The Kigali Amendment: Tenth anniversary

Briefing note, draft 4 (12 July 2026) – FOR REVIEW AND COMMENTS (By 11 September 2026)

1 Introduction

At 7.45 am on Saturday 15 October 2016, in Kigali, the Rwandan capital, delegates to the Twenty-Eighth Meeting of the Parties to the Montreal Protocol burst into applause. Seven years of detailed negotiations had finally come to a conclusion; after an all-night sitting of the conference, agreement was reached to amend the Protocol to introduce control measures for hydrofluorocarbons (HFCs) – the 'Kigali Amendment' to the Protocol. News reports and commentators later that day were enthusiastic. 'Kigali deal on HFCs is big step in fighting climate change', declared *The Guardian*; 'Kigali delivers second big climate deal' announced the *Indian Express*; 'October 15, 2016: the day the Earth got a little cooler' tweeted the US Environmental Protection Agency.

Ten years on from the adoption of the Kigali Amendment, 2026 offers a suitable opportunity for analysis and reflection. This briefing note summarises the measures introduced over the last ten years to implement the provisions of the Amendment and the achievements reached, and looks forward to future challenges and opportunities. Drawing on existing reports and materials, it focuses on the main areas of HFC phase-down and the development of alternatives, energy efficiency, sustainable cooling and lifecycle refrigerant management.

1.1 The Kigali Amendment: an exercise in innovation

Under the Kigali Amendment, parties committed to progressively reduce the production and consumption of HFCs relative to their respective baseline levels, reaching final reduction steps of 85 per cent by 2036 for non-Article 5 parties and 2047 for Article 5 Group 2 parties, and to 80 per cent by 2045 for Article 5 Group 1 parties. Control measures took effect from 2019 for non-Article 5 parties and 2024 for Article 5 Group 1 parties, and are scheduled to commence in 2028 for Article 5 Group 2 parties.

In the absence of the Kigali Amendment, global HFC emissions were projected almost to triple by 2050, from 1.45 gigatonnes (Gt) carbon-dioxide-equivalent (CO_2-eq) in 2020 to 4.26 Gt CO_2e. Accordingly, the phase-down schedule agreed at Kigali is projected to prevent more than 80 billion tonnes of CO_2-eq emissions by 2050, avoiding 0.1°C of global average temperature rise by mid-century and up to 0.5°C by 2100.[1]

The Amendment entered into force on 1 January 2019, the ratification threshold of 20 parties having been achieved more than a year earlier. At the time of publication it has been ratified by 173 out of the total of 198 parties to the Protocol, representing over 92 per cent of the global population.

The Kigali Amendment was an innovative step forward for the Montreal Protocol in several different ways. Most obviously, HFCs were the first category of chemicals included in the Protocol – a treaty designed to protect the ozone layer – that are not themselves ozone-depleting substances. Legally this was justified by the obligations of the Vienna Convention to protect human health and the environment against adverse effects, including considerations of changes in the climate that affect the ozone layer.

[1] Guus Velders et al, 'Projections of hydrofluorocarbon (HFC) emissions and the resulting global warming based on recent trends in observed abundances and current policies' Atmos. Chem. Phys., 22, 6087–6101, https://doi.org/10.5194/acp-22-6087-2022, 2022.

In practical terms, inclusion also clearly made sense. In 2016, HFC consumption was expanding at a rate of 10–15 per cent per year, driven mostly by the need to replace the CFCs and HCFCs then being phased out under the Protocol, together with the steady rise in the number of cooling appliances worldwide. Given that substitutes existed for many (though not all) uses of HFCs, the consumption-and-production-phase-out model of the Montreal Protocol was better suited than the emissions control regime of the UN Framework Convention on Climate Change and Paris Agreement.

Another novel element of the Kigali Amendment was the flexibility it displayed in setting control schedules. Like the production and consumption targets for almost every other category of substances controlled by the Protocol, the Kigali control measures for non-Article 5 parties are differentiated from those for Article 5 parties – but unlike all the other categories, both non-Article 5 and Article 5 parties are themselves each split into two groups, recognising their different circumstances.

Some of the alternatives to HFCs available in 2016, and subsequently, function less well in high-ambient-temperature countries, and further time was expected to be needed to develop acceptable replacements. Accordingly, the first group of Article 5 parties – the majority – are required to freeze consumption by 2024, and start to phase down in 2029, ending with an 80 per cent reduction by 2045. The second group – a list of ten high-ambient-temperature countries in the Middle East and South Asia − will meet a later deadline, with a freeze in 2028 and consumption reductions starting in 2032, ending with an 85 per cent reduction by 2047. There are also possible exemptions for some uses in these countries. Five non-Article 5 parties in eastern Europe and central Asia also have slightly different baselines and phase-down steps.

The third innovative element was the explicit recognition of the importance of maintaining or improving energy efficiency when transitioning to alternative refrigerants. In many refrigeration and air-conditioning systems, electricity consumption over the equipment's lifetime creates more greenhouse gas emissions than losses in refrigerant; a poorly managed refrigerant transition could therefore increase power-sector emissions even while reducing HFC emissions. On the other hand, when combined with improvements in the energy efficiency of the cooling equipment, the climate benefit of the Amendment could increase significantly.

Decisions XXVIII/2 and XXVIII/3, adopted alongside the Kigali Amendment at the 2016 Meeting of the Parties, accordingly formed a key part of the Kigali package. Through these decisions, the parties highlighted the importance of the energy efficiency issue and requested the Executive Committee of the Multilateral Fund to develop cost guidance associated with maintaining and enhancing the energy efficiency of replacement technologies and equipment, and the Technology and Economic Assessment Panel (TEAP) to review energy efficiency opportunities in the refrigeration and air-conditioning and heat-pump sectors. After Kigali, energy efficiency became a recurring agenda item in Meetings of the Parties and in meetings of the Executive Committee.

This briefing note summarises the achievements of the Kigali Amendment to date (Section 2) and the current challenges and opportunities (Section 3), while looking ahead to the next ten years and beyond (Section 4). The boxes at the beginning of Sections 2 and 3 contain brief summaries. The annex includes concise summaries of a number of case studies of activities undertaken in response to the Kigali Amendment.

[This is a preliminary version of the briefing note. The revised and final version, which will include an expanded range of case studies, will be available at the Thirty-Eighth Meeting of the Parties in Kigali.

We hope that it provides food for thought as the ozone community commemorates the tenth anniversary of the Kigali Amendment and looks ahead to the future of the Montreal Protocol.]

2 Achievements, 2016–26

Summary of main achievements

- Almost all parties have met their initial phase-down targets.
- World-wide production and consumption of HFCs peaked in 2023, and fell in 2024; in Article 5 parties, production and consumption started falling in 2023.
- A comprehensive policy and funding framework has been developed to provide support to Article 5 parties through the Multilateral Fund, including approval of stage I Kigali HFC Implementation Plans (KIPs) in 91 countries, with total funding of US$172 million.
- Transitions are creating a major opportunity to upgrade equipment simultaneously to more climate-friendly refrigerants and higher efficiency, supported by the Multilateral Fund with dedicated funding windows, an operational framework and a revolving fund.
- The development and application of lower-GWP alternatives for the refrigeration, air conditioning and heat pump sector has accelerated; equipment energy and usage efficiency have improved, including through controls, building integration and automation.
- Sustainable cooling has evolved from narrow focus on refrigerant substitution to an integrated policy and technology agenda, with a focus on the 'Sustainable Cooling Pathway' combining passive cooling, low-energy and hybrid cooling, high-efficiency equipment and accelerated HFC phase-down.
- There is now a greater focus on lifecycle refrigerant management (LRM), covering refrigerant leakage prevention, recovery, recycling, reclamation and destruction. The Multilateral Fund is providing support to 127 Article 5 countries for the development of national inventories of banks of used or unwanted controlled substances and action plans for collection, transport and disposal.

The first ten years following the adoption of the Kigali Amendment have been primarily about laying secure foundations for future implementation. Almost 90 per cent of the parties to the Montreal Protocol (173 out of 198 to date) have now ratified the Amendment, which means they have started to report their annual data on production and consumption, as well as their baseline data. Overall trends in production and consumption are reviewed below in Section 2.1.

All except one non-Article 5 Party have met their first phase-down targets, of 10 per cent from baseline by 2019 and 40 per cent by 2024. Almost all Article 5 Group 1 parties have also met their first target, a freeze at baseline by 2024; for a few of them, improved data collection identified errors in the initial reporting of baseline data, and their requests for revision have been dealt with by the Implementation Committee and Meetings of the Parties.

Financial and technical assistance has been mobilised through the Montreal Protocol's existing financial mechanism, the Multilateral Fund for the Implementation of the Montreal Protocol. Working through its four implementing agencies and bilateral agencies, its initial focus on institutional strengthening – establishing the framework necessary for successful implementation in each Article 5 party – and technical assistance is now being supplemented by investment projects affecting HFC production and consumption. This is considered in more detail below in Section 2.2.

HFC use is heavily concentrated in the refrigeration, air-conditioning and heat pumps (RACHP) sector, which in 2020 accounted for 91 per cent of global HFC emissions. This was followed by foams (5.5 per cent), aerosols and solvents (1.9 per cent), fire protection (1.6 per cent), and HCFC-22 production, which produces HFC-23 as a by-product (0.03 per cent).[2] Three HFCs – HFC-134a, HFC-32, and HFC-125 – together contributed to more than 80 per cent of total emissions

Like all the previous amendments and adjustments to the Montreal Protocol, the Kigali Amendment has accelerated the global transition away from the substances it covers and towards lower-global warming potential (GWP) alternatives and technologies.[3] Manufacturers have increasingly invested in alternatives such as hydrofluoroolefins (HFOs), hydrocarbons, ammonia and carbon dioxide refrigerants; see Sections 2.3 and 2.4.

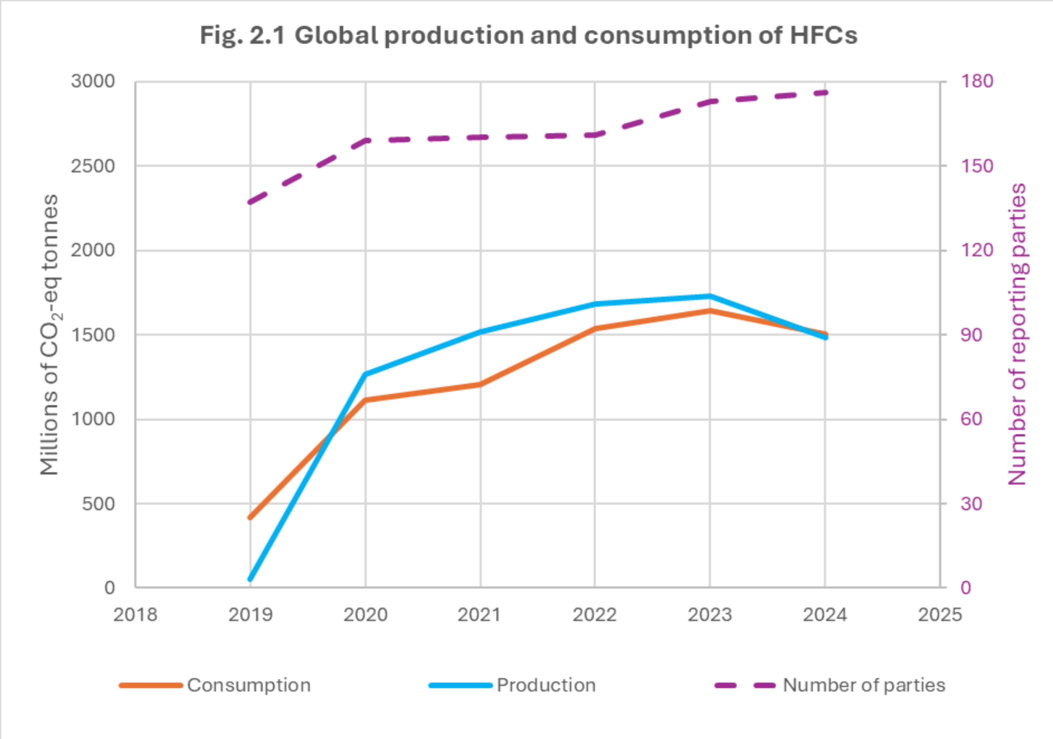
The Kigali Amendment has strengthened recognition of the importance of energy-efficient cooling. Although improving energy efficiency is not a binding obligation under the Amendment, implementation has stimulated substantial international cooperation on efficient cooling technologies, and the broader concept of a sustainable cooling pathway, with potential climate benefits extending well beyond refrigerant substitution; see Section 2.4.

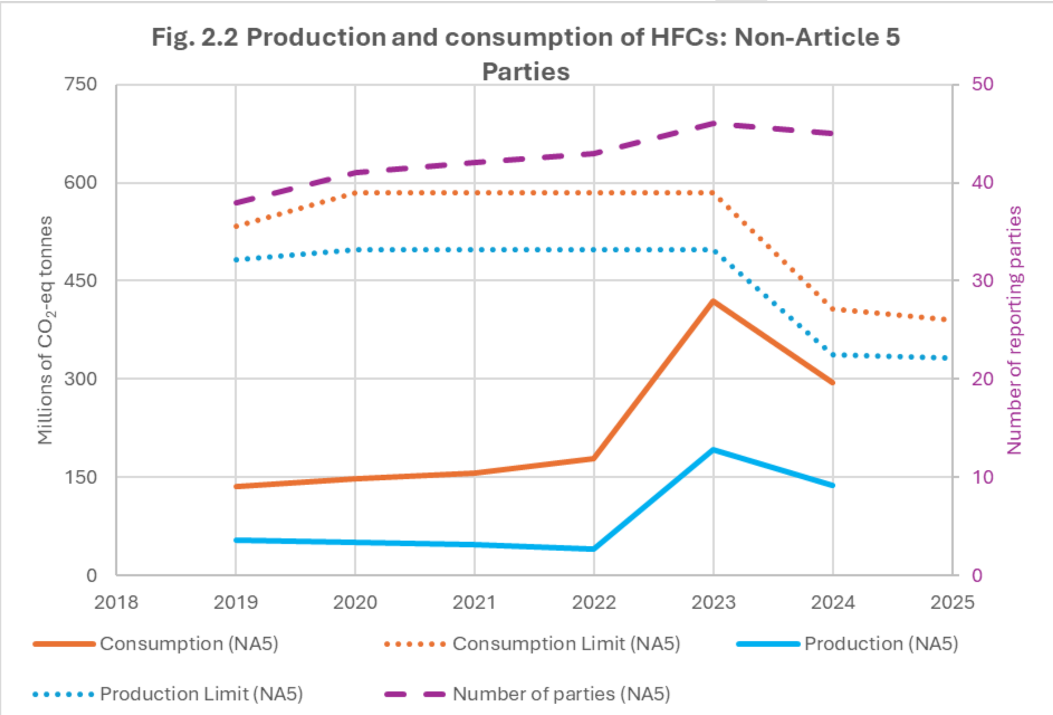
Finally, the Amendment has helped to refocus attention on the handling and disposal of banks of chemicals – both ozone-depleting substances (ODS) and HFCs – contained in existing equipment, products, foams and infrastructure. A major and growing source of greenhouse gas emissions, extensive work is now being carried out on lifecycle refrigerant management (LRM). This is considered further below in Section 2.5.

2.1 HFC phase-down

Figures 2.1 to 2.3 contain data on the production and consumption of HFCs at the global level (2.1), broken down for non-Article 5 parties (2.2) and Article 5 parties (2.3). In each case the solid lines (and the left-hand axis) show production and consumption, and the dashed lines (and the right-hand axis) the number of parties reporting data. In Figures 2.2 and 2.3 the dotted lines show the control limits prescribed by the Protocol.

[2] P. Purohit et al, 'Electricity savings and greenhouse gas emission reductions from global phase-down of hydrofluorocarbons', *Atmos. Chem. Phys*., 20, 11305–11327, https://doi.org/10.5194/acp-20-11305-2020, 2020.
[3] Note that since there is no agreed definition of 'low-GWP' for refrigerants, the term 'lower-GWP' is used throughout this briefing note.



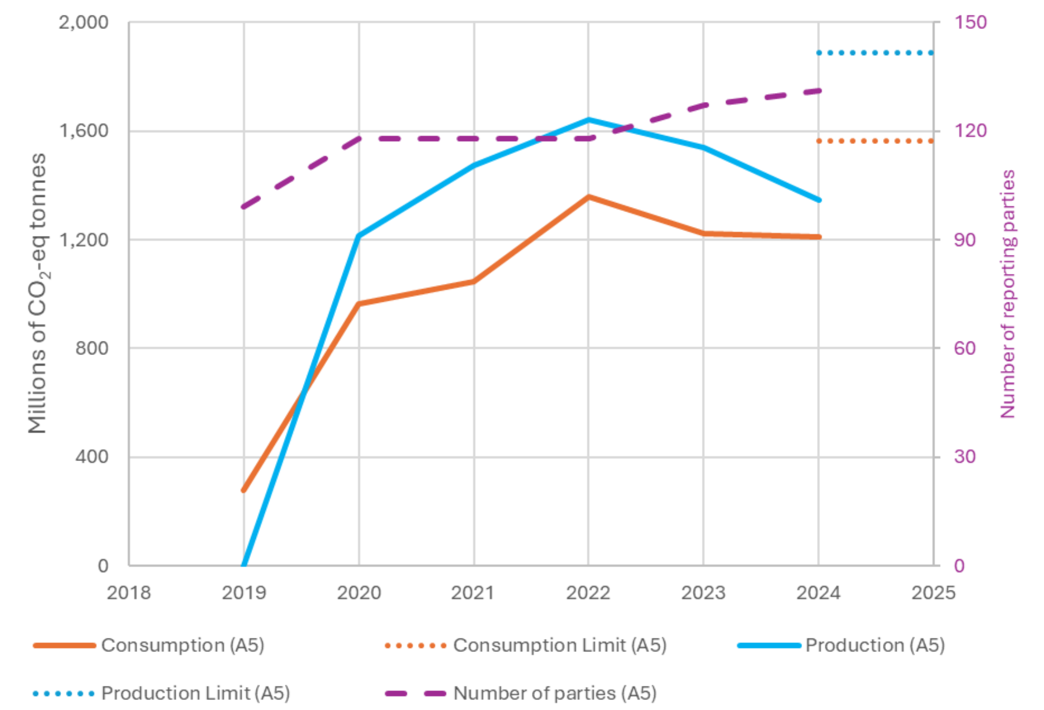


Notes:

1. The slight rise in the production/consumption limits between 2019 and 2020 is due to the start of control limits for Non-Article 5 Group 2 parties, whose control measures started in 2020.
2. The drop in the production/consumption limits between 2023 and 2024 is due to the start of the 40 per cent reduction requirement (from baseline) for Non-Article 5 Group 1 parties starting from 2024.

3. The slight drop in the production/consumption limits between 2024 and 2025 is due to the start of the 35 per cent reduction requirement (from baseline) for Non-Article 5 Group 2 parties starting from 2025.

Fig. 2.3 Production and consumption of HFCs: Article 5 Parties



Notes:

1. The HFC baseline years for Article 5 Group 2 parties are 2024, 2025 and 2026, and will be established starting from 2027 when those parties will have reported all the three baseline years.
2. The control measures (with associated limits) for Article 5 Group 2 parties start in 2028.

As can be seen, world-wide, production and consumption both peaked in 2023, and fell in 2024. This is not only due to non-Article 5 countries meeting their obligations; production and consumption also fell in Article 5 countries, after a peak in 2022, well ahead of any of their obligations – a significant achievement.

2.2 The Role of the Multilateral Fund and progress in Article 5 parties

Since the Kigali Amendment was agreed in 2016, the Multilateral Fund (MLF) has developed a comprehensive framework to support Article 5 countries in phasing down HFCs, moving from early enabling activities through to full investment projects covering refrigerant transition, energy efficiency and initial inventories and plans of action for refrigerant banks, including end-of-life refrigerant management.

The first stage was building the foundations. The MLF approved enabling activity projects in 141 Article 5 countries – for a total of US$18.7 million – to support the ratification of the Amendment and establish the institutional, regulatory and technical capacity needed to meet their HFC control obligations. These projects supported the development of national reporting systems, regulatory frameworks for controlling HFC imports and exports, and initial engagement with industry and government stakeholders.

The central vehicle for delivering HFC phase-down support has been the Kigali HFC Implementation Plan (KIP). To date, 106 Article 5 countries have been supported by US$21.6 million funding for projects for the preparation of their KIPs, and 91 countries have had stage I of their KIPs approved, with total funding of US$171.8 million. KIPs are helping countries regulate HFC trade, update safety standards for lower-GWP alternatives, train technicians and customs officers, raise public awareness and support businesses, from small and medium-sized enterprises to large manufacturers, in transitioning to climate-friendly refrigerants.

Transitioning refrigerants used in refrigeration and air-conditioning equipment creates a major opportunity to simultaneously upgrade to higher-efficiency equipment, while training on safe practices for working with new refrigerants offers the chance to incorporate best practices to maintain and enhance energy efficiency in existing equipment. Parties to the Montreal Protocol have explicitly endorsed this link, and the MLF has approved dedicated funding windows to capture cost-effective energy efficiency gains alongside refrigerant transition.

In December 2022 a US$20 million window was established, under which 69 projects have been approved to maintain and/or enhance the energy efficiency of replacement technologies and equipment in the context of HFC phase-down, for a total of US$14.8 million. These projects assist countries to introduce or strengthen minimum energy performance standards (MEPS) for RACHP equipment and build the capacity of technicians, customs and government officials to implement energy efficiency improvements and classifications, and support enterprises through technical assistance for demonstration projects in commercial and industrial equipment.

A further US$100 million window and operational framework was established in May 2024, under which 15 projects have so far been approved, for a total of US$30.9 million. These projects will assist enterprises to enhance energy efficiency in the manufacturing of domestic refrigerators, commercial refrigeration display cabinets, commercial refrigeration chest freezers, residential air conditioners and heat pumps and commercial air conditioners, while transitioning to more climate-friendly refrigerants.

Looking ahead, a further initiative points to an increasingly sophisticated and integrated approach to sustainable cooling. In December 2024 a US$40 million funding window was established for an energy efficiency revolving fund. Managed through implementing agencies and national financial institutions, this will provide low- or zero-interest financing to end users making energy efficiency improvements alongside refrigerant transitions, with funds to be repaid over eight years and recycled for further projects – an innovative model that stretches the impact of donor contributions. Two projects – one covering one country and a global project covering three countries – were approved for that amount at the 98th meeting of the Executive Committee in June 2026.

In addition, 127 Article 5 countries have been supported with US$12.0 million through another funding window, to develop national inventories of banks of recoverable, used and unwanted controlled substances and a plan for collection, transport and disposal. This work underpins the broader action on LRM, which could be an important area of focus in the years to come (see further in Section 2.5).

2.3 Progress in the refrigeration, air conditioning, and heat pump sector

In recent decades the RACHP sector has experienced significant growth, driven by climate change, rapid urbanisation and rising expectations for thermal comfort and food security. Left unchecked, this trajectory would have precipitated an energy and environmental crisis, given that RACHP equipment is energy-intensive and has historically relied on refrigerants with significant ozone depletion potential (ODP) and high GWP.

For the RACHP community, the adoption of the Kigali Amendment created a strategic opportunity to transition to sustainable cooling technologies and, particularly for Article 5 parties, to leapfrog directly to lower-GWP solutions rather than follow the incremental technology paths taken by developed nations. Critically, this transition addresses not only direct emissions from refrigerant leakage but also the indirect emissions associated with energy consumption during operation.

Since the Kigali Amendment entered into force, the RACHP sector has focused on four interconnected priorities: identifying and deploying lower-GWP refrigerant alternatives; improving equipment energy efficiency; enhancing usage efficiency through controls, building integration and automation; and expanding access while reducing costs in developing markets.

A major trend is the accelerated development and application of alternative refrigerants and refrigerant blends. The transition is not uniform across RACHP sub-sectors, because refrigerant selection remains application-specific and depends on safety classification, operating pressure, temperature lift, capacity range, climate, cost, availability and accessibility, energy performance and service infrastructure. Use of hydrocarbons, ammonia and carbon dioxide have expanded in several applications, while lower-GWP HFCs, HFOs and HFC/HFO blends are being introduced in others. This diversification has increased the importance of safety standards, codes, risk assessment and technician competence, particularly where refrigerants with flammability, toxicity, high pressure or chemical-stability considerations are used.

TEAP has identified room air conditioning and heat pumps and self-contained commercial refrigeration as the most critical sub-sectors, owing to their rapid growth in developing countries. In the former, the most significant development has been the broad roll-out of variable-speed compressor technologies, which can substantially reduce energy consumption, particularly when paired with electronic expansion devices and electronically commutated motors. For refrigerant selection, HC-290 (propane) offers a sustainable, lower-GWP solution for smaller units, while HFC-32 has emerged as a scalable lower-GWP option for larger systems. The industry is also advancing charge reduction technologies, including small-diameter tubing, optimised compressor shell sizing, and microchannel heat exchangers, alongside leak minimisation measures such as advanced detection systems, improved pipe connections and better installation practices.

In stand-alone commercial refrigeration, the transition to HC-290 or HC-600a (isobutane) is well advanced. For larger commercial split systems, lower-GWP blends such as R-448A and R-449A, both classified as non-flammable, provide viable alternatives. Energy efficiency progress in this sector is equally broad, encompassing variable-speed compressors, electronic expansion valves and electronically commutated fan motors on the cycle side, and advanced insulation, low-emissivity coatings, triple-pane doors, improved air curtains, night set-back controls and internet-enabled building management systems on the load side.

Other RACHP sectors that have seen significant progress over the past decade include larger air conditioning and heat pump systems, cold chain equipment, mobile air conditioning and transport refrigeration. Beyond these established applications, several emerging sectors are gaining increasing prominence: district cooling is establishing itself as a sustainable alternative to conventional air conditioning in dense urban areas; data centre cooling is becoming an urgent priority, driven by the rapid expansion of digital infrastructure; and high-temperature heat pump applications are attracting growing attention as a viable pathway for industrial decarbonisation. Across all of these sectors, established and emerging alike, the progress follows a consistent dual-track approach: identifying and deploying lower-GWP refrigerant alternatives alongside technological advancements targeting refrigerant charge reduction, leakage minimisation and improved energy efficiency.

Across the sector, the convergence of refrigerant transition and energy efficiency improvement represents a compounded climate benefit, one that positions RACHP as a meaningful contributor to the Montreal Protocol's legacy.

2.4 Progress in sustainable cooling

Activity in the cooling sector has evolved from a narrow focus on refrigerant substitution to a whole-system approach – an integrated policy and technology agenda – for sustainable cooling that addresses direct refrigerant emissions, indirect energy-related emissions, cooling demand reduction and equitable access to cooling.

Progress on direct emissions is being advanced through the transition to lower-GWP refrigerants and the growing recognition of LRM, including leak prevention, recovery, reuse, reclamation and end-of-life management, although many LRM systems remain at an early stage of implementation (see further in Section 2.5). Progress on indirect emissions is being pursued through higher equipment efficiency, strengthened minimum energy efficiency standards (MEPS), improved servicing and maintenance and measures that reduce cooling and heating loads before mechanical cooling is deployed, such as passive design, insulation, shading, reflective surfaces, natural ventilation and urban cooling.

This broader framing reflects a central policy shift: cooling is now understood as both a climate-mitigation and a climate-adaptation priority. Refrigeration, air conditioning and heat pumps are essential for health, food security, vaccine storage, productivity and heat resilience, but their rapid growth could also increase electricity demand, peak loads and greenhouse gas emissions if not properly managed. UNEP's *Global Cooling Watch 2025* captures this integrated approach through a 'Sustainable Cooling Pathway,' which combines passive cooling, low-energy and hybrid cooling, high-efficiency equipment and accelerated HFC phase-down. Under this pathway, projected 2050 cooling emissions could be reduced by 64 per cent below business-as-usual levels, and by 97 per cent when combined with rapid power-sector decarbonisation.[4]

The first area of progress is the successful twinning of National Ozone Officers and energy policy-makers. This effort started in 2018 and continues to bring them together in national, regional and international settings to support the transition towards lower-GWP refrigerants while raising energy efficiency ambitions. This effort was further reinforced by the integration of energy efficiency with HFC phase-down.

[4] *Global Cooling Watch 2025 – The free degrees: How sustainable, passive-first cooling can save lives, money and food* (UNEP, 2025).

A notable milestone was the Energy Efficiency Workshop organised by the Ozone Secretariat in Nairobi in October 2023, which brought together 300 participants, including government representatives, industry experts, international organisations, academic institutions and other stakeholders, to exchange experiences and assess challenges related to improving the availability and accessibility of energy-efficient equipment using lower- or zero-GWP refrigerants. Discussions highlighted the importance of integrated policy approaches combining refrigerant transition, energy efficiency, financing, technician training, market surveillance, MEPS and national cooling action plans. The workshop reinforced the need for stronger coordination among ozone, energy, and climate authorities and emphasised that achieving the full climate benefits of the Kigali Amendment requires simultaneous action on both refrigerant management and energy efficiency. The Multilateral Fund has operationalised this agenda, as described above in Section 2.2.

The second area of progress is the growing attention to LRM within the Montreal Protocol, discussed below in more detail in Section 2.5.

Digitalisation is emerging as an enabling trend across equipment design, operation, servicing and policy implementation. Sensors, connected controls, IoT (internet of things) platforms, fault detection and diagnostics, predictive maintenance, refrigerant monitoring and demand-response functions can improve energy performance, reduce leakage, support better maintenance and provide data for measurement, reporting and verification. Digitalisation is particularly relevant for complex systems such as supermarkets, cold stores, variable refrigerant flow systems, chillers, heat pumps, data centres and integrated heating and cooling systems. However, its impact depends on affordability, data quality, cybersecurity, technician capacity and the ability of owners and service providers to act on the information generated.

Finally, passive cooling has moved from isolated architectural or building-design measures to a core pillar of sustainable cooling policy. It is increasingly recognised as a demand-reduction strategy that can reduce the need for mechanical cooling by lowering heat gains through improved building envelopes, shading, natural ventilation, reflective surfaces, cool roofs, urban greenery and climate-responsive design. This shift places passive cooling alongside energy efficiency and refrigerant management as part of an integrated policy approach for reducing cooling-sector emissions. Ongoing efforts are focused on strengthening building energy codes, urban planning requirements, public procurement, financial incentives, technical guidance and enforcement mechanisms to scale passive cooling in both new and existing buildings. The main implementation challenge is ensuring that passive cooling measures are not treated as optional design features but are systematically embedded in national cooling strategies, building codes, affordable housing programmes and heat-resilience planning.

2.5 Progress in lifecycle refrigerant management

Since the early 1990s, leak prevention, refrigerant recovery and the environmentally sound management of controlled substances have formed part of the Montreal Protocol framework. Yet despite decades of technical innovation, progress has been uneven in establishing a circular path between refrigerant consumption and its end-of-life management. The need to improve material flows by recycling and reclaiming, and to prevent end-of-life leaks through recovery and destruction, was translated into what we now refer to as lifecycle refrigerant management (LRM).

While the concepts of refrigerant recovery, recycling, reclamation and destruction had existed for decades under the Montreal Protocol framework, the integrated concept of LRM fully entered the policy discussion at the Thirty-Fifth Meeting of the Parties in 2023. Decision XXXV/11 requested a dedicated TEAP Task Force assessment on leak prevention and end-of-life refrigerant management. This assessment, published in 2024, drew attention to the need to address this stage of refrigerant value chains to minimise direct emissions of refrigerants, while also improving refrigerant reuse through recycling or reclamation. This was followed by an Ozone Secretariat workshop on LRM in October 2024, which provided an opportunity to exchange experiences.

For non-Article 5 parties, the phase-down of HFCs which had begun earlier paved the way for refrigerant management. Even before the adoption of the Kigali Amendment, some parties had already introduced domestic fluorocarbon regulations driven by climate concerns and the high GWP of HFCs. This includes the European Union’s F-gas Regulations (2006, 2014 and 2024, each with an increasing level of ambition) and Japan’s Act on the Rational Use and Proper Management of Fluorocarbons, as well as federal and state-level initiatives in the United States, later consolidated under the American Innovation and Manufacturing (AIM) Act. Similar measures were also introduced in Australia and Canada.

For most non-Article 5 parties, Kigali control obligations began in 2019. The phase-down of virgin HFC supply created increased the economic value of recovered refrigerants and stimulated investment in leak prevention, recovery infrastructure, reclamation capacity and end-of-life management systems. As a result, several non-Article 5 parties have already observed declining HFC consumption alongside the growth of reclamation markets and strengthened refrigerant management frameworks. The EU F-Gas Regulation is a good example of what can be achieved, with a 72 per cent HFC consumption cut from baseline by 2024 and a planned 88 per cent cut by 2027, well ahead of the Kigali control measures.

For Article 5 parties, early activities under enabling environment projects focused primarily on establishing the institutional foundations for Kigali implementation, including HFC licensing and quota systems, data collection and policy development. These initial efforts also helped identify the growing relevance of refrigerant banks and the need progressively to integrate circular approaches into refrigerant management.

As HFC supply becomes controlled under phase-down schedules, the management of refrigerants already contained in existing equipment becomes more important for ensuring future servicing demand while minimising emissions. However, despite growing awareness and the first national assessments of end-of-life management needs, a significant gap remains between the identification of challenges and the establishment of operational systems for recovery, reclamation and destruction.

Since the adoption of the Kigali Amendment, Article 5 parties have taken early steps to address this gap. As KIP Stage I activities are being implemented, several parties have already included refrigerant recovery and reclamation activities within their national strategies, reflecting the recognition that reducing future emissions will also require addressing refrigerants already contained in existing equipment and banks. As discussed in Section 2.2, in 2022, the Multilateral Fund created a funding window with the objective of supporting countries in quantifying their refrigerant banks and developing the first action plans for collection, transport and disposal, and since then 127 parties have received support.

At the same time, experience with destruction activities has shown that implementation remains technically and institutionally challenging. Earlier pilot destruction projects funded by the Multilateral Fund struggled to meet their targets due to limited infrastructure, high transport costs, regulatory barriers and insufficient quantities of recoverable substances to sustain operations. Nevertheless, destruction activities continued to evolve under the Montreal Protocol framework.

Under Article 2J of the Kigali Amendment, parties are required to destroy HFC-23 generated as a by-product of HCFC-22 production ‘to the extent practicable’. Since the entry into force of these control provisions in 2020, Article 5 parties with HCFC-22 production facilities have received technical and financial assistance for HFC-23 monitoring and destruction activities. The parties and the Executive Committee of the MLF have adopted additional guidance and reporting requirements, informed by technical assessments provided by TEAP, to support their implementation and reporting obligations.

3 Challenges and opportunities

Summary of main challenges and opportunities

- Refrigeration: the sector is evolving from a narrow focus on refrigerant substitution toward a broader sustainable-cooling approach combining lower-GWP refrigerants, improved energy efficiency, better system design, load reduction, digital monitoring, leakage reduction, LRM and expanded access to reliable cooling services. Progress has bene substantial but uneven across applications and regions.
- Air-conditioning and heat-pumps: now experiencing rapid growth in demand, so substitution of high-GWP refrigerants cannot be the only approach. An integrated cooling and heating system transition is needed, combining HFC refrigerant phase-down, energy efficiency, cooling access, building-load reduction, heating electrification, digital controls, servicing-sector readiness and LRM.
- Sustainable cooling is now central to health protection, food security, productivity, thermal comfort, public services and climate resilience. Actions include: (1) minimising cooling loads (urban cooling, planning, passive building design, etc.); (2) using low-energy cooling solutions (fans, evaporative cooling, etc.); (3) maximising efficiency through MEPS, labelling, advanced controls and high-quality maintenance; (4) shifting to lower-GWP refrigerants and technologies in line with Kigali obligations.
- LRM is essential to address emissions from existing banks during the long servicing tail of RACHP equipment. Potential measures include national regulation requiring refrigerant recovery, recycling and reclamation and destruction; and support for reverse supply chain infrastructure, including regional destruction facilities in Article 5 parties.
- Other HFC-using sectors have in general experienced good but sometimes uneven progress. Particular challenges including introducing alternative propellants for pMDIs and the absence of fully viable alternatives in some fire suppression technologies.

3.1 Sectoral assessment: refrigeration

Cold chains are integrated, temperature-controlled systems that preserve the quality, safety and value of perishable and temperature-sensitive products from production or harvest through processing, storage, transport, distribution, retail and final use. Including food and pharmaceutical cold chains, they consist of domestic, commercial, transport and industrial refrigeration systems. Over the last decade, the sector has evolved from a narrow focus on refrigerant substitution toward a broader sustainable-cooling approach that combines lower-GWP refrigerants, improved energy efficiency, better system design, load reduction, digital monitoring, leakage reduction, lifecycle refrigerant management and expanded access to reliable cooling services.

Cold-chain access remains a major equity, food-security and public-health challenge. Efficient cold-chain systems are fundamental for meeting rising demand for temperature-sensitive food and healthcare products, including vaccines, but access remains uneven and under-assessed. As of May 2023, only 62 countries had mapped their cold chains to minimise food loss, and only 94 had reported food-loss data. Strengthening cold-chain access requires not only efficient and lower-GWP refrigeration technologies, but also national cold-chain mapping, integration into cooling and food-security strategies, support for off-grid and weak-grid refrigeration, finance and capacity-building for smallholders and local enterprises, reliable health-care cold chains for vaccines, medicines and blood products and stronger servicing and maintenance infrastructure.

In domestic refrigeration and self-contained commercial refrigeration, the transition toward hydrocarbons is well established in many markets. HC-600a (isobutane) is the dominant lower-GWP option for domestic refrigerators, while HC-290 (propane) and HC-600a are increasingly used in plug-in commercial equipment, subject to applicable charge limits, safety standards and technician competence. Progress in Article 5 parties has continued through HCFC Phase-out Management Plans and KIPs, although the pace differs by market structure, local manufacturing capacity, standards adoption, servicing readiness and consumer affordability. Energy efficiency remains central to this transition, particularly because domestic and plug-in commercial equipment are high-volume products with long operating lifetimes and large aggregate electricity demand.

Larger commercial refrigeration split systems show a more differentiated transition pathway, as system architecture, charge size, operating temperature, store format and servicing capacity vary widely. Condensing units are moving away from HCFC-22 and R-404A toward lower-GWP HFC/HFO blends, hydrocarbons or R-744 (carbon dioxide), depending on application, market conditions, safety requirements and component availability. In centralised and distributed systems, R-744 has gained significant market traction, particularly in Europe, Japan and other markets where regulatory drivers, system design experience and contractor capability support deployment. R-744 transcritical systems have demonstrated improved performance in warmer climates when enhanced architectures are used, including ejectors, parallel compression, mechanical sub-cooling and other system-efficiency measures. Nevertheless, wider uptake in Article 5 parties depends on cost, technical capacity, supply chains, safety practices and after-sales support.

Transport refrigeration remains one of the most difficult sub-sectors to transition in the cold chain. Equipment must operate over wide ambient-temperature ranges, withstand shock and vibration, maintain precise temperature control and remain serviceable across dispersed transport routes where trained technicians and refrigerant supplies may be limited. Road transport and large truck/trailer systems continue to rely heavily on R-404A and R-452A, with R-452A becoming an important lower-GWP replacement in Europe and some other markets. For next-generation equipment, A2L refrigerants such as R-454A and HFO-1234yf are being considered or introduced in selected applications. Wider adoption of hydrocarbons and R-744 remains constrained by safety requirements, cost, component availability, infrastructure readiness and operating conditions. In intermodal containers, HFC-134a remains widely used, while R-513A has been offered as a retrofit or alternative in some cases, and HFO-1234yf is receiving increased attention following standardisation and recent industry announcements. In maritime applications, many systems still use fluorinated refrigerants such as R-407C, HFC-134a and R-404A, while refrigerated cargo ships and fishing vessels more commonly use R-717 (ammonia) and, increasingly, R-744 or R-717/R-744 cascade systems where suitable.

Industrial refrigeration is a foundational part of the cold chain, particularly for food processing, cold storage, beverages, fisheries and other temperature-controlled industrial processes. It is technically mature and already has robust long-term lower-GWP options. R-717 remains the dominant refrigerant in large industrial systems because of its long operating history, high efficiency and very low climate impact, provided that appropriate safety design, training, maintenance and regulatory controls are in place. R-744 is also increasing in use, particularly in cascade, transcritical and secondary-loop systems, sometimes in combination with R-717. Existing HCFC-22 and high-GWP HFC systems remain in service in some regions, especially in Article 5 parties. Their replacement or conversion requires careful technical assessment of the constraints posed by pressure levels, materials compatibility, lubricants, safety requirements, equipment age and capital cost. Depending on the system, replacement, staged conversion, cascade redesign, charge reduction or lower-GWP retrofit options may be more appropriate.

Overall, the refrigeration and cold-chain sector has made substantial progress toward lower-GWP refrigerants and improved efficiency, but progress is uneven across applications and regions. Future progress will depend on integrating refrigerant transition with energy efficiency, system optimisation, leakage prevention, recovery and reclamation, digital monitoring, cold-chain access and robust safety and servicing infrastructure.

3.2 Sectoral assessment: air conditioning

The air-conditioning and heat-pump sector is entering a more complex phase of the Kigali Amendment transition. The sector can no longer be addressed only through the substitution of high-GWP refrigerants; it must now be considered through an integrated cooling and heating system transition combining refrigerant phase-down, energy efficiency, cooling access, building-load reduction, heating electrification, digital controls, servicing-sector readiness and LRM. This is especially important because comfort cooling demand is growing rapidly in high-ambient and emerging economies, while heat pumps are expanding in colder regions as part of building heating decarbonisation strategies.

Cooling access has become a central policy issue for the air-conditioning sector. Extreme heat is increasing the need for safe indoor thermal conditions in homes, schools, health facilities, workplaces and public spaces, but access to adequate cooling remains uneven in many Article 5 parties. A sustainable cooling approach could maximise access while avoiding lock-in to inefficient, high-GWP and high-electricity-demand technologies. This requires prioritising cooling-load reduction, efficient equipment, lower-GWP refrigerants, grid-responsive operation and affordability measures, particularly for vulnerable populations and public-service buildings.

Low-energy and hybrid solutions should be treated as part of the air-conditioning sector assessment rather than as peripheral measures. Fans, evaporative coolers, indirect evaporative systems, hybrid evaporative-mechanical systems, ventilation strategies, shading, reflective surfaces, insulation and improved building envelopes can reduce the required capacity, operating hours and peak-load contribution of conventional vapour-compression air conditioning. These measures are particularly important in high-growth markets because they can reduce equipment size, refrigerant charge, electricity demand and lifecycle cost, while improving resilience where grid capacity is constrained.

For small air-to-air air conditioners and heat pumps, especially room air conditioners and mini-splits, the refrigerant transition is well advanced but uneven. R-410A remains in use in many existing systems and in some new equipment, while HCFC-22 persists in legacy equipment and in some Article 5 markets. New equipment, however, is increasingly moving toward lower-GWP options. HFC-32 has gained significant market share, particularly in major Article 5 manufacturing and growth markets such as China and India. HC-290 solutions are also technically available and commercially demonstrated, particularly for small-capacity room air conditioners, portable units and selected split systems. In Article 5 parties, HFC-32 and HC-290 continue to be promoted through leapfrogging HCFC Phase-out Management Plans, KIPs, servicing-sector capacity-building and awareness activities that address safety, efficiency and climate benefits of energy-efficient lower-GWP technologies.

The transition in large air-to-air air conditioners and heat pumps, including ducted splits, packaged units, rooftops and variable refrigerant flow systems, is more differentiated by region and product architecture. R-410A remains important in the installed base, but its role is declining under HFC phase-down pressure and regional fluorinated gas policies. HFC-32 and R-454B are among the prominent lower-GWP options for new equipment, depending on product type, charge size, applicable standards and regional regulation. The use of variable refrigerant flow systems continues to expand because of zoning flexibility, part-load performance and building-integration benefits, while rooftop units remain important in North America, the Middle East and some commercial building markets. The main constraint for larger air-to-air systems is the interaction between refrigerant charge, refrigerant distribution inside buildings, refrigerant safety requirements, leak detection, ventilation, building codes and service competence.

Small water/glycol chillers and hydronic heat pumps are expanding in regions promoting electrification of space and water heating. These systems are increasingly used for residential and small commercial heating, domestic hot water and reversible heating/cooling. HFC-32, HC-290, R-454B, R-454C, R-744 and other lower-GWP options are being deployed depending on application temperature, charge size, safety requirements and regional regulation. R-744 is particularly relevant for domestic hot-water applications because it can deliver high water temperatures, although high-pressure design and performance sensitivity require careful application. Larger chillers, reversible chillers, heat pumps and district cooling/heating systems follow a portfolio approach: low-pressure HFOs and HFO/HFC blends in centrifugal chillers; HFC-32, R-454B and other blends in positive-displacement systems; and R-717, R-744, hydrocarbons or R-718 in selected applications where safety, pressure, water-use and regulatory constraints can be managed.

Energy efficiency is central to the climate value of the refrigerant transition. MEPS and energy labelling programmes are increasingly adopted for room air conditioners and, to a lesser extent, for larger air-conditioning systems. Many countries have adopted MEPS either as mandatory requirements or voluntary measures, often combined with labelling schemes. These requirements are increasingly based on seasonal efficiency metrics rather than single-point ratings, which better reflect part-load operation and real-use performance. MEPS or efficiency regulations exist in 149 countries for room and 128 for central air conditioning, but only 47 room-air-conditioning regulations and 29 central-air-conditioning regulations integrate refrigerant GWP limits with efficiency requirements. IEA analysis suggests that, as of 2024, MEPS covered around 89 per cent of global air-conditioning energy consumption, but only around 50 per cent in Africa.[5] CLASP's World's Best MEPS tool provides a useful benchmark by comparing current MEPS across major economies and identifying the most stringent standards for appliances including air conditioners.[6] Key equipment-level efficiency improvements include variable-speed compressors, improved heat exchangers, electronically commutated fan motors, electronic expansion valves and improved controls.

Safety remains one of the main determinants of transition speed. Lower-GWP refrigerant options increasingly include A2L (lower flammability) HFOs and HFC/HFO mixtures, A3 (higher flammability) hydrocarbons, R-717 with toxicity considerations, and R-744 with high-pressure design requirements. Their safe deployment requires updated product standards, building codes, charge limits, risk assessment, leak detection, ventilation provisions, safe installation practices and technician certification. In non-manufacturing Article 5 parties, servicing-sector readiness is

[5] International Energy Agency, *Energy Efficiency 2024* (IEA, 2024).
[6] 'World's Best MEPS: Tracking Leaders in Appliance Energy Efficiency Standards'; https://www.clasp.ngo/tools/worlds-best-meps/.

particularly important because many countries will import lower-GWP equipment before they have a fully mature installation, commissioning and maintenance ecosystem.

LRM is therefore essential for the air-conditioning and heat-pump sector. Good design, installation, commissioning, leak prevention, maintenance, recovery, reuse, recycling, reclamation and destruction reduce direct emissions and can help maintain equipment efficiency over time. In the air conditioning sector, LRM is particularly important because installed banks of HCFC-22, R-410A, HFC-32 and other refrigerants will continue to require servicing for many years. Poor servicing practices can undermine Kigali compliance, increase refrigerant emissions and reduce the energy-efficiency gains expected from new equipment.

Digitalisation is becoming a cross-cutting enabler for efficiency, reliability and refrigerant management. In small equipment, connected controls, occupancy sensing, smart thermostats, remote diagnostics and demand-response capability can reduce operating hours and peak electricity demand. In larger systems, digital tools support predictive maintenance, optimised sequencing, fault detection, grid-interactive operation, leak detection and integration with building energy management systems. These capabilities are increasingly important as cooling loads grow and electricity systems face higher peak demand.

The air-conditioning and heat-pump sector has made significant progress toward lower-GWP refrigerants and higher efficiency, but the transition remains uneven across equipment classes, regions and market segments. The remaining barriers are high upfront cost, uneven MEPS coverage and enforcement, safety-code readiness, technician training, high-ambient performance, refrigerant availability, legacy equipment banks and limited integration of refrigerant policy with energy-efficiency and building policies. Future progress will depend on aligning Kigali implementation, MEPS, safety standards, building codes, public procurement, servicing-sector capacity, lifecycle refrigerant management and access-to-cooling strategies into a coherent sustainable cooling pathway.

3.3 Sectoral assessment: sustainable cooling

As discussed in Section 2.4, although not itself an obligation established by the Kigali Amendment, sustainable cooling is directly relevant to Kigali implementation because poorly managed growth in cooling demand could lock in inefficient equipment, increase electricity demand, expand refrigerant banks and make HFC phase-down more costly. A practical framework for the sector is a sustainable cooling hierarchy:

- First, countries should minimise cooling loads through urban cooling, climate-responsive planning, passive building design, shading, cool roofs, reflective materials, efficient building envelopes, natural ventilation and nature-based solutions.
- Second, they should use low-energy cooling solutions where appropriate, including fans, evaporative cooling, hybrid systems and other refrigerant-free or low-energy approaches.
- Third, they should maximise the efficiency of mechanical cooling through MEPS, energy labelling, seasonal performance metrics, variable-speed technologies, improved heat exchangers, advanced controls, proper installation and high-quality maintenance.
- Fourth, they should shift rapidly to lower-GWP refrigerants and technologies in line with Kigali obligations.

This hierarchy reduces demand first, then improves the systems that remain necessary, thereby lowering both indirect emissions from electricity use and direct emissions from refrigerants.

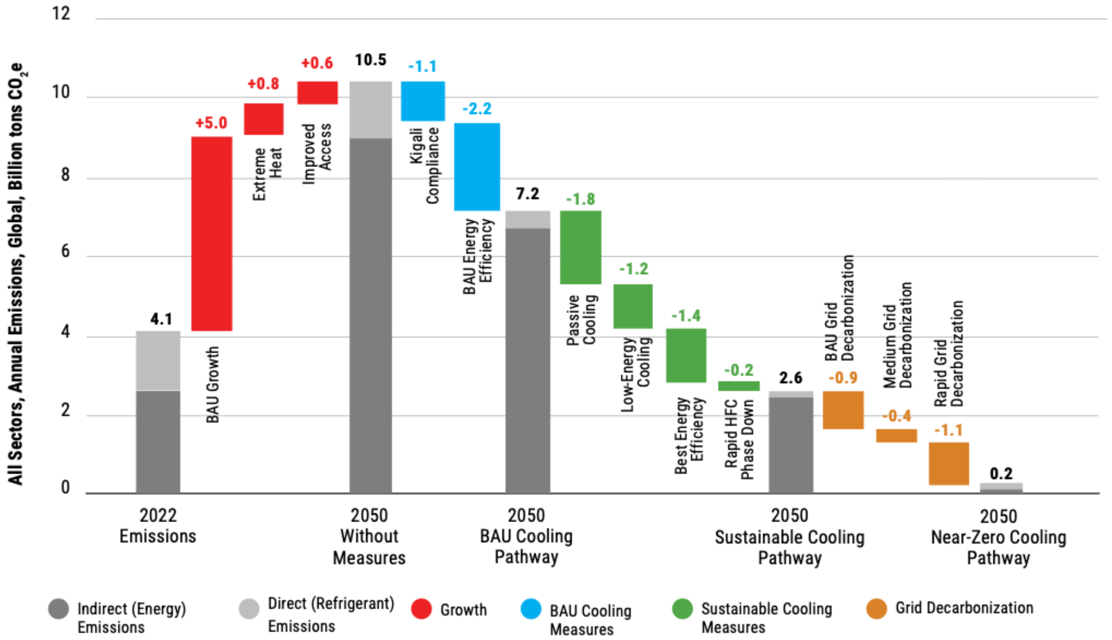
Sustainable cooling is not a single technology pathway; it is a progression from no access to increasingly reliable, affordable and low-emission cooling services. This is particularly important for vulnerable households and communities exposed to extreme heat, where the goal is not simply to deploy more equipment but to provide safe thermal conditions through the lowest-cost and lowest-emission mix of passive, low-energy and efficient mechanical cooling. Recent evidence shows that sustainable cooling is increasingly being embedded in national climate and energy policy. Regional data reported in *Global Cooling Watch 2025* on the inclusion of cooling in national strategies, including Nationally Determined Contributions, National Adaptation Plans, Long-Term Low Emission Development Strategies and energy plans, and on cooling-related greenhouse gas reduction targets , shows that 172 countries have prioritised sustainable cooling, and 134 are integrating cooling into national plans and international commitments.[7]

Large economies illustrate how the sustainable cooling agenda is being operationalised. China's 2019 Green and High-Efficiency Cooling Action Plan set 2030 targets to improve overall cooling energy efficiency by more than 25 per cent, improve cooling efficiency in large public buildings by 30 per cent, and increase the market share of green and high-efficiency cooling products by more than 40 per cent. The plan also emphasises strengthened efficiency standards, lower-GWP refrigerants, green procurement, cooling-system retrofits, data-centre cooling upgrades and cold-chain logistics improvements. India's Cooling Action Plan provides a national framework for reducing cooling demand, improving appliance efficiency, managing refrigerant transition and expanding access to cooling across buildings, cold chains, transport and industry. India has also used appliance policy instruments, including revised room air-conditioner efficiency standards and a 24°C default temperature setting requirement, to influence both efficiency and user behaviour. Morocco's integrated approach, combining building energy performance regulation, appliance energy labelling and air conditioner MEPS, is also a relevant Article 5 example because it links cooling demand reduction with equipment efficiency and market transformation.

Figure 3.1 shows the projected greenhouse gas emissions reductions deriving from implementation of the Kigali Amendment and accompanying potential sustainable cooling measures, reaching near-zero emissions by 2050. By 2050, compliance with the Kigali Amendment by itself reduces GHG emissions by 1.1 billion tonnes CO_2-eq, helping to cut the contribution from direct emissions of refrigerant from 36 per cent in 2022 to 6 per cent (in the BAU Cooling Pathway) or less. Energy efficiency improvements accompanying and partly stimulated by Kigali compliance add a further reduction of 2.2 billion tonnes CO_2-eq. Further measures (indicated to the right of the BAU Cooling Pathway in the diagram) – passive cooling, low-energy cooling, best energy efficiency, rapid HFC phase-down and the rapid decarbonisation of electricity generation – have the potential to cut emissions to just 0.2 billion tonnes of CO_2-eq.

[7] *Global Cooling Watch 2025.*

Fig. 3.1 Modelled pathway to near-zero GHG emissions from cooling in 2050



Source: *Global Cooling Watch 2025 – The free degrees: How sustainable, passive-first cooling can save lives, money and food* (UNEP, 2025)

3.4 Sectoral assessment: lifecycle refrigerant management

Lifecycle refrigerant management can deliver cost and environmental benefits by reducing direct refrigerant emissions, improving energy efficiency and lowering dependence on virgin refrigerant supply. The scale of the opportunity is considerable. According to the latest Climate and Ozone Protection Alliance assessment, global ODS and HFC banks in 2022 were estimated at 7,680 kt of substances, equivalent to 13.4 Gt CO_2-eq of emissions if released.[8] The same study projects that while ODS banks continue to decline, HFC banks are expected to continue growing until around 2030, especially in Article 5 parties where cooling demand and refrigeration and air conditioning equipment ownership continue to expand. In Article 5 parties alone, ODS/HFC banks increased from 6.1 Gt CO_2-eq in 2014 to 7.6 Gt CO_2-eq in 2022. China alone accounts for around 29 per cent of the global ODS/HFC bank, followed by Saudi Arabia, India and Brazil.

Leakage prevention through improved maintenance and better practices contributes to reducing refrigerant and energy consumption. This combined effect is equivalent to approximately 39 Gt CO_2-eq of emissions between 2025 and 2050. Increasing the use of reclaimed refrigerants can also reduce the need for virgin refrigerant production and improve refrigerant availability during the servicing tail. In the US, the material saving of using reclaimed refrigerant as opposed to new refrigerant could fully meet HFC demand by 2029, recovering only 35 per cent of the total HFC available for recovery.

[8] GIZ, *Global Banks of Ozone Depleting Substances (ODS) and Hydrofluorocarbons (HFCs): A Country-Level Estimate 2024*, (Climate and Ozone Protection Alliance, April 2025).

Japan provides one of the most advanced examples of operational LRM, built through a set of laws that cover fluorocarbons from equipment manufacturing and use through recovery, recycling, reclamation and destruction. Its Fluorocarbon Emissions Control Act, first adopted in 2001, introduced obligations for commercial refrigeration and air-conditioning equipment. Enforcement has been strengthened: a 2019 amendment to the Act introduced direct penalties for equipment managers who fail to recover fluorocarbons at disposal and requires collection certificates before waste disposers or recyclers accept equipment. As of May 2025, Japan reported more than 55,000 registered filling and recovery operators, 32 licensed recycling operators and 47 licensed destruction operators. In 2023, fluorocarbons recovered from around 1.49 million units of end-of-life equipment amounted to 4,163 tonnes, with recycled and reclaimed quantities increasing since 2020.

The EU has also demonstrated how HFC phase-down policies can be linked with broader refrigerant management. Its framework combines the Ozone Regulation, which governs ODS, with successive F-Gas Regulations, most recent Regulation (EU) 2024/573, which lays down rules on containment, recovery, recycling, reclamation and destruction of fluorinated greenhouse gases, together with certification, reporting and quota obligations. (Sulphur hexafluoride is also included in the basket of gases to be managed.) For fluorinated gases, companies report annually on production, imports, exports, reclamation and destruction, allowing the market effects of the HFC phase-down to be tracked. In 2024, 2,086 tonnes of HFCs were reported as reclaimed, equivalent in mass terms to total EU virgin HFC production, and around 5 per cent of total EU HFC supply. In 2024, 6,526 tonnes of ODS were destroyed in the EU, a 62 per cent increase compared with 2023, equivalent to 6,480 ODP tonnes.

The EU case illustrates how quota constraints, recovery obligations, reporting systems and market oversight can support the emergence of a reclamation market, even while challenges such as illegal trade and enforcement continue to require attention. These advantages will only materialise if countries can develop the infrastructure and acquire the skills for full value chain management. TEAP's LRM Task Force highlighted that the reverse supply chain infrastructure needed, from recovery to reuse and destruction, is limited in several countries, particularly in Article 5 parties. Recovery remains the critical first step.

Institutional and policy barriers also remain significant. Refrigerant management affects ozone units, customs agencies, environmental regulators, waste authorities and servicing sectors. In some countries, recovered refrigerants transported for destruction may fall under hazardous waste classifications and Basel Convention procedures. These procedures may limit the use of destruction approaches by hindering the export of unwanted substances.

Infrastructure and economic requirements also differ substantially between countries and end users. Large industrial and commercial users may justify investment in leak detection systems, reclamation technologies and recovery logistics, while informal servicing sectors often lack even basic recovery equipment. Reclamation infrastructure remains complex and costly, and challenging to establish in many countries lacking capacity.

Several Article 5 parties have started to explore localised solutions to overcome these constraints. Ghana is developing a rotary kiln destruction facility with support from GIZ, while Vietnam has piloted smaller-scale steam decomposition systems under bilateral cooperation initiatives. Mexico has installed a reactor to transform ODS-containing foam waste streams, illustrating how existing industrial infrastructure can support end-of-life management. In Colombia, a national project to substitute old refrigerators resulted in the adoption of a new regulation which made waste electronic equipment efforts mandatory from 2022.

Looking forward, LRM creates opportunities to go beyond the direct requirements of the Kigali Amendment by addressing emissions from existing banks during the long servicing tail of refrigeration and air conditioning equipment. As phase-down schedules tighten, higher refrigerant prices may create stronger economic incentives for recovery and reclamation. Realising this potential will require stronger policy frameworks, enforcement against venting and illegal trade, financing for recovery infrastructure and differentiated solutions adapted to the needs of large industrial users, informal servicing sectors and high ambient-temperature markets.

3.5 Sectoral assessment: other sectors

Foams

Over the past decade, the foam sector, which produces insulation and structural materials used in buildings, refrigeration systems and other applications, has made significant progress in transitioning away from HCFC-141b and HCFC-142b in Article 5 parties and high-GWP HFCs such as HFC-245fa and HFC-134a in non-Article 5 parties. These substances have historically been associated with two main families of foam products: polyurethane (PU)-type foams (including polyurethane, polyisocyanurate and phenolic foams) and extruded polystyrene (XPS) foams, which require different blowing agents. HCFC-141b and HFC-245fa have primarily been used in PU-type foams, while HCFC-142b (often in combination with HCFC-22) and HFC-134a have been mainly used in XPS applications.

In non-Article 5 parties, the transition is largely complete, with the vast majority (well above 90 per cent) of foam applications now relying on lower-GWP alternatives, while in Article 5 parties the transition is ongoing. This shift has been driven by regulation and supported by the growing uptake and continued development of lower-GWP options, including HFO-1234ze, HCFO-1233zd, hydrocarbons (such as cyclopentane and n-pentane), water-blown systems, CO_2, methyl formate and methylal, as well as emerging alternatives and innovations such as HCFO-1224yd(Z) and the increasing use of co-blowing agents (e.g. dichloroethylene) and tailored blends with new additives to optimise cost and performance.

However, adoption remains uneven. In many Article 5 parties, high costs, limited access for small and medium enterprises, and safety requirements for flammable foam blowing agents continue to delay transitions, while non-Article 5 markets face tighter regulatory timelines, including through the EU F-Gas Regulation, which restricts high-GWP HFCs through a quota system and bans HFCs above GWP 150 in foam applications, as well as similar regulatory phase-downs such as the US AIM Act Technology Transition Rule, which introduces GWP limits of 150 for most foam-blowing agents. Performance constraints, particularly in spray foam and extruded polystyrene, also remain, alongside ongoing issues such as illegal trade in HCFC-141b based polyols and continued reliance on HFC-245fa. Looking ahead, further optimisation of blends and wider use of CO_2 and water-based systems offer practical opportunities, although regulatory and safety issues will continue to influence the pace of change.

Aerosols

The aerosol sector has undergone a significant transition over the past several decades. In the 1980s, CFCs, particularly CFC-12, were widely used as propellants across almost all aerosol applications. Following their phase-out under the Montreal Protocol, most aerosol uses successfully transitioned to non-fluorocarbon alternatives, primarily hydrocarbons and dimethyl ether (DME), which now dominate consumer, personal care and household products. As a result, only a limited number of aerosol applications continue to rely on fluorinated propellants, most notably technical aerosols requiring non-flammable properties and pressurised metered dose inhalers (pMDIs) used in healthcare. These have experienced gradual substitution pathways, with alternatives such as HFO-1234ze(E) already in use in several markets.

The main remaining use is for pressurised metered dose inhalers (pMDIs) used to deliver medicines for asthma and chronic respiratory diseases. In this sector CFCs were replaced mainly by HFC-134a, with some HFC-227ea; this now accounts for a growing share of remaining HFC emissions as other sectors are transitioning away. For example, pMDIs accounted for around 11 per cent of fluorinated greenhouse gas emissions in the UK in 2022, compared to approximately 8 per cent a decade earlier. This is a much more challenging use to replace because of the cost of the research and development needed to prove that a new propellant is effective and safe for human use, including demonstrating compliance with health regulations.

Progress is under way, however, with lower-GWP propellants such as HFC-152a and HFO-1234ze(E) approaching commercialisation. However, the transition is slower and more resource-intensive, requiring reformulation, clinical validation, regulatory approval and new manufacturing systems. Differences between Article 5 and non-Article 5 parties are particularly pronounced: non-Article 5 markets are shifting more rapidly, supported by regulation and alternatives such as dry powder inhalers, while many Article 5 parties remain reliant on affordable salbutamol pMDIs, raising concerns about cost and access. These challenges underscore that, beyond technical feasibility, successful transition depends on affordability, supply security and public health considerations.

Fire suppression

Fire suppression, which is used to protect lives and critical infrastructure from fire risks in sectors such as aviation, computer hubs, energy and industry, presents a different set of challenges. Despite long-standing efforts to reduce reliance on ODS, halon 1301 remains essential in certain enduring uses such as civil aviation, shipping and military equipment, where very high safety standards apply. Following the phase-out of halons under the Montreal Protocol, HFC-227ea was widely adopted as a replacement in many non-aviation fire suppression applications, particularly in total flooding systems for critical infrastructure. However, due to its very high global warming potential, efforts are increasingly focused on replacing or avoiding HFC-227ea where feasible.

Alternatives, including FK-5-1-12 and 2-BTP (3,3,3-trifluoro-2-bromopropene) are available in a range of fire suppression applications, including total flooding systems for critical infrastructure such as data centres, archives and industrial facilities, as well as aviation-related fire protection systems under development or transition; in many non-aviation applications, however, lower-GWP options such as FK-5-1-12, inert gas systems and water-based solutions are already available and increasingly deployed. Progress has been observed in specific segments, notably the near-complete transition from halon 1211 to 2-BTP in portable extinguishers in civil aviation, alongside increasing deployment of inert gas and water-based systems in fixed installations such as server rooms and industrial applications.

However, for some key applications, the absence of fully viable alternatives, combined with long equipment lifetimes, has led to continued reliance on existing technologies. Ongoing discussions, including with the International Civil Aviation Organisation, about extending halon use in aviation, along with proposals for long-term supply arrangements, highlight the importance of ensuring safety while continuing to explore viable alternatives.

Per- and polyfluoroalkyl substances (PFAS)

Evolving PFAS related regulations are beginning to influence decision-making in the phase-out and phase-down of controlled substances, and the development and deployment of their alternatives. In fire suppression, for example, concerns that leading alternatives may be classified as PFAS, or be subject to future PFAS restrictions, have delayed their deployment and contributed to renewed reliance on halons. In other sectors such as foams and aerosols, similar uncertainty is influencing investment choices for the use of fluorinated gases as alternatives. Continued regulatory and technology developments would need careful consideration and management for sustained progress to protect the ozone layer and climate, while at the same time ensuring that the health, safety and functioning of society are not compromised.

4 The Kigali Amendment: Future outlook

The Kigali Amendment's first ten years have laid solid foundations for the future. Parties have already reduced the production and consumption of HFCs ahead of their first phase-down targets, and there seems every reason to expect this progress to continue. Nevertheless, as the previous section has discussed, challenges remain which will require coordinated action in response.

The principal driver of future HFC demand is the rapid growth in demand for cooling. Global cooling capacity is projected to more than triple between 2022 and 2050 as rising incomes, urbanisation, higher temperatures and population growth increase demand for refrigeration and air conditioning. Without additional action, cooling-related emissions could almost double by mid-century despite the Kigali phase-down.

One of the key elements behind the success of the Montreal Protocol is its ability to respond to changing circumstances. Several studies suggest that faster transitions are possible in major HFC-using sectors such as room air conditioning. Analyses for both China and India, for example, found that accelerating refrigerant transitions could significantly reduce HFC demand beyond Kigali requirements.[9] It is notable that, as seen in Section 2, parties are already reducing their production and consumption ahead of the limits set in the Kigali Amendment, and most approved KIPs have shown that Article 5 parties have been able to progress at a rate faster than the mandated phase-down schedule. The high ambition demonstrated by parties strongly suggests that the Kigali Amendment is set to achieve even more ozone and climate benefits.

The biggest challenge is increasingly not the replacement of HFCs but the demand for cooling itself, and the energy it uses. Section 3 discussed the wide range of measures that can be adopted alongside the replacement of HFCs – stronger MEPS, building codes promoting passive cooling, National Cooling Action Plans, better integration of Kigali implementation with climate and energy policies, and so on. The emergence of the Global Cooling Pledge at COP28 in 2023 – which set out the aims of reducing cooling-related emissions by 68 per cent by 2050, significantly increasing access to sustainable cooling by 2030, and increasing the global average efficiency of new air conditioners by 50 per cent – is a strong signal that cooling is emerging as a major climate opportunity.

Another major future opportunity lies in combining Kigali implementation with energy-efficiency improvements. As discussed above, in many air-conditioning systems, electricity consumption over the equipment's lifetime creates more greenhouse gas emissions than refrigerant losses. When combined with improvements in the energy efficiency of cooling equipment, the climate benefit of the Kigali Amendment could increase significantly. This outcome can be reinforced by the decarbonisation of electricity grids, providing a potential pathway, alongside the other cooling strategies mentioned above, to near-zero GHG emissions from cooling by mid-century.

The final opportunity – and challenge – lies in LRM. As phase-down schedules are increasingly implemented, banks of refrigerants contained in equipment, buildings and stockpiles will become proportionally more important as a source of emissions. Comprehensive management strategies will therefore be essential, including recovery, reuse, reclamation or regeneration where technically feasible, and destruction where no further circular use is possible. This creates an important circular-

[9] See, for example, Alex Hillbrand et al, 'Scenarios for future Indian HFC demand compared to the Kigali Amendment' 2022 *Environ. Res. Lett*. z17 074019; Nikit Abhyankar et al, 'Accelerating room air conditioner efficiency in India: Grid, economic and policy implications through 2035', *The Electricity Journal*, Vol. 38, Issue 3, 2025; Pengnan Jiang et al, 'Cooling China without warming the planet: climate and co-benefits of HFC phase-down', *npj Clim Atmos Sci* 9, 18 (2026).

economy opportunity: recovered refrigerants can help meet residual servicing needs while reducing demand for virgin production and avoiding unnecessary emissions. Often these strategies can be highly cost-effective in terms of reducing GHG emissions, more so than many other climate mitigation options – reinforcing the need for greater coherence between Montreal Protocol and climate strategies.

The Montreal Protocol is widely recognised as one of the most effective environmental treaties in existence – indeed, as former UN Secretary-General Kofi Annan observed, ‘perhaps the single most successful international agreement to date’. Throughout its lifetime it has continued to evolve and to rise successfully to new challenges. The Kigali Amendment, the latest stage in that evolution, demonstrates that with political will and determination, the global community can continue to meet the challenges and realise the opportunities of the future.

Annex: case studies

This annex includes concise summaries of a number of case studies of activities undertaken in response to the Kigali Amendment.

This is a preliminary selection only, designed to indicate the format for inclusion. It is our intention to publish longer summaries of a wider range of case studies in the revised version of this briefing note, which will be available at the Thirty-Eighth Meeting of the Parties in Kigali.

Note to readers: Parties and other stakeholders are welcome to submit suitable case studies for inclusion here and or in a separate webpage (under development); please send your suggestions to the Ozone Secretariat at mea-ozoninfo@un.org by 4 September 2026.

HFC phasedown	
Description	• GIZ project 'Cool contributions fighting Climate Change' funded by BMUKN and International Climate Initiative (IKI) to support countries in climate-friendly cooling • Implemented in Costa Rica, Grenada, Philippines, Vietnam, Nigeria, and Liberia • Focus on reducing emissions from the RAC (Refrigeration and Air Conditioning) sector
Achievements	• National RAC GHG inventories, Cooling Action Plans, and MRV systems developed/updated • Cooling integrated into Nationally Determined Contributions (NDCs) • Installed 140+ R-290 AC systems in pilot buildings • Trained 210+ technicians and instructors, including promoting women in the sector • Created global tools: NDC Helpdesk & Green Cooling Finance Platform • Introduced innovative financing and procurement mechanisms
Benefits	• Improved emissions tracking and transparency • Scaled adoption of low-GWP, energy-efficient cooling technologies • Strengthened technical capacity and workforce skills • Increased access to climate finance solutions • Reduced long-term costs and environmental impact of cooling systems
Next steps	• The project operated from 2016-2021 and build the foundation to equip countries with the tools, capacities, methods, and case studies to take action. The next intention was to scale what works.
Source	• 250808_C4-ClosingDocument_final.pdf
Energy efficiency	
Description	• Funded by the International Climate Initiative (IKI), implemented by GIZ Proklima under the Cooling Programme for Southern Africa (CooPSA), and carried out in collaboration with the Ministry of Energy of Eswatini • 3-day technical workshop (Feb 2026) focused on operationalising Minimum Energy Performance Standards (MEPS) for air conditioners in Eswatini including standards, registration, data systems, border control, inspections and penalties
Achievements	• Defined roles, timelines, and regulatory improvements. • Designed systems for product registration, databases, and border checks.

	• Agreed on institutional implementation plans
Benefits	• Stronger coordination and enforcement readiness. • Prevents inefficient/non-compliant imports. • Supports energy savings, climate goals, consumer protection
Next steps	• Finalise MEPS regulations • Implement systems (registration, inspections, penalties)
Source	• From Policy to Practice: Operationalising MEPS for Air Conditioners in Eswatini - GIZ Proklima
Lifecycle refrigerant management	
Description	• Implemented by GIZ project 'Proklima' and by UTO Colombia and funded by IKI (BMUKN) • Project installing refrigerator degassing equipment in Colombia (2019) • Supports safe recovery of refrigerants and oils from old appliances
Achievements	• Installed 2 degassing machines (first of their kind in Colombia) • Equipped 2 waste management plants • Trained 10+ operators through 2 training sessions (3 days each)
Benefits	• Safer refrigerant recovery • Reduced emissions from old appliances • Stronger waste management capacity
Next steps	• Scale up technical solutions and infrastructure • Expand capacity building and training programs • Strengthen policy frameworks and national strategies • Support international cooperation under the Montreal Protocol
Source	• Recovering refrigerants properly - GIZ Proklima
Sustainable cooling	
Description	• GIZ project 'ROCA' funded by EU and BMZ aims to promote Green Cooling in West and Central Africa • Combines natural refrigerants, energy efficiency, and sustainable cooling applications and covers sectors like buildings, food systems, and healthcare
Achievements	• 350+ AC units replaced with R290 in 4 countries (Burkina Faso, Cameroon, Mali, Senegal) • 1 national energy strategy developed (Cameroon) • Pilot projects in 2 sectors: food, healthcare • RAC inventories & policy support delivered in multiple countries • Training programs for technicians • Regional finance workshops conducted • Climate-friendly systems installed in public facilities
Benefits	• Reduced use of ozone- and climate-damaging cooling systems • Improved energy efficiency and lower operating costs • Strengthened food security and medical cold chains • Enhanced skills development and local workforce capacity • Increased resilience through sustainable and reliable cooling access

Next steps	• The project operated from 2021-2025 and advised for further regional cooperation and financing models to replicate and scale pilot projects across more sectors
Source	• Ozone and Climate Friendly Cooling in West and Central Africa (ROCA) - GIZ Proklima • National energy efficiency strategy for domestic and industrial air conditioning and refrigeration in Cameroon - GIZ Proklima • Preserving Meat and Climate in Ouagadougou, Burkina Faso - GIZ Proklima
Cross-cutting	
Description	• Global study under GIZ Proklima (C4 programme), funded by BMUKN, on advancing green public procurement (GPP) for cooling appliances. Identifies barriers, enablers, and practical implementation pathways for GPP based on multi-country surveys and case studies
Achievements	• Developed a global framework of barriers and enablers for green public procurement • Documented successful country applications, especially: • India: large-scale bulk procurement of efficient ACs reducing prices and expanding supply • Costa Rica: institutionalised GPP through legal frameworks and enforcement mechanisms
Benefits	• Shows that GPP can lower lifecycle costs despite higher upfront investment.
Next steps	• The project operated from 2016-2021 and build the foundation to equip countries with the tools, capacities, methods, and case studies to take action. The next intention was to scale what works.
Source	• GIZ_Proklima_Green_Cooling_in_Public_Procurement_final.pdf

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Multilateral Fund secretariat

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