocol drove the EU to be a leader in restricting the export of cooling equipment with obsolete and high-GWP refrigerants not qualified for sale domestically; EU environmental authorities have determined that the use of those refrigerants is not in European self-interest or in global commons interest.

Another lesson of hope is that the MLF, which was once reluctant to provide incentives to finance phase out faster than required for compliance has realized that prolonged sales of cooling equipment with obsolete refrigerants will increase the ultimate cost of compliance in many A5 Parties due to that equipment's energy inefficiency. And most of the KIPs approved so far go beyond the first reduction step for compliance obligation, that is, the 10% GWP-weighted reduction in consumption. However, the MLF has not yet solved finance gaps and the provision of adequate incentives for the low-volume consuming (LVC) Article 5 Parties most vulnerable to climate change that are committing to accelerated phase down.

The response to these lessons can be to 1) streamline stronger MEPs and make clear national demands for best available technology, 2) develop funding from outside the MLF to phase down and phase out obsolete RACs sooner than the Montreal Protocol control schedules, and 3) break out from the status quo box with fast government action already implemented in times of employment, financial, national security, and other crises.

Executive and other authorities can issue high-level orders, decrees, announcements, and other directives on short notice when fast action is in the interest of national security, natural or climate disaster response, or avoiding the threat of catastrophe to environment, health, or prosperity.

The power of such directives is conveyed in the following subnational Executive Order:

> *"…I, Gavin Newsom, Governor of the State of California, by virtue of the power and authority vested in me by the Constitution and the statutes of the State of California, do hereby issue the following Order to become effective immediately to require that every aspect of state government redouble its efforts to reduce greenhouse gas emissions and mitigate the impacts of climate change while building a sustainable, inclusive economy."*
>
> Source: Newsom 2019

Appendix A: From Scientific Warnings to Montreal Protocol ODS Phaseout Resolve

In the early 1970s, Professor Paul J. Crutzen, Harold Johnston, and colleagues warned that nitrogen oxides (NO_x) from human activities could deplete stratospheric ozone and contribute to global warming (Crutzen 1970, 1972, 1974; Johnston 1971, 1973, 1974). In 1971, James E. Lovelock warned that manufactured synthetic chlorofluorocarbons (CFCs) were accumulating in the atmosphere (Lovelock 1971). In June 1974, Dr. Mario J. Molina and Professor F. Sherwood Roland warned that fluorocarbons deplete stratospheric ozone (Molina and Rowland 1974), and in November 1974, Lovelock reported that CFC levels collected on an air sampling flight to ~14,000 meters (~45,000 feet) fell dramatically in the stratosphere, suggesting the compound was breaking down into chlorine atoms that attack and destroy ozone, as Molina and Rowland had warned a few months earlier (Lovelock 1974). In 1975, Professor Veerabhadran Ramanathan warned that most ODSs GHGs that force climate change (Ramanathan 1975).

Citizens in North America and Scandinavia responded to the warnings with boycotts of CFC cosmetic and convenience aerosol products such as deodorants, hairspray, and household pesticides. This public concern motivated the United States, and then Canada, Denmark, Japan, Norway, and Sweden and other jurisdictions to ban or restrict sales of CFC aerosol products (Andersen and Gonzalez 2023).

At a 1984 conference of Antarctic science, Shigeru Chubachi *reported* but did not appreciate the significance of seasonal decline of total column ozone (TCO) at the Japanese Syowa Station in Antarctica, which provided the first evidence of Austral springtime ozone depletion. In 1985, Joseph Farman and colleagues—who did appreciate the significance—*warned* in the journal *Nature* of alarming Antarctic ozone depletion likely caused by CFCs (Chubachi,1985; Farman et al. 1985). Professor Sherwood Rowland branded this evidence "the Antarctic Ozone Hole," and the graphic depiction (Figure 8) by the National Aeronautics and Space Administration (NASA) went viral (Andersen and Sarma 2002; Andersen and Gonzalez 2023).

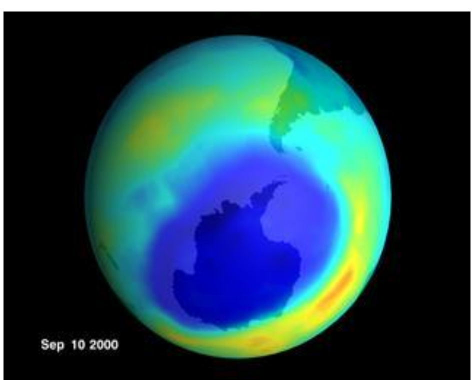

Figure 8. Antarctic Ozone Hole Graphic
Source: https://visibleearth.nasa.gov/

Environmental activists, corporate executives, policy makers, and scientists responded to the Antarctic Ozone Hole by adopting the 1987 Montreal Protocol (Benedick 1998; Tolba and Rummel-Bulska 1998; Andersen and Sarma 2002; Bhartia and McPeters 2018; Andersen and Gonzalez 2023). Meanwhile, ground-based and satellite measurements confirmed this dramatic thinning of the ozone layer over the South Pole, and scientists mounted emergency campaigns to investigate and attribute the cause of the Antarctic Ozone Hole (Anderson, Brune, and Proffitt 1989; Bhartia and McPeters 2018). Although the chemical dynamics and polar stratospheric clouds research from the ground captured the press, it was the 1987 Airborne Antarctic Ozone Experiment (AAOE) that yielded the "smoking gun" evidence, linking human-produced CFCs to the ozone hole by showing a clear anticorrelation between chlorine monoxide (ClO) and ozone levels (Anderson, Brune, and Proffitt 1989).

Appendix B: The Governance Framework of the Montreal Protocol

The Montreal Protocol is a start-and-strengthen treaty that started in 1987 with basic production and consumption control measures on only a few CFCs and halons. The Protocol was then promptly and continuously strengthened by *Amendments* that added more controlled substances, *Adjustments* that accelerated the pace of phaseout, and *Decisions* that guided Parties on the treaty's implementation—including establishing control measures, deadlines, synergy with other multilateral environmental agreements (MEAs) and addressing ozone and climate protection issues such as LRM. below provides examples of fast precautionary action, including agreement on the Vienna Convention and its Montreal Protocol, and related Amendments, Adjustments, and Decisions.

Table 6. Fast Precautionary Actions Under the Montreal Protocol

Year	**Year(s) Since Last Action**	**Action**	**Controlled Substance(s)**
1985		Vienna Convention	Framework for the Montreal Protocol
1987	2	Montreal Protocol	CFCs (Annex A, Group I), halons
1989	2	Entry Into Force	46 Parties @ Entry into Force
1990 MOP2	1	London Amendment and Adjustment	CFCs (Annex B, Group I), methyl chloroform (CH_3CCl_3), carbon tetrachloride (CCl_4)
1992 MOP4	2	Copenhagen Amendment and Adjustment	HCFCs, methyl bromide (CH_3Br), hydrobromofluorocarbons (HBFCs)
1995 MOP7	3	Vienna Adjustment	Article 5 Basic Domestic Needs
1997 MOP9	2	Montreal Amendment and Adjustment	Methyl bromide trade measures
1999 MOP11	2	Beijing Amendment and Adjustment	Bromochloromethane (CH_2BrCl) Production controls on HCFCs
2007 MOP19	8	Montreal Adjustment	Accelerating the HCFC phaseout to protect ozone and climate
2016 MOP28	9	Kigali Amendment and Energy-Efficiency Decision	HFCs
2018 MOP30	*	Quito Adjustment	Annex C, Group 1 substances
2023 MOP 35	7	US $1 Billion 3-yr replenishment budget pledge; Decision XXXV/13 aimed at stopping dumping of inefficient cooling equipment in vulnerable A5 Parties, and facilitating MLF funding for A5 Parties seeking safeguards against dumping[25]	ODSs and HFCs
2025 Pending		Narrow ODS and HFC Feedstock Exemptions	

Note: HCFC = hydrochlorofluorocarbon; HFC = hydrofluorocarbons; MOP = Meeting of the Parties (to the Montreal Protocol).
* The Quito Adjustment corrected an oversight in the Kigali Amendment and is not counted here as a precautionary action (Andersen and Gonzalez, 2023, updated June 2025).

[25] Decision XXXV/13 on the import and export of prohibited cooling equipment reflected vulnerable A5 Party efforts to stop the dumping in their jurisdictions of new, inefficient cooling equipment with obsolete ozone-depleting and climate-forcing refrigerants. The Decision reflects the understanding that this problem requires a solution involving both exporting and importing parties (also referred to as "shared responsibility"). The Decision also tees up requests to the MLF for funding to build A5 Party capacity to prevent introduction of prohibited cooling technology.

Acronyms and Abbreviations

A5	Article 5 (of the Montreal Protocol)
BRI	Belt and Road Initiative (China)
ABRAVA	Associação Brasileira de Refrigeração, Ar Condicionado, Ventilação e Aquecimento (Brazil)
CFC	chlorofluorocarbon
CGIEE	Energy Efficiency Indicators and Levels Management Committee (Brazil)
CO_2	carbon dioxide
CSPF	Cooling Seasonal Performance Factor
DOU	Diário Oficial da União (Brazil)
EC	European Community
ECEEE	European Council for an Energy Efficient Economy
EPE	Empresa de Pesquisa Energética
ESG	Environmental, Social, Governance (ranking)
EU	European Union
GBC	Green Building Council
GHG	greenhouse gas
GWh	gigaWatt hours
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin
ICOLP	Industry Cooperative for the Ozone Layer
IEI	International Energy Initiative (Brazil)
IEE	Instituto de Energia e Ambiente
IGSD	Institute for Governance & Sustainable Development
INMETRO	Instituto Nacional de Metrologia Qualidade e Tecnologia (Brazil)
IPCC	Intergovernmental Panel on Climate Change
IPEN	Instituto de Pesquisas Energéticas e Nucleares (Brazil)
LBNL	Lawrence Berkeley National Laboratory
LLCP	Long-lived climate pollutant
LRM	Life Cycle Refrigerant Management
LVC	low-volume consuming (Article 5 Parties)
MEA	multilateral environmental agreement
MEPS	minimum energy performance standard
MLF	Multilateral Fund for the Implementation of the Montreal Protocol
MME	Ministry of Mines and Energy (Brazil)
NOAA	National Oceanographic and Atmospheric Administration (USA)
MOP	Meeting of the Parties to the Montreal Protocol
NASA	National Aeronautics and Space Administration (USA)
NGO	non-governmental organization
NIK	not-in-kind (non-fluorocarbon)
NOU	national ozone unit
NRDC	National Resources Defense Council
ODP	ozone-depletion potential
ODS	ozone-depleting substance

PBE	Programa Brasileiro de Etiquetagem (Brazil)
PFAS	per- and poly-fluoroalkyl substances
PROCEL	Programa Nacional de Conservação de Energia Elétrica (Brazil)
R-22	$CHClF_2$ (chlorodifluoromethane)
R-32	CH_2F_2 (difluoromethane)
R-125	CF_3CHF_2 (pentafluoroethane)
R-290	C_3H_8 (propane)
R-600	C_4H_{10} (n-butane)
R-600a	C_5H_{12} (isobutane)
R-410A	CH_2F_2 (R-32) + CHF_2CF_3 R-125) 50% - 50% mixture
R-1234yf	$C_3H_2F_4$ (2,3,3,3-Tetrafluoropropene)
RAC	room air conditioner
RPM	revolutions-per-minute
S&L	standards and labels
SAP	Scientific Assessment Panel (Montreal Protocol)
SLCP	Short-lived climate pollutant
SUFRAMA	Superintendência da Zona Franca de Manaus (Brazil)
TCSPF	Total Cooling Season Performance Factor
TEAP	Technology and Economic Assessment Panel (Montreal Protocol)
TFA	trifluoroacetic acid
TCO	total column ozone
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
US	United States
USA	United States of America
UV	ultraviolet
VOC	volatile organic compound
ZMF	free-trade zone (Brazil)

Glossary of Specialized Vocabulary

Environmental Dumping is defined as the practice of exporting products to another country or territory that: 1) contain hazardous substances, 2) have environmental performance lower than is in the interest of consumers or that is contrary to the interests of the local and global commons, or 3) can undermine the ability of the importing country to fulfil international environmental treaty commitments (Andersen et al. 2018).

Net Zero Carbon is achieved when the quantity of CO_2-eq emissions from human activates is equal to the quantity of CO_2 removal by human action. Net Zero Carbon can be achieved by a combination of reducing emissions or increasing capture. Carbon emission reduction can occur through various measures including switching to renewable low-carbon energy sources (hydroelectric, nuclear, solar, and wind), decreasing energy demand, improving energy efficiency, and transitioning away from biomass and fossil fuels. Carbon removal can be increased through measures such as reforestation, afforestation, and carbon capture and storage technologies (Levin et al. 2023).

Obsolete Refrigerants are defined in the context of dumping of cooling equipment as 1) scheduled for phaseout or phasedown under the Montreal Protocol, 2) inferior in economic, environmental, and/or technical performance, and/or 3) banned in significant markets due to GWP, TFA, VOC, or toxicity.

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