Annexes

Annex 1 Technologies primer

Table A-1: Summary of space cooling technologies

Technology type	Application	Capacity range	Market size	Current trends
Window air conditioners – small air-conditioning units that fit into a standard window frame or wall opening. **Packaged terminal air conditioners (PACs)** – larger-capacity units typically used in hotels and installed under a window. **Package portable** – units that can be easily moved from one location to another inside a building using a flexible hose to provide heat rejection to the outdoors. **Through-the-wall air conditioners** – units that are typically installed through wall openings.	Small rooms in residential and commercial building using factory built sealed systems.	1 to 10 kW with an average size of 2.7 kW	Globally, around 17 million small self-contained air conditioners are produced annually (JRAIA 2022), split roughly equally between developing and developed countries. With a service life of over 10 years, more than an estimated 200 million units remain in operation globally.	In Europe, a shift to low-GWP propane (HC-290) in PACs was accelerated by the European F-gas regulation.
Non-ducted single-split – small-capacity units made of an outdoor unit and an indoor unit connected by refrigerant lines; they have design flexibility and can reduce distribution losses, increase energy efficiency and improve comfort.	Single rooms in residential and commercial buildings.	2 to 30 kW with an average size of 3.8 kW	The global market is around 80 million units per year (JRAIA 2022), with around 20 per cent going to developed countries and 80 per cent to developing countries. An estimated 1 billion units are installed globally.	Typically employ hermetic rotary compressors. Variable-speed compressor technology has around 50 per cent of the market share for smaller systems and 10 to 20 per cent for larger systems.
Ducted residential split – an outdoor unit and an indoor unit connected by refrigerant lines that deliver cooling through a ducted air system, providing cooling for an entire residential building controlled by a single thermostat.	Multiple rooms served with a ducted air system controlled by a single thermostat in residential and small commercial buildings.	4 to 17.5 kW with an average size of 10 kW	Current annual output is around 5 million units (JRAIA 2022), with around one-third in developing countries and two-thirds in developed countries. An estimated 70 million units are installed globally.	Typically employ hermetic scroll compressors. Reversible air conditioners are gaining market acceptance. Reversible systems are standard in Europe.

Table A-1: Summary of space cooling technologies (continued)

Technology type	Application	Capacity range	Market size	Current trends
Ducted commercial split – an outdoor unit and an indoor unit that are connected by refrigerant lines, providing cooling for a commercial building through a system of ducts where temperature in each zone can be controlled separately.	Multiple rooms served with a ducted air system in commercial and institutional buildings.	10 to 1,000 kW	Current annual output is around 12 million units (JRAIA 2022), with around a third in developing countries and two-thirds in developed countries. An estimated 80 million units are installed globally.	Can provide a large degree of customization, including different fractions of ventilation (up to 100% fresh air).
Multi-split and variable refrigerant flow (VRF) – systems that use one outdoor unit and separate indoor evaporator units for each room. VRF systems can improve energy efficiency by delivering variable refrigerant quantity to each indoor unit based on the cooling load.	Large-capacity residential and commercial buildings. Offers a high degree of flexibility and control.	4 to 300 kW with an average size of 20 kW	Around 2 million systems (outdoor modules) are produced annually (JRAIA 2022), of which a quarter go to developed countries and three-quarters to developing countries. An estimated 10 million units are installed globally.	In some configurations, these systems can have independent cooling or heating functionality for each indoor unit, thus simultaneously heating and cooling separate indoor spaces. The outdoor unit modulates the total refrigerant flow using various compressor capacity control methodologies, with compressor types being variable speed rotary or scroll type.
Packaged – large-capacity systems that deliver comfort conditions through ducted air systems.	Large residential and commercial applications.	5 to 1,000 kW	The annual market is around 14 million units (JRAIA 2022), with around a third in developing countries and two-thirds in developed countries. An estimated 100 million units have been installed over the last eight years.	The current focus is on refrigerant conversion towards mildly flammable refrigerants and improved part-load performance.
Air-cooled chillers – units that produce chilled water while directly rejecting waste heat to the atmosphere, using one or more fans to cool the heat exchange coils.	Large buildings with chilled water systems providing cooling throughout a building or larger cooling network, as in the case of district cooling applications.	Up to 1,900 kW	Global chiller demand reached US$8.89 billion in 2021, up 9.9% over 2020 (JRAIA 2022). The largest market shares are in China (32.2%), Europe (19.8%) and the United States of America (14.6%). Airside equipment accounts for most sales, at US$7.75 billion.	Low-GWP refrigerant solutions are readily available for chiller applications and widely adopted in developed countries. Chillers are one of the potential solutions for smart cities and near-zero energy buildings.
Evaporative-cooled chillers – involve the use of a water spray to reject heat more efficiently.		Up to 700 kW		
Water-cooled chillers – units that reject condenser heat to water and typically use cooling towers to release this heat to the atmosphere.		Up to 21,000 kW		There is renewed interest in large-scale district cooling to utilize and recover heat from various sources when developing new cities, and thus increased interest in water-cooled chillers.

Table A-2: Summary of cold chain technologies

Technology type	Application	Capacity range	Market size	Current trends
Residential refrigeration – refrigerators, freezers and combined refrigerator-freezers. These units are factory built and sealed systems.	Mainly provides refrigeration for food and drink in residential settings; may have some minor use for commercial and medical applications in developing countries.	0.1 to 0.5 kW	The residential market is around 215 million units annually (Statista 2023). The estimated total global stock is 1.35 billion units (IEA 2022).	This market has primarily transitioned towards low-GWP HC-600a refrigerant. Recent developments in energy efficiency focus on load reduction through cabinet design optimization, refrigeration circuit design and use of higher-efficiency variable speed compressors.
Self-contained commercial refrigeration – units that are built and sealed in the factories.	Used primarily for retail, display or storage of chilled or frozen food and drinks.	0.5 to 3 kW	Globally, the self-contained commercial refrigeration stock was an estimated 120 million units in 2019 (IIR 2019).	This market is shifting towards low-GWP highly flammable HC-290 and other mildly flammable refrigerant options. Use of flammable refrigerants is expected to grow as safety standards are updated. Efforts for higher energy efficiency are focused on load reduction, advanced controls and use of variable speed compressors.
Condensing units – split units made of a display or storage unit containing the evaporator, which is connected to a condensing unit located outdoors or in a plant room.	Used for retail or storage of chilled or frozen food and drink in small stores.	3 to 20 kW	Not available	Low-GWP replacements for HCFC-22 and R-404A include high-pressure R-744, hydrocarbons (HCs) and lower-flammability HFC/HFO blends. Use of flammable refrigerants is expected to grow as safety standards are updated. HC-290 and R-744 are increasing in use, particularly in Europe and Asia.
Centralized systems – split units made of many display or storage units containing the evaporators, which are connected to a compressor rack and condenser through a system of site-installed pipework.	Used for retail or storage of chilled or frozen food and drink in large commercial/retail applications.	Small: 15 to 40 kW	Not available	The replacement of R-404A with non-flammable and lower-GWP alternatives is under way, leading to technical options such as R-744 at all temperature levels or low-GWP HFC/HFO blends at medium temperature. Low-GWP and mildly flammable HFC/HFO blends are increasing in use, mainly in Europe and the United States of America. This shift to flammable lower-GWP alternatives is promoting innovations in system architecture, charge reduction strategies, variable speed technology, and better control, leak detection and isolation valves. An integrated approach to system design should consider the presence of other equipment, such as space heating, air conditioning, dehumidifying and water heating, to minimize refrigerant usage, reduce leaks and improve the life-cycle climate performance of food retail and food service refrigeration systems.

New and emerging technologies for cooling

The cooling sector is facing new technological challenges and opportunities. The industry must increasingly focus on energy efficiency while also addressing challenges related to resilience, global warming, dispatchability and control, and a higher rate of electrification. New cooling technologies need to support populations and industries to adapt to extreme weather events (such as heat waves), a high heat index, drought and food insecurity. They also need to be aligned with the Kigali Amendment to the Montreal Protocol, which mandates a phase down of high-GWP refrigerants.

With the increasing penetration of renewable energy in the power grid, cooling loads need to be flexible and responsive to balance electricity supply and demand. This includes smart cooling technologies that leverage the Internet of Things to optimize energy use, reduce peak demand, integrate with other devices and services, and provide ancillary benefits such as grid stability and storage. In addition, as heat pumps emerge as a viable solution for decarbonizing heating end-uses by replacing fossil fuels, they often can be used in a reverse mode to provide cooling.

The cooling industry has continued to research and develop emerging technologies for cooling to improve system performance and reduce costs. Variable-speed cooling equipment is now widely available and is dominant in some sectors in mature markets for space cooling, such as Australia, Europe, Japan and the United States of America. Due to the parallel shift towards seasonal energy efficiency metrics for space cooling – such as the Seasonal Energy Efficiency Ratio (SEER) and the Annual Performance Factor (APF) – the industry has shifted its focus to maximizing seasonal (versus peak) efficiency to yield further energy savings.

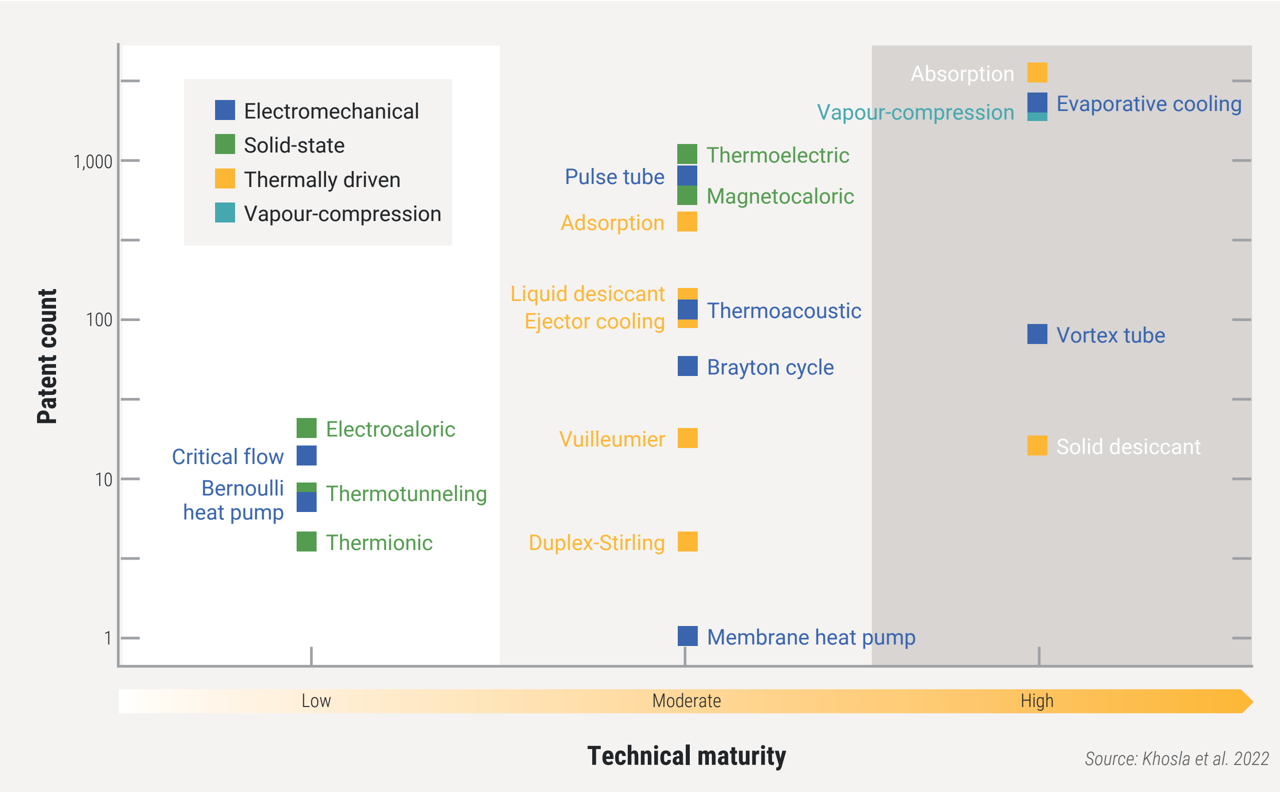
As of 2021, roughly 89 per cent of the room air-conditioner market in China had shifted to variable-speed air conditioners (Japan Refrigeration and Air Conditioning Industry Association [JRAIA] 2022). Developments in cooling technology have occurred for all key technology components, and advancements in systemic performance have been made through better controls and smart features (such as occupancy sensors). Notable advances include recent developments in heat exchanger design and optimization, and the emergence of small-diameter heat exchangers. These designs can reduce refrigerant charge and achieve higher performance.

There are also alternative emerging technologies that do not employ a vapour compression cycle* (also known as "not-in-kind" technology). These disruptive innovations may achieve higher levels of energy efficiencies. Some of the not-in-kind cooling technologies are seen as promising alternatives to the mature vapour compression cooling technology. A review of not-in-kind cooling technologies shows that many of them are not ready for widespread use and have slow technical progress: energy efficiency and cost are considered to be the main challenges.

Major technical improvements are needed to increase the market share of not-in-kind cooling technologies. A study based on patents identifies some promising emerging technologies for space cooling, such as absorption, evaporative, thermoelectric, magnetocaloric, and adsorption, as shown in Figure A-1. A supportive deployment-oriented policy is required to expand the installation of cooling technologies with moderate-to-high technological maturity, even while further research is needed to improve the performance of low-to-moderate maturity technologies.

* Vapour compression cycles are the most established technology used for cooling using a compressor, a condenser, an expansion valve, and an evaporator to extract heat from low temperature and reject it at higher temperature.

Figure A-1: Maturity level and patent number counts of not-in-kind cooling technologies



Note: The y-axis (patent family count) is in logarithmic scale. The technical maturity levels are based on qualitative evaluations of the technology. The clusters of cooling technologies are expected to follow a diagonal trend line; *i.e.* mature technologies will have higher patent family counts. There is an order of magnitude patent count threshold between technical maturity levels.

Annex 2 Modelling future scenarios for cooling

The modelling and analysis conducted for this report were aimed at producing quantifiable results to enable decisions on the most effective and rapid means of reducing GHG emissions from the cooling sector, towards the goal of achieving near-zero emissions from cooling by 2050.

GHG emissions from refrigeration and space cooling fall into two distinct categories:

- **Direct emissions:** released from refrigerants that leak from cooling equipment during operation or are emitted during equipment manufacturing, installation, servicing and end-of-life.

- **Indirect emissions:** released from the power generation required for operating the cooling equipment (electric power for most stationary equipment and engine power for most vehicles).

Modelling inputs

The modelling for this report covered stationary cooling applications (mainly powered by electricity) and transport cooling applications (mainly powered by gasoline and diesel engines, though the transition to electric vehicles is accelerating). The six market sectors modelled were:

- **Stationary cooling:** 1) residential space cooling, 2) non-residential space and process cooling, 3) residential cold chain, 4) non-residential cold chain; and

- **Transport cooling:** 5) mobile air conditioning, 6) refrigerated transport.

The modelling did not include space cooling provided by fans because they have no direct refrigerant emissions impact, although there is great potential to reduce their indirect (energy-related) emissions through increased efficiency, and fans are an important strategy to reduce the need for air conditioning (see chapter 4 on space cooling). The model also excluded the energy used to provide heating with heat pumps, as this was considered outside the scope of the cooling sector.

For each of the six cooling applications, historical and current estimates of the cooling equipment stock were made for each country and verified to the extent possible against published data. The equipment stock was modelled with a high degree of granularity, with 40 different types of cooling technology used to represent the diverse range of applications in the six sectors. Stock estimates were made at the country level using algorithms that account for several influencing factors, including population, gross domestic product (GDP), climate and access to electricity.

Based on the individual country data, 14 regional sub-models were developed, taking into consideration the status of each country as designated under the 1987 Montreal Protocol, which distinguishes between Article 5 parties (mainly developing countries) and Article 2 parties (more developed countries that contribute funding to the treaty's Multilateral Fund; also called non-Article 5 parties).

Under the Kigali Amendment to the Montreal Protocol, Article 5 parties and Article 2 parties have different baseline calculations, freeze dates and deadlines for phasing down the use of HFCs, which are refrigerants that have high global warming potential (UNEP Ozone Secretariat 2016). The model further categorized the Article 5 countries into two groups (Group 1 and Group 2) based on their HFC phase down schedules. In addition, specific analyses were performed for the G20 and the G7 country groups.

A list of the countries included in each of the 14 modelled regions are provided in Annex 7.

Modelling outputs

Data on relevant equipment stocks were used to estimate the annual consumption of refrigerants and energy, as well as the related direct and indirect GHG emissions. Key factors that influence future emission trajectories for cooling, as developed in the model, include:

- **Growth in the cooling equipment stock.** Much of this growth will occur in developing countries, driven by rising population and GDP and by the impacts of climate change. Providing access to cooling for populations at risk of extreme heat could add to the growth in the equipment stock in many countries (see section 2.1 and Annex 3 for modelling of growth).

- **Strategies to improve the efficiency of cooling.** Without improvements in energy efficiency, operating the growing stock of cooling equipment will require massive investments in electricity generation infrastructure and will lead to large increases in GHG emissions. Strategies to mitigate these impacts include: 1) reducing the growth in cooling loads (for example, through better building design); 2) maximizing the energy efficiency of new equipment; and 3) improving the operating efficiency of existing equipment through better control and maintenance (see section 2.2 and Annex 4 for modelling of energy efficiency scenarios).

- **Strategies to reduce emissions from refrigerants.** Most of the direct GHG emissions from cooling are related to the use of refrigerants that have high global warming potential (GWP), including hydrochlorofluorocarbons (HCFCs) and HFCs. Strategies to reduce direct emissions include: 1) using refrigerants with lower GWP in new equipment; 2) reducing refrigerant leakage rates during operation; 3) ensuring that refrigerants are recovered during servicing and at end-of-life; and 4) retrofitting existing equipment to replace high-GWP refrigerants with low-GWP alternatives (see section 2.3 and Annex 5 for modelling of refrigerant emission scenarios).

- **Transition to electric vehicles.** Most mobile air-conditioning and refrigerated transport applications today are operated using power from gasoline or diesel engines, which release emissions from the burning of fossil fuels. As these internal combustion engines are replaced with electric motors, the indirect emissions from transport applications will decline depending on the carbon intensity of the grid.

- **Decarbonization of the electricity supply.** Most stationary cooling equipment today is operated using electricity. As cars transition to battery-powered electric motors, most mobile cooling applications also will run on electricity by 2050. The speed of the transition from fossil-based to low- or zero-carbon electricity generation will greatly impact future GHG emissions from cooling.

Based on these factors, forecasts between 2023 and 2050 were made using independent modelling pathways for rates of:

- equipment stock growth
- implementation of passive measures to reduce cooling loads
- improvements to energy efficiency
- phase down of the use of high-GWP refrigerants
- transition to electric vehicles
- decarbonization of electricity generation

All output parameters were estimated for each of the 40 technologies in the model and aggregated to the six market sectors covered. The outputs are available for the whole Global Model, for Article 5 and Article 2 parties, for each of the 14 regional sub-models, and for the G20 and G7 country groups. Selected global and regional results are presented in the following sections. Further details on the Global Cooling Emissions Model can be found in Annex 7 and Gluckman Consulting (2023).

Annex 3 Global installed capacity of cooling equipment

Table A-3: Estimated global stock and cooling capacity in the modelled market sectors, 2022

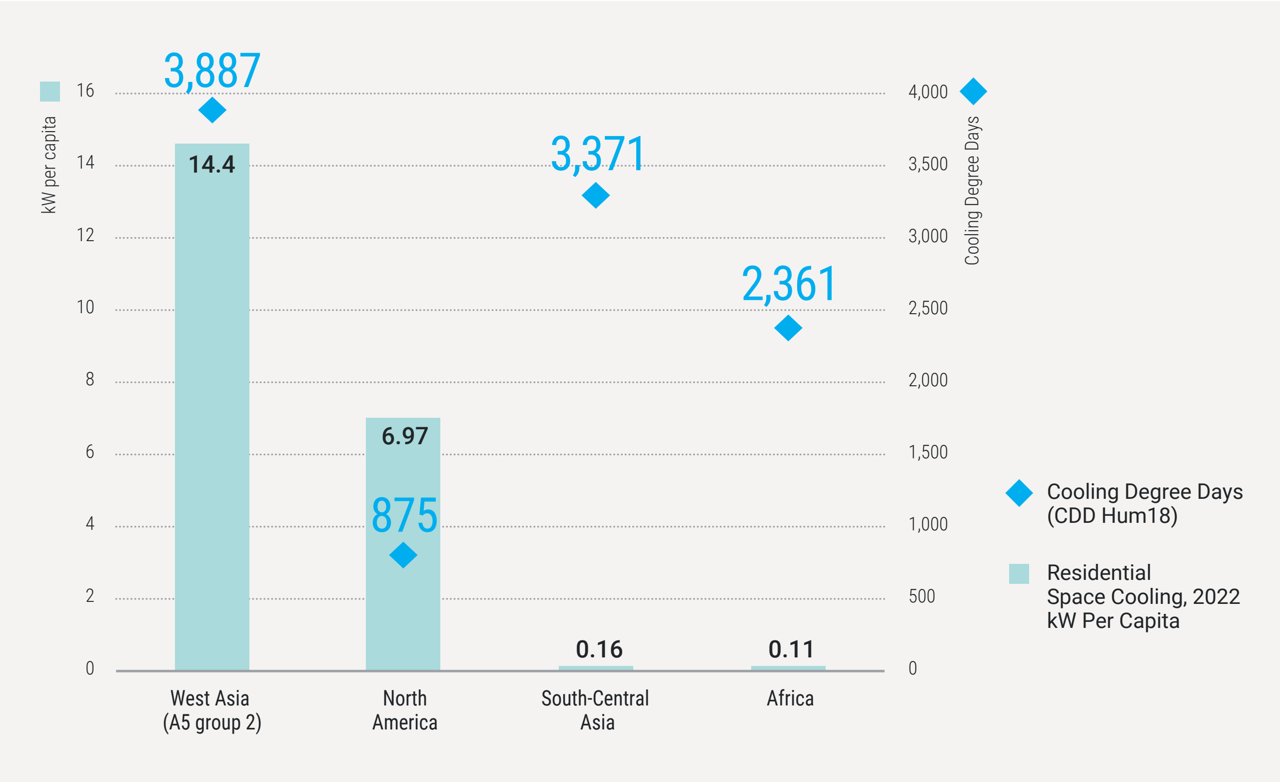
	Market	Installed cooling capacity (TW)	Number of equipment units (billions)	Average capacity (kW per equipment unit)
Stationary cooling	Residential space cooling	9.1	1.8	5.2
	Non-residential space cooling and process cooling	6.2	0.6	11.0
	Residential cold chain	0.4	2.1	0.2
	Non-residential cold chain	1.0	0.2	4.6
Transport cooling	Mobile air conditioning	5.8	1.2	4.7
	Refrigerated transport	0.03	0.007	5.0
Global total		**22.4**	**5.8**	**3.9**

Source: Global Cooling Emissions Model

On a regional basis, the current cooling capacity varies, affected by both GDP and climate. However, many of the world's hottest regions have low GDP per capita, contributing to significant global inequality in access to cooling. Figure A-2 shows the estimated residential space cooling capacity per capita in four of the modelled regions as of 2022. The number of cooling degree days (CDDs) – reflecting the typical cooling load required based on local weather conditions – for each region is shown on the right-hand axis, providing an indicator of the need for space cooling. The figure shows that a large share of households in North America have air conditioning, hence the high average of 7 kW of space cooling per capita.

In the West Asia region, which includes Saudi Arabia and five Persian Gulf countries, temperatures are extremely high (CDDs are 4.5 times higher than North America), and most households have air conditioning. However, in other extremely hot regions of the world – such as Africa and South Asia (including Bangladesh, India and Pakistan) where CDDs are three to four times higher than North America – access to space cooling is extremely limited, as few households can afford air conditioning.

Figure A-2: Residential space cooling capacity per capita and cooling need (in cooling degree days) in selected regions in 2022



Source: Global Cooling Emissions Model

Annex 4 Variables used to estimate annual energy consumption of cooling equipment

The Global Cooling Emissions Model estimates the annual energy consumption of cooling equipment considering several variables:

- **The growing stock and age profile of the equipment.** The Model considered the expected lifespan of each technology type, ranging from under 15 years (e.g. for small room air conditioners) to more than 30 years (e.g. for large industrial equipment).

- **The intrinsic efficiency of the equipment.** Efficiency levels are directly dependent on the temperature at which cooling is needed; for example, it takes more energy to supply 1 kW of cooling at -20°C for frozen food storage than to supply 1 kW at +4°C for chilled food. Efficiency is also directly dependent on the ambient temperature conditions into which heat is rejected. The Model considered these drivers using 40 technology types, each with a relevant cooling temperature, and by using appropriate climate data for each of the 14 regions.

- **The efficiency of new equipment bought.** While the intrinsic efficiency depends on the application, the actual efficiency of new equipment depends on many aspects of the design. Equipment on the market ranges widely in efficiency for the same application; for example, the energy efficiency of room air conditioners on the market varies by a factor of 5. The Model included estimates of 10 efficiency levels for each equipment type, ranging from "worst" (typical of equipment bought 20 years ago) to "best" (an efficiency higher than the best currently on the market). These efficiency levels vary by region due to different ambient temperature profiles. For each year, it was assumed that the equipment bought is a mix of efficiency levels and that this mix improves over time, driven by technology developments, such as the use of variable-speed drive compressors and by policy, such as minimum energy performance standards (MEPS).

- **Equipment use patterns.** A key parameter that affects annual energy consumption is the use pattern for each equipment type. For some refrigeration applications, such as residential refrigerators and large cold stores, the use pattern is simple: the equipment is required to operate 24 hours a day, 365 days per year. However, for air-conditioning applications, the use patterns are highly variable, driven by climate and by end-user preference.

- **Efficiency of operation.** For any given temperature conditions, the design efficiency of a piece of cooling equipment sets an upper efficiency limit. However, it is easy to operate at lower efficiencies through 1) poor operation and control, and 2) poor installation and maintenance.

Annex 5 The transition to low-GWP refrigerants

Consumption of the high-GWP refrigerants shown in Table A-4 is controlled under the Montreal Protocol. HCFC-22, as an ozone-depleting substance, is being phased out globally. Developed countries have already completely phased out HCFCs, and developing countries will have completed their HCFC phase out by 2030. For HFCs, the phase down is controlled under the Kigali Amendment, and as of October 2023, 154 countries (presenting 86 per cent of the global population) had either ratified, accepted or approved the Kigali Amendment (UNEP Ozone Secretariat 2023a) and had started the process of planning their HFC phase down. It is expected that all countries will ratify the Kigali Amendment within the next few years.

Market status

Table A-5 summarizes the market status of low-GWP refrigerants by end use. The most mature markets for these alternatives are residential cold chains and mobile air conditioning, followed by food retail and food service refrigeration. The focus of the industry transition is on air-to-air air conditioners and heat pumps, with different refrigerant options being pursued in different markets, including R-32, HC-290 and low-GWP HFC and HFO refrigerant blends such as R-454B, R-452B, R-463A and others.

Table A-4: Global warming potentials of common refrigerants and alternatives.

	Refrigerant	GWP*	Example applications
Widely used high-GWP refrigerants	R-404A	3922	Non-residential cold chain refrigeration
	R-410A	2088	Residential and commercial room air conditioners
	HCFC-22	1810	Room air conditioners; non-residential cold chain refrigeration
	HFC-134a	1430	Residential refrigerators; chillers
Low-GWP alternatives	R-32	675	Alternatives to R-410A in room air conditioners
	R-454B	466	
	R-454C / R-455A	148	Alternatives to R-404A
	HFO-1234ze	7	Alternative to HFC-134a in chillers
	HFO-1234yf	4	Alternative to HFC-134a in mobile air conditioning
	HC-290 (propane)	3	Alternative to R-404A in stand-alone refrigeration Alternative to R-410A in small room air conditioners
	HC-600a (isobutane)	3	Alternative to HFC-134a in residential refrigerators
	R-744 (CO_2)	1	Alternative to R-404A in commercial and industrial refrigeration
	R-717 (ammonia)	0	Alternative to R-404A and HCFC-22 in industrial refrigeration

** 100-year GWP, based on UNFCCC 2007.*

Table A-5: Market status of low-GWP alternatives by end use

End use	Low-GWP alternatives
Food retail and food service refrigeration	The most common ultralow- and low-GWP refrigerants being applied in new systems are R-744, HC-290, and HFO blends such as R-454C, R-454A and R-455A. Existing high-GWP R-404A and HFC-134a systems are being proactively converted to medium-GWP A1 refrigerants (e.g. HFO blends such as R-448A, R-449A, R-450A, and R-513A).
Transport refrigeration	Most trucks and trailers still use R-404A, but new equipment in Europe and North America uses R-452A with a significant reduction in GWP. Light commercial vehicles mainly use HFC-134a, while some have begun to use HFO-1234yf. Most marine container refrigeration units still use HFC-134a; however, R-513A is an attractive alternative medium-GWP refrigerant. Air conditioning in cruise liners, which has used HFC-134a, is being replaced by HFC-1234ze(E). R-717 is returning in fishing vessels. Future systems may be based on HC-290, R-744, A2L or A1 refrigerant blends.
Air-to-air air conditioners and heat pumps	Alternatives gaining market share include medium-GWP refrigerant HFC-32 and blends such as R-454B, R-452B and R-463A. HC-290 is being used for some single-split and portable air-conditioning units in China, South-East Asia, Europe and Latin America. Larger, more complex and distributed systems pose the greatest challenges to adoption of more flammable medium- and low-GWP alternatives, although larger ducted and variable refrigerant flow (VRF) systems with medium-GWP alternatives are becoming available.
Chillers	A complete range of new chillers that use ultra-low-GWP refrigerants, such as HFO-1233zd and HFO-1234ze(E), is available in all major markets. These chillers maintain or improve full and part load performance. However, products using high-GWP refrigerants have not yet been discontinued and remained dominant in most markets except Europe as of 2022. Regulations being adopted in other regions will accelerate the shift. Non-fluorinated refrigerants R-717 and HC-290 are often used.
Mobile air conditioning and heat pumps	HFO-1234yf is the main replacement for HFC-134a in markets that require or reward use of refrigerants with GWP<150 in vehicles, including Europe, North America and Japan. Some R-744 systems were commercialized in limited numbers. Both fluorinated and non-fluorinated refrigerant alternatives are under evaluation for heat pump applications for electric vehicles.
Industrial refrigeration and heat pumps	Industrial refrigeration and heat pumps traditionally use R-717, but R-744 is also increasingly being used. An emerging trend is to use hydrocarbon (HC) and HC mixtures, especially for low-temperature applications. Additional standards-making activity is expected to facilitate wider adoption of ultra-low GWP alternatives, such as the safety standard for closed-circuit R-744 refrigeration systems published recently by the International Institute of Ammonia Refrigeration (IIAR) and the American National Standards Institute (ANSI) (IIAR 2023).
Hot water heat pumps	Newly installed water heating heat pumps use high-GWP R-410A, HFC-134a and R-407C, medium-GWP R-32 and low-GWP R-454C, HC-290, HC-600a, R-744 and R-717. Most new equipment uses R-410A and R-32. In some Article 5 Parties, HCFC-22 is still being used.

Source: IIR 2022b.

Two sectors globally that are fast transitioning to ultra-low-GWP alternatives are domestic refrigeration (HC-600a) and mobile air conditioning (HFO-1234yf). In the supermarket and industrial refrigeration sectors, the number of R-744 (CO_2) installations as of December 2022 totalled 57,000 in Europe, 6,960 in Japan, 1,150 in the United States of America and 745 in Canada (ATMOsphere 2022). Additional public pilots exist for supermarkets in Europe, Japan, the United States, and Canada (using R-744) and in Kenya (using R-717) (SuperSmart 2016; IIR 2020; R744 2020; R744 2021a; R744 2022).

Solutions are being further engineered to achieve high systems performance of R-744 under various ambient temperature conditions. Ongoing research and development projects include the Norwegian-funded COOLFISH to develop energy-efficient and climate-friendly cooling, freezing and heating on Norwegian fishing vessels, and INDEE+ to demonstrate R-744 refrigeration technology in India for high energy-demanding sectors (supermarkets, hotels and fish processing) coping with high ambient temperatures.

Annex 6 GHG emissions from global cooling equipment

In 2022, the GHG emissions from global cooling equipment totalled an estimated 4.1 billion tons of CO_2e (Table A-6). Of these emissions, the majority (64 per cent) were indirect (energy-related) and 36 per cent were direct (from refrigerant emissions). The direct emissions include HCFC emissions as well as HFC emissions, as significant use of HCFCs still occurs in developing countries.

The balance between direct and indirect emissions varies among the six modelled market sectors, based on the differing technology characteristics. For example, refrigerators used in the residential cold chain have low leakage and use low-GWP refrigerants, but they have long annual operating hours, so indirect emissions are 95 per cent of the total. In non-residential cold chain equipment, which have more leakages and use high-GWP refrigerants, indirect emissions are only 57 per cent of the total. The share of indirect emissions in stationary cooling applications has fallen in recent years due to grid decarbonization that has already occurred in some regions.

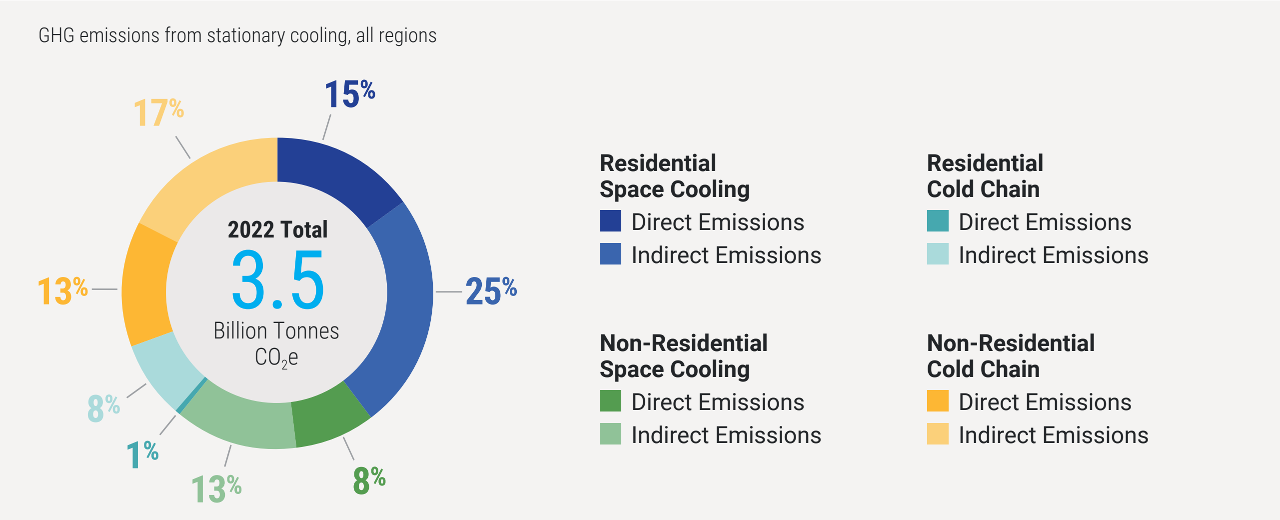
The breakdown of total emissions for stationary cooling applications among the four main stationary cooling markets is shown in Figure A-3, including the split between direct and indirect emissions in each market. In 2022, space cooling represented 61 per cent of emissions. As noted earlier, the cold chain's proportion of global cooling capacity is modest (around 6 per cent), but its electricity consumption and GHG emissions are significant, as this equipment is ubiquitous and operates for long duration. The stationary cold chain sectors represent 39 per cent of GHG emissions from stationary cooling applications.

Table A-6: GHG emissions from global cooling equipment (billion tons of CO_2e), 2022

	Market sector	Indirect emissions	Direct emissions	Total emissions	Indirect as share of total	Share of global total
Stationary cooling	Residential space cooling	0.86	0.52	1.38	62%	34%
	Non-residential space and process cooling	0.45	0.28	0.74	61%	18%
	Residential cold chain	0.28	0.02	0.30	95%	7%
	Non-residential cold chain	0.60	0.45	1.05	57%	26%
Transport cooling	Mobile air conditioning	0.39	0.18	0.57	68%	14%
	Transport refrigeration	0.034	0.015	0.050	69%	1%
Global total (billion tons of CO_2e)		**2.6**	**1.5**	**4.1**	**64%**	**100%**

Source: Global Cooling Emissions Model.

Figure A-3: Global GHG emissions from stationary cooling, by main market, 2022



Source: Global Cooling Emissions Model

On a per capita basis, global GHG emissions from cooling equipment totalled 0.51 tons of CO_2e in 2022. Emission levels vary widely across the 14 modelled regions, driven by the lower levels of cooling equipment in developing countries. The highest per capita emissions from cooling in 2022 were in West Asia (4.5 tons of CO_2e), and the lowest were in Africa (0.08 tons of CO_2e).

Annex 7 Global Cooling Emissions Model

The modelling carried out for this project, as described in chapter 2 and Annex 2, is based on the Global Cooling Emissions Model. This model was developed using the modelling software HFC Outlook.

Overview of Modelling

The HFC Outlook Model has the capability to estimate both direct and indirect GHG emissions from refrigeration, air-conditioning and heat pump (RACHP) equipment and direct emissions from other hydrofluorocarbons (HFC) applications. The software incorporates a Stock Model, Refrigerants Model and an Energy Model. Key aspects of the model are:

1. The analysis uses a “bottom-up stock model” of RACHP and other relevant markets, providing historic modelling from 1990 to 2022 and forecasts to 2050. The model uses a “cohorts” methodology to track individual equipment items on an annual basis through their life cycle.

2. The **Stock Model** is a core part of the modelling platform, representing the growing stock of RACHP equipment. The Stock Model has a high degree of granularity, with 40 different RACHP technology types used to represent the diverse range of RACHP applications in the residential, commercial, industrial and transport sectors. Each of the 40 technology types is represented by a nominal system with a specified cooling or heating capacity and an expected life. Stock Model outputs include annual estimates of number of equipment items in use, the number of new items entering the market and the number of items reaching end-of-life. A set of **Economic Growth Scenarios** is used to represent uncertainties in the forecast rates of growth.

3. The 40 technology types used in the stock model are mapped into the six main market sectors used in this study. Four sectors are for stationary applications: residential space cooling, non-residential space cooling and process cooling, residential cold chain and non-residential cold chain. Two sectors are for transport applications: mobile air conditioning and refrigerated transport.

4. The **Refrigerants Model** provides outputs that include information on annual refrigerant consumption and refrigerant banks as well as estimated direct GHG emissions. All types of refrigerants are represented in the Refrigerants Model (CFCs, HCFCs, HFCs, HFOs and natural refrigerants). Future estimates of use and emissions of HFCs are based on a set of **HFC Mitigation Scenarios** that represent different measures that can be taken to reduce HFC emissions.

5. The **Energy Model** provides outputs that include information on amount of cooling delivered and annual energy consumption as well as estimated indirect GHG emissions. Future energy consumption estimates are based on a set of **Energy Efficiency Scenarios** that represent different combinations of measures that can be taken to reduce energy use. To estimate indirect GHG emissions the Energy Model uses a set of **Grid Decarbonization Scenarios** to represent different rates at which electricity generation is being decarbonized.

6. The HFC Outlook modelling platform can be used for an individual country or region, with stock data based on market research in that country and the future scenarios customized to the circumstances of that country.

7. The modelling platform has also been used to create Regional Models and a Global Model to provide a broader picture of GHG emission pathways for the RACHP sector. In these large-scale models, stock data are estimated using algorithms based on key macroeconomic parameters such as population, GDP and climate.

In this Annex some details about modelling assumptions used in the Global Cooling Emissions Model are provided. Further details can be found in Gluckman Consulting (2023).

Regional structure of the model

The Global Cooling Emissions Model is based on 14 regional sub-models. The regions were defined taking into account the Kigali Amendment group that each country belongs to.

Table A-7 lists the countries in each of the 14 regions modelled. Article 2, Article 5 (Group 1) and Article 5 (Group 2) countries have different HFC phase down schedules and are modelled in separate regions.

The Global Stock Model

For the Global Stock Model, equipment stock is estimated at country level and then aggregated into the 14 regional sub-models. Stock is estimated using algorithms based on population, GDP, climate and various other parameters such as the number of households, access to electricity and number of vehicles. Table A-8 shows the assumptions used for population and GDP, aggregated for Article 2 and Article 5 regions, as well as the global total. Table A.9 shows the evolution of stock in each main market sector, given in kW per capita, aggregated for Article 2 and Article 5 regions.

A "cohort methodology" is used to analyse the equipment stock on an annual basis, with the characteristics allocated to new equipment items used throughout the life of each item of equipment. Each technology type is characterized by a nominal size (in terms of kW cooling capacity) and an expected life. Retirement of old equipment is estimated using a uniform distribution between two-thirds and four-thirds of expected life. The number of new items is calculated based on replacement of retiring equipment plus new growth. When a new cohort of equipment enters the market, it is allocated these primary characteristics together with various important secondary characteristics such as refrigerant type, leakage rate and energy efficiency.

The Energy Model

For each piece of equipment in the stock model, the Energy Model provides estimates related to: 1) the amount of cooling delivered; 2) the amount of energy used to provide that cooling; and 3) the CO_2 emissions associated with the energy use.

Cooling delivered

The cooling delivered by each item of equipment is dependent on the application, the equipment size and the operating pattern. For cold storage applications (e.g. residential refrigerators, large cold stores, food retail displays), the equipment is operating 24 hours per day, 365 days per year. For space cooling applications, the operating pattern is much more complex, dependent on both climate and end-user preference. Most space cooling equipment spends significant periods of time working under part-load conditions and is often switched off for lengthy periods of time, for example when a building is not occupied.

Algorithms have been developed for each of the 40 technology types in the model to estimate annual operating hours and thus to estimate the annual amount of cooling delivered (in kWh).

Table A-7: Countries included in each of the 14 regions in the Global Cooling Emissions Model

Region	Kigali Amendment group	Countries
South America	Article 5, Group 1	Argentina, Plurinational State of Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
Central America and Caribbean	Article 5, Group 1	Antigua and Barbuda, Bahamas, Barbados, Belize, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago
North America	Article 2	Canada, United States of America
Africa	Article 5, Group 1	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, United Republic of Tanzania, Togo, Tunisia, Uganda, Western Sahara, Zambia, Zimbabwe
Europe	Article 5, Group 1	Albania, Armenia, Bosnia and Herzegovina, Georgia, Moldova, Montenegro, North Macedonia, Serbia, Türkiye
	Article 2	Andorra, Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Palestinian National Authority, Poland, Portugal, Romania, San Marino, Slovakia, Slovenia, Spain, Sweden, Switzerland, United Kingdom of Great Britain and Northern Ireland
Former Soviet Union	Article 2	Azerbaijan, Belarus, Kazakhstan, Russian Federation, Tajikistan, Ukraine, Uzbekistan
West Asia	Article 5, Group 1	Jordan, Lebanon, Syrian Arab Republic, Yemen
	Article 5, Group 2	Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates
South-Central Asia	Article 5	Afghanistan, Bangladesh, Bhutan, Kyrgyzstan, Maldives, Nepal, Sri Lanka, Turkmenistan
	Article 5, Group 2	India, Islamic Republic of Iran, Iraq, Pakistan
East Asia	Article 5, Group 1	China, Mongolia, Democratic People's Republic of Korea
South-East Asia and Pacific Islands	Article 5, Group 1	Brunei Darussalam, Cambodia, Cook Islands, Federated States of Micronesia, Fiji, Indonesia, Kiribati, Lao People's Democratic Republic, Malaysia, Marshall Islands, Myanmar, Nauru, Niue, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Timor-Leste, Tonga, Tuvalu, Vanuatu, Viet Nam
Asia Pacific	Article 2	Australia, Japan, New Zealand, Republic of Korea

Table A-8: Input assumptions for population and GDP

	Population (millions)			GDP per capita (PPP, constant 2017 Int. US$)		
	Article 2	Article 5	**Global Total**	Article 2	Article 5	**Global Total**
2000	1,299	4,838	**6,137**	33,732	5,262	**11,073**
2010	1,359	5,614	**6,973**	39,054	8,072	**13,914**
2020	1,417	6,411	**7,828**	42,259	10,693	**16,219**
2030	1,436	7,097	**8,533**	49,334	14,995	**20,577**
2040	1,443	7,731	**9,175**	55,939	19,448	**25,009**
2050	1,436	8,260	**9,696**	61,108	23,617	**29,022**

Note: PPP = purchasing power parity.

Table A-9: Input assumptions for cooling equipment stock

	Cooling capacity, kW per capita													
	Article 2 regions							Article 5 regions						
	Residential Space Cooling	Residential Cold Chain	Non-Residential Space Cooling	Non-Residential Cold Chain	Transport Space Cooling	Transport Cold Chain	**Total**	Residential Space Cooling	Residential Cold Chain	Non-Residential Space Cooling	Non-Residential Cold Chain	Transport Space Cooling	Transport Cold Chain	**Total**
2010	2.20	0.14	2.57	0.30	1.65	0.010	**6.87**	0.38	0.02	0.13	0.05	0.12	0.002	**0.70**
2020	2.71	0.15	2.90	0.34	2.32	0.012	**8.42**	0.71	0.03	0.27	0.07	0.31	0.002	**1.39**
2030	3.32	0.16	3.37	0.39	2.74	0.013	**9.99**	1.10	0.04	0.45	0.10	0.55	0.004	**2.25**
2040	4.04	0.16	3.88	0.44	3.04	0.015	**11.58**	1.70	0.05	0.67	0.14	0.83	0.005	**3.39**
2050	4.65	0.17	4.30	0.48	3.22	0.016	**12.83**	2.54	0.07	0.90	0.17	1.08	0.006	**4.77**

Energy efficiency of new equipment

For most of the 40 technologies modelled, the applications are stationary and the equipment is operated with electric motors. For the transport applications, the energy source is usually a gasoline or diesel engine, although a transition to electric battery-powered vehicles has begun and will have a significant impact on transport cooling energy sources by 2050.

Each item of equipment is given a "design efficiency" in the year it is installed. The design efficiency is calculated using a thermodynamic model, considering numerous factors that affect RACHP efficiency, including: 1) the temperature at which cooling is delivered (e.g. -20°C for frozen food, +4°C for chilled food, +21°C for space cooling); 2) the temperature differences in evaporator and condenser; 3) the Carnot Ratio (to account for the difference between an ideal Carnot cycle and a real cycle with various sources of efficiency loss); and 4) the method of part-load control (variable-speed compressors provide better part load performance than fixed speed). The design efficiency is affected by the climate in which the equipment operates, so the same equipment will have unique design efficiencies in each of the 14 regions in the Global Cooling Emissions Model.

For each technology and for each region, the thermodynamic modelling provides a "worst efficiency" (which represents the lowest efficiency equipment likely to have been sold 20 years ago) and a "best efficiency" (which represents the efficiency level that might be achievable by 2050). Table A-10 shows examples of worst and best efficiencies for various cooling applications.

Table A-10: Input assumptions for worst and best Annual Energy Efficiency Ratios, for four technologies

Sector	Technology	Application temperature (°C)	Worst AEER	Best AEER
Non-residential cold chain	Condensing units, chill	2	1.9	9.9
	Condensing units, frozen	-20	1.2	4.7
Residential space cooling	Split air conditioners	19	2.4	11.4
Non-residential space cooling	Water chillers	8	2.2	8.0

Note: Annual Energy Efficiency Ratio (AEER) provides an estimate of the annual energy efficiency, like the seasonal energy performance indicators

The model uses 10 levels of design efficiency, evenly distributed between the worst (Level 1) and best (Level 10) values.

In each year there is a mix of efficiency levels chosen for new equipment, and over time the efficiency mix improves, driven by a progression in the efficiency of models brought to the market by manufacturers, by rising consumer expectations and by government policies such as MEPS and energy labels that force or encourage higher levels of efficiency. Table A-11 shows an example of the efficiency levels allocated annually to small-split air-conditioning units, for new equipment entering the market between 2000 and 2050.

From 2023, the efficiency levels allocated depend on the Energy Efficiency Scenario. These scenarios were summarized in Table 2-1. Under the "No efficiency gain" scenario, the efficiency levels for new equipment are frozen at 2022 levels. Under BAU efficiency gain, there is a slow and steady efficiency improvement. Under Mid and High efficiency gain, the rates of efficiency improvement are higher, as illustrated in Table A-10 and Figure A-5.

Table A-11 shows the distribution of efficiency levels for the Energy Efficiency scenarios "BAU efficiency gain" and "Rapid efficiency gain." It should be noted that the "No efficiency gain" scenario freezes the efficiency of new equipment at 2022 values, and the "Mid efficiency gain" scenario lies in between the two examples in Table A-10. Figure A-4 shows the average AEER of new split air-conditioning units being sold for each of the four Energy Efficiency scenarios.

Figure A-4: Average annual energy efficiency ratio of new split air-conditioning units, 2000-2050

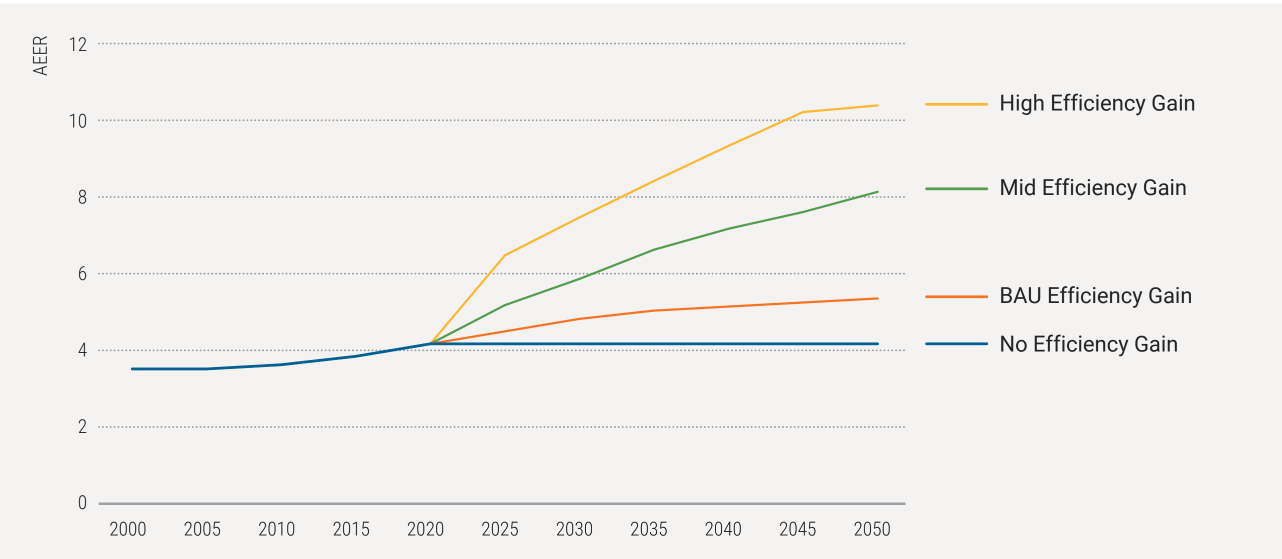


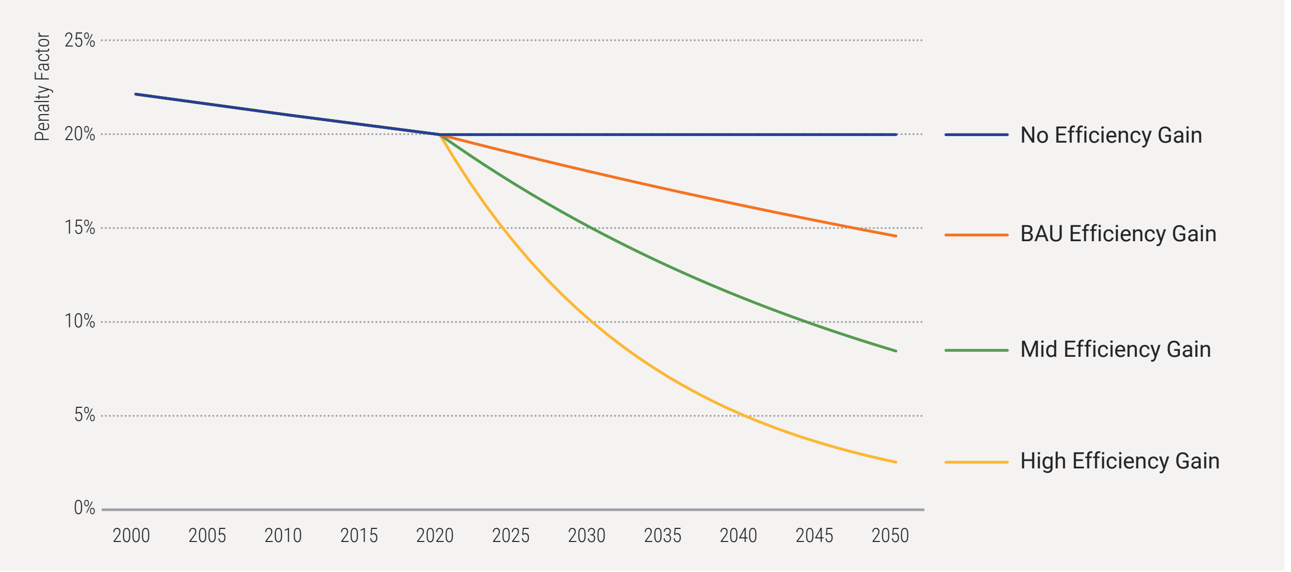
Table A-11: Example input assumptions for energy efficiency of small-split air-conditioning units

Efficiency level AEER	1	2	3	4	5	6	7	8	9	10	Average AEER of new equipment in year
	2.4	3.6	4.7	5.8	6.8	7.8	8.7	9.7	10.5	11.4	
BAU efficiency gain	**% of new equipment sold at each efficiency level**										
2000		100%									**3.6**
2010		90%	10%								**3.7**
2020		50%	40%	10%							**4.2**
2030		10%	60%	30%							**4.9**
2040			50%	50%							**5.2**
2050			30%	70%							**5.4**
Rapid efficiency gain	**% of new equipment sold at each efficiency level**										
2000		100%									**3.6**
2010		90%	10%								**3.7**
2020		50%	40%	10%							**4.2**
2030					40%	40%	20%				**7.6**
2040							40%	40%	20%		**9.5**
2050								30%	40%	30%	**10.5**

Energy consumption of existing equipment

The design efficiency allocated to each item of equipment represents the highest possible operating efficiency for that item. In practice, most end users do not operate their equipment at the highest efficiency level due to poor operational control and poor maintenance. The model applies an energy penalty to represent the likely level of operational efficiency. Examples of the energy efficiency penalties applied are shown in Figure A-5.

Figure A-5: **Operating energy efficiency penalties: split air-conditioning units**



Calculation of annual energy consumption

Using data on cooling delivered, design efficiency and operational efficiency, the model produces an estimate of the annual energy consumption for each item of equipment. For electrically driven equipment this considers the typical electric motor efficiency of 90 per cent. For transport applications, the fuel use is calculated using an assumed internal combustion engine efficiency of 30 per cent.

Calculation of indirect CO_2 emissions

For each country, the historic and current electricity grid emission factors are established from the online database OurWorldInData. These are aggregated by region (weighted by electricity consumption), and forecasts of slow (BAU), mid and rapid grid decarbonization have been assumed, as illustrated in Table 2-3. These grid factors are used to convert the electricity consumption estimates into CO_2 emissions.

For transport applications, fuel consumption is calculated and converted to CO_2 emissions using factors for gasoline (0.24 kgCO_2e/kWh) and for diesel (0.25 kgCO_2e/kWh).

The Refrigerants Model

For each piece of equipment in the stock model, the Refrigerants Model identifies the type of refrigerant used and provides estimates of 1) the quantity of refrigerant added to the item when new; 2) the bank of each refrigerant in existing equipment; and 3) the refrigerant emissions at each stage of the equipment life cycle (during manufacture / installation, during operating life and at end-of-life).

Refrigerant choice for new equipment

The refrigerant choice is technology dependent and changes over time, in response to changing regulations. For some technologies there are simple refrigerant transitions, with one refrigerant dominant at a given time. For example, all car air-conditioning systems used CFC-12 (GWP 10,900) until the impact of CFC phase out (in 1996 for Article 2 countries and 2010 in Article 5 countries), when the car air-conditioning market quickly transitioned to HFC-134a (GWP 1,430). This was the globally used option until some countries started to ban HFC-134a in car air conditioning in response to the HFC phase down. For example, HFC-134a was banned in new cars in the European Union and the United Kingdom of Great Britain and Northern Ireland from 2017. Almost all cars in regions that cannot use HFC-134a have transitioned to HFO-1234yf (GWP 3). Table A-12 illustrates the model assumptions for new car air-conditioning systems in the EU region of the model.

For many RACHP technologies, the refrigerant choices are much more complex, with no dominant refrigerant historically and with various future options. Table A-13 illustrates the refrigerant choices used in the model for large supermarket refrigeration systems.

Table A-12: Example input assumptions for refrigerant choice for new car air conditioning, EU region

	1990	1995	2000	2005	2010	2015	2020	2025	2030
CFC-12	100%								
HFC-134a		100%	100%	100%	100%	70%			
HFO1234yf						30%	100%	100%	100%

Table A-13: Example input assumptions for refrigerant choice, large supermarket refrigeration, EU region, rapid HFC phase down

	1990	2000	2010	2015	2020	2025	2030	2040	2050
CFC-12	50%								
HCFC-22	50%	20%							
HFC-134a		10%	10%	15%	13%				
R-404A		70%	87%	36%					
X-1950*			3%	30%					
X-1400*					29%				
X-600*					5%				
X-150*						20%	11%	10%	10%
R-744				18%	43%	66%	74%	75%	75%
HC-290 integrals				1%	10%	14%	15%	15%	15%
Total new	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

** There are several patented refrigerants competing for market share. The model uses 'X-numbers' to represent two or more similar refrigerants that can be used in the same application. The number represents the approximate GWP of the alternative. X-1950 represents blends such as R-407A and R-407F; X-1400 represents blends such as R-448A and R-449A; X-600 represents blends such as R-450A and R-513A; and X-150 represents blends such as R-454C and R-455A*

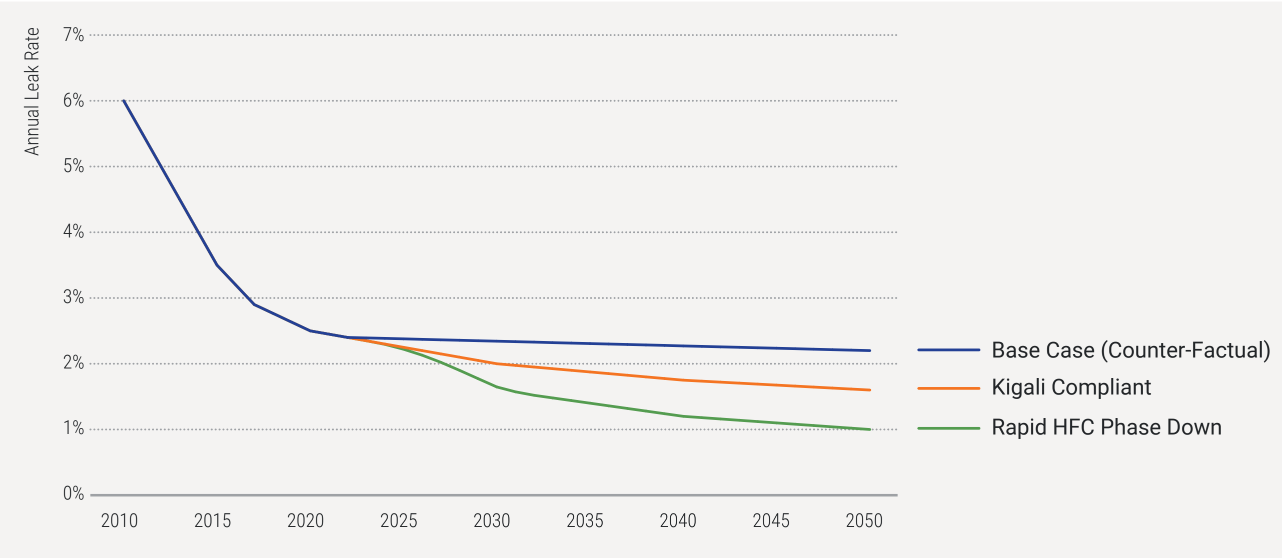
The rate at which new equipment refrigerant transitions occur is policy dependent. The model uses four HFC Mitigation scenarios that use different levels of ambition to phase down HFC use; these were summarized in Table 2-2. The Base case is not Kigali compliant, but it assumes some slow transition to low GWP refrigerants. The BAU scenario meets the requirements set in the Kigali Amendment, with different rates of transition for Article 2, Article 5 Group 1 and Article 5 Group 2 countries. The Faster Action and Rapid HFC phase down scenarios represent faster transitions to low-GWP refrigerants that are already being used in some regions.

Refrigerant leakage during operating life

Most RACHP equipment suffers from some level of leakage during operating life. For small factory-sealed systems such as residential refrigerators, the leak rates are exceptionally low (well under one per cent per year), but for site-installed split systems leakage can be significant (e.g. more than 25 per cent per year was typical for large supermarket refrigeration systems). A key policy action to reduce HFC consumption and emissions is to reduce leak rates, through improved design, installation and maintenance.

For each technology type, modelling assumptions are made about the leak rate of new equipment. The leak rates assumed are highest in regions with poor maintenance infrastructure. Leakage rates are assumed to improve going forward, in response to policy measures to reduce leakage. The improvement in leakage rates is fastest and greatest for the Rapid HFC phase down scenario, as illustrated in Figure A-6.

Figure A-6: **Leakage rate for new systems for small-split air-conditioning systems, EU region**



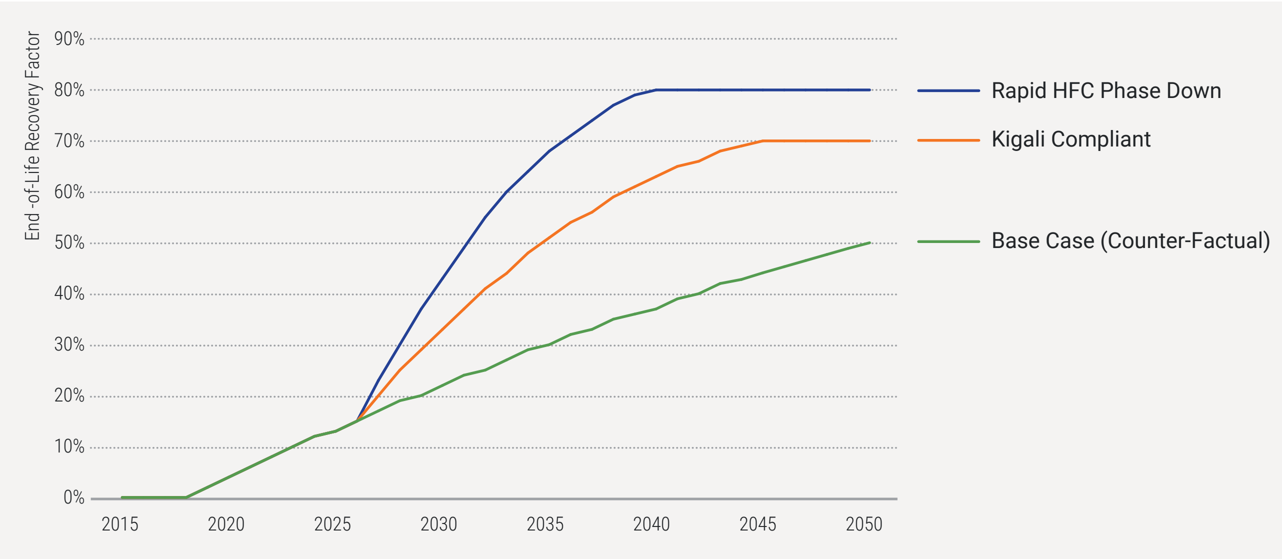
Leakage deterioration with age

It is assumed that older equipment leaks more than new equipment, with a leakage deterioration factor that starts at two-thirds life of each equipment item. A nominal increase of 5 per cent relative to the "when new" leakage rate is assumed by the time the item reaches its expected end of life.

End-of-life emissions

When equipment reaches end-of-life there is potential for emissions to the atmosphere. With good policies in place, gas recovery will take place at end-of-life, with recovered gas either destroyed or re-processed for further use. Many Article 2 countries have end-of-life gas recovery policies in place, but most Article 5 countries currently have limited infrastructure to recover and reuse old refrigerants. Figure A-7 illustrates some of the assumptions for end-of-life emissions.

Figure A-7: End-of-life recovery factor for air-conditioning water chillers, Article 5 region



Annex 8 Global Cooling Policy Stocktake Survey

Table A-14 presents a snapshot of results from the Global Cooling Policy Stocktake survey discussed in Chapter 3. The entire dataset can be accessed at the UNEP Data Catalogue search engine under "Global Cooling Policy Stocktake" here and directly downloaded as an excel file at this link.

Table A-14: Global Cooling Stocktake survey summary statistics

No.	Question	Number of countries responding		
		Yes	No	N/A
Q1	Have cooling access rate and gaps been identified?	114	75	3
Q2	Is data on cooling appliance sales/ownership publicly available?	108	83	1
Q3	Are there any national adaptation plans and/or strategies that address extreme heat and cooling access?	87	104	1
Q4	Does a national level strategy/policy envision increasing cooling access?	96	95	1
Q5	Have National Building Codes been established? ("Yes" responses include mandatory and voluntary national building energy codes, as well as those under development. The latter have been highlighted as such in the excel sheet.)	114	78	
Q5a	Do building energy codes stipulate minimum material performance standards with material testing and reporting standards (e.g., calculation and reporting of insulation performance/U-value of window, frame, glass, etc.)?	122	65	5
Q5b	Are subnational building energy codes required to support the stringency of the national building energy code in sub-national jurisdictions?	30	37	125
Q6	Are cool & reflective surfaces included in building codes?	49	139	4
Q7	Do building energy codes include methodology for energy efficiency rating system?	72	118	2
Q8	Do building energy codes consider the use of high-efficiency appliances, as defined by minimum energy performance standards (MEPS)?			192
Q9	Are there any established application and inspection process to verify enforcement of building energy code?	31	34	127
Q10	Are existing buildings required to meet current building codes at the time of renovation and refurbishment?	63	32	97
Q11	Is there increased stringency in building energy codes for government-owned buildings?	33	32	127
Q12	Is there a national centre to support sustainable and energy efficient urban and/or building design available as a resource to provinces and cities?	34	30	128
Q13a	Are there government-supported incentives to adopt building codes?	54	39	99
Q13b	Are there minimum energy performance standards (MEPS) established for space cooling appliances?	132	60	0
Q14	Residential	122	70	0
Q14a	Commercial	117	75	0
Q14b	Are MEPS updated at a minimum every two years, keeping pace with best available technology?	26	163	3
Q15	Are there mandatory labels required for residential cooling appliances?	89	38	65
Q16	Are there mandatory efficiency standards and corresponding labels required for all residential cooling appliances?	89	37	66
Q17a	Is there a linkage of equipment efficiency to buildings' system level efficiency standards in building energy codes?	29	31	132

Table A-14: Global Cooling Stocktake survey summary statistics (continued)

No.	Question	Number of countries responding		
		Yes	No	N/A
Q19	Are agricultural cold chains part of national development or implementation strategy?	38	68	86
Q20	Has the cold chain been mapped to understand gaps that lead to food waste and shortage?	62	127	3
Q21	Is food loss and waste measured and reported each year?	94	96	2
Q22	Are there government programs for off grid refrigeration?	22	44	126
Q23	Is there a dedicated government sponsored multi-disciplinary centre for cold chain and best practices development?	11	52	129
Q24	Are there MEPS established for equipment in the refrigeration sector?	117	74	1
Q25	Are MEPS as a per cent of best available technology and updated regularly to keep pace with best available technology?	73	118	1
Q26	Are there efficiency standards and corresponding labels required for all refrigeration appliances?	116	74	2
Q27	Is equipment efficiency linked to system-level efficiency in cold chain codes and standards?	26	33	133
Q28	Is there a Kigali Implementation Plan (KIP)?	135	55	2
Q28a	Is the Kigali Implementation Plan under development and timeline being implemented?	136	52	4
Q29	Are there regulations on refrigerant recovery during servicing?	111	78	3
Q30	Are there regulations on refrigerant disposal?	114	77	1
Q31	Are low-GWP refrigerant based equipment/appliances readily available at scale in the market?	48	45	99
Q32	Does government have procurement standards for equipment using low/zero-GWP refrigerants in government buildings?	19	41	132
Q33	Is there a National Cooling Action Plan (NCAP)?	35	156	1
Q34	Are cooling projections included explicitly in electricity capacity planning?	40	60	92
Q35	Are cooling targets included in NDC and/or climate strategies/net-zero plans?	73	117	2
Q36	Is there clarity on ministerial responsibility for all aspects of a transition to sustainable cooling?	19	40	133
Q37	Are there national import tariffs that restrict or constrain access to refrigeration or cooling equipment?	28	40	124
Q38	Are there Government established funding and financing programs in place to support a transition to more sustainable cooling solutions (supply or demand side interventions)?	48	47	97
Q39	Are there any incentives/training programmes for servicing technicians to upgrade their skills vis-à-vis new refrigerants?	120	69	3
Q40	Are there any consumer-centric programmes to encourage appliance usage with greater energy savings/energy efficiency (encouraging regular servicing, purchasing low-GWP and/or high-efficiency appliances, information on higher temperature settings, etc.)?	42	46	104
Q41	Has the national or regional government established a knowledge centre to support city evaluation and feasibility studies for district cooling development?	17	42	133

Note: The total number of countries surveyed was 193, but since data for Democratic People's Republic of Korea could not be collected, responses have only been made available for 192 countries. Source: UNEP Global Cooling Stocktake 2023.

Annex 9 Policy primer

This section provides a quick summary of policies that are most relevant to achieving net-zero emissions from cooling. The aim is to highlight the landscape of policy instruments for policymakers interested in creating stronger impetus around sustainable cooling.

The three most critical policies or directives that can enable countries to move towards net-zero cooling are: setting efficiency standards for buildings; setting efficiency standards for cooling and refrigeration appliances; and enabling a transition to low-GWP refrigerants across cooling end uses:

- **Building energy codes** set minimum energy efficiency standards for building technologies and design elements such as building envelope; heating, ventilation and air conditioning; lighting; and water heating systems (UNEP Global Alliance for Buildings and Construction 2021). More generally, building codes are laws or regulations that prescribe a set of requirements for the design and construction of various aspects of residential and commercial buildings, including structural systems, plumbing, electric and natural gas systems, and heating, ventilation and air conditioning (HVAC).

- **Minimum energy performance standards (MEPs)** are a regulatory tool that benchmarks the minimum level of energy performance that electrical applications, appliances and equipment must meet or exceed before they can be offered for sale or used for residential/commercial purposes.

- Countries have also adopted and started implementing the **Kigali Amendment to the Montreal Protocol,** which aims to phase down the use of hydrofluorocarbons (HFCs), gases that have high global warming potential (GWP) and are commonly used across all heating, cooling and refrigeration applications.

  - **Ratification/approval of the Kigali Amendment to the Montreal Protocol** refers to the final and formal seal of approval on the Amendment by a Party to the Montreal Protocol aimed at phasing down of high-GWP HFCs used for the cooling and refrigeration applications.

  - A **Kigali Implementation Plan** is an individual country's strategy that outlines steps and targets for phasing down HFCs as per the guidelines set by the Kigali Amendment (UNEP Ozone Secretariat 2020).

  - **Phase down regulations for HFCs and ozone-depleting substances (ODS)** are the set of rules and policies guiding the gradual reduction in the production and consumption of ozone-depleting and high-GWP refrigerants such as CFCs, HCFCs and HFCs in accordance with the Montreal Protocol (UNEP Ozone Secretariat 2020). These regulations guide the amount of newly added HFCs and ODS to the market through production and import, minus exports and destruction (Bhasin *et al.* 2019; United States Environmental Protection Agency [U.S. EPA] 2023a; U.S. EPA 2023b).

The impact of these policies at a global scale is tremendous, as noted in the chapters above.

The first next step, therefore, should be to develop these policies and to strengthen the policy benchmarks. Chapter 3 includes examples of countries where these have been designed effectively, and the impacts that they are accruing.

The second step is to adopt complementary policy action. A large array of well tested, mature policy instruments is available to increase the effectiveness of minimum standards. For instance, while MEPS and building codes set minimum requirements, they do not encourage individual and commercial consumers to go beyond the standard. Moreover, the general pledge of the Kigali Amendment can be backed by efficient end-of-life and sectoral policies.

Complementary policy actions include: 1) information-based policies; 2) procurement and market-shaping policies; 3) end-of-life policies; 4) capacity-building; 5) national strategies to prioritize cooling; and 6) a set of relevant sectoral policies.

1) **Information-based policies** have been found to have a significant impact on consumer decisions in the housing market as well as in the markets for white goods:

- **Labelling programmes** are among the most cost-effective tools to encourage environmentally friendly purchasing among consumers; a label/sticker displays the energy consumption level of the appliance/unit/system compared to others offering the same service.

- **Consumer awareness programmes** are targeted at informing buyers about products, services and goods to enable them to make choices that suit their requirements and the effects of using these services or products.

- **Behavioural change programmes** are aimed at directing consumers to make more environmentally sound purchasing and usage decisions. They aim to direct the use and maintenance patterns that a consumer can adopt.

- **Regulating business disclosures and ESG reporting, including appliance production, ownership and investments** involves policies that regulate businesses to disclose information on their environmental, social and governance (ESG) footprint in their annual reports and mainstream regulatory filings (OECD 2020). This fosters accountability and sustainability in business operations. Information-based policies even extend to shareholder decisions to influence sustainable investment in the financial sector.

2) **Procurement and fiscal policies** also can speed the adoption and diffusion of new technologies:

- **Public procurement** refers to the purchase by governments and state-owned enterprises of goods, services and works. It is expected that public procurement be carried out efficiently and with ambitious standards of conduct to ensure high quality of service delivery and to safeguard the public interest, including environmental protection.

- **Bulk procurement** involves the procurement (international and/or local) of goods and services from commercial entities, usually at a lower price than what is available as the retail price.

- **Government-facilitated fiscal incentives** refer to financial incentives offered by governments to businesses or individuals to encourage certain behaviours or investments. These incentives can include tax breaks, grants, subsidies and other forms of financial support (Jensen *et al.* 2020). They could also be developed as economic instruments to support investments in cleaner technologies through the development of bonds and risk guarantees, among others, as well as instruments that directly support business model development such as energy servicing companies (ESCOs). Several of these financing support mechanisms are discussed in chapter 7.

3) **End-of-life policies** ensure that, following their use, products are adequately disposed of. Given the compounding growth expected in cooling appliances and systems, for these to be truly sustainable, ensuring effective end-of-life management, recycling and destruction will be key.

- **End-of-life management** refers to the policies guiding environmentally benign management of waste, meaning disposal, recycling and handling of products at their end of useful life.

- **Life-cycle management of refrigerants** prescribes the effective handling of a refrigerant throughout its life cycle to minimize its environmental impact while ensuring safe usage. It includes minimizing refrigerant leakage, promoting recovery, recycling and reclamation for reuse; as well as ensuring the proper destruction of gases at the end of life (Kumar *et al.* 2023).

- **E-waste regulations** are the set of rules and guidelines aimed at proper disposal, recycling, and management of electronic waste, preventing electronic waste from reaching landfills and environmental pollution and promoting responsible electronic consumption (UNEP 2019). For example, Japan's Home Appliance Recycling Law 2001 delineates e-waste management processes, the responsibilities of multiple stakeholders involved in the reverse supply chain and the cost-bearing mechanism (CEEW 2023).

4) **Capacity-building**

- **HVAC servicing, maintenance and installations:** The installation and operating maintenance and servicing of heating, ventilation and air-conditioning (HVAC) equipment or appliances are regulated by a code of practices or standards within specific jurisdictions. These apply to a minimum criterion for trainings for technicians and can be further regulated through a certification system that recognizes the level of skill and training of technicians – and the kind of equipment they are qualified to install/service.

- **Understanding and targeting data gaps:** This involves measures aimed at prioritizing public access to crucial data on energy access rates, cooling access rates, appliance ownership, affordability segmentation and other key variables, to enable a deeper understanding of the current and potential cooling market. By facilitating disclosure of these metrics, policymakers and stakeholders can make informed decisions, direct resources effectively and tailor interventions to address gaps and challenges. This data-driven strategy enhances the precision and impact of policies.

5) **National plans are a critical component of simultaneously developing multiple policies and ensuring effective and systematic implementation.**

- **Electricity generation planning** is done by governments and energy authorities to strategize electricity production, distribution and consumption, with the aim of ensuring a reliable, affordable and sustainable energy supply while considering factors such as environmental impact, advancements in technology, and energy demand (IEA 2020).

- **A National Cooling Action Plan** is a valuable tool devised by countries that sets out comprehensive strategies to address the ongoing refrigerant transition and escalating cooling demand while minimizing the ecological impact, focusing on energy efficiency, sustainable cooling alternatives and mitigating heat-related challenges (UNEP Cool Coalition n.d.b).

- **A Heat Action Plan** is a strategic document that encompasses the proactive measures designed to protect vulnerable populations from extreme heat events and build heat reslience. Among other interventions, it incorporates early warning systems, health system interventions and public awareness campaigns to reduce health risks associated with heat waves (WHO 2023).

- **Disaster risk management/regulations (for heat stress)** are a set of rules within a country's disaster risk management strategies that are instrumental in mitigating and preventing heat stress impacts. For example, India, to mitigate heat stress impacts, has developed provisions to establish drinking water kiosks in high-risk areas and expanded access to shaded areas and shelters for outdoor workers and vulnerable people, and to set up medical camps and stocks of oral rehydration salts, and train medical staff and employers to recognize the signs and danger of heat strokes (United Nations Office for Disaster Risk Reduction 2023).

- **National adaptation plans, policies and strategies** are the comprehensive strategies developed by countries to assess the vulnerability to climate change and accordingly prioritize medium- and long-term actions to enhance resilience and reduce the adverse impacts of climate impacts (UNFCCC n.d.).

- **Nationally Determined Contributions** are the voluntary commitments made by countries in accordance with the Paris Agreement to curtail GHG emissions and contribute to global climate goals, outlining specific mitigation and adaptation actions. They are reviewed and enhanced every five years by each country to take more ambitious actions to reduce emissions (UNEP 2023c).

6) **Additional sectorial policies**

- **Regulating supply chains/manufacturing** refers to the set of standards and regulations that control how goods are produced, where they are sourced, and how they are distributed across supply chains to support resource conservation, ethical working conditions and sustainability. These rules seek to reduce the adverse environmental and social impacts caused by manufacturing and trade operations while developing a more just and sustainable global economy by enforcing standards and encouraging openness (UNIDO 2005).

- **Industrial policy** refers to the government efforts and strategies aimed at promoting the development and growth of certain industries over others. These policies are designed to support and enhance the industry's competitiveness, technological advancement, and contribution to economic growth and sustainability (Schwarzer 2013).

- **Customs regulations to minimize imports of banned substances (such as ODS and HFCs)** refer to the rules and measures implemented by customs authorities of a country to prevent the entry of prohibited or controlled substances in that specific country. Customs regulations may include requirements for proper monitoring, inspections and penalties for non-compliance.

- **Passive and nature-based solutions** are green approaches that leverage natural processes and material for cooling buildings and cities. While passive solutions for cooling buildings include natural ventilation, thermal insulation, shading, reflective surfaces and evaporative cooling (CEEW 2023), nature-based solutions for cooling cities involve integrating natural elements and processes into urban planning and design to mitigate urban heat island effects and enhance cooling (UNEP Cool Coalition 2021). These approaches reduce active cooling demand by reducing energy use, enhance thermal comfort and create climate-resilient cities.

- **Cold chain development, implementation programmes and regulations** are government-led efforts to develop efficient systems for storing and transporting temperature-sensitive goods such as foods, dairy products and pharmaceuticals, to prevent loss and ensure product quality and safety (for vaccines) throughout the supply chain.

- **Regulations and government programmes for off-grid refrigeration** are aimed at promoting the use and development of off-grid refrigerators in sectors such as health care, households, micro-enterprises, farm-gate and dairy in locations that do not have reliable electricity grids and rely on solar power to meet their refrigeration needs. For example, a scheme led by the Government of India, Scale-up of Access to Clean Energy for Rural Productive Use, is aimed at providing clean energy sources to power refrigeration systems in rural settings.

Annex 10 Summary of national policies and regulations related to the HFC phase down

The Kigali Amendment requires an 80 per cent phase down of HFC consumption by 2045 for most Article 5 parties, an 85 per cent phase down by 2047 for ten Article 5 parties with high ambient temperatures, and an 85 per cent phase down by 2036 for non-Article 5 parties. Altogether, the HFC phase down scenarios are estimated to avoid the use of 80 gigatons of CO_2e by 2050 (Velders *et al.* 2015; Newberg 2016).

Strengthen the Montreal Protocol to narrow exemptions for feedstocks and process agents that create opportunities for illegal trade in banned substances.

Article 5 parties are developing HFC phase down management plans, called Kigali Implementation Plans (KIPs), which must be approved by the executive committee of the Multilateral Fund to receive funding (UNEP Ozone Secretariat 2016). Countries can draw from a range of options such as controls on supply and demand of chemicals and equipment, activities on servicing sector and other policy measures for sustained reduction of HFCs (Table A-15). These are addressed through life-cycle refrigerant management policies as well as through national/regional regulation, which enables the implementation of HFC reductions consistent with the Kigali phase down schedules.

Table A-15: **Sample of national policies and regulations related to the HFC phase downs in the Kigali Amendment**

Country/Region (year of Kigali ratification)	Key measures	Description
European Union (2018, non-Article 5)	Mobile air conditioning directive, 2006/40/EC	• The directive established refrigerant leakage restrictions and limited the 100-year GWP of refrigerants used in new vehicles to 150, resulting in eventual transition to HFO-1234yf (European Union 2006).
	F-gas regulations, EC 842/2006 and EC 517/2014	• The initial regulation set requirements for leak checking and recovery of used refrigerants to reduce emissions (European Environment Agency 2006). • The 2014 update progressively reduces high-GWP HFCs in the European market by 2030, banning their use in new equipment and requiring regular checks, good servicing practices and management plans for end-of-life (European Union 2014; European Commission 2023). • Updates proposed in 2022 would tighten quota systems, accelerate the phase down and reduce the climate impact of HFCs placed on the market 98 per cent by 2050 (European Commission 2023). • In 2017, HFC consumption in the EU was 12 per cent below its first stepdown agreed under the Kigali Amendment (European Commission 2019).
United States of America (2022, non-Article 5)	American Innovation and Manufacturing (AIM) Act (2020)	• The AIM Act phases down HFCs nationwide (United States House of Representatives 2020; IIR 2023b). • To implement the reductions, the United States Environmental Protection Agency (EPA) has begun issuing regulations – including an 'allocation rule' that caps new HFC production, consumption, and imports; and a proposal to prohibit the use of high-GWP HFC refrigerants in most new applications starting in 2025 (U.S. EPA 2023a; U.S. EPA 2023b). • The EPA estimates that this will reduce up to 903 million tons of CO_2e emissions from 2025 to 2050 (U.S. EPA 2022).
	State-level policies	• Many American states have passed restrictions on HFCs, and many state building codes restrict what types of refrigerants may be used. • American industry, states and environmental groups have been working to assure that such restrictions do not impede the availability of HFC substitutes by the time the EPA's proposed rules go into effect.
India (2021, Article 5 Group 2)	National Strategy (forthcoming 2023)	• The government is working with industry to develop a national strategy for accelerating the HCFC phase out by 2030 and starting the HFC phase down. • The national strategy will prioritize raising awareness of different stakeholders on the HFC phase down; collecting information about production, import and export of HFCs; and developing a national policy framework for implementing a licensing and quota system. • As a first step, in March 2022, the Indian licensing system for import and export of HFCs and HFC blends was set up (UNEP Ozone Secretariat 2023d).

Table A-15: Sample of national policies and regulations related to the HFC phase downs in the Kigali Amendment

Country/Region (year of Kigali ratification)	Key measures	Description
China (2021, Article 5 Group 1)	Green Cooling Action Plan for China (2019)	• The action plan, jointly released by the National Development and Reform Commission (NDRC) and six ministries (NDRC 2019), is aimed at realizing the synergy between energy efficiency improvement and green transformation of refrigerants (NDRC 2019). • The plan proposes speeding up the revision of climate-friendly refrigerant standards and safety standards; guiding enterprises to accelerate the adoption of low-GWP refrigerant production lines; strictly controlling refrigerant leakage and discharge; and regulating the recovery, dismantling and re-use of waste refrigeration products and refrigerants.
	Regulating the phase down of HFCs	• To execute the Kigali mandate, the government added HFCs to the 'Checklist of Ozone Depleting Substances (ODS) under National Control' (China, Ministry of Ecology and Environment 2021a) and issued the 'Notice on Emission Control of HFC-23 as a By-product of HCFC-22' (China, Ministry of Ecology and Environment 2021b). • The 2021 'Notice on Strictly Controlling the First Batch of Hydrofluorocarbon Chemical Production and Construction Projects' controls the production of five types of HFCs with large output and high-GWP value and prohibits new production capacity for these (China, Ministry of Ecology and Environment 2021c). • In addition to active reduction projects, a study is being undertaken on the accounting methods and reporting of HFC-23 emissions (Hu *et al.* 2021). • The next priority will potentially be to set up an HFC quota management system in China. Research and technical support with clear action plans and technology confidence are necessary to continue the regulatory push for phasing out HFCs and other ozone-depleting substances.
	Industry action	• China's industry has consensus to speed the development and application of low-GWP refrigerants, such as R-32, HC-290, HFC-161 and HFO. • With the enforcement of MEPS for room air conditioners in China in 2020, the market share of room air conditioners using R-32 has increased to more than 50 per cent, gradually replacing the dominance of high-GWP refrigerants.

Annex 11 Life-cycle management initiatives of refrigerant gases in selected countries

Table A-16: Life-cycle management initiatives of refrigerant gases in selected countries

Country	Initiatives
Australia	• Refrigerant Reclaim Australia programme, implemented by industry stakeholders for recovery and reclamation/destruction of gases. • Tax on manufacturing and import of gases to fund this programme. • Only trained and licensed service technicians are allowed to handle refrigerants.
Canada	• Regulation for mandatory destruction of HCFC and HFC gases that are no longer needed within a specified period.
Colombia	• Refrigerant life-cycle management is the responsibility of the manufacturer and/or importer from the extraction of raw materials to final disposal. • Red Verde programme supports the recovery of refrigerants at end-of-life, with collection points and services in place to help end users dispose of old refrigerators (Red Verde n.d.). •Operators oversee transferring the refrigerants to the recycling facility. A government-enacted data recording system tracks the entire process for refrigerant destruction (IIR 2023c).
Denmark	•Deposit-and-refund scheme for recovery and reclamation/destruction of gases. A refund is made after deducting a fixed cost for refrigerant management.
Japan	• Regulation for rational use and mandatory life-cycle management of fluorocarbons in commercial applications. • Regulations for recycling of specified home appliances and vehicles at the end of life; mandatory provision for recovery and destruction of refrigerants from these devices. • Training and mandatory licence for refrigerant handlers at all life-cycle stages. • Robust systems for record keeping and monitoring of the programme.
New Zealand	• Regulation for mandatory recovery of gases from decommissioned devices • A voluntary product stewardship scheme run by industry stakeholders for destruction of recovered gases • Only trained and licensed service technicians are allowed to handle refrigerants
Norway	• Tax-and-refund scheme that involves a tax on gases based on their GWP and a refund (tax amount minus cost of refrigerant management) after collection and destruction of gases. • Training and certification of technicians involved in refrigerant handling. • Regulations for collection and recycling of electronic and electrical goods and vehicles at the end of life; recovery of gases from devices at recycling facilities.
United States of America	• Clean Air Act regulation prohibiting the intentional venting of gases, and mandatory certification of technicians involved in refrigerant handling; data recording system for reporting on use and recovery of gases. • Voluntary Responsible Appliance Disposal (RAD) partnership programme that encourages collection and recycling of discarded appliances, including recovery of refrigerant from these appliances. • U.S. EPA is developing HFC management rules under the AIM Act Subsection H, 'Management of Regulated Substances' (U.S. EPA 2023c).
Brazil and Morocco	• Pilot programmes in economically feasible sectors for bulk procurement of energy-efficient appliances with low-GWP gases and controlled replacement of old and inefficient appliances with obsolete ODS and HFC gases. • Destruction of recovered gases from old appliances.
Other countries	• In Singapore, Malaysia, Sweden and Republic of Korea, recovery and destruction of gases are primarily linked with regulations on collection and recycling of discarded appliances and vehicles at end of life. • In Viet Nam and Thailand, pilot projects are supported by Japan on collection and destruction of gases.

Source: Climate and Clean Air Coalition 2022; CEEW 2023; sources cited within the table.

Annex 12 Examples of the commercial use of natural refrigerants in the cold chain and resulting energy savings

Table A-17: Commercial use of natural refrigerants in the cold chain and resulting energy savings

Company/Project	Description
ASDA (United Kingdom of Great Britain and Northern Ireland)	ASDA reported a 35 per cent energy consumption reduction in its R-717 and R-717/R-744 systems through 24/7 monitoring of the cooling system energy performance. The technology uses advanced controller software with an MRI scan instead of X-rays and provides users with maintenance advice and requirements to reduce energy use (Stausholm 2022).
Eroski (Spain)	In 2016, an Eroski supermarket in Oñati, Spain adopted a R-744 refrigeration system, heat recovery and renewable energy, achieving a 65 per cent reduction in energy consumption and becoming a zero-emission supermarket (The Corner 2013).
EU Multipack project (Southern Europe)	The EU Multipack project integrated a transcritical CO_2 booster system in three supermarkets in southern Europe, resulting in energy savings of 25–30 per cent (European Commission 2022). The systems were modular and scalable, with lower capital and operational expenditures compared to traditional HFC systems. These systems had roughly 30 per cent higher capital expenditure compared to the traditional systems, but these are recovered in a moderate payback period.
Lidl (Germany)	Lidl stores in Germany have achieved significant energy savings – including 100 per cent heating energy savings, 47 per cent reduction in energy use, 30 per cent reduction in costs and 43 per cent reduction in CO_2 emissions – by applying R-744 refrigeration technology with heat recovery alongside other good practices such as energy flow monitoring, passive cooling, automatic control systems and geothermal storage (Proklima International 2010; The Hydrocarbons Marketplace 2013).
Makro (Colombia)	Makro installed a transcritical CO_2 system at its Valle del Lili supermarket in Cali, Colombia in 2019 (Shecco 2020). The system has a 130-kW medium-temperature cooling capacity and a 4-kW low-temperature cooling capacity. The installation includes a controlled suction-gas super heater, gas cooler, electronic expansion valves and self-service doors for energy efficiency.
Pick n Pay (South Africa)	South African grocer Pick n Pay opened its first store using transcritical CO_2 refrigeration in 2018 and had installed 22 such stores by 2020. The cost premium of the CO_2 system has fallen from 40 per cent down to 10 per cent, and the company is committed to using natural refrigerants (R744 2021b).
Rema 1000 (Norway)	Rema 1000 Kroppanmarka in Trondheim, Norway has implemented a CO_2-based heat recovery system, achieving 100 per cent green certification. The system, designed by Danfoss and Sintef Energy, provides full cooling and heating and resulted in 30 per cent energy savings, making the store among the most energy efficient in Norway (Danfoss 2014).