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Keeping it chill

How to meet cooling demand, while cutting emissions

Cool Coalition

Global Cooling Watch 2023

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Glossary

°C	Degrees Celsius
ACES	Africa Centre of Excellence for Sustainable Cooling and Cold-Chain
AEER	Annual energy efficiency ratio
BAU	Business as Usual
CaaS	Cooling-as-a-service
CDD	Cooling degree day
CFC	Chlorofluorocarbon
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties
ESCO	Energy service company
ESG	Environmental, social and governance
EU	European Union
F-gas	Fluorinated gas
GCF	Green Climate Fund
GDP	Gross domestic product
GHG	Greenhouse gas
GWP	Global warming potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoro-olefin
HVAC	Heating, ventilation and air conditioning
IEA	International Energy Agency
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
KIP	Kigali Implementation Plan
kW	Kilowatt
kWh	Kilowatt-hour
MEPS	Minimum energy performance standard
MLF	Multilateral Fund
MoNRE	Ministry of Natural Resources and Environment of Viet Nam
MW	Megawatt
NCAP	National Cooling Action Plan
NDC	Nationally Determined Contribution
PAYG	Pay-as-you-go
PCM	Phase-change material
RACHP	Refrigeration, air conditioning and heat pump
R&D	Research and development
TW	Terawatt
TWh	Terawatt-hour
U4E	United for Efficiency
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VRF	Variable refrigerant flow

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Sao Paulo, Brazil
Photo: Nelson Antoine/shutterstock

Foreword

Cooling protects people from rising temperatures, maintains food quality and safety, keeps vaccines stable and enables economic productivity. It is central to achieving the sustainable development goals. The flip side is that cooling growth, under business as usual, would lead to a doubling of the sector's greenhouse gas emissions by 2050 – which cannot be allowed to happen if the world is to limit climate change to manageable levels.

There are, however, solutions to this dilemma, which would allow cooling to reach an additional 3.5 billion people and dramatically reduce predicted emissions. The Global Cooling Watch report, *Keeping it Chill: How to meet cooling demands while cutting emissions*, lays out measures that would, by 2050, reduce greenhouse gas emissions from cooling by at least 60 per cent below business-as-usual, reduce peak load demand by between 1.5 and 2 terawatts, and save US$22 trillion for end-users and the power sector.

The report, from the UNEP-led Cool Coalition, looks at actions in three areas. Deploying passive cooling measures, such as insulation, natural shading and ventilation, would dramatically reduce cooling loads. Higher efficiency standards, including through updated Minimum Energy Performance Standards and better labelling, would triple the global average efficiency of cooling equipment by 2050. A faster phase down of climate-warming hydrofluorocarbon (HFC) refrigerants through the Kigali Amendment to the Montreal Protocol would also make a huge difference. If rapid grid decarbonization were added to these actions, predicted 2050 emissions could be reduced by 96 per cent.

To deliver these benefits, governments must introduce aligned policies that support and integrate passive cooling, energy efficiency and faster refrigerant phase down – including through frameworks like National Cooling Action Plans. Some countries already have policies in place, but they need to be better implemented. Other nations must catch up. Finance for cooling also needs to rise – although US$22 trillion in savings and the societal benefits of deep emissions cuts would make the sustainable cooling transition affordable.

I ask all nations, cities and private sector to commit to sustainable cooling with concrete actions. The Global Cooling Pledge, a joint initiative between the Cool Coalition and the United Arab Emirates as host of the 2023 United Nations Climate Change Conference (COP28), provides a real opportunity to act. If we follow the recommendations in this report, we will deliver a cooler, and better, world for all.

Inger Andersen
Executive Director
United Nations Environment Programme

A comprehensive and systemic shift to sustainable cooling is required to minimise growth in the emissions from cooling while increasing overall access to cooling for vulnerable and underserved communities.

Hong Kong, China
Photo: mm7, shutterstock

Executive Summary

As the world warms, and as incomes and populations grow, demand for cooling is rapidly growing and it is increasingly being recognized as a critical service. People need cooling to protect themselves from rising temperatures and to keep food fresh, vaccines viable and economies productive.

Based on current policies, between now and 2050 the installed capacity of cooling equipment globally will triple, resulting in a more than doubling of electricity consumption. This will lead emissions from cooling to surge to 6.1 billion tons of carbon dioxide equivalent (CO_2e) in 2050, equivalent to more than 10 per cent of global projected emissions that year[1]. This rapid increase in cooling will strain electricity grids in many countries, presenting a major hurdle to the ongoing transition from fossil fuels to renewable energy sources.

Cooling is a double burden on climate change. Rising demand for power-hungry equipment, such as air conditioners and refrigeration, will drive greater indirect emissions from the associated electricity consumption. At the same time, these emissions are compounded by direct emissions from the release of refrigerant gases in cooling equipment, the majority of which have a much higher global warming potential than CO_2.

A comprehensive and systemic shift to sustainable cooling is required to minimise growth in the emissions from cooling while increasing overall access to cooling for vulnerable and under-served communities. Meeting growing cooling demand sustainably presents one of the biggest opportunities to protect people, prosperity and the planet.

Integrated action is needed in three key areas:

1) **Passive strategies** to address extreme heat and reduce cooling demand in buildings and in the cold chain.

2) **Higher energy efficiency** standards and norms for cooling equipment.

3) **A phase down of climate-warming hydrofluorocarbon (HFC) refrigerants at a faster rate than is required under the Kigali Amendment to the Montreal Protocol**, while improving the energy efficiency of cooling equipment.

Japan
Photo: Ryoji Iwata, unsplash

1 Calculated based on the Current Policies Scenario in the United Nations Environment Programme's (UNEP) 2023 Emissions Gap Report; see UNEP 2023a.

Near-zero emissions from cooling – with improved access to cooling – can only be accomplished through the implementation of synergistic policies, regulations, training and financial instruments that work together to create a strong and sustainable cooling ecosystem. It requires mainstreaming cooling within a national-level regulatory or legal framework as well as developing National Cooling Action Plans and streamlining finance.

Importantly, the G20 countries represent 73 per cent of the potential for reducing cooling emissions to 2050, of which 11 per cent is from the G7 countries. This illustrates that leadership from the G20 countries play a key role.

Fully implementing the measures outlined in this report can:

- **Reduce the 2050 greenhouse gas (GHG) emissions** from cooling by at least 60 per cent (around 3.8 billion tons of CO_2e emissions), and this could increase to a 96 per cent reduction depending on rates of grid decarbonization. The cumulative savings, measured at a social cost of carbon of US$185 per ton of CO_2e, are US$16.5 trillion (2020 US$).
- **Create electricity savings for end users** of US$1 trillion in 2050 (2020 US$) and reduce the peak power requirement by between 1.5 and 2 terawatts (TW), avoiding power generation investments in the order of US$4 trillion to US$5 trillion.

Budapest, Hungary
Photo: Andocs shutterstock

Cooling is a necessity in a warming world

In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change states that: "Heat is a growing health risk, due to burgeoning urbanization, an increase in high temperature extremes, and demographic changes in countries with ageing populations" (IPCC 2023). Given these trends, cooling will need to expand for both stationary applications (residential and non-residential space cooling, cold chains and process cooling) and transport applications (mobile air conditioning and refrigerated transport).

Under a business-as-usual (BAU) projection, the global installed capacity of cooling equipment is envisaged to almost triple by 2050 to 58 TW[2]. Meeting this rising demand will require large investments in electricity generation and distribution infrastructure, and will also result in higher electricity bills for end users, particularly in Africa and South Asia where the fastest growth is predicted.

Yet, despite this significant growth in equipment, the world's poorest and most vulnerable populations will continue to lack access to cooling. Providing access to cooling in developing countries overall requires an additional 10 per cent growth in the 2050 cooling capacity.

Access is enhanced through passive cooling, bringing nature back to cities for comfortable microclimates, lower upfront and running costs for efficient cooling equipment, more reliable grids and enhanced support based on assessment of needs.

To minimize the multiple and severe negative impacts from cooling growth, a rapid transition to sustainable cooling is needed. This requires the adoption of cooling technologies and approaches that are accessible, affordable and scalable but that minimize negative impacts on people, the economy and the environment. Fortunately, solutions exist that can provide cooling for all while protecting economies and the planet.

2 Such an increase in installed capacity of cooling equipment would require an estimated 2 to 2.8 TW of additional electrical power under BAU energy efficiency assumptions.

About the report

This report shines a spotlight on cooling policy trends, technologies and investment opportunities to help close the gaps in access, affordability and information. It focuses not only on space cooling but also on cold chains for food and health.

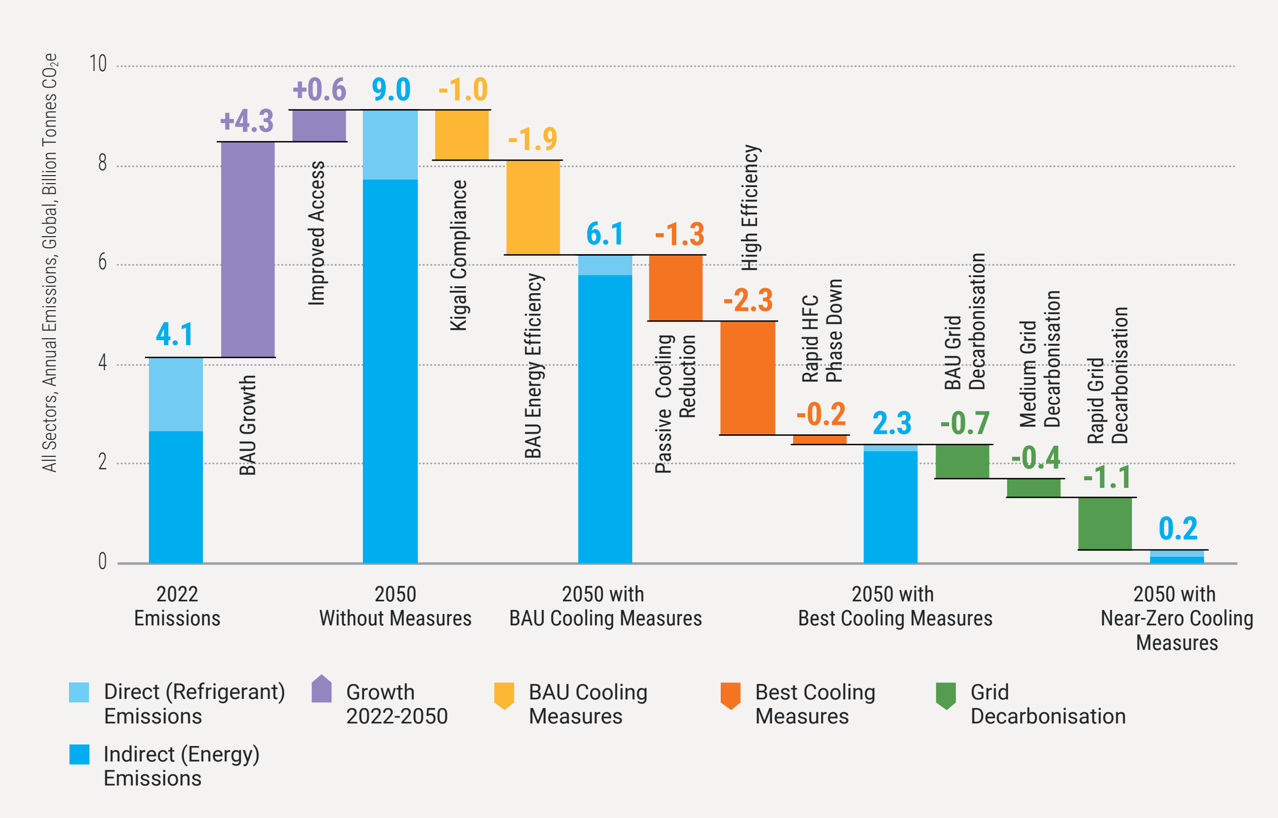
Prepared as a collective output of the Cool Coalition, led by the United Nations Environment Programme (UNEP), the report undertakes, for the first time, modelling of the totality of emissions from cooling, both direct and indirect. It models cooling emissions across all sectors – including space cooling, cold chain and refrigeration, and transport globally – while considering cooling access needs and evaluating the benefits of a comprehensive approach and a pathway to near-zero emissions from cooling.

The report looks at a 2022 baseline and provides projections and intervention scenarios to reduce emissions, while improving access, up to 2050. The modelling allows evaluation of the different measures and pathways by which near-zero emissions from cooling can be achieved, alongside development priorities such as access to cooling for all. The report also provides a status check and an overview of national policy and regulatory actions across all cooling sectors in 192 United Nations Member States (no data was available for the Democratic People's Republic of Korea).

"Heat is a growing health risk, due to burgeoning urbanization, an increase in high temperature extremes, and demographic changes in countries with ageing populations"

Vancouver, Canada
Photo: Margarita Young, shutterstock

Figure ES-1: Global pathway and key steps to achieve near-zero GHG emissions from cooling, 2022-2050



Note: Blue bars show emissions in 2022 and 2050. Purple bars indicate growth. Yellow bars indicate BAU Cooling Measure emission reductions. Orange bars indicate Best Cooling Measure emission reductions. Green bars indicate emission reduction due to electricity grid decarbonisation.

Figure ES-1 illustrates the BAU growth in cooling emissions between 2022 and 2050, together with a pathway to reduced emissions in 2050. This pathway has been developed as a viable way to achieve near-zero emissions from cooling, and also provides significant cumulative energy and economic savings while expanding cooling access to the majority of vulnerable households in 2050.

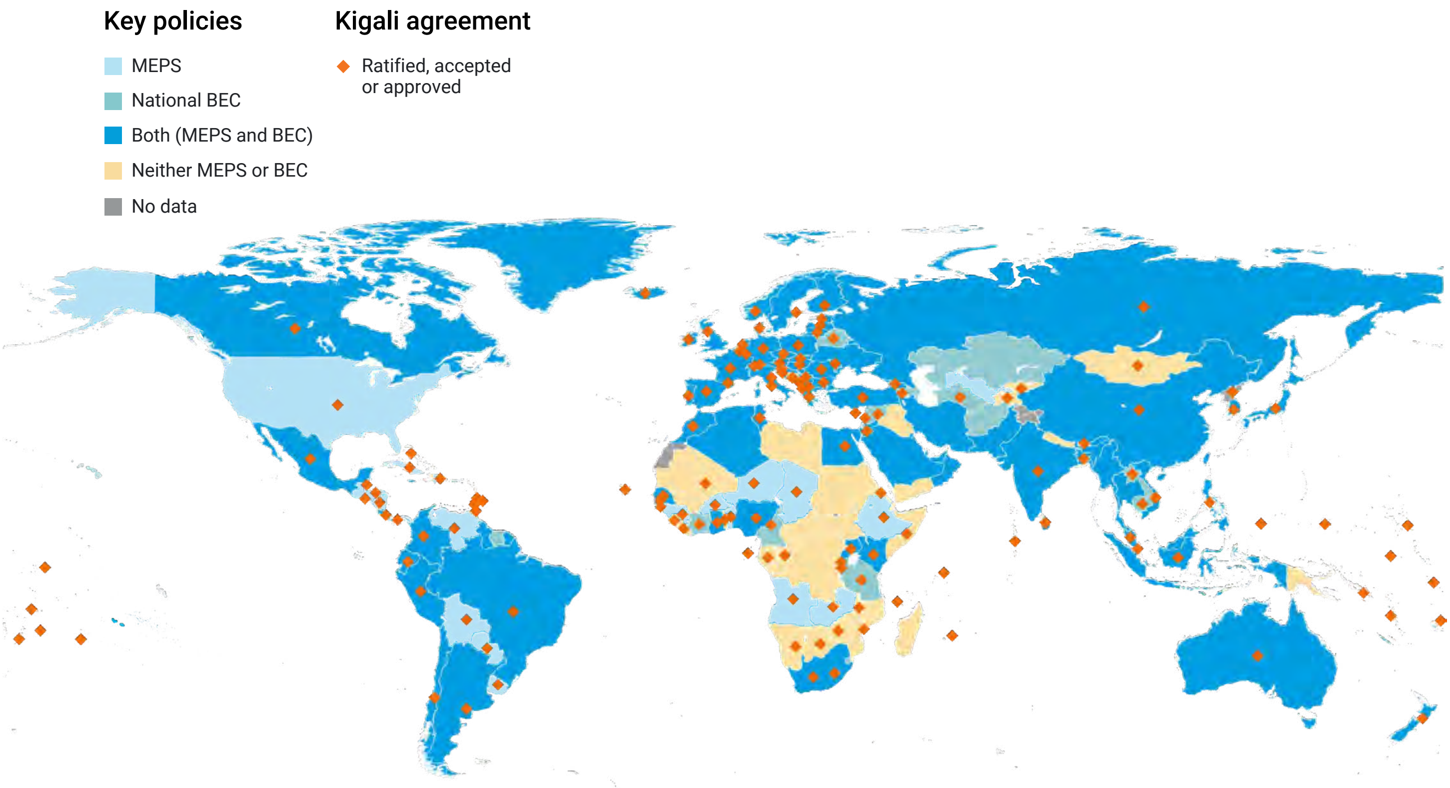
> *"Fully implemented Near-Zero Cooling Measures can reduce the 2050 emissions from cooling by 96 per cent—around 5.9 billion tons of CO_2e emissions—compared with business-as-usual."*

Making it a reality: Three priority action areas to cut cooling emissions

A majority of countries (over 80 per cent) have recognized the importance of advancing sustainable cooling through at least one of three key policy actions at the national level (Figure ES-2). However, efforts are often pilot-scale or siloed, and challenges to implementation are significant.

In addition to compliance with the Kigali Amendment to the Montreal Protocol (which oversees the phase down of HFC refrigerants), it is imperative for countries to take further action in three key areas to achieve near-zero emissions cooling.

Figure ES-2: Distribution of critical national policies to lower cooling emissions across countries



Note: Number of policies in place among the following three: 1) minimum energy performance standards (MEPS) established at the national level for appliances in the cooling sector; 2) national building energy codes (BECs), mandatory, voluntary and under development; and 3) ratification, approval or acceptance of the Kigali Amendment to the Montreal Protocol.

1) Implementing passive cooling strategies
Passive cooling measures can dramatically reduce cooling loads while maintaining indoor thermal comfort as well as temperatures in cold storage. Techniques that can minimize heat ingress and building cooling demand include improved insulation, reflective surfaces, thermal mass, shading through nature and building design, natural ventilation, urban design, landscaping and orientation, and specifications for windows and doors.

Building energy codes that explicitly incorporate such passive cooling measures are one of the most effective regulatory instruments to help reduce cooling demand. These codes can also be extremely important in driving uptake of efficient cooling equipment with low global warming potential (GWP). Sub-national governments can integrate building energy codes into municipal bylaws, and drive their enforcement, but need sufficient capacity to do so.

Such passive cooling measures can curb the growth in demand for cooling capacity in 2050 by 24 per cent, result in capital cost savings in avoided new cooling equipment of around US$1.5 trillion to US$3 trillion (2020 US$) and reduce 2050 emissions by 1.3 billion tons of CO_2e.

Photo: Jeff Smith Perspectives, shutterstock

2) Driving energy efficiency
Installing and operating equipment at high energy efficiency, combined with passive cooling load reduction, could lower 2050 electricity use for stationary cooling equipment below the 2022 level despite the massive increase in cooling. To deliver such a reduction, the global average efficiency of all cooling equipment operating in 2050 would need to be almost triple the average efficiency of equipment operating today. Such efficiency levels are already achieved with today's leading technologies, but these need to be scaled.

Minimum energy performance standards (MEPS) are one of the most effective regulatory instruments that governments can use to increase the efficiency of cooling products. They are most impactful when combined with effective labelling of products to inform consumer choice, financial instruments that drive consumer demand for higher efficiency products, and alignment with regulations for phasing down high-GWP refrigerants. By implementing, regularly updating and enforcing MEPS, countries can accelerate the phase out of the most outmoded cooling technologies, ensure that the existing stock is replaced with more efficient models and avoid becoming a dumping ground for used or outdated products from other countries. A major global push on MEPS and labels will further drive technology development and build the demand base to take innovative, super-efficient appliances to scale.

Driving efficiency in cold chain and refrigeration through MEPS and passive cooling can deliver 30 per cent of the required energy savings by 2050 while greatly reducing food loss and waste. This large energy saving is due to the 24-hour, year-long operation of refrigeration and requires increased policy attention.

3) Phasing down climate-warming refrigerants faster than the timelines established under the Kigali Amendment to the Montreal Protocol, accompanied by energy efficiency drive.
Additional policy actions, beyond the goals of the Kigali Amendment, can achieve the HFC phase down at a faster rate. These include the rapid uptake of low-GWP technologies in all new equipment and enhanced refrigerant life-cycle management to prevent leakages and end-of-life emissions. This can halve the HFC emissions in 2050 as compared to the Kigali phase down timetable.

This should be accompanied by an energy efficiency drive in order to maximize synergies. Key elements are MEPS that incorporate low-GWP refrigerants; increasing the enforcement of building energy codes that reduce the cooling capacity and therefore the amount of refrigerant; and linking with efficiency programmes, such as those of utilities, to incorporate cost-effective opportunities to mitigate refrigerant emissions. Enhanced implementation of stronger regulations on refrigerant recovery during servicing and/or disposal are critical, as is expanded service sector training and consumer awareness programmes.

Strengthening enforcement of the Montreal Protocol and its Kigali Amendment nationally will speed the transition and prevent the illegal trade in banned substances. Survey results show that so far, only 28 countries (out of 68 where data was available) have set up national import tariffs that restrict or constrain access to refrigeration or cooling equipment to prevent dumping.

The above measures can, if fully implemented, reduce the 2050 emissions from cooling by more than 60 per cent—around 3.8 billion tons of CO_2e emissions—compared with business-as-usual (Figure ES-1). The emission reductions grow to 96% when these actions are combined with rapid electricity grid decarbonization. However, so far only 53 countries (27 per cent) have established such policies, via mandatory building codes (68 countries) and MEPs for cooling and refrigeration (115 countries), while more than 150 countries have ratified the Kigali Amendment's action on HFC phase down.

Enabling actions

Countries must urgently examine how, institutionally, they can enhance coordination and sectoral planning for cooling, and explore how regional cooperation and policy harmonization can help unlock economies of scale. Strengthening of monitoring, verification and enforcement, and expanded industry partnership and action, are also critical to success. However, two of the most important areas for enabling action on cooling involve legislative frameworks and financing.

1) An integrated approach

Integrating or aligning policies that support passive cooling, energy efficiency and faster refrigerant phase down is needed to maximize benefits. Governments should incorporate cooling into a comprehensive legislative framework, and in parallel develop National Cooling Action Plans (NCAPs) to ensure coordination and create coherent delivery across stakeholders – including government, manufacturing industry, private sector, research and civil society. By setting a baseline, NCAPs can help countries track efficiency improvements and provide input to HFC phase down plans. Several countries have used NCAPs to begin to align cooling policies such as building codes with passive cooling, MEPS, and refrigerant regulations, and to unlock finance for implementation.

Mainstreaming cooling in a Nationally Determined Contribution (NDC) and in climate strategies, net-zero plans and/or other relevant policy frameworks is another way that countries can drive action towards sustainable cooling and development priorities. Integrating cooling within climate and energy decrees and laws provides a foundation for action, including mandating reporting on annual cooling GHG emissions, or adopting and enforcing standards and codes that may otherwise be voluntary.

Targeted policy support will be necessary. NCAPs, national adaptation plans and strategies, and sub-national climate or heat action plans offer a key opportunity for countries to map and identify the size of their cooling challenge. Countries that currently lack a national strategy on cooling access, but that collect data on equipment ownership and on cooling access rates and gaps, are well placed to integrate cooling access into relevant climate, energy and development policies.

Surabaya, Indonesia
Photo: Jimmy Ofisia, unsplash.com

2) A step-change in financing

Finance is a major challenge and needs to be streamlined, scaled up and better targeted to support the most vulnerable and to scale market adoption of high-efficiency and climate-friendly solutions. The life-cycle cost savings and the societal benefits of deep emissions cuts in cooling will make the transition affordable. Business models, such as cooling-as-a-service (CaaS), energy service company (ESCO) financing, and district cooling, along with finance instruments such as on-bill financing, can take advantage of these life-cycle cost savings and lower the upfront costs for consumers and businesses. At the same time, bulk purchasing of building materials and equipment that cater to green procurement criteria can also lower the construction costs for energy-efficient buildings and equipment. Green mortgages, risk-sharing facilities, on-wage financing and microfinance can enhance access to finance and be targeted to sustainable cooling. In some areas, significant public investment or incentives are needed alongside private investment to ensure the incorporation of sustainable cooling, whether through social housing, urban nature-based solutions, lowering cooling demand in built structures and critical infrastructure such as rural cold chains.

Accelerated action is required to remove barriers to these finance instruments and business models, put in place proper risk management frameworks, and enhance reliable market data to unlock and redirect finance. Critically, a step-change in public, industry, philanthropic and international finance and technical assistance is needed to pilot and scale all these approaches. For many developing countries, dedicated concessional finance will underpin the success of these models and help target finance instruments to the most vulnerable.

Call to action

Industry, governments, investors and others will have to step out of their comfort zones to come together and prioritize the acceleration of sustainable cooling as a means to deliver thermal comfort to vulnerable people and a robust global cold chain that can transform livelihoods and economies.

A strong foundation has been laid thanks to the Kigali Amendment to the Montreal Protocol, and integrating this transition towards low-GWP refrigerants with energy efficiency measures will have a far greater impact on climate change mitigation.

There is a unique opportunity to act thanks to the Global Cooling Pledge issued in conjunction with the 2023 United Nations Climate Change Conference (COP28) in the United Arab Emirates. The pledge provides a strong political push to take immediate steps to reduce emissions, increase passive strategies, bring back nature to cities, improve energy efficiency while phasing down HFCs in the cooling sector and increase access for those most vulnerable. And that can help take the heat off a warming world.

District cooling plant
Photo: Plamen Galabov, shutterstock

The cooling sector is at a critical juncture in its growth and impact trajectory, and its course will depend on action by multiple stakeholders, across various levels of governance.

Telangana, India
Photo: balajisrinivasan, shutterstock

01 Cooling as a global challenge

Cooling is a fundamental necessity in a warming world. As global cooling needs are increasingly met, cooling will be a key contributor to the increasing demand for electricity and refrigerant consumption between now and 2050. Unless rapid actions are taken to transition to sustainable cooling and to lower cooling demand, cooling will play a growing role in accelerating climate change.

As the Earth gets hotter, cooling has become a necessity. It provides thermal comfort, maintains food quality and safety from farm to fork, reduces food loss and waste, and ensures that vaccines are stable and accessible. Cooling enables workforces to remain productive, allows digital economies to be viable and is particularly critical for vulnerable populations. At the same time, the combination of unprecedented growth in electricity demand for cooling, as well as the leakage of refrigerants that have high global warming potential (GWP), makes cooling a key driver of climate change (Woods *et al.* 2022). New analysis in this report shows that, based on current policies, the installed capacity of cooling equipment globally will triple between now and 2050.

This growing demand for cooling is being driven by rising temperatures and increased frequency and intensity of extreme heat waves, rapid urbanization, growing populations, and rising household incomes, especially in the hottest parts of the world (Box 1-1). Such growth in cooling demand and associated greenhouse gas (GHG) emissions is a major driver of climate change and threatens the achievement of a global goal of net-zero GHG emissions.

Mother turning on the air conditioner
Photo: yamasan0708, shutterstock

Cooling enables workforces to remain productive, allows digital economies to be viable and is particularly critical for vulnerable populations.

Box 1-1: Key drivers of cooling demand and related energy use

As the need for cooling grows, the global stock of cooling equipment is expected to increase rapidly over the next few decades, along with the corresponding energy consumption and GHG emissions (International Energy Agency [IEA] 2023). Cooling is already a significant contributor to peak power demand in many regions, and its growth will add further pressure on power grids, especially in developing countries (IEA n.d.). Key drivers that will affect these trends include:

- **Climate change.** The Intergovernmental Panel on Climate Change (IPCC) estimates that GHG emissions from human activities have contributed around 1.1 degrees Celsius (°C) of warming since 1850-1900, and that, averaged over the next 20 years, warming will reach or exceed a further 1.5°C (IPCC 2021). Africa, Latin America, South and East Asia, and the Middle East will see the largest absolute increase in "cooling degree days" as the planet warms – an indicator of the typical cooling required based on local weather conditions (Miranda *et al.* 2023).
- **Population growth.** More than 98 per cent of the population growth between 2022 and 2050 is expected to occur in developing countries, especially in warmer climates (Population Reference Bureau [PRB] 2022; United Nations Department of Economic and Social Affairs [UN DESA] 2022). Africa, which has the highest rate of population growth among major world regions, is expected to account for more than half of global population growth between now and 2050, with the population of sub-Saharan Africa doubling in size (PRB 2022).
- **Income growth.** The global economy has expanded 35 per cent over the last decade (World Economics n.d.), leading to a rising middle class in many developing countries. For households that have growing incomes in hot countries, cooling is high on the list of "must-have" technologies to enable thermal comfort for well-being and productivity (Howarth *et al.* 2023).
- **Urbanization.** The global urban population is expected to grow by 2.3 billion between 2020 and 2050 (UN DESA 2019). By 2040, there will be 64 megacities—cities with more than 10 million inhabitants—with 22 of the 23 new megacities located in the Global South (Oxford Economics 2022). Urban areas are drivers of cooling demand given their density, disappearing green and blue infrastructure, the urban heat-island effect and often higher standards of living.
- **Policies to improve access to cooling.** The amount of cooling consumed per capita varies widely by region. Improving access to cooling will improve health and productivity in hot regions with low gross domestic product (GDP) and will reduce inequalities (thereby supporting Sustainable Development Goal 10). The expected growth in GDP will help improve some of the existing lack of access to cooling, but policy action will be needed to provide cooling to the lowest-income households.
- **Passive strategies to reduce cooling loads.** Insufficient action to ensure building efficiency and passive cooling will be major drivers of cooling growth (see section 2.1).

It is increasingly urgent to meet people's needs for cooling and heat adaptation while also achieving GHG mitigation and development goals, conserving natural resources and improving the local environment.

Kibera, Nairobi, Kenya
Photo: Kuznetsov Alexey, shutterstock

1.1 The urgent need for sustainable cooling

Heat waves and related droughts have devastated lives and livelihoods across the globe in recent years (Yin *et al.* 2023). July 2023 was the hottest month ever recorded in Earth's history (National Aeronautics and Space Administration 2023). In 2021, rising temperatures exposed vulnerable populations to 3.7 billion more "heatwave days[3]" than they did annually during 1986-2005, and heat-related deaths increased 68 per cent between the 2000-2004 period and the 2017-2021 period (Romanello *et al.* 2023).

Many of the world's most vulnerable people have limited or no access to modern cooling technologies – such as air conditioners and refrigerators – whether at home, at school or in the workplace. Cooling is increasingly being understood as a critical infrastructure service, akin to energy, water and others. Without adequate cooling, the challenge of achieving global Sustainable Development Goals (SDGs) will be further exacerbated.[4] A 2023 analysis found that, across 77 countries, an estimated 1.2 billion people are at high risk due to a lack of access to cooling, with women making up 52 per cent of the high-risk population in rural areas and 54 per cent in urban areas (Sustainable Energy for All [SEforALL] 2023a).

Heat impacts have gender implications, including but not limited to longer recovery times for women suffering from heat stress (Iyoho, Ng and MacFadden 2017; Alele *et al.* 2020; SEforALL 2021; Limaye 2023). Several studies have noted that pregnant women are more vulnerable to heat stress and that such vulnerability can also harm the foetus (Jacklitsch *et al.* 2016; International Labour Organization 2019; Scorgie *et al.* 2023). Furthermore, the gendered development thresholds for women, such as lower access to health care, higher incidence of poverty, and burden of household work, are further exacerbated by extreme heat stress events, or worsen the impacts of heat stress on women (Raval 2015; Venugopal 2016; Azhar 2017; SEforALL 2021; Limaye 2023; SEforALL 2023a).

In addition to cooling for thermal comfort, there is an increasing demand for refrigeration and cold chains. This need is especially acute in developing countries, which face growing populations and high levels of malnutrition, yet are confronted with a food system that lacks connectivity and is increasingly insecure due to climate change, leading to high levels of food loss and low prices for producers (UNEP and Food and Agriculture Organization of the United Nations [FAO] 2022). The absence of refrigerated food cold chains resulted in an estimated additional 1 billion tons of carbon dioxide equivalent (CO_2e) emissions from food loss as of 2021 (International Institute of Refrigeration [IIR] 2021). A lack of proper engineering and supply chains results in inefficient operation and financial overruns.

Under the current approach to cooling, referred to as the business-as-usual (BAU) growth scenario, the installed capacity of cooling equipment globally will triple between now and 2050. This would increase emissions from such equipment to 6.1 billion tons of CO_2e per year.

Photo: Maria Orlova, pexels

3 A heatwave day is a meteorological term used to describe a day when the temperature greatly exceeds the long-term average for a specific location and is characterized by unusually hot and often oppressive weather conditions. The specific definition of a heatwave day can vary from one region or country to another, as it depends on local climate norms and thresholds.
4 See, for example, UNEP Cool Coalition (n.d.a); Khosla *et al.* (2021).

It is increasingly urgent to meet people's needs for cooling and heat adaptation while also achieving GHG mitigation and development goals, conserving natural resources and improving the local environment. This requires a rapid transition to sustainable cooling – cooling technologies and approaches that are accessible, affordable and scalable but that minimize the impacts on people and the planet, including through large reductions in GHG emissions (Khosla *et al.* 2021). Cooling should be pursued in a manner that downsizes cooling systems and cooling needs, decreases resource consumption and minimizes the overall environmental impact of cooling.

The transition to sustainable cooling requires taking stock of where the global cooling sector currently stands, analysing where and which actions can have the largest impacts in reducing emissions and improving sustainability, and finding the policy measures that can enable scale and ensure equitable access. Such action on cooling will deliver on a complex set of issues, including the potential to mitigate climate change (by reducing the growth in cooling-related GHG emissions), the urgency of identifying measures to adapt to rising extreme heat, the goals of equity and access to cooling for all, and achievement of the SDGs.

The cooling sector is critical to advancing progress on two international climate-related agreements: the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer, and the Paris Agreement on climate change. The Kigali Amendment, which entered into force in 2019, has been ratified by over 150 Parties and aims for the conversion of refrigerant gases used largely in refrigeration and air-conditioning equipment to environmentally friendly alternatives, which can result in a reduction in global warming of up to 0.5°C (United Nations Environment Programme [UNEP] Ozone Secretariat 2022; UNEP Ozone Secretariat 2023a). The Paris Agreement, which entered into force in 2016 and has been adopted by 196 Parties, calls on countries to reduce GHG emissions, with the goal of limiting the rise in average global temperature to 2°C above pre-industrial levels, and ideally to 1.5°C

1.2 Global cooling stocktake report

The cooling sector is at a critical juncture in its growth and impact trajectory, and its course will depend on action by multiple stakeholders, across various levels of governance. This first global cooling stocktake report provides an overview of implemented country actions and activities on

Action on cooling will deliver on a complex set of issues, including the potential to mitigate climate change (by reducing the growth in cooling-related GHG emissions), the urgency of identifying measures to adapt to rising extreme heat, the goals of equity and access to cooling for all, and achievement of the SDGs.

Kowloon, Hong Kong, Asia
Photo: Geeyom, shutterstock

cooling, and presents a modelled pathway to get to near-zero GHG emissions from cooling. It aims to answer the following questions:

- **What is the policy landscape for national sustainable cooling actions around the world?**
- **What is the impact of national cooling policy actions on GHG emissions?**
- **What are the fastest and most effective means of achieving near-zero emissions from cooling while providing access to cooling for all?**

The report relies on predictive modelling and on an extensive literature review and analysis to provide a comprehensive review of cooling applications in both stationary settings (such as buildings) and mobile settings (such as cars and trucks). It specifically explores space cooling and cold chains in the residential, commercial, industrial, agricultural and transport sectors. Space cooling refers to thermal comfort applications in all types of buildings and in vehicles. The cold chain refers to the processing and storage technologies responsible for keeping food, drinks, pharmaceuticals and other products at controlled temperatures.

Modelling data presented are from a Global Cooling Emissions Model adapted specifically for this report (Gluckman Consulting 2023). It is a comprehensive, bottom-up stock modelling tool for assessing the GHG emissions from refrigeration and air conditioning. The tool is based on 14 regional sub-models that represent geographic regions and country groupings under the Kigali Amendment. It provides historical modelling from 1990 to 2022 as well as forecasts up to 2050.

Although the modelling did not include emissions from food loss associated with an incomplete cold chain and lack of refrigeration, the report features case studies that demonstrate the importance of cooling for limiting food loss and reducing urban heat islands.

Current space cooling technologies include room air conditioners, packaged units and chillers. Residential refrigeration is served largely with sealed systems, while commercial refrigeration may be served with small sealed systems, or large centralized or decentralized refrigeration systems. Industrial refrigeration is served largely with centralized refrigeration systems. Transport applications for cooling include mobile air conditioning in vehicles (cars, vans, trucks, buses and trains) as well as refrigerated transport (in vans, trucks and iso-containers).

These cooling technologies rely mostly on the vapour compression cycle, composed of a compressor, condenser, expansion device and evaporator. Improving the efficiency of cooling equipment can be achieved through a range of transformative emerging technologies – such as advanced heat exchangers and variable-speed compressors – that provide higher energy efficiency gains and and minimize the need for refrigerants with high global warming impact. More details on different cooling equipment, their capacity range, typical usage and current market size can be found in the technologies primer in Annex 1.

Kyoto, Japan
Photo: Jason Low, unsplash.com

Emissions from cooling in 2050 could be cut by over 60 per cent (around 3.8 billion tons of CO_2e emissions) compared to business-as-usual that year, while expanding cooling access to 3.5 billion people; the cuts could reach 96 per cent depending on rates of electricity decarbonization.

France
Photo: Bee Bonnet/shutterstock

02 The pathway to near-zero emissions from cooling

Emissions from cooling in 2050 could be cut by over 60 per cent (around 3.8 billion tons of CO_2e emissions) compared to business-as-usual that year, while expanding cooling access to 3.5 billion people; the cuts could reach 96 per cent depending on rates of electricity decarbonization.

This chapter provides the results of modelling GHG emission scenarios from cooling equipment between 2022 and 2050. The scenarios all assume significant growth in cooling equipment stock. The modelling covers equipment in four main markets for stationary cooling (residential space cooling, non-residential space and process cooling, residential cold chain, and non-residential cold chain) as well as two main areas of transport cooling (mobile air conditioning and refrigerated transport). It calculates both the direct emissions from refrigerants, emitted and leaked from cooling equipment, and indirect emissions, released from the power generation required for operating the cooling equipment.

The four modelled scenarios are:

a) **"Without Measures"** – a worst-case scenario which assumes, from 2022, no improvements to energy efficiency, no compliance with the Kigali Amendment and no further electricity decarbonization.
b) **"BAU Cooling Measures"** – which assumes that emissions from cooling will steadily reduce via existing cooling-related policy measures that will slowly improve energy efficiency and deliver compliance with the Kigali Amendment.
c) **"Best Cooling Measures"** – which assumes that improved cooling-related policy measures will 1) minimize growth in the cooling load through passive cooling strategies; 2) maximize the energy efficiency of new cooling equipment; 3) improve the operational efficiency of existing equipment; and 4) reduce the use and emissions of hydrofluorocarbon (HFC) refrigerants at a faster rate than required by the Kigali Amendment.
d) **"Near-Zero Cooling Measures"** – which combines Best Cooling Measures with rapid electricity decarbonization (leading to zero-carbon electricity by 2050 in developing countries and by 2035 in developed countries). In this scenario, 2050 emissions are 94 per cent below 2022 emissions and 96 per cent below those in the 2050 BAU Cooling Measures scenario.

Compared to the BAU Cooling Measures scenario, the Best Cooling Measures scenario could reduce the overall growth in the cooling equipment stock by 24 per cent (up to 2050) without compromising access to cooling, and it could save end users US$1 trillion (2020 US$) in 2050 due to reduced electricity use.

Under the Best Cooling Measures scenario, the reduction in cumulative electricity consumption between 2022 and 2050 is modelled to be 110,000 terawatt-hours (TWh), creating savings of US$17 trillion (2020 US$) for end users over this 28-year period. This also translates into a reduction in peak electricity demand of between 1.5 terawatts (TW) and 2 TW in 2050, thereby avoiding the construction of 1,500 to 2,000 large power stations with a capacity of 1,000 megawatts (MW) each and the related transmission and distribution infrastructure. This represents a power sector investment savings of US$4 trillion to US$5 trillion (2020 US$) by 2050.

Furthermore, the significant reduction in global cooling-related emissions can be translated into savings in the social cost of carbon, as discussed in Rennert *et al.* 2022. Using the authors' preferred social cost of carbon of US$185 per tonne of CO_2e, the cumulative savings between 2022 and 2050 are US$16.5 trillion (2020 US$).

Full details of the modelling methodology are outlined in Annex 2.

2.1 Cooling equipment stock

In 2022, the global installed capacity of cooling equipment totalled an estimated 22 TW, and nearly all this equipment – 94 per cent of the total installed cooling capacity – was for space cooling of buildings and vehicles (see Annex 3). The modelling covered most equipment used for stationary and transport cooling, with the notable exceptions of heating-only heat pumps and ceiling fans.

Based on the modelling results, 46 per cent of the cooling capacity as of 2022 was installed in developing countries (so-called Article 5 countries under the Montreal Protocol) and is expected to increase to 67 per cent by 2050. Developing countries drive the growth in installed cooling capacity as well as in related electricity consumption and GHG emissions, and are expected to consume a higher percentage of the electricity used for cooling globally than their share of the installed cooling capacity. This is due mainly to the higher temperatures in these locations, along with the use of lower-efficiency equipment.

Projected stock growth

The global stock of cooling equipment is expected to grow rapidly over the next few decades, driven by rising populations, incomes and temperatures (Box 1-1). To model population growth, the Global Cooling Emissions Model used mid-growth forecasts from the United Nations (UN DESA 2022). To model income growth, it used the Shared Socio-Economic Pathway SSP2 ("Middle of the Road") GDP forecasts from the United Nations Framework Convention on Climate Change (UNFCCC) (International Institute for Applied Systems Analysis 2018).

The Global Cooling Emissions Model explored three scenarios for growth in the cooling equipment stock:

- **Business-as-usual (BAU) growth**, which uses published mid-level forecasts for population and GDP growth and assumes a further 1°C of global warming by 2050.
- **Improved access growth**, which represents an increase to BAU Growth, taking into account efforts to improve access to cooling globally and leading to extra growth in space cooling and cold chain refrigeration.
- **Improved access growth with passive load reduction**, which leads to a reduction in cooling equipment growth through the use of passive measures such as improved building design.

Figure 2-1 illustrates the three modelled growth scenarios for cooling equipment from 2022 to 2050.

Business-as-usual growth (BAU)

uses published mid-level forecasts for population and GDP growth and assumes a further 1°C of global warming by 2050

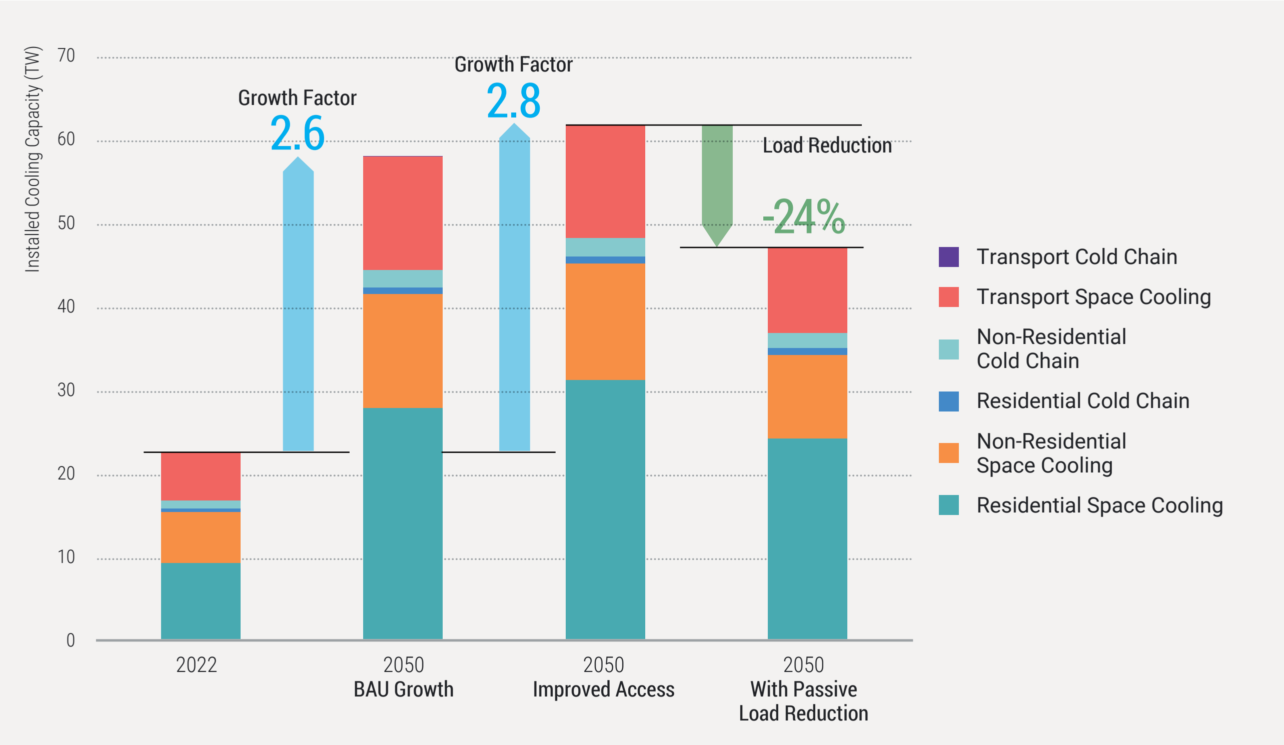
Improved access growth

represents an increase to BAU Growth to give cooling access to around 1 billion of the poorest households

Improved access growth with passive load reduction

leads to a reduction in cooling equipment growth

Figure 2-1: Global cooling capacity in 2022 and under three scenarios for growth to 2050



Source: Global Cooling Emissions Model

BAU growth scenario

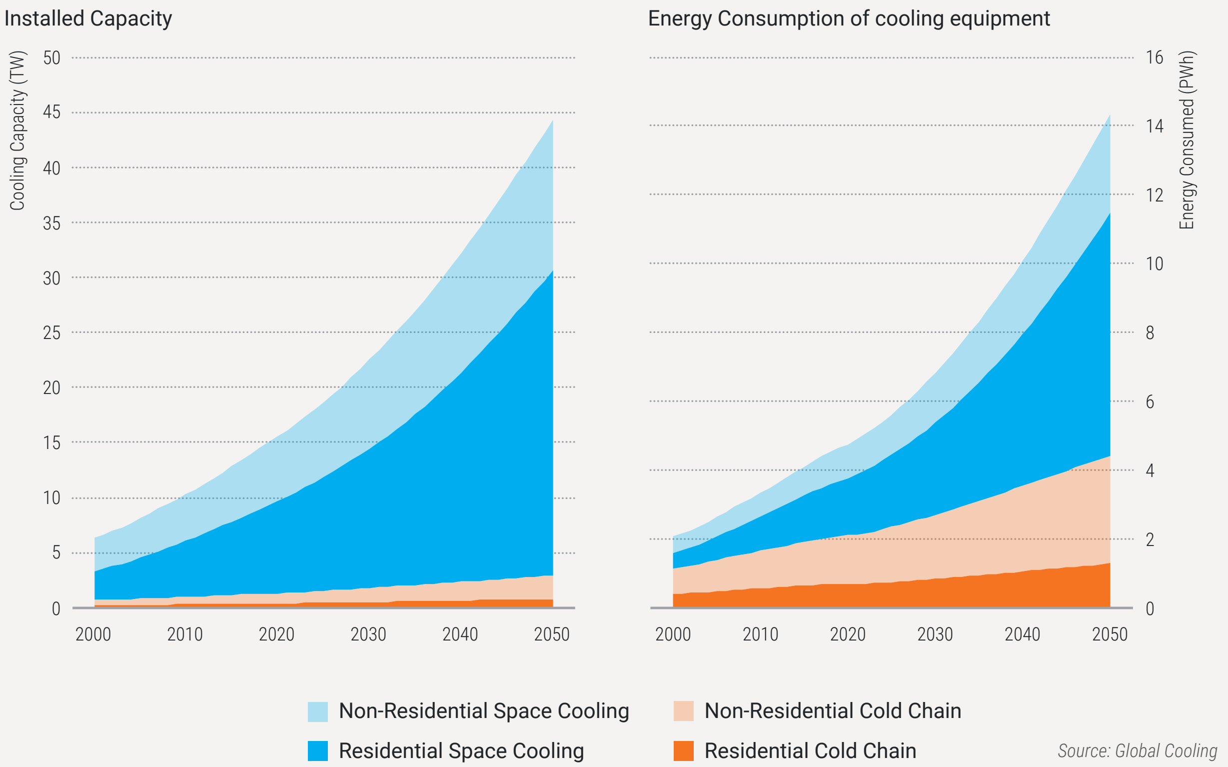
Under this scenario, the cooling equipment stock increases in capacity by a factor of 2.6, rising from 22 TW in 2022 to 58 TW in 2050 (Figure 2-1). This is the equivalent of 16 billion mini-split air-conditioning units, assuming a typical capacity of 3.5 kilowatts (kW).

Growth in the installed cooling capacity is fastest for residential space cooling equipment (it is expected to increase by a factor of three between 2022 and 2050, whereas the cold chain and non-residential space cooling are expected to grow by a factor of two (Figure 2-2a). Energy use grows faster for space cooling than for cold chain refrigeration because the expected rise in global temperatures will increase the operating hours of space cooling equipment. However, in terms of energy consumption, cold chain makes a significant contribution to the global total (Figure 2-2b). This is because most space cooling equipment operates for fewer running hours annually than cold chain equipment.

Jakarta, Indonesia
Photo: Dewi Karuniasih/ unsplash.com

The relationship between the installed cooling capacity and the annual energy consumption from cooling has important policy implications. The peak electrical demand from cooling equipment is created largely by the use of space cooling equipment in hot weather. However, the annual energy-related GHG emissions from cooling are more evenly split between space cooling and the cold chain. This makes it equally important to focus on policies aimed at improving cold chain efficiency as on policies for space cooling.

Figure 2-2: **2a) Installed capacity and 2b) energy consumption of stationary cooling equipment under the BAU Growth scenario, 2000-2050**



Source: Global Cooling Emissions Model

Improved access growth scenario

A report from Sustainable Energy for All assessed populations at risk of having no access to cooling and found that, across 76 countries, 1.1 billion people were at high risk of having no cooling access and 3.8 billion people were at moderate or low risk, as of 2022 (SEforALL 2023). Looking ahead, a study by Andrijevic *et al.* (2021) forecasts that by 2050, the number of people without access to cooling could reach two to five billion, depending on GDP growth. The study provides a mid-range estimate of 3.5 billion people at risk under the UNFCCC's Shared Socio-Economic Pathway (SSP2), which is the pathway used for GDP growth in the Global Cooling Emissions Model.

Under the BAU growth scenario, the expected increase in GDP over the coming decades will allow a greater share of households in hot regions to have space cooling and refrigeration. However, the poorest households in many regions could still face a lack of access in 2050. The improved access growth scenario models the increase to BAU growth that is required to expand cooling access to most of the world's population by 2050. It assumes that each household in warm and hot regions needs a minimum of one air-conditioning unit (of 3.5 kW, or one refrigeration-ton) and one refrigerator, and that passive cooling measures are used wherever possible.

Based on the assumption that extra cooling equipment for 3.5 billion people will be needed to meet global cooling needs in 2050, the total cooling capacity in 2050 increases 7 per cent under the improved access scenario, from 58 TW to 62 TW. Across developing countries overall, this means an added 10 per cent growth in cooling capacity on average; however, in Africa the required capacity growth for improved access is higher at 27 per cent (rising from 5.3 TW under BAU growth to 6.7 TW in 2050).

Improved access growth scenario with passive load reduction

Some of the growth in cooling demand in the BAU and improved access scenarios can be avoided through the implementation of so-called passive measures (as distinguished from "active" cooling measures that involve the use of electric equipment such as air conditioners and refrigerators).

A range of building design strategies are available to reduce space cooling loads passively, such as optimizing the types of construction materials selected, using reflective surfaces, providing natural ventilation and using shading. For new building construction projects, reductions in load of 30 to 40 per cent are typical, and in some circumstances reductions of more than 50 per cent are feasible (Al-Tamimi 2022). However, the rate of change in the building stock is slow, and new building design measures take a long time to affect the total space cooling capacity. For existing buildings, cooling loads can be reduced through retrofits, resulting in typical load reductions of 10 to 20 per cent (Hondeborg *et al.* 2023).

Reducing cooling loads in the cold chain is equally important because the replacement cycle for cold chain refrigeration equipment is typically around 10 to 15 years, which is much shorter than for buildings (50 years) (Ji, Lee and Yi 2021). Therefore, relevant cold chain policies can have a faster impact on reducing cooling capacity and GHG emissions.

Passive measures in the cold chain – such as the mandatory use of doors on food and drink retail display cases – can quickly lead to reduced cooling loads. Display cases with doors consume less than half the energy of open display cases (Foster *et al.* 2018), and the cost of adding doors to new display cases is offset by the reduced cost of a considerably smaller refrigeration system. Doors can also be retrofitted to existing display cases. Another example of passive cooling is the use of ambient free cooling (such as from cold water) in some food manufacturing processes (see chapters 4 and 5).

Opportunities for load reduction through passive cooling were modelled for each of the six market sectors covered in this study. Overall, the adoption of passive measures is forecast to reduce the growth in the cooling load in 2050 by 24 per cent (falling from 62 TW to 47 TW), as shown in Figure 2-1. This reduction in cooling capacity will save end users a significant capital investment. If cooling equipment costs in the range US$100 to US$200 per kW (2020 US$), then a 15 TW reduction in cooling capacity will avoid costs of between US$1.5 trillion and US$3 trillion by 2050 (2020 US$).

"Passive measures could reduce cooling loads by 24%, with savings in investment costs, energy costs and GHG emissions."

Dubai,
United Arab Emirates
Photo: John Wreford/
shutterstock

2.2 Cooling equipment energy efficiency

In 2022, stationary cooling accounted for 19 per cent of global electricity use. Without improvements to energy efficiency, the growing stock of cooling equipment will lead to much higher electricity loads, resulting in significant investment in electricity generation infrastructure, much higher electricity bills for end users and a massive increase in GHG emissions. However, there is great potential to meet the rise in cooling demand without such significant growth in electricity consumption (UNEP and International Energy Agency [IEA] 2020).

The Global Cooling Emissions Model estimates the annual energy consumption of cooling equipment considering several equipment variables: the growing stock, efficiency of new equipment, use patterns and operational efficiency (see Annex 4).

Energy saving scenarios

Four energy efficiency scenarios have been assessed, as summarized in Table 2-1.

Table 2-1: Energy efficiency scenarios for cooling equipment modelled

Energy efficiency scenario	Description
No efficiency gain	Efficiency levels of new equipment are frozen at 2022 levels. This is a counterfactual without-measures scenario.
BAU efficiency gain	Medium energy efficiency levels are introduced slowly. This is the BAU pathway, with efficiency improvement being driven by relatively weak policies.
Mid efficiency gain	Medium energy efficiency levels are introduced more rapidly, and some high-energy efficiency levels are introduced.
High efficiency gain	High energy efficiency levels are introduced rapidly.

Hong Kong, China
Photo: Chromatograph/unsplash.com

19%

of global electricity in 2022 was used for stationary cooling

The impact of improving energy efficiency can be significant. Combining the high efficiency gain scenario with passive load reduction measures would result in electricity use in 2050 that is below that in 2022. Figure 2-3 illustrates the electricity consumption from stationary cooling applications under four scenarios:

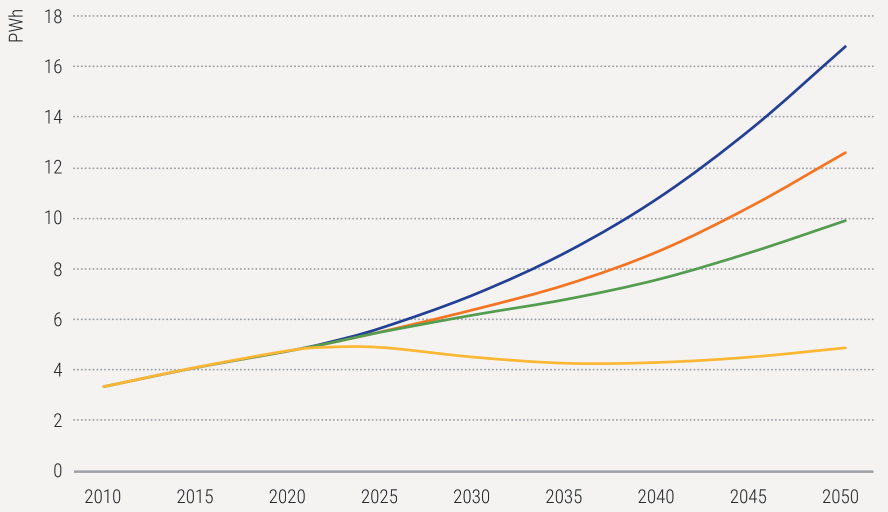
(A) With improved access and no efficiency gain, the use of electricity increases by a factor of 3.3, from 5,000 TWh in 2022 to 16,800 TWh in 2050.

(B) With improved access and BAU efficiency gain, the use of electricity increases by a factor of 2.5, from 5,000 TWh in 2022 to 12,600 TWh in 2050.

(C) With the addition of passive load reduction measures, electricity consumption is 9,900 TWh in 2050.

(D) With the addition of high efficiency gain, electricity use drops in 2050 to 4,800 TWh, despite the substantial increase in equipment stock.

Figure 2-3: Projected global electricity use for stationary cooling under four scenarios, 2010-2050



Source: Global Cooling Emissions Model

"Best efficiency measures are essential to avoid a tripling of electricity consumption from increased cooling demand."

Thailand
Photo: sutipong/shutterstock

Financial benefits of cooling efficiency

The cost benefits of following a pathway with high efficiency gain together with passive load reduction measures are considerable, both for end users and for electricity producers. In comparison to the BAU Cooling Measures scenario (BAU efficiency gain without passive load reduction measures), the global benefits for stationary space cooling and cold chain refrigeration are estimated to be:

- **A reduction in electricity consumption** of 7,200 TWh in 2050. Assuming an electricity cost of US$0.15 per kilowatt-hour (kWh), this would create annual savings for end users of around US$1 trillion in 2050 (2020 US$).

- **A reduction in cumulative electricity consumption** between 2022 and 2050 of 110,000 TWh, creating savings of US$17 trillion for end users over this 28-year period (2020 US$).

- **A reduction in peak electricity demand** of between 1.5 TW and 2 TW in 2050, thereby avoiding the construction of 1,500 to 2,000 large power stations with a capacity of 1,000 MW each. Assuming it costs US$2 million per MW to build a new electric power station plus a further 30 per cent for extra transmission and distribution costs, this represents a power sector investment savings of US$4 trillion to US$5 trillion by 2050 (2020 US$).

Savings associated with the social cost of carbon are also essential to quantify. A 2022 study by Rennert *et al.* suggested that the social cost of carbon may vary significantly due to economic and social factors. Their estimates are based on regionally disaggregated damage functions for four sectors (agriculture, energy, mortality and sea-level rise). Their mean social cost of carbon estimate using the preferred discounting scheme is US$185 per ton of CO_2e (US$44 to US$413 per ton of CO_2e: 5-95 per cent range) in 2020 US$. This suggests that the cumulative savings range from US$4 to US$38 trillion (2020 US$), with a likely value of US$16.5 trillion (2020 US$).

Although new high-efficiency cooling equipment is often more expensive than low-efficiency alternatives, experience with energy performance standards and labelling initiatives has shown that as a new high-efficiency technology matures, any capital cost difference between low- and high-efficiency designs will likely shrink. In the United States of America, a series of minimum energy performance standards (MEPS) applied to domestic refrigerators over a 40-year period led to a 75 per cent reduction in electricity consumption and to a 50 per cent reduction in capital cost (United States Association of Home Appliance Manufacturers 2016). The IEA (2018) estimates an equipment cost increase of only one per cent between 2022 and 2050 for the rapidly growing air-conditioning market. The considerable electricity savings described above are likely to be achieved without significant extra investment cost.

Energy efficiency improvements

The average operating energy efficiency of all existing cooling equipment in 2022 is estimated to be 2.5 (expressed in terms of an annual energy efficiency ratio or AEER, the ratio of annual cooling delivered to the annual energy used).
The modelling shows that in 2050, the AEER improves to 3.6 with BAU efficiency gain and to 7.2 with high efficiency gain.

Mayfield, Australia
Photo: Janaya Dasiuk/unsplash.com

2.3 Reducing direct GHG emissions from refrigerants

Refrigerants with high global warming potential, such as R-404A and HCFC-22, are widely used in cooling equipment, although various low-GWP alternatives are entering the market. Refrigerants create direct GHG emissions in two main ways: 1) through leakage during equipment operating life and 2) during equipment manufacture, installation, maintenance and at end-of-life. The phase out and phase down of high-GWP refrigerants is controlled under the Montreal Protocol and its Kigali Amendment, with different timelines for different developed and developing country groups. For a discussion of common refrigerants and their GWPs in the context of the refrigerant transition, see Annex 5.

In the Global Cooling Emissions Model (described in detail in Annex 7), reductions in direct refrigerant emissions were modelled considering the following:

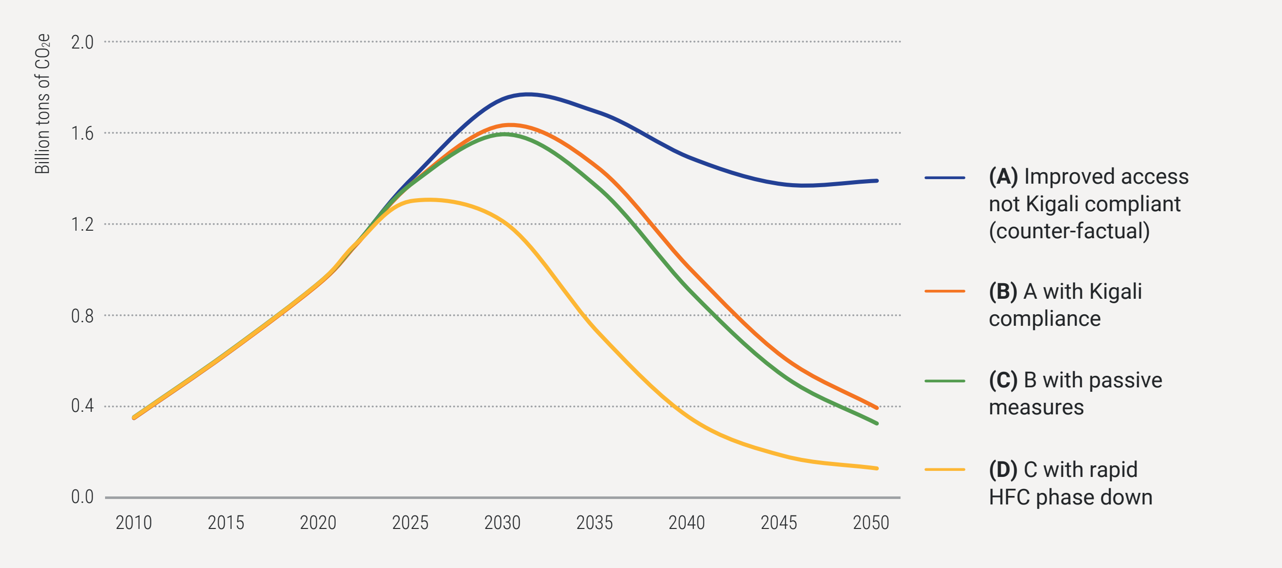
- the use of lower-GWP refrigerants in new equipment being purchased
- reduction in the rate of leakage during operating life
- reduction of emissions during servicing and at end-of-life
- retrofitting high-GWP refrigerants with lower-GWP alternatives in existing equipment.

The rate of emission reduction is dependent on the level of uptake of these opportunities. For this report, four scenarios for HFC refrigerant consumption and emission reduction were modelled, as shown in Table 2-2. The Faster Action and Rapid HFC Phase Down scenarios illustrate that it is possible to achieve the HFC phase down at a faster rate than in the Kigali Amendment (Figure 2-4).

Table 2-2: HFC mitigation scenarios

HFC mitigation scenario	Description
Base Case	Slow transition away from high-GWP refrigerants without Kigali compliance. This is a counterfactual without-measures scenario.
Kigali Compliant (BAU)	Achieving the Kigali Amendment targets according to the schedule agreed by Parties to the Montreal Protocol in 2016. This is the BAU pathway, as most countries have already ratified the Kigali Amendment.
Faster Action	A faster phase down of HFCs than required under the Kigali Amendment.
Rapid HFC Phase Down	Rapid uptake of low-GWP technologies and emission reduction policies. This is a realistic Best Cooling Measures pathway that is based on the use of low-GWP technologies already in use in some regions.

Figure 2-4: Global HFC emissions from cooling under four mitigation scenarios, 2010-2050



Source: Global Cooling Emissions Model

2.4 Cooling in transport applications

In addition to stationary cooling applications, the Global Cooling Emissions Model considered two transport applications: mobile air conditioning and refrigerated transport. Mobile air conditioning of vehicles (including cars, vans, trucks, buses and trains) creates a significant demand for space cooling, with the installed capacity projected to increase from 6 TW in 2022 to 14 TW in 2050. As of 2022, most mobile air conditioners in road vehicles were powered by either a gasoline or diesel internal combustion engine.

As the transition to electric vehicles continues, a large share of road vehicles is expected to be powered using battery electric motors. This will reduce the indirect GHG emissions from mobile air conditioners. Internal combustion engines are inefficient and have high GHG emissions, whereas electric vehicle batteries are charged from the grid, which is rapidly being decarbonized. Although the pathway for electrifying heavy trucks and other large, long-distance vehicles is still unclear, these have only a small share of the overall stock of mobile air conditioners.

Transport refrigeration systems are currently powered either directly from the vehicle engine (for refrigerated vans and small trucks) or with a small, dedicated diesel engine. Transport refrigeration is a vital part of the cold chain, but in terms of cooling capacity it represented less than 0.5 per cent of the total global cooling capacity in 2022.

Transport refrigeration is a vital part of the cold chain, but in terms of cooling capacity it represented less than

0.5 per cent

of the total global cooling capacity in 2022.

2.5 Grid decarbonization

In parallel with efforts to reduce cooling loads and to improve the efficiency of cooling equipment, all countries are expected to decarbonize their electricity supply. For each of the 14 regions in the Global Cooling Emissions Model, the current average carbon emission factor for the grid was established (measured in grams of CO_2 emitted per kWh generated) (Our World in Data 2023).

Three decarbonization scenarios were modelled in each region, based on assumptions about the pace of grid decarbonization (Table 2-3).

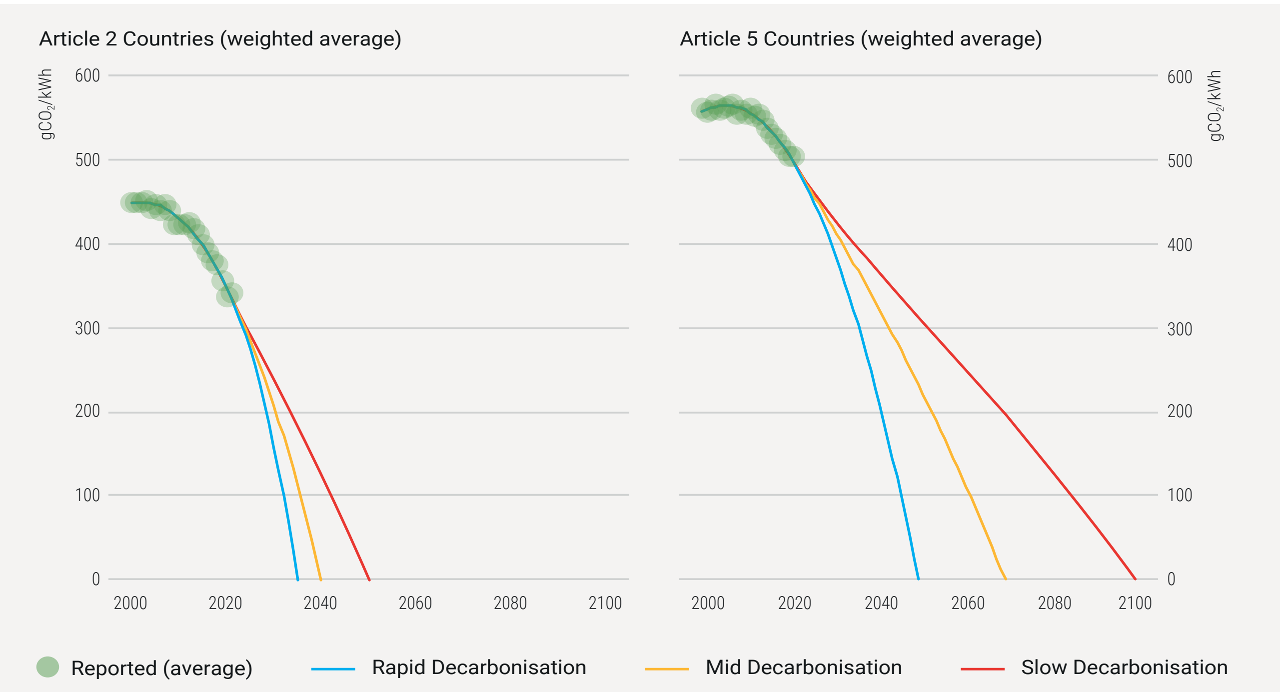
Niksic, Montenegro
Photo: Appolinary Kalashnikova/unsplash.com

Table 2-3: Basis of grid decarbonization scenarios modelled

Grid decarbonization scenario	Developed countries	Developing countries
BAU decarbonization	Reaching zero in 2050	Reaching zero in 2100
Mid decarbonization	Reaching zero in 2040	Reaching zero in 2070
Rapid decarbonization	Reaching zero in 2035	Reaching zero in 2050

Figure 2-5 illustrates historical grid factors and the three decarbonization scenarios for the average of all developed (Article 2) countries and the average of all developing (Article 5) countries.

Figure 2-5: Electricity decarbonization profiles for Article 2 and Article 5 regions, 2010-2100



Source: Global Cooling Emissions Model

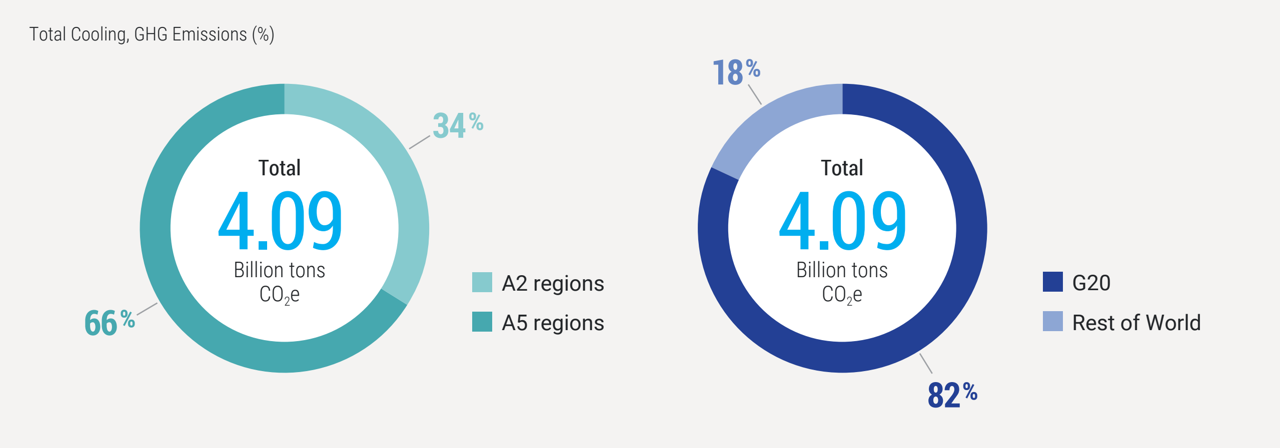
2.6 Reducing GHG emissions from cooling

For each of the six modelled markets, the Global Cooling Emissions Model was used to project the estimated trajectory of GHG emissions between 2022 and 2050.

In 2022, the GHG emissions from global cooling equipment totalled an estimated 4.1 billion tons of CO_2e (see Annex 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 emissions of hydrochlorofluorocarbons (HCFCs) as well as hydrofluorocarbons (HFCs), as significant use of HCFCs still occurs in developing countries.

Figure 2-6a provides a breakdown of the GHG emissions from cooling in 2022 between developed (Article 2) and developing (Article 5) regions (see country list in Annex 7). Figure 2.6b shows a breakdown of these emissions between G20 countries and the rest of the world. These results indicate that cooling action in G20 countries would have a profound impact on achieving a scenario of near-zero emissions from cooling.

Figure 2-6: GHG emissions from cooling by region, 2022



Source: Global Cooling Emissions Model

Photo: Sebastiano Piazzi/unsplash.com

GHG emission pathways to 2030 and 2050

As described in sections 2.1 to 2.5, several independent variables affect future GHG emissions from cooling. These are the rates of:

- growth in the cooling equipment stock
- implementation of energy efficiency improvements for new and existing cooling equipment
- implementation of HFC emission mitigation actions
- transition to electric vehicles
- decarbonization of the electricity supply.

Different combinations of these variables lead to a wide range of pathways between now and 2050. Around 150 pathways were modelled, with results available for the global total, for the 14 regions, and for country groupings such as developed/developing countries and the G20 and G7 countries (Gluckman Consulting 2023). The outputs highlighted in this section illustrate a progression from a Without Measures scenario (no improvements after 2022), through BAU Cooling Measures, Best Cooling Measures to the Near-Zero Cooling Measures scenarios in 2030 and 2050. Table 2-4 describes the steps that lead to the Near-Zero Cooling Measures scenario, based on the modelling assumptions given earlier.

Table 2-4: Steps leading to a pathway of near-zero emissions from cooling

<table>
<tr><th></th><th>Pathway</th><th>Stock growth</th><th>HFC mitigation</th><th>Energy efficiency</th><th>Grid decarbonization</th></tr>
<tr><td>A</td><td>Without Measures – BAU growth</td><td>BAU</td><td rowspan="2">No Kigali compliance</td><td rowspan="3">No efficiency gain</td><td rowspan="7">No decarbonization</td></tr>
<tr><td>B</td><td>Without Measures – Improved access</td><td rowspan="3">Improved access</td></tr>
<tr><td>C</td><td>B + Kigali compliance</td><td rowspan="4">Kigali compliant</td></tr>
<tr><td>D</td><td>C + BAU energy efficiency gain</td><td rowspan="2">BAU efficiency gain</td></tr>
<tr><td>E</td><td>D + Passive cooling load reduction</td><td rowspan="6">Improved access plus Passive cooling load reduction</td></tr>
<tr><td>F</td><td>E + High energy efficiency gain</td><td rowspan="5">High efficiency gain</td></tr>
<tr><td>G</td><td>F + Rapid HFC phase down</td><td rowspan="4">Rapid HFC phase down</td></tr>
<tr><td>H</td><td>G + BAU grid decarbonization</td><td>BAU</td></tr>
<tr><td>I</td><td>H + Mid grid decarbonization</td><td>Mid</td></tr>
<tr><td>J</td><td>I + Rapid grid decarbonization</td><td>Rapid</td></tr>
</table>

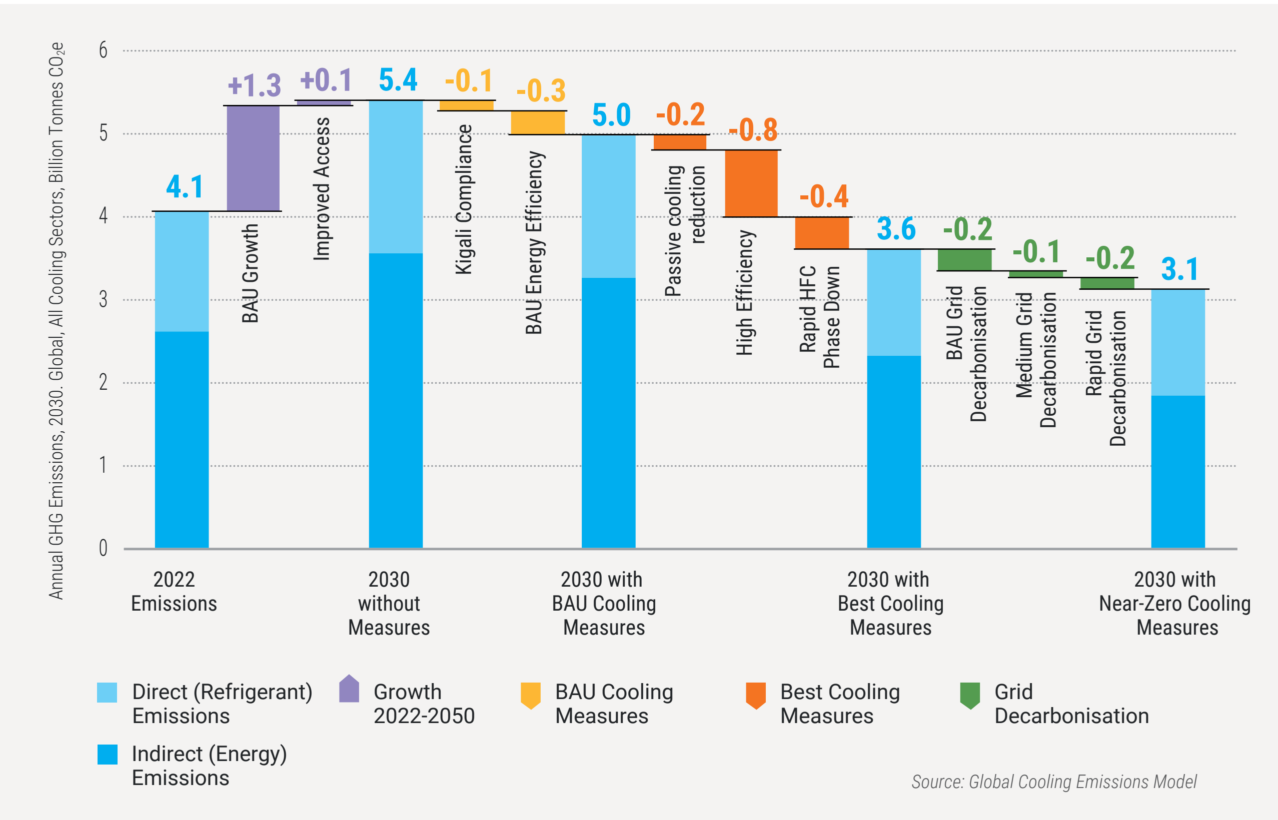
> *"The adoption of passive measures can reduce the growth in the cooling load in 2050 by 24 per cent (falling from 62 TW to 47 TW)."*

Rajasthan, India
Photo: Damini Rathore/unsplash.com

Pathway to 2030

Figure 2-7 shows the possible pathway towards near-zero emissions from cooling in the period to 2030. The BAU Cooling Measures scenario would create a 33 per cent increase in GHG emissions between 2022 and 2030, whereas the Near-Zero Cooling Measures scenario will create a 23 per cent reduction in emissions.

Figure 2-7: Global pathway: progress toward near-zero GHG emissions from cooling as of 2030



Note: Blue bars show emissions in 2022 and 2050. Purple bars indicate growth. Yellow bars indicate BAU Cooling Measure emission reductions. Orange bars indicate Best Cooling Measure emission reductions. Green bars indicate emission reduction due to electricity grid decarbonisation.

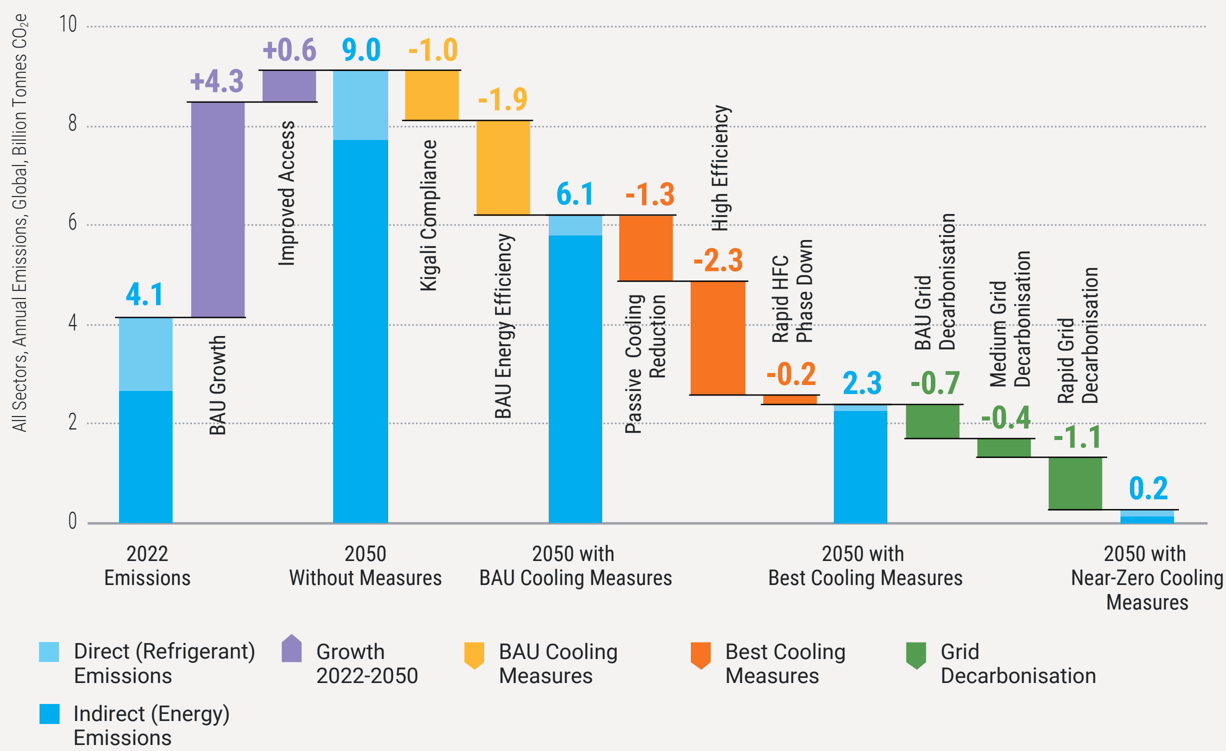
Global emission forecast to 2050

The global pathway towards near-zero emissions from cooling in 2050, for all cooling applications, is shown in Figure 2-8. With rapid grid decarbonization, the projected 2050 emissions fall to around 0.2 billion tons of CO_2e. This represents a 97 per cent reduction from the Without Measures scenario, a 96 per cent reduction from the BAU Cooling Measures scenario and a 94 per cent reduction compared with the 2022 emissions from cooling. The Best Cooling Measures plus a medium grid decarbonization scenario is forecast to deliver a 68 per cent reduction in annual emissions in 2050 compared to 2022. This is the overarching goal, as captured in the Global Cooling Pledge being negotiated under the aegis of the United Arab Emirates Presidency of the 2023 United Nations Climate Change Conference (COP28).

Near-zero

GHG emissions are feasible by 2050 by applying "Best Cooling Measures" combined with rapid grid decarbonisation. Best Cooling Measures include maximizing passive cooling opportunities, high energy efficiency gain and rapid HFC phase-down.

Figure 2-8: Global pathway and key steps to achieve near-zero GHG emissions from cooling in 2050



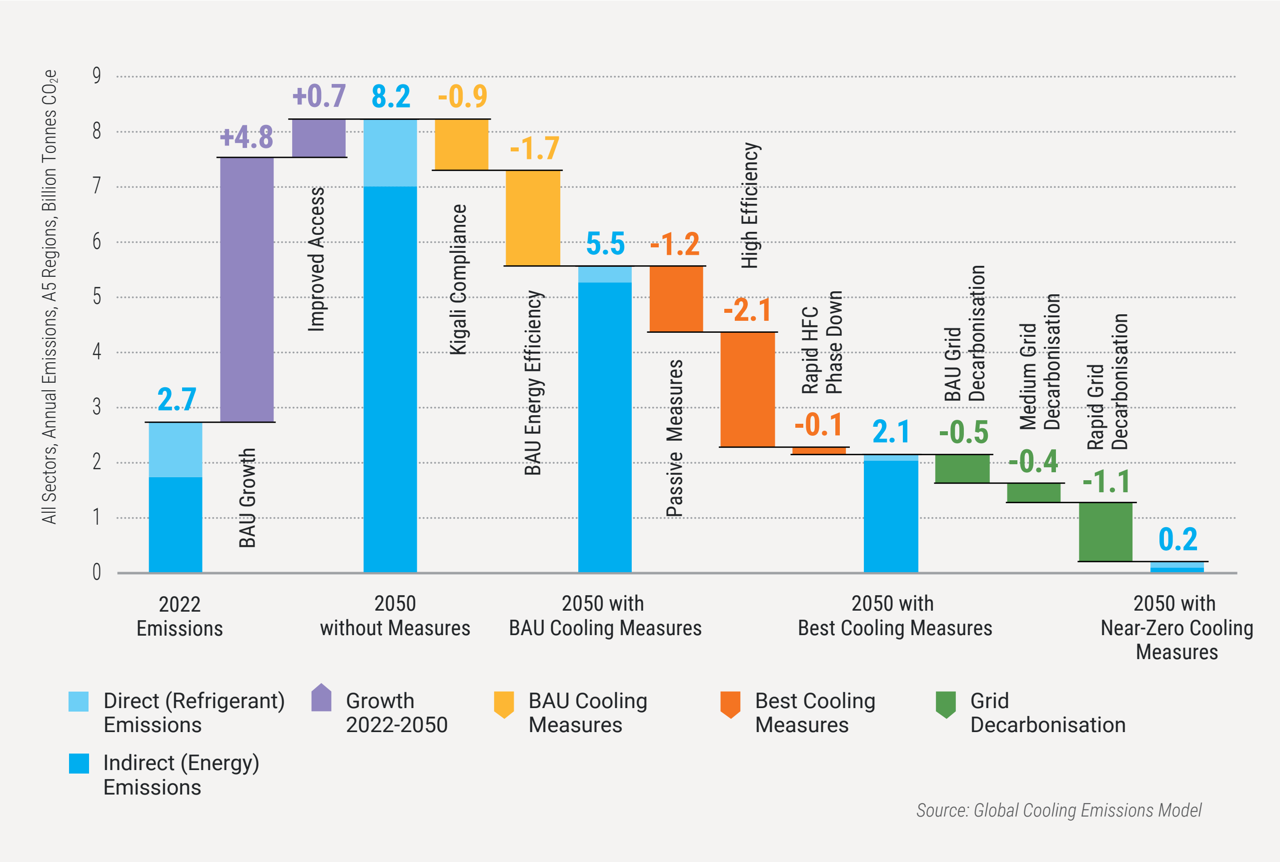
Source: Global Cooling Emissions Model

Note: Blue bars show emissions in 2022 and 2050. Purple bars indicate growth. Yellow bars indicate BAU Cooling Measure emission reductions. Orange bars indicate Best Cooling Measure emission reductions. Green bars indicate emission reduction due to electricity grid decarbonisation.

Regional emission forecasts to 2050

Passive measures and high energy efficiency create the biggest opportunities for emission reduction for all developing (Article 5) countries to 2050 (Figure 2-9).

Figure 2-9: Pathway towards near-zero GHG emissions from cooling in developing countries in 2050



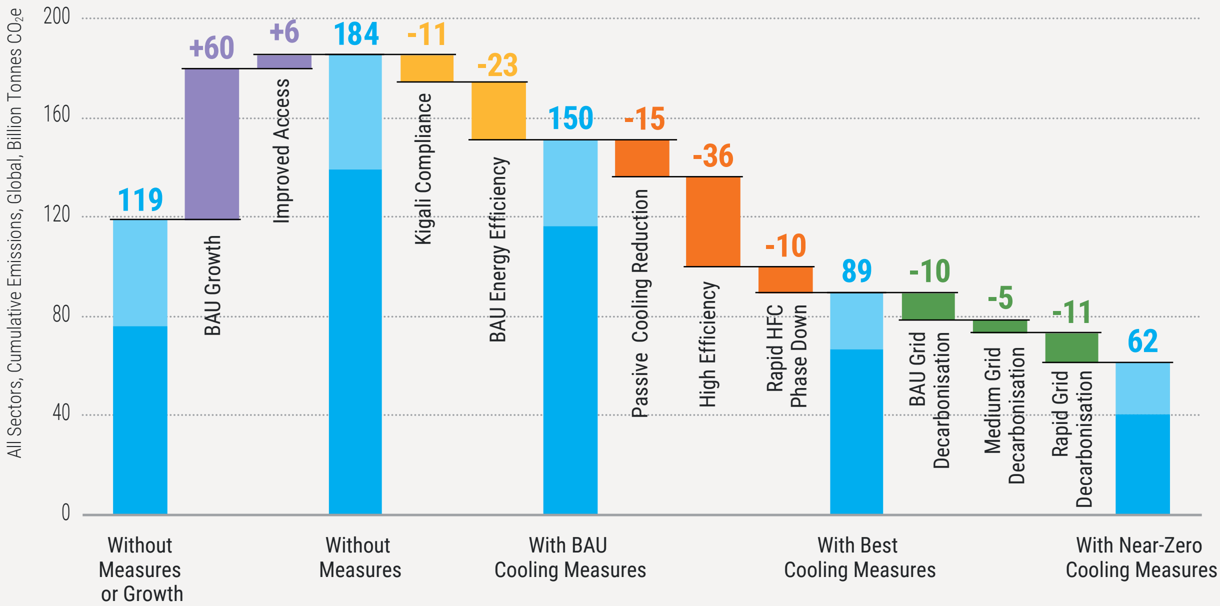
Source: Global Cooling Emissions Model

Many **A5** developing countries have limited access to cooling. The expected growth in A5 countries will be the main driver for increased global cooling capacity in 2050.

Sware, Kenya
Photo: Tucker Tangeman/unsplash.com

Cumulative global emission forecast to 2050
The cumulative emissions between now and 2050 are also of immense importance if a rise in the average global temperature above 1.5°C is to be avoided. Figure 2-10 shows the pathway of cumulative emissions from cooling applications between 2022 and 2050.

Figure 2-10: Cumulative global GHG emissions from cooling, 2022-2050



Source: Global Cooling Emissions Model

Photo: stockfour/shutterstock

> ***"Meeting the rising demand for cooling will require large investments in electricity generation and distribution infrastructure"***

82%

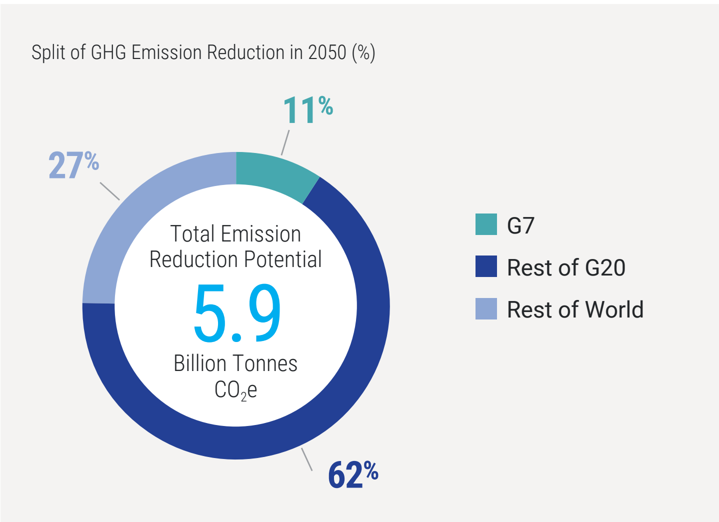
of global cooling related GHG emissions came from G20 countries, in 2022

Italy
Photo: Giulio_Fornasar/ shutterstock

G20 and G7 contributions to emission reductions in 2050

As shown in Figure 2-6b, G20 countries were responsible for an estimated 82 per cent of global cooling-related GHG emissions in 2022. The contributions of different regions to the potential emission savings created by the full adoption of Near-Zero Cooling Measures by 2050 is illustrated in Figure 2-11. G20 countries represent 73 per cent of the 2050 emission reduction potential, of which 11 per cent is from G7 countries. The figure clearly illustrates that leadership from G20 countries will encourage the adoption of Best Cooling Measures.

Figure 2-11: Contribution to Best Policies emission reduction in 2050, by country group



Source: Global Cooling Emissions Model

73%

of the 2050 emission reduction potential are in G20 countries

“Regulatory instruments need to be strengthened to increase access to cooling while also reducing energy use and emissions.”

External units of industrial freezer
Photo: ready made, pexels

03 Global cooling policy and legislative landscape

More than 80 per cent of countries have recognized sustainable cooling as a priority in at least one key policy or legislative instrument. However, only 53 countries (27 per cent) have established regulations or regulatory frameworks to enable action on all three areas required to support a future of near-zero emissions from cooling: implementing passive cooling measures; enhancing energy efficiency; and rapid phase down of high-GWP refrigerants.

3.1 Landscape of national cooling policies

The selection and implementation of different regulatory instruments to achieve sustainable cooling objectives and targets varies across countries and jurisdictions. Key policy and legislative instruments[5] to achieve near zero pathway include minimum energy performance standards (MEPS), building energy codes and standards, standards to reduce the environmental impact of refrigerants, tariffs and financial incentive schemes, information-based policies, cross-cutting policy actions to ease access to cooling, and National Cooling Action Plans (see Annex 8). Some of these regulatory instruments have the force of law or are underpinned by legislation, and some do not.

Global Cooling Policy Stocktake survey

In May 2023, a survey was conducted to review the existing national regulatory landscape for sustainable cooling across 193 countries[6]. The aim of this Global Cooling Policy Stocktake survey was to provide an overview of the status and implementation of the main regulatory instruments on cooling selected by countries.

The survey was designed by the UNEP Cool Coalition and reviewed by 20 global cooling experts. It examined responses to 41 questions that directly and indirectly relate to the ongoing transition towards sustainable cooling at the national level, including: 1) national mandates on cooling; 2) access to cooling; 3) cold chains; 4) energy-efficient cooling; 5) building (energy) codes; 6) refrigerants; and 7) enabling policies. The survey was structured around identifying actions that reduce GHG emissions from cooling, as well as actions, data and plans that enhance access to cooling and development of the cold chain.

For an overview of the survey questions and results, see Annex 8. The data was gathered primarily through desk research in addition to direct responses from policymakers and experts working on sustainable cooling. The results are based on available open-source data and therefore are best estimates. These survey outputs were corroborated against other public reports to check for accuracy and alignment. There is a need for ongoing rigorous and consistent tracking of regulatory instruments on cooling across countries to further refine the accuracy of the data.

Regulatory instruments at the regional level relevant to cooling were not covered in the survey. For example, several Caribbean countries have adopted the CARICOM Regional Energy Efficiency Building Code, which aims to improve the energy efficiency of buildings in tropical environments, with potential repercussions for sustainable cooling and access to cooling. Similarly, the West African Economic and Monetary Union has focused on developing a voluntary regional building code for energy efficiency.

5 For the purposes of this report, a policy is understood to be a plan, guideline, strategy or set of principles to guide actions to achieve a goal (e.g. National Cooling Action Plans, information schemes etc.). Legislation is understood to mean any primary legislation passed by a legislative body (e.g., parliament, congress or assembly) as well as any secondary legislation (e.g. regulations, decrees, by-laws or statutory instruments) enacted or issued by an authority empowered by primary legislation to do so. Both policies and legislation are collectively referred to in this report as regulatory instruments.

6 This survey was conducted across all 193 UN Member States. However, no data was available for the Democratic People's Republic of Korea. This survey focused only on national policies; regional and sub-national policies were not included in the assessment.

Main takeaways from the survey

The results of the Global Cooling Policy Stocktake reveal that nearly all of the surveyed countries have recognized the importance of advancing sustainable cooling through at least one of three main regulatory instruments: MEPS, building energy codes and efforts to address refrigerant emissions. In addition, some countries (such as Cambodia and Kenya) have adopted framework policies such as National Cooling Action Plans (Kingdom of Cambodia 2022; Republic of Kenya 2022), and some countries (such as Bangladesh and Viet Nam) have included cooling in their Nationally Determined Contributions (NDCs) under the Paris Agreement (Bangladesh, Ministry of Environment, Forest and Climate Change (2021; Socialist Republic of Viet Nam 2022).

<60% of countries have established **MEPS for cooling and refrigeration technologies**

<45% have established a **national-level building energy code**

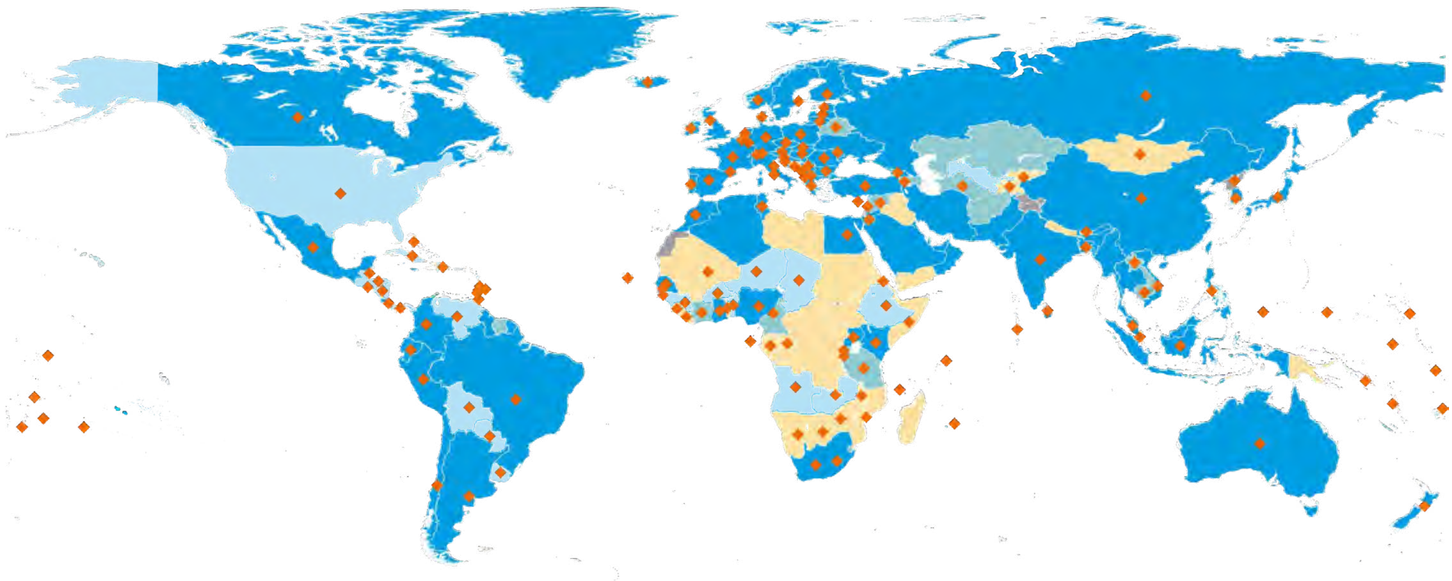
>75% have **ratified, accepted or approved the Kigali Amendment**

- In total, more than 80 per cent of countries surveyed have established at least one of the three main regulatory instruments that underpin an objective of shifting the cooling sector to near-zero emissions (Figure 3-1). In addition, around 75 countries have identified cooling and related policies in their NDCs, climate plans or strategies towards achieving near-zero GHG emissions.
  - 115 countries (59 per cent) have established **MEPS for cooling and refrigeration technologies**. However, in Asia, Oceania and Africa, 40 to 60 per cent of countries do not have MEPS that cover cooling or refrigeration appliances.
  - 83 countries (43 per cent) have established a **national-level building energy code** to ensure a minimum standard of energy efficiency performance. However, only 68 of these national building energy codes are mandatory; and several more (32) are under development globally.
  - More than 150 countries (over 75 per cent) have **ratified, accepted or approved the Kigali Amendment** to the Montreal Protocol, which prescribes the phase down of high-GWP refrigerants. More than 110 countries (60 per cent) consider refrigerant recovery during equipment servicing, or refrigerant disposal in their policies.
- Unfortunately, only 53 countries (27 per cent) have established regulations or regulatory frameworks to enable action on all three fronts via MEPS for cooling and refrigeration, mandatory building codes and ratification of the Kigali Amendment.

Singapore
Photo: Sergio Sala

53 countries have established regulations or regulatory frameworks to enable action on all three fronts

Figure 3-1: Distribution of relevant national policies to lower cooling emissions across countries



Note: Number of policies in place among the following three: 1) minimum energy performance standards (MEPS) established at the national level for appliances in the cooling sector; 2) national building energy codes (BECs), mandatory, voluntary and under development; and 3) ratification, approval or acceptance of the Kigali Amendment to the Montreal Protocol.

Identified gaps and needs

Despite these existing instruments, a BAU scenario will lead to an emissions profile from cooling that is only two per cent lower in 2050 than in 2022, based on the modelling in chapter 2. The survey results indicate that, in many countries, regulatory instruments may need to be strengthened to increase access to cooling while also reducing energy use and emissions. Regular updates to relevant regulatory measures are needed in many countries to ensure effective outcomes.

G20 countries are well positioned to lead the transition to sustainable cooling, as they are responsible for around 85 per cent of global GHG emissions and for 75 per cent of international trade flows (G20 2023). However, the survey found that only half of G20 countries currently incorporate standards for cool and reflecting surfaces in their building codes.

Similarly, only half of G20 countries have mapped out their cold chains, which are critical to nutrition and food security, access to health care, and jobs in agriculture and related sectors.

Regulatory instruments aimed at providing access to cooling for all are limited and should be strengthened in the face of rising extreme heat and the expected inequity in future cooling scenarios.

Photo: TommyStockProject, shutterstock

3.2 Integrating and implementing an optimal package of regulatory instruments

The choice and design of the optimal package of regulatory instruments must be informed by the specific context, commitments and goals of the country in question. The legal norms and traditions, political feasibility and social context of a country will have a material impact on what regulatory package should be pursued. A combination of national, sub-national and city-based approaches may also be appropriate to ensure that local policies complement national approaches. In all cases, there are cross-cutting issues that will need to be considered in the design and implementation of the mix of regulatory instruments. These include issues around a human rights-based approach, clear and coordinated mandates, institutional capacities, and regular review mechanisms, among other tools to ensure effective implementation, compliance and enforcement.

The regulatory ecosystem for cooling can be complex and involve multiple stakeholders. The first line of instruments are MEPS for appliances that directly promote the use of energy-efficient appliances and regulate refrigerant use in line with the Kigali Amendment to the Montreal Protocol. Additional instruments range from building energy codes that integrate passive strategies to requirements for public disclosure of food loss data to support the business case for investing in the cold chain. Effective governance and mandates are also needed to support the transition to low-GWP refrigerants and to reduce emissions from refrigerant leakage and the end-of-life of refrigerant-based appliances.

The following sections provide more details on regulatory instruments at three levels: 1) cooling equipment and appliances; 2) building codes and the built environment; and 3) systems-level sustainability that integrates a range of instruments. (For a primer on cooling policy solutions, see Annex 9.)

Cooling policies at the equipment level

Energy efficiency standards and labelling programmes

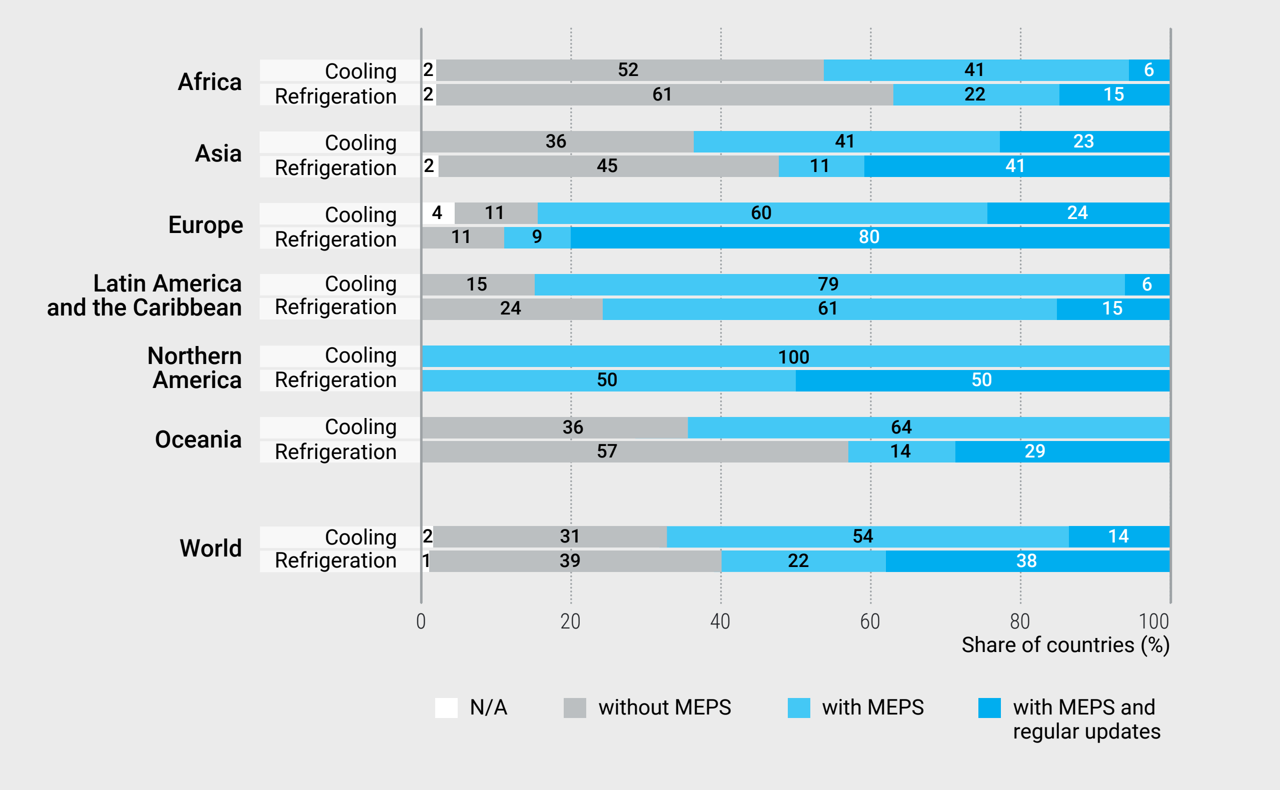
Standards and labelling policies to promote improved energy efficiency in appliances and equipment have been in existence since the 1970s. Such steps are useful to avoid markets becoming dumping grounds for used or outdated products that are unable to be sold elsewhere (UNEP United for Efficiency [U4E] 2017). These policies use one or both of the following complementary tools as the basis to improve the efficiency performance of cooling appliances and equipment (IEA 2021):

- **Minimum energy performance standards (MEPS),** which establish the minimum energy efficiency requirements for new products being placed on the market (IEA 2022). By implementing and enforcing MEPS, countries can accelerate the phase out of the most outmoded cooling technologies, ensure that the existing stock is replaced with the most efficient models and avoid becoming a dumping ground for used or outdated products (UNEP U4E 2017).

  Survey results show that 131 countries (68 per cent) have established MEPS for space cooling, and 117 countries (61 per cent) have established MEPS for refrigeration (Figure 3-2). These include the world's largest economies, the United States of America and China. However, within regions universal application of MEPS is lacking and stakeholder engagement across policy departments is needed to realize actual energy and emissions savings.

- **Energy labels.** These provide consumers with a clear indication of the energy efficiency and other key features of products at the point of purchase. Long-running energy labelling programmes in locations such as the United States and the European Union have resulted in annual reductions of electricity consumption of around 15 per cent (UNEP Ozone Secretariat 2023b).

Figure 3-2: **Share of countries, by region, that have implemented MEPS in the space cooling and refrigeration sectors (and update them regularly), as of May 2023**



Note: In the space cooling sector, the survey assessed whether countries updated MEPS biannually (identified as MEPS and regular updates). In the refrigeration sector, the survey assessed whether MEPS were updated regularly as a share of the best available technology (BAT) (identified as MEPS and regular updates).

Survey results show that more than half of the world's countries lack programmes targeted at encouraging high-efficiency behaviour among consumers. United for Efficiency's Model Regulation Guidelines and Energy Labelling Guidance (UNEP U4E n.d.a; UNEP U4E 2021a) are key resources for countries to consider. Tools such as Country Savings Assessments (UNEP U4E n.d.b) provide a first national-level estimate of potential electricity savings, electricity bill reductions and GHG mitigation potential of adopting new or revising existing MEPS and labels. Such interventions must be underpinned by monitoring, verification, and enforcement, as described in United for Efficiency's guides on Ensuring Compliance with MEPs and Energy Labels and on using Product Registration Systems (UNEP U4E 2021b; UNEP U4E, Global Environment Facility and Kigali Cooling Efficiency Program 2019). Capacity-building is key to ensure that officials and suppliers understand their roles and responsibilities.

Regional cooperation and policy harmonization help unlock economies of scale for compliant products and enable better oversight and enforcement. For example, the East African Community, the Southern African Development Community (SADC), the Association of Southeast Asian Nations (ASEAN) and other regional groups are pursuing roadmaps for the adoption of robust MEPS (UNEP U4E 2021c; UNEP U4E 2023a). In Africa, the East African Centre of Excellence for Renewable Energy and Efficiency (EACREEE) and the SADC Centre for Renewable Energy and Energy Efficiency (SACREEE) have partnered with UNEP's United for Efficiency initiative to develop harmonized MEPS and labelling for residential refrigerators and room air conditioners, with the goal of accelerating the transition to energy-efficient appliances that use low-GWP refrigerants (UNEP U4E 2021d). Communications and outreach to target audiences are essential to convey why and how to leverage these policies and programmes.

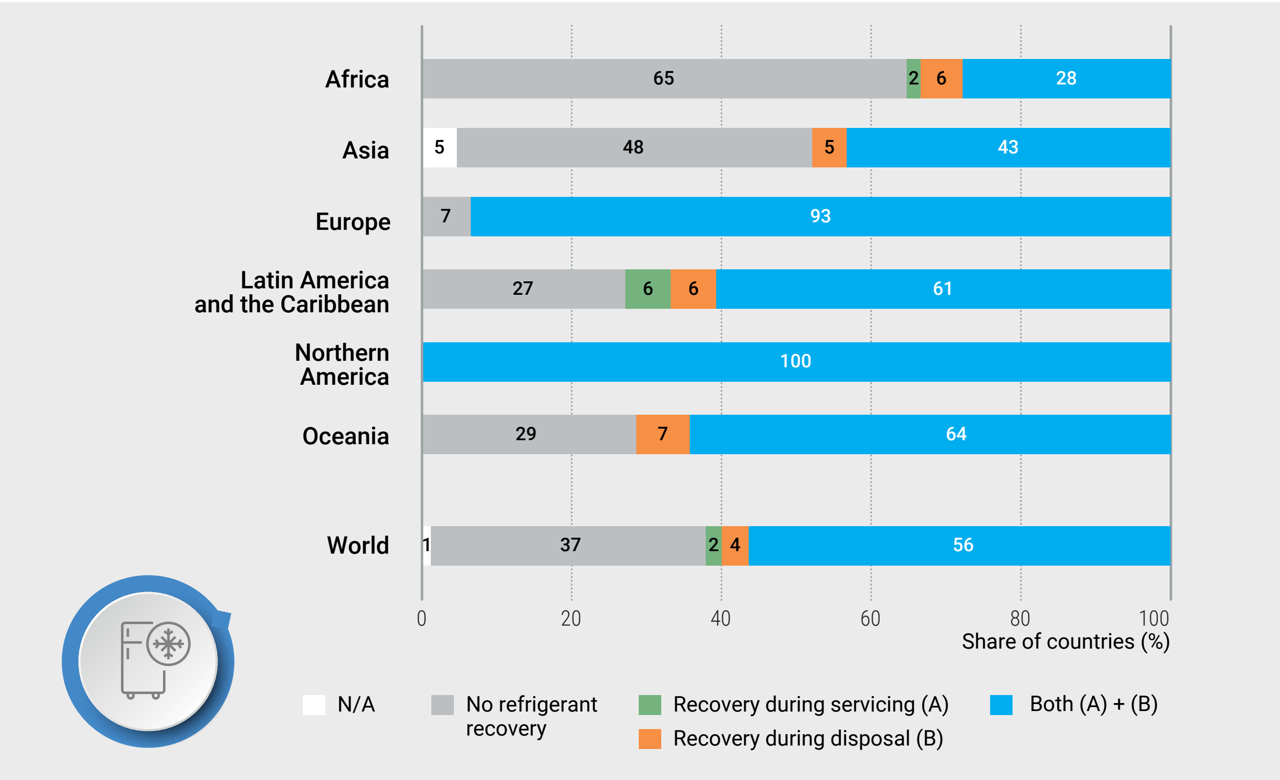
Phase down of refrigerants with high global warming potential
The phase down of refrigerants with high GWP, as mandated in the Kigali Amendment, is essential to achieving near-zero emissions from cooling equipment. Implementation of this phase down may be in the form of Kigali Implementation Plans (KIPs), regulations to phase down the use of fluorinated gases (F-gases) and amendments to existing regulations that countries have introduced to control ozone-depleting refrigerants.

Figure 3-3 shows the share of countries, by region, that have implemented relevant regulations for GWP refrigerants, including for recovery during servicing and/or for refrigerant disposal. Ideally, countries should be aligning MEPS with their regulations for phasing down high-GWP refrigerants, although very few have done so (for more on synergies between energy efficiency and the refrigerant phase down, see section 6.4).

Instruments to stop the dumping of obsolete equipment and illegal trade of refrigerants
As high-income economies implement stricter equipment standards, they often sell their lower-quality cooling appliances to developing countries through secondary markets. For recipient countries, this can increase the time between the adoption of efficiency standards and the phase out of older products. The illegal trade in counterfeit and controlled refrigerants also poses a significant threat to developing countries.

Establishing national import tariffs and international protocols alongside enforcement of standards is necessary to prevent the dumping of obsolete equipment. One of the most effective policies to stop the dumping is to develop proper MEPS and labelling programmes and the corresponding enabling ecosystem (Agyarko 2020). The survey results show that 28 countries (out of 68 where data was available) have set up national import tariffs that restrict or constrain access to refrigeration or cooling equipment to prevent dumping.

Figure 3-3: Share of countries, by region, that have implemented (a) regulations for GWP refrigerant recovery during servicing and/or (b) regulations for GWP refrigerant disposal, as of May 2023



Without adequate regulatory environments, sub-Saharan African countries could be locked into obsolete technologies for 15 to 20 years (CLASP and Institute for Governance and Sustainable Development [IGSD] 2020). Analysis of 10 African countries found that a quarter of the total air conditioners sold in 2018 fell below the MEPS mandates of the original countries of manufacture, and 25 per cent of the low-efficiency air conditioners imported from non-African companies used refrigerant gases that were subject to controls (CLASP and IGSD 2020). The Union of African Associations of Refrigeration and Air Conditioning Stakeholders has condemned the dumping of outdated air conditioners and signed the Casablanca statement to limit the leakage of high-GWP refrigerants and prevent future costs associated with their phase out under the Montreal Protocol (Union des Associations Africaine des Acteurs de la Réfrigération et de la Climatisation 2022).

Governments may be able to improve the cost effectiveness and affordability of environment-friendly cooling equipment by providing an import and tax reduction, alongside other financing mechanisms (see chapter 7).

Cooling policies at the building level

Building codes that integrate standards for energy efficiency and passive cooling

Currently, around one-fifth of all the electricity consumption in buildings is used for operating air conditioners and other cooling equipment (IEA 2018). One of the most effective regulatory instruments to achieve low energy loads (and associated cost savings) is to implement building energy codes for the residential and commercial sectors. These codes should ensure the incorporation of passive cooling measures (for example nature-based solutions, cool materials, building envelope, natural ventilation and artificial shading) to prevent, modulate or dissipate heat (see chapter 4). Research suggests that passive cooling can help reduce a building's energy consumption by 8 to 70 per cent (Song *et al.* 2021).

Building energy codes can lead to large reductions in the cooling load and thus reduction in the growth of cooling equipment and its associated energy use and emissions. Currently, only 83 countries (43 per cent) have building energy codes. Amongst these, only 68 countries (35 per cent) have mandatory building codes while another 32 governments are in the process of developing and publishing their codes (UNEP Global Alliance for Buildings and Construction 2022). Less than 50 countries (26 per cent) include passive cooling solutions, e.g. cool and reflective surfaces, in codes.

Building codes can be further enhanced with specific requirements for energy and materials performance to allow for system-level efficiency. For example, in Ghana the implementation of MEPS has been coupled with the establishment of a new building code (Ghana Standards Authority 2018; UNEP U4E 2020). In the United States of America, the building energy codes implemented sub-nationally in the last four decades have reduced the energy use in buildings by more than 40 per cent (Alliance to Save Energy 2022).

While building energy codes exist in some parts of the world, clear metrics on their progress and implementation remain weak, and in many countries, they are rarely adequately enforced, despite their environmental effectiveness. Authorities often lack building efficiency requirements due to insufficient knowledge, incomplete statistics, inconsistent assessment methodologies, and inadequate enforcement and monitoring (Ürge-Vorsatz *et al.* 2020). Mandating building energy code compliance in public buildings can be an important strategy to enhance uptake at scale.

Green buildings

In addition to building codes, numerous countries use rating systems to improve building performance. For example, in Indonesia, the Ministry of Environment has added requirements for green buildings, including the use of non-ozone-depleting materials, energy conservation infrastructure and sustainable materials. The Greenship rating system of Green Building Council Indonesia assesses energy and refrigerant efficiency, integrating environmental, climate and energy policies (Green Building Council Indonesia n.d.). To achieve a global transition to near-zero emissions from cooling, however, all countries will need to support strong implementation of building energy codes.

Integrated instruments to enhance sustainability

An integrated policy approach is recommended to accelerate the transition to cooling appliances that are energy efficient and use low-GWP refrigerants (Box 3-1).

Marrakesh, Morocco
Photos: Max Brown, unsplash.com

Integration across MEPS, building codes and refrigerant actions

In isolation, MEPS, building codes and refrigerant actions are not sufficient for the challenge at hand. Policymakers should consider developing regulatory frameworks to ensure that policies are targeting a synergistic implementation of building codes, the transition to low-GWP refrigerants, higher energy efficiency and non-fossil energy production (see Box 3-1 for a case study on Morocco). National Cooling Action Plans offer an example of such integrated regulatory frameworks, which align these multiple cohorts and chart ways forward to enable the overlap and compounding of new and existing policies to reap benefits. This is discussed in the following sub-section.

Box 3-1: Case study: Integrating sustainable cooling policies in Morocco

Since 2010, Morocco has rolled out a range of policies and initiatives at the regional and national levels that are aimed at reducing energy consumption in buildings and appliances (Table 3-1) and are thus key to sustainable cooling. In the buildings sector, policies include eco-design, energy labelling and guidelines for building energy performance and energy efficiency, which have been included in the Thermal Regulation of Construction since 2015 and are required at the level of building permits. For refrigeration and air-conditioning units, Morocco has set out different labelling standards depending on the capacity of the unit, and it defines the energy class of an air conditioner according to its seasonal performance.

The Moroccan government is partnering with domestic banks and international non-governmental organizations on related activities, including the development (and pilot) of an analytical metric for the life-cycle carbon footprint; public and bulk procurement of efficient and super-efficient air conditioners; and the development of a supply chain for affordable super-efficient air conditioners in Morocco.

Table 3-1: Policies affecting the energy efficiency of buildings and appliances in Morocco

Que ratet	Poratus andistion
Decree n. 927-20 on the compulsory application of Moroccan standards. Photovoltaic products and solar thermal installations	2020
Decree n. 2-17-746 on mandatory energy audits and energy audit organizations	2019
Energy efficiency programme for public buildings	2019
MEPS for air conditioners	2018
Nationally Determined Contribution (NDC)	2016
MorSEFE	2015
Decree n. 2-13-874 on thermal regulation of buildings	2014
Moroccan Standard NM 14.2.300	2010

Source: Merini et al. 2020; El Hafdaoui, Khallaayoun and Ouazzani 2023.

Multi-stakeholder initiatives

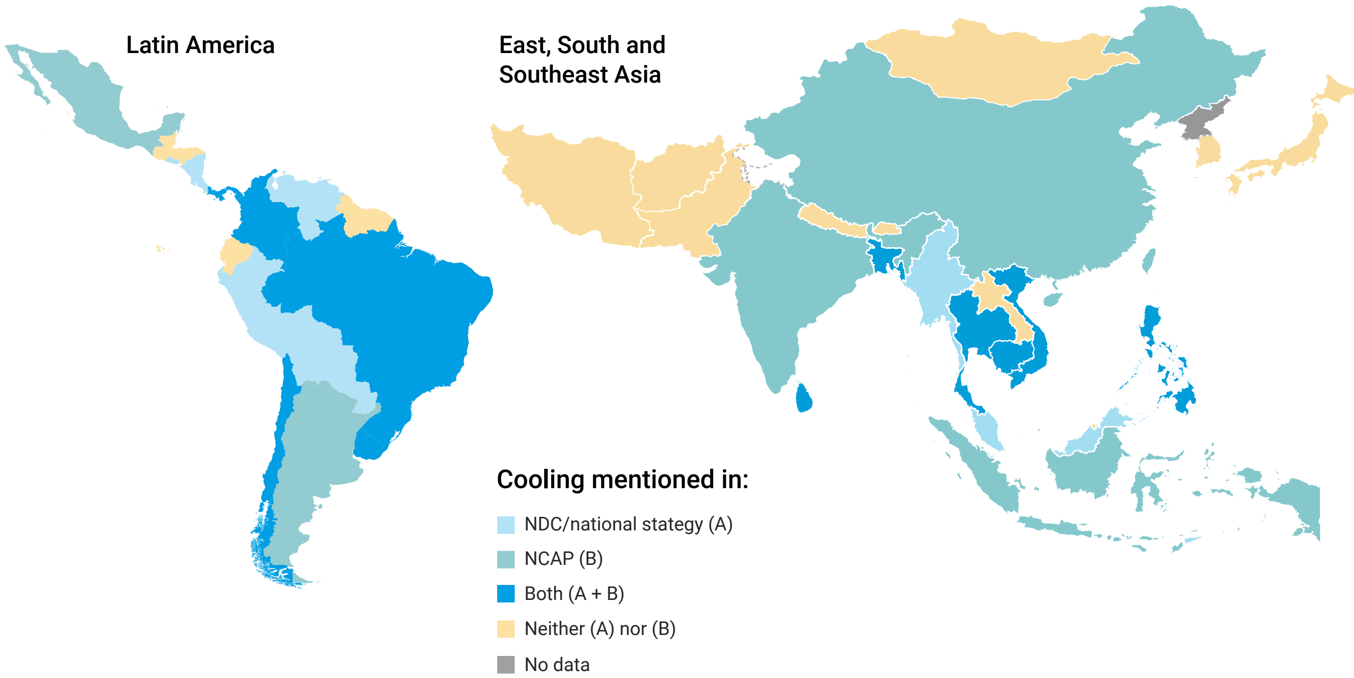
As the demand for cold chains surges, governments are starting to develop cold chain guidelines and frameworks and to pull together multi-stakeholder initiatives at multiple scales to support the transition towards near-zero emission and equitable cold chains. Developing countries struggle with both developmental and food provision challenges. Governments must urgently recognize that achieving these goals will require establishing an end-to-end, sustainable, resilient, inclusive and equitable cold chain for food and pharmaceuticals.

ENOUGH is a multi-million Euro four-year programme gathering 30 partners from nine European Union countries as well as Norway, the United Kingdom and Türkiye (SINTEF 2023). The project will support the EU's farm-to-fork strategy, providing technical and non-technical tools and solutions to reduce GHG emissions by 2030 and to support food industry efforts to achieve carbon neutrality by 2050. The project will generate current information on emissions from the food chain, create strategic roadmaps (technical, political and financial) and develop digital and smart data tools to quantify and benchmark energy use and emissions in the food chain. It will demonstrate clean and sustainable technologies for food sectors from post-farm gate to consumption.

National Cooling Action Plans and Heat Action Plans

The development of National Cooling Action Plans (NCAPs) in more than 40 countries is an encouraging step towards coordinated action and increasing ambition. The landscape is evolving rapidly, especially in Latin America and Asia, where Argentina and Mexico, as well as China, India and Indonesia have all recently adopted NCAPs. Several countries in Latin America (for example, Chile, Colombia, Panama and Uruguay) and South and Southeast Asia (such as Bangladesh, Cambodia, Sri Lanka and Thailand) have both adopted an NCAP and refer to cooling in their key climate strategies (Figure 3-4). As of October 2023, 25 countries were at various stages of preparing their NCAPs.

Figure 3-4: Countries in Latin America and East, South and Southeast Asia with (a) cooling mentioned in their Nationally Determined Contribution, climate or net-zero strategy, and/or (b) a National Cooling Action Plan, as of May 2023



NCAPs are being recognized as a catalyst to link increasing efficiency and the refrigerant transition. They allow for better integration across various cooling policies and priorities, including MEPS, building codes, the refrigerant transition, and electricity capacity planning to power cooling appliances. Such priorities are usually managed by different government bodies or entities, such as stakeholders from energy, industry, technology and commerce, environment, investment and finance, and international cooperation. As cross-ministerial plans, NCAPs enable countries to attract finance for implementation. If designed and implemented well, they can lead to a mainstreaming of cooling in national development and environmental agendas; identification of gaps in cooling access; and improved institutional and inter-ministerial coordination, public awareness and stakeholder participation.

NCAP implementation has varied. Although some countries (such as India and China) have included implementation mechanisms in their NCAPs, roll out has been slow. To support the implementation of India's Cooling Action Plan (Government of India 2019), the World Bank has identified investment opportunities of US$1.6 trillion in India's cooling market, which would create 3.7 million jobs (World Bank 2022a). To mobilize such investment opportunities, NCAPs should be developed as multi-ministerial, cross-institutional, national efforts that display the government's prioritization of cooling (UNEP Cool Coalition *et al.* 2021a). Targeted structures, timelines and financing mechanisms for implementation will aid the development of a near-zero emission trajectory for cooling at the country level. Global cooling experts, including at UNEP, have researched a NCAP development methodology that offers a blueprint for countries to follow (UNEP Cool Coalition *et al.* 2021a).

Beirut, Lebanon
Photos: Alev Takil,
unsplash.com

Box 3-2:
Developing Heat Action Plans: The Heat Action Platform online resource

As local and regional governments recognize the need for heat preparedness initiatives, they require locally relevant tools to support and streamline implementation. The Heat Action Platform is an online resource that draws from global experience and expertise to enable urban practitioners, policymakers and development finance institutions to reduce the risks and impacts of heat.

The Platform's comprehensive heat planning framework walks the user through best practices for risk assessment, developing Heat Action Plans, selecting interventions, and financing, monitoring and evaluating projects. The Platform's Heat Policy Tool, a filterable repository of 90 heat resilience solutions with a growing database, is a prioritization tool that provides tailored solutions to users anywhere in the world.

The Heat Action Platform (heatactionplatform.onebillionresilient.org) was co-developed by the Adrienne Arsht-Rockefeller Foundation Resilience Center, the UNEP-led Cool Coalition, the Extreme Heat Resilience Alliance, the Global Covenant of Mayors for Climate and Energy, Mission Innovation, the Rocky Mountain Institute (RMI) and the World Economic Forum.

Source: Atlantic Council n.d

Nice, France
Photos: Jonas Weckschmied, unsplash.com

90
heat resilience solutions with a growing database

Notably, 87 countries have established broader national adaptation plans and strategies, with a focus on identifying and addressing their climate change adaptation needs in the medium and long terms. Many countries also have implemented Heat Action Plans (Box 3-2), which can similarly help to streamline and coordinate sustainable cooling actions. Portugal's Heatwave Contingency Plan, developed in response to a 2003 heat wave, mitigates the health impacts of heat stress during high-temperature periods, with daily alerts guiding the implementation of protective measures to safeguard the population (Climate-ADAPT 2023a). North Macedonia's National Heat-Health Action Plan includes a heat health warning system, policies that integrate health protection, awareness-raising efforts, and resource allocation to manage heat-related health effects (Climate-ADAPT 2023b).

87 countries
have established broader national adaptation plans and strategies

Embedding cooling actions in Nationally Determined Contributions (NDCs)

Sustainable cooling can play a key role in increasing the ambition of countries' Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement. Cooling is expected to contribute an estimated 3.9 billion tons of CO_2e emissions in 2050, the equivalent of 15 per cent of today's global emissions. Explicit mentions of cooling and refrigeration in NDCs would foster the use of cost-effective mitigation solutions and support emission reductions aimed at meeting broader net-zero targets, with the potential for strong development co-benefits.

So far, 73 countries (39 per cent) mention cooling and cooling-specific policies in their NDCs, climate strategies or net-zero strategies. Actionable measures that countries can adopt to strengthen their NDCs via climate-friendly cooling strategies include passively cooled buildings, more efficient equipment and appliances, and ultra-low (<30) GWP refrigerators (Clean Cooling Collaborative 2021).

Pakistan's NDC submission, which prioritizes cooling, includes the development of an NCAP as an adaptation measure (SEforALL 2022b). Cambodia has developed a comprehensive NCAP and incorporates extensive cooling measures in its revised NDC, with a focus on integrating passive cooling strategies into green building guidelines, which in turn unlocked climate finance (Kingdom of Cambodia 2020; Kingdom of Cambodia 2022; UNEP 2023b). Viet Nam, in both its National Climate Change Strategy to achieve net-zero emissions by 2050, and in its updated NDC, prioritizes urban cooling and passive strategies along with cold chain deployment to reduce emissions while maximizing socio-economic development (Climate Action Tracker 2022; Socialist Republic of Viet Nam 2022; UNEP Cool Coalition 2023).

International cooperation and coordination

Temperature-controlled supply chain networks are complex, requiring coordination across stakeholders, countries and continents. The lack of proper solutions to address cold storage, limited technical training, and obsolete technologies can lead to flawed solutions, the loss of emission mitigation opportunities and higher financial costs. Addressing these issues requires promoting the sustainability of cold chain systems across regions and communities, as is occurring in Africa through the establishment of a dedicated centre for this purpose (Box 3-3).

Box 3-3: Case study: Africa Centre of Excellence for Sustainable Cooling and Cold-Chain

The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain (ACES) is a first-of-kind, not-for-profit centre dedicated to sustainable cooling and cold chain for food and health. The aim is to be a one-stop provider for technical and business assistance, training, and knowledge transfer along "farm-to-fork" and "vaccine manufacturer-to-arm". ACES will also foster international collaborations to advance innovations, create new business opportunities and identify, coordinate and secure funding, as well as provide advice on policy.

ACES, which is hosted by the University of Rwanda at the Rubirizi Campus in Kigali, undertakes collaborative research, tests new equipment and develops knowledge, training programmes and robust business models. These are then complemented with Specialized Outreach and Knowledge Establishments (SPOKEs) across the continent that will display how solutions can be deployed in practical, real-world applications and provide the outreach learning, training and knowledge transfer and technical assistance centres to support local community uptake. The first of these is being developed in Kenya, with a further three planned for Phase 1.

The ACES model is planned to be the flagship of a global network with two other Centre of Excellence partners in India (Hyderabad and Haryana). At the community level, the programme will deliver on-the-ground training and support for farmers and their communities on designing sustainable community cooling and cold chain solutions and developing financeable business models for post-harvest management. It will also provide support to local and international technology companies to bring their technologies to market at scale. At the macro level, ACES is developing tools, models and assessment methodologies to better understand cold chain needs both at the community and national levels, as well as the unintended consequences of bringing that access.

Source: ACES n.d.

3.3 Regulatory instruments to enhance access to cooling

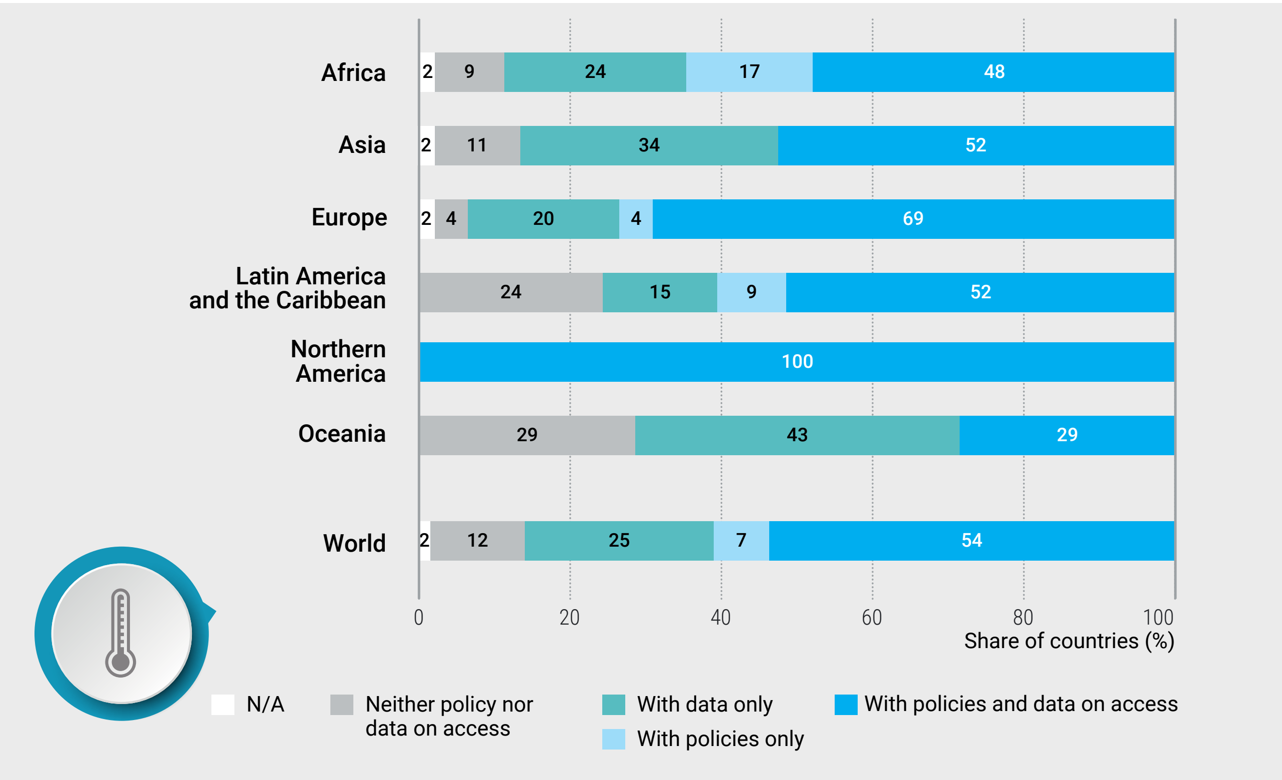
Access to cooling is unevenly distributed globally, despite the clear benefits of cooling for health, productivity and food security. To enhance access, there is a need for policies that increase the affordability of cooling equipment, improve passive thermal comfort, and integrate nature-based solutions, particularly in the residential sector (the fastest growing cooling segment) and for vulnerable populations. Under the BAU scenario, the world's most vulnerable populations will lack access to cooling despite the expected growth in global cooling capacity.

Enhancing access to space cooling for thermal comfort

In the face of increasing heat stress and warming days, national-level policy instruments such as national adaptation plans and strategies, NCAPs and Heat Action Plans offer a key opportunity for countries to identify the size of their cooling challenge and to improve access. However, only 96 countries – around half of all countries – have established a national-level strategy or policy to increase access to cooling (Figure 3-5). This leaves many countries, including in very warm regions such as Africa, Asia, and Latin America, without such policies. Similarly, as discussed earlier, not every country has put forward national adaptation plans and strategies addressing heat and access to cooling.

Currently, more than a fifth of the global population either does not have access to electricity or lacks access to reliable electricity (CDC Group 2019) and cannot afford a refrigerator. Under these conditions, access to thermal comfort through passive interventions (including nature-based solutions) as well as viable off-grid solutions becomes critical (see section 5.2). The integration of nature-based solutions for cooling and reducing heat stress – such as urban forests, lakes and water bodies, green corridors and open green spaces – have been shown to reduce temperatures by up to 12°C (Schwaab *et al.* 2021).

Figure 3-5: Share of countries, by region, with (a) national-level cooling policies and (b) data on access to cooling, as of May 2023



Only 20 countries (out of 58 countries where data were available) have government policies or programmes for off-grid refrigeration, which will be key to enhancing cooling access for those who need it most. These include, for example, Botswana and South Africa in Africa; India, Indonesia and Islamic Republic of Iran in Asia; and Colombia and Paraguay in Latin America. Given the nascent market for off-grid cooling applications, greater policy focus is needed on increasing heat resilience for those without grid access in urban and rural contexts. It is important to consider resilient technologies that can work either off-grid or with unstable electricity supply,

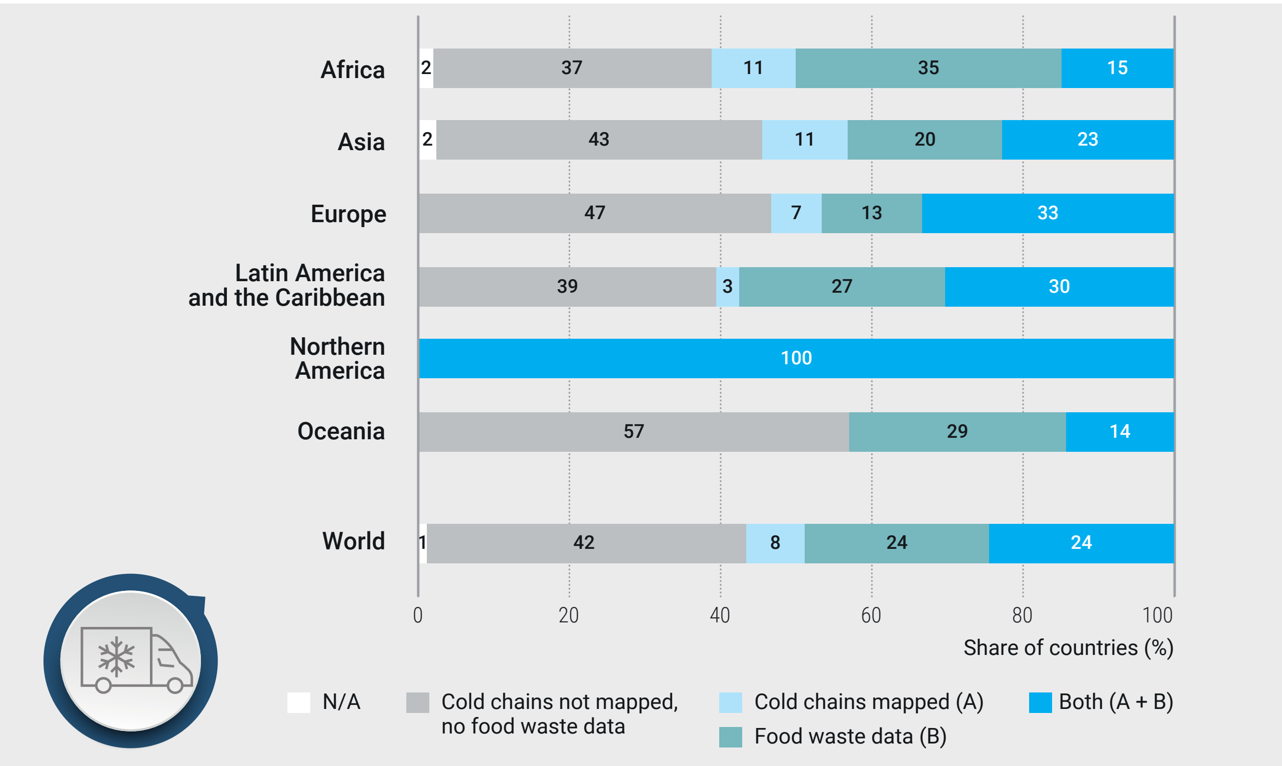
Another area for priority policy focus is institutionalizing data collection. Countries that lack a national strategy on cooling access, but that collect data on equipment ownership and on cooling access rates and gaps (Figure 3-5), such as Ireland and Nicaragua, could set goals and targets for access to cooling and integrate these into relevant climate and energy policies.

Enhancing access to cold chains to prevent food loss

As the demand for food grows rapidly, reducing food loss through better refrigeration could cushion price increases and improve food security, especially for the poorest households. Efficient cold chain systems are fundamental in meeting the growing demand for temperature-sensitive food and health care products, including vaccines (UNEP and FAO 2022).

Currently, 94 countries, or around half of all countries globally, are reporting on their food loss, including low- and middle-income countries (Figure 3-6). However, only 62 countries (32 per cent) are mapping their cold chains to minimize food loss. Cold chain mapping refers to the process of planning out the transport of temperature-sensitive products along a supply chain through thermal or refrigerated packing methods, as well as the logistics required to ensure secure delivery (Rodrigue 2020). Despite the crucial need to improve cold chains in locations where poverty and malnourishment are more pronounced, many countries in Asia, Africa, Europe and Latin America have not mapped their cold chains or undertaken assessments of food loss and shortage.

Figure 3-6: Share of countries, by region, for which (a) food waste is reported each year and (b) the cold chain has been mapped to identify risks of food waste and shortage, as of May 2023



Sumut Prakan, Thailand
Photos: Roylan Tkg, shutterstock

Examples exist of recent policy steps at the national level to address food loss and assess cold chains. In 2015, India's National Centre for Cold Chain Development carried out an inaugural assessment that identified significant defects in reefer transport and modern packhouses, prompting a shift in focus from indiscriminate investments in cold storage capacity to initiating a comprehensive end-to-end cold chain system (UNEP and FAO 2022). Viet Nam also has taken extensive steps to develop an integrated policy framework for expanding cooling access while reducing emissions (Box 3-4).

Since 2019, the Efficient and Clean Cooling Programme (ECCP) of the World Bank's Energy Sector Management Assistance Program (ESMAP) has funded more than 40 technical assistance activities in over 30 countries to support the scale up of sustainable cooling solutions in sectors such as buildings and cities (space cooling), health (vaccine cold chains) and agriculture and fisheries (food cold chain). For example, the ECCP-funded US$500 million Livestock and Dairy Development Program supported the development of sustainable livestock and dairy cold chains in Bangladesh, where less than 10 per cent of cold chain operations are well developed. The project enabled a comprehensive diagnostic of the refrigeration requirements for the livestock and dairy sectors, and identified potential sustainable solutions and policy recommendations (ESMAP 2023).

Only
62 countries
(32 per cent) globally are mapping their cold chains to minimize food loss.

Box 3-4: Case study: Viet Nam Integrated Policy Framework

Viet Nam has been focusing on mainstreaming cooling in its national policy framework, prioritizing heat stress and cooling energy demand as key areas. However, cooling was not considered as an emission reduction target. Since the announcement of net-zero emissions at the 2022 United Nations Climate Change Conference in Glasgow (COP 26), Viet Nam is aligning its cooling strategies with net-zero targets through the National Climate Change Strategy (NCCS), aiming to achieve net-zero emissions by 2050. The Ministry of Natural Resources and Environment (MoNRE) conducted a comprehensive GHG assessment, which informed Viet Nam's long-term mitigation pathways for the cooling sector and generated policy, technical and institutional recommendations for various segments such as space cooling, food cold chains and refrigerants.

Key strategies in the NCCS include enhancing urban green cover to combat extreme heat, prioritizing efficient cold chain infrastructure to reduce food loss and energy emissions, and implementing MEPS and building codes. Innovative financing models are also being encouraged to adopt efficient cooling equipment, low-carbon building designs and passive cooling solutions to achieve sustainable cooling access while curbing energy use and HFC consumption.

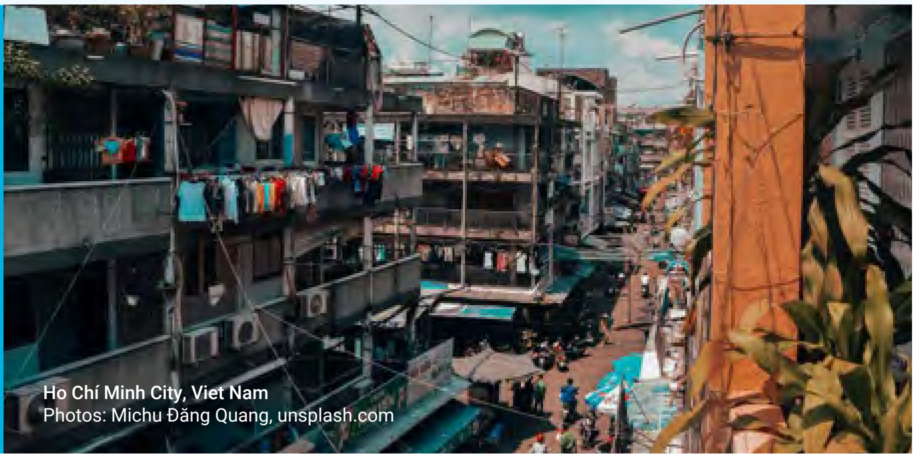
Viet Nam is also developing a National Green Cooling Plan to cover both passive and active cooling, aligning with its national and international socio-economic and environmental commitments as per its NDC, which was updated in 2022 and analysed the cooling sector's GHG emission pathways for 2030. The updated NDC underscores the criticality of cooling, considering emissions from the air-conditioning and refrigeration sub-sector. The impact of heatwaves and rising temperatures on public health and energy consumption due to cooling is a highlighted priority.

Viet Nam has taken a synergistic approach towards climate action through Decree No. 06/2022/ND-CP on Mitigation of Green House Gas (GHG) Emissions and Protection of Ozone Layer, which integrates certain aspects of the cooling into the regulatory framework. MoNRE included cooling aspects under the GHG emission monitoring framework and inventorization. In addition to regulating refrigerant consumption, the Ministry included cooling under the regulating mitigation of GHG emissions, where:

- Large cold-chain establishments, public and commercial buildings (including airports, offices, hotels, malls, etc.) are mandated to report on annual GHG emissions and to take measures to reduce them. Under the implementation framework of the Decree, the Ministry of Construction will be responsible for maintaining the GHG inventory for certain categories of large buildings (commercial and public buildings with total energy consumption of 1,000 tons of oil equivalent or more).

- Relevant ministries including the Ministry of Construction and the Ministry of Industry & Trade will promulgate the plans for sectoral GHG reduction by 2030 as prescribed in the NDC. Cooling is included as a key sector in the NDC of 2022.

Viet Nam
has taken a synergistic approach towards climate action, including sustainable cooling.



Ho Chi Minh City, Viet Nam
Photos: Michu Đăng Quang, unsplash.com

3.4 Market readiness for sustainable cooling solutions

Supply chain readiness

For a technology transition to be successful, an industry must be prepared to revamp its existing manufacturing set ups, including by setting up suppliers for new components and services (Gereffi 1999; Sampson 2021). Larger, more-resourced firms are often better placed to integrate new technologies into their manufacturing processes than are the small and medium enterprises that constitute the value chains of products (Jones-Evans 1998; Andrews 2015). Policy and regulatory roadmaps that are aimed at achieving sustainable cooling will have to confront this asymmetry.

If the implementation of an energy efficiency policy requires the use of high-quality components in cooling equipment, then the ability of suppliers to ensure that these components are available at a reasonable cost will be crucial in determining if the efficiency outcomes are achievable or not. Small and medium enterprises across the value chain are responsible for supplying key components for product upgrades and for the overall efficiency and affordability of products. Without a thriving spare parts market, more cooling units will face early obsolescence, and without access to repairability, end users will face a higher cost of ownership. In India, where small and medium enterprises typically manufacture the smaller components for air-conditioning units and provide servicing, knowledge of the refrigerant transition is paramount so that firms can invest in training infrastructure (UNEP 2019a).

Jakarta, Indonesia
Photos: Aginc Zetiawan, shutterstock

Policies and programmes targeting energy efficiency and F-gas transition will need to focus on the entire supply chain, enabling local small and medium enterprises to adopt modern technologies through research support, collaboration with multinational firms and capacity-building mechanisms (Park *et al.* 2021). National and international programmes could provide small and medium enterprises with capital for technology adoption, affordable access to quality, testing and certification infrastructure, and enrolment in industrial upgrading initiatives (Dixit and Bhasin 2022).

Supporting the servicing sector

Servicing is a key factor in determining the market readiness of sustainable cooling solutions, particularly low-GWP and natural refrigerants for which technicians require additional skills and safety protocols. In developing countries, the servicing sector reports high consumption of refrigerants (UNEP Ozone Secretariat 2022a), and in India the sector represents around 40 per cent of total refrigerant consumption (Ozone Cell 2019).

The Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol has estimated that proper maintenance and servicing can result in up to 50 per cent improvement in appliance performance (UNEP Ozone Secretariat 2018). Moreover, effective life-cycle refrigerant management (which includes minimizing leakages and promoting recovery, recycling, reclamation and destruction) is a sizable opportunity to reduce GHG emissions (see section 6.2). In India alone, effective life-cycle refrigerant management could mitigate around 2 billion tons of CO_2e emissions by 2050 (Kumar *et al.* 2023).

Proper maintenance and servicing can result in up to 50 per cent improvement in appliance performance

Porong, Indonesia
Photos: iansbaru, shutterstock

However, having qualified technicians to install and maintain the system could be a challenge for businesses. Today's global servicing market often involves informal work (untrained technicians offering installation and maintenance services) due to the shortage of certified technicians and lack of consumer awareness. As such, it is important to upgrade or develop training materials and programmes for air-conditioning technicians in vocational institutions and national associations, to incorporate the specialized knowledge and skills needed to install and maintain energy-efficient refrigeration systems with low or zero GWP.

Excellent online resources include the refrigerants driver's license and the energy efficiency literacy course (American Society of Heating, Refrigerating and Air-Conditioning Engineers n.d.). A study funded by the European Union found that training employees in energy-saving methods improves workplace energy savings in the food and beverage industry. A pilot project in 15 companies achieved 490 measures of energy efficiency, saving 554 gigawatt-hours a year (five times the project goal) and avoiding some 13,500 tons of CO_2e emissions annually (CORDIS n.d.).

Under the Montreal Protocol implementation and national skilling frameworks, many countries have rolled out capacity-building programmes for the servicing sector. The survey results show that a majority of countries globally (more than 70 per cent) have incentives or programmes to support service technicians as the sector transitions to low-GWP refrigerants.

Encouraging women to pursue education and job opportunities in the servicing sector for cooling equipment has particularly high potential (IIR and UNEP 2022). With the growing use of the Internet of Things in appliances, and growth in the sheer demand for trained technicians, the diversity of jobs in the sector could expand (Dixit, Bhasin and Janakiraman 2021). Women could be positioned to take on the role of trainers as well as back-end jobs in managing such digitally enable systems. Pilot activities have been implemented in developing countries to tackle cultural and perceived technical barriers and to encourage greater gender diversity in this sector; however, such action needs to be amplified.

>70%

of countries globally have incentives or programmes to support service technicians

Consumer awareness

It is important to raise consumer awareness around equipment selection and use. The lack of knowledge about energy-efficient products and about the environmental impact of high-GWP refrigerants is a significant barrier to consumer investment in new technologies. Typically, consumers select equipment based on upfront cost rather than life-cycle cost, and they often do not consider ways to minimize the operating costs of equipment, such as by keeping refrigerator door openings to a minimum, improving the thermal envelope of dwellings and using proper thermostat set points for air-conditioning units. One way to overcome such lack of awareness is through educational campaigns in local dialects, such as animations, short videos and local drama series (UNEP Ozone Secretariat 2023b).

3.5 Electricity generation and capacity planning

The need for additional electricity generation capacity across most countries will require significant investments in the power infrastructure and grid capacity, not just to meet the growing demand, but also in many cases to manage already-strained electricity systems, most notably in the form of peak loads. The survey results show that only 40 countries, out of a total of 100 countries evaluated, are currently using cooling projections in their electricity capacity planning.

A study of four countries in the Maghreb region of North Africa (Algeria, Libya, Morocco and Tunisia) found that the growing use of air conditioning is already contributing 30-70 per cent of the peak load, depending on the country (World Bank 2016). Policies such as feed-in-tariffs for energy storage (for example, batteries or thermal storage mediums such as chilled water or ice) could support greater use of renewable energy. Such storage measures, either applied locally – for instance, using a battery pack or water tank – or through district energy solutions (see section 4.2), could take advantage of synergies across energy supply and demand to achieve affordable, low-carbon cooling.

Box 3-5: Case study: Cooling by Climate Saathis in India

In recognition of the significant role that women can play in building climate resilience and improving the lives of those living in informal settlements, the Climate Saathis ("Friends") project, led by the Mahila Housing Trust in India, trains women to be energy auditors (Gadhvi 2023). The trained women encourage households to switch to more energy-efficient lighting, fans and cooling devices. As such, they become grassroots-level micro entrepreneurs, forming a women-led distribution network for efficient and off-grid products.

By July 2023, around 28,000 energy audits had been undertaken in slum communities, saving families more than US$700,000 per year in electricity costs. In addition, solar-reflective white paint was installed on more than 200 modular roofs and 500 roofs, leading to a reduction of 105 tons of CO_2e per year.

Source: SEforALL 2023b.

28,000

energy audits in slum communities until July 2023

Photos: Pixel-Shot, shutterstock

3.6 Employment and participation of women

Given the projected increase in demand for cooling, jobs in the sector are expected to grow rapidly. As of 2022, more than 15 million people were employed globally in the refrigeration, air-conditioning and heat pump sectors (IIR and UNEP 2022). Women constitute a small fraction of this workforce, representing only 6 per cent of the members of national refrigeration associations, organizations and institutions (IIR and UNEP 2022). Reasons for low female participation include overarching socio-cultural factors associated with physical safety, as well as biased gender norms around mechanical engineering and the refrigeration and air-conditioning sector.

As the sector expands, it will be important to increase and strengthen the employment of women. The evolution of the air-conditioning and refrigeration sector involves a “nexus of mechanical, electrical, chemical, big data, photovoltaics, renewables, economics, policy and the social sciences to bring about behavioural change” (UNEP and UN Women 2019, p. 21). This provides a unique opportunity for women, particularly in emerging economies, to take part in varying professional capacities (UNEP and UN Women 2019). Training and empowering women to support environmentally and socially sound practices may lead to benefits at a household and community level (Box 3-5).

To encourage more gender diversity in the sector, the following actions may be considered, several of which are recognized by the International Network of Women in Cooling:

- Publicize the decadal growth in jobs in the cooling sector to encourage it as a choice of higher education, as well as the linkages between sustainability themes and professions in the sector, through courses in sustainability and the environment.
- Increase the visibility of women working in the sector by promoting role models and mentorship programmes that benefit both individuals and organizations.
- Support hiring programmes that target gender diversity as well as public disclosure of employees by gender in the sector; and encourage industries to volunteer targets to increase female workforces. For example, Daikin Turkey aims to increase its share of female employees to 50 per cent by 2025 (Daikan Turkey 2022), and Danfoss has pledged to have 30 per cent of its leadership positions be held by women (Danfoss 2020).

"An integrated approach to sustainable space cooling – considering the linkages between the urban, buildings and equipment levels – offers multiple benefits."

Belarus
Photo: Katya Tsiganok/shutterstock

04 Space cooling

An integrated approach to sustainable space cooling – considering the linkages between the urban, buildings and equipment levels – offers multiple benefits. Governments and industry need to prioritize the acceleration of sustainable cooling as a means to deliver thermal comfort to vulnerable people.

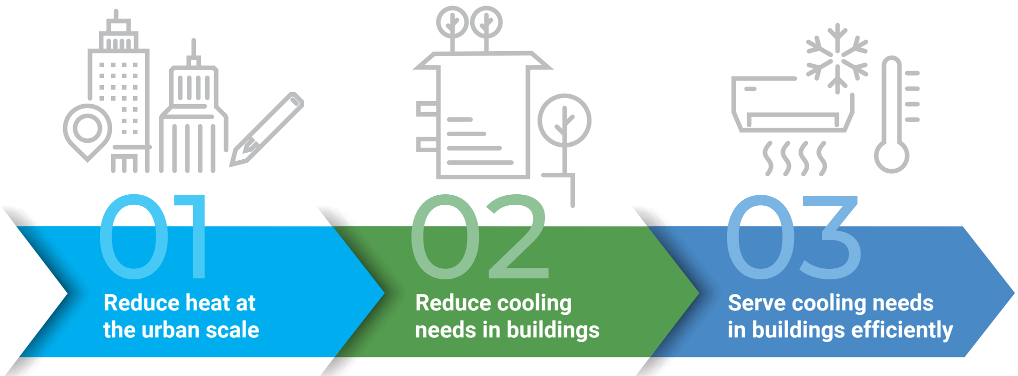
Under the BAU scenario, space cooling will be responsible for 70 per cent of the cooling energy consumed in 2050, with the fastest growth occurring in residential space cooling (see chapter 2). Any pathway to near-zero GHG emissions requires strong and rapid policy action, as well as technological innovation, to provide cooling access while also reducing emissions.

Appropriate urban design, infrastructure strategies and policy interventions by national and local governments can reduce heat at the urban scale, lower the cooling loads of buildings and increase system efficiencies. Innovations in passive technologies, often enabled by building codes, along with high-energy efficiency equipment and improved operational efficiency, can yield significant energy savings. Space cooling policies should promote sustainable cooling and heat resilience by downsizing cooling systems, maximizing equipment efficiency, reducing high-GWP refrigerant consumption and minimizing overall environmental impact.

4.1 An integrated, whole-systems approach

A coordinated approach considers the interrelated impact of space cooling at the urban, buildings and equipment levels (Figure 4-1), resulting in multiple benefits. Specifically, such an approach will minimize the need for active cooling equipment, leading to reductions in refrigerant consumption, costs to consumers, electricity-related GHG emissions, and the need to expand the electricity grid.

Figure 4-1: A whole-systems approach towards sustainable cooling



Efficient planning and design at the scale of the city or urban district, with an emphasis on heat minimizing urban form and design, nature-based solutions, and cool surfaces designed to reduce the urban heat island effect, in turn also reducing cooling loads in buildings.

Enhancing the thermal performance of buildings and minimizing cooling loads using passive building design practices, with an emphasis on leading-by-example city-owned buildings, and raising the floor with building energy codes and standards.

Efficient and best-fit cooling technologies and operations to deliver the required amount of cooling with the least amount of energy, emissions and anthropogenic heat.

Source: UNEP et al. 2021

Appropriate urban design, infrastructure strategies and policy interventions by national and local governments can reduce heat at the urban scale. For example, the urban heat island effect, which can increase surface temperature by 5°C (European Space Agency 2022; Santamouris and Vasilakopoulou 2023), or by up to 24°C in extreme cases (Chow and Chugh 2022), could be mitigated by measures that have proven to be extremely effective. These include nature-based solutions (such as adding greenery and water-based techniques), the use of cool materials on ground surfaces and building envelopes, and artificial shading through fabric canopies and pergolas.

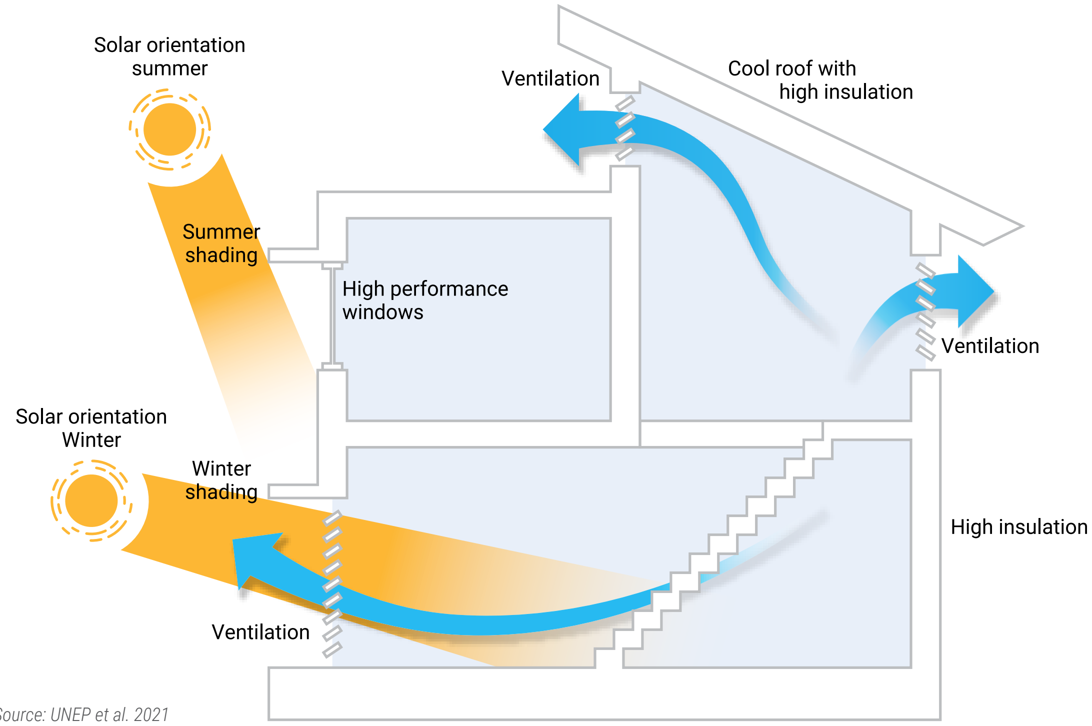
The cooling loads of buildings can be minimized through proper design strategies (e.g. passive designs, optimized envelopes, orientations, façade design, shading, material selection, nature-based greening and water features, natural ventilation, etc.). These could be implemented through enhanced building codes, standards and advanced energy design guides, as described in chapter 3.

Examples include the standards and guidelines of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), BUILD_ME and the IEA Heat Pump Annex 75.

Importantly, buildings should be designed to have the lowest possible cooling load, and this load should be served using the most efficient and environment-friendly equipment available. The efficiency and environmental footprint of appliances vary based on local and regional market dynamics (e.g. purchasing power, market size, technician capacity, consumer education, competent authority, availability of MEPS, etc.). Policies are needed that support reduced building cooling loads, as well as global best practices in energy efficiency standards.

Photo: Chuttersnap/ unsplash.com

Figure 4-2: Passive cooling principles in buildings



Source: UNEP et al. 2021

4.2 Technological innovation for space cooling

Passive cooling and integrated design

Investment in passive cooling technologies is key particularly in residential space cooling, as it has the large potential for reduction from passive measures at 28 per cent (Figure 4-2). Ventilation has historically been the dominant passive cooling technology, but new innovations in radiative measures (such as radiative panels) and solar control techniques are evolving rapidly.

Actions for passive cooling, which include nature-based approaches, can be widely structured in three categories that reduce, avoid or end the need for mechanical cooling and make the built environment thermally comfortable (Miranda et al. 2021). The categories are: 1) heat prevention – blocking solar radiation, using microclimate applications and applying solar control measures such as shading, glazing and aperture; 2) heat modulation – using building materials to capture or displace peak temperatures; and 3) heat dissipation – extracting heat from buildings and disposing of it in heat sinks such as the air, water or sky.

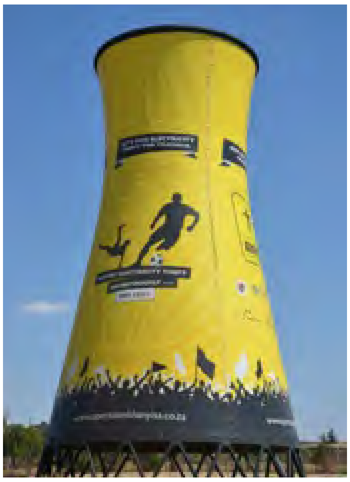
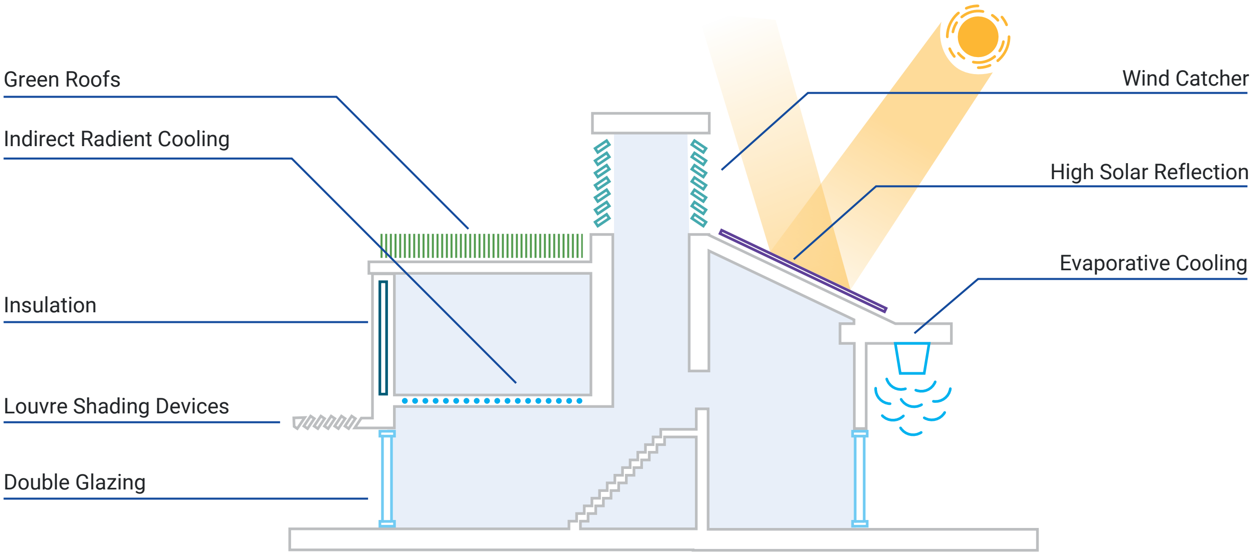


Photo: Michael Schofield/ unsplash.com

Commercial buildings have additional opportunities for passive cooling, as shown in Figure 4-3. Research suggests that passive cooling can help reduce a building's energy consumption by 8 to 70 per cent with the use of various techniques (Song et al. 2021). Advanced design architecture may offer improved cooling performance but requires an integrated design approach (Freewan 2019).

Dubai, VAE | Photo: Mohsen Esmati/shutterstock

Figure 4-3: Passive cooling opportunities in commercial buildings



Source: Sharma 2022

Thailand
Photo: kyozstorage_stock/shutterstock

Innovation and scaling of super-efficient equipment for residential space cooling

Active cooling strategies involve the use of mechanical means to remove or transfer the heat from an indoor space. The dominant space cooling technology today is vapour compression – or the commonly used air conditioner. Currently, nearly 70 per cent of the global installed air-conditioning capacity is in the residential sector (IEA 2023) (see Annex 3). Unfortunately, a significant gap exists between the most efficient residential air-conditioning products available in the market, and those that are most purchased by users. This difference is reflected in the most efficient products available and the corresponding MEPS for different countries.

Policies that support innovation and scale for super-efficient low-GWP air-conditioning equipment are vital to changing the emissions curve of residential space cooling. Active cooling strategies that need to be supported include:

- **Increased use of variable-speed compressors.** These consume 30 per cent less power than fixed-speed compressors for the same aggregate cooling. Variable-speed room air conditioners are quieter and have longer-lasting parts than fixed-speed units.

- **Encouraging consumers to use high-efficiency equipment.** A high-efficiency room air conditioner can greatly reduce energy costs, typically repaying the incremental cost in less than three years through accrued energy savings, depending on hours of usage.

- **Investment in variable refrigerant flow technology (VRF).** VRFs (used mainly for larger, non-residential systems) provide a greater efficiency option, especially as they potentially supply simultaneous heating and cooling and are primarily (more than 99 per cent) powered by variable-speed compressors. When compared to traditional packaged units, they can provide an efficiency boost of 30-50 per cent (Lee et al. 2018). Investments in VRF systems will promote scaling of this technology, especially when supported with policy measures. Investing in higher-efficiency air- or water-cooled air-conditioning systems is also an option, as these systems require far lower refrigerant charges and can use flammable refrigerants in applications where building safety codes do not allow the use of VRF systems with their high refrigerant charges.

- **Expansion of district cooling systems.** Although not an innovation per se, a primary advantage of such systems is their ability to integrate energy sources that might not be available or practical for individual cooling units, such as waste heat from industrial and service sectors. This integration supports displacing less efficient stand-alone cooling applications with more cost-effective, energy-efficient and environment-friendly cooling solutions. District cooling can reduce energy consumption for cooling by up to 50 per cent compared to traditional air-conditioning systems (Shi, Lu and Wang 2017).

Dubai, UAE
Photo: Tupungato/ shutterstock

4.3 Overcoming barriers to space cooling

Achieving sustainable cooling requires navigating the opportunities and barriers presented by the dominant air-conditioning technology, which remains the go-to solution for growing cooling demand, with other alternatives often overlooked. This has contributed to a range of barriers to advancing other approaches to sustainable cooling, such as low-tech passive measures. Barriers include slow innovation in alternative comfort technologies, ignoring the role of humidity and not accounting for it in efficiency ratings, having building-centric rather than occupant-centric systems (e.g. with low set-point temperatures) that limit opportunities to save on cooling, and paying attention only to the standard operational phase of air conditioning rather than its life cycle.

A focus on passive design and meeting the thermal comfort needs of occupants

Policies are needed to overcome the various barriers to more sustainable forms of space cooling (Figure 4-4). Building policies need to not focus exclusively on energy efficiency and instead also include passive design, which involves the use of layout, fabric and form to reduce or remove demand for energy-consuming technologies. Policies need to consider cooling beyond the emphasis on temperature, and to extend to other thermal comfort variables such as humidity, air speed, etc.

The focus of cooling systems needs to shift to being occupant-centric, and innovation needs to consider impacts during the full life cycle of the air-conditioning technology. Such energy management practices are required in all sectors, particularly in residential and government buildings, to optimize energy use. In addition, space cooling policy should include measures that promote access to cooling among the poor and off-grid populations, who are among the most vulnerable in both residential settings and institutional settings, such as clinics, hospitals and schools.

Figure 4-4: Policies to overcome barriers in the cooling sector and scale sustainable space cooling

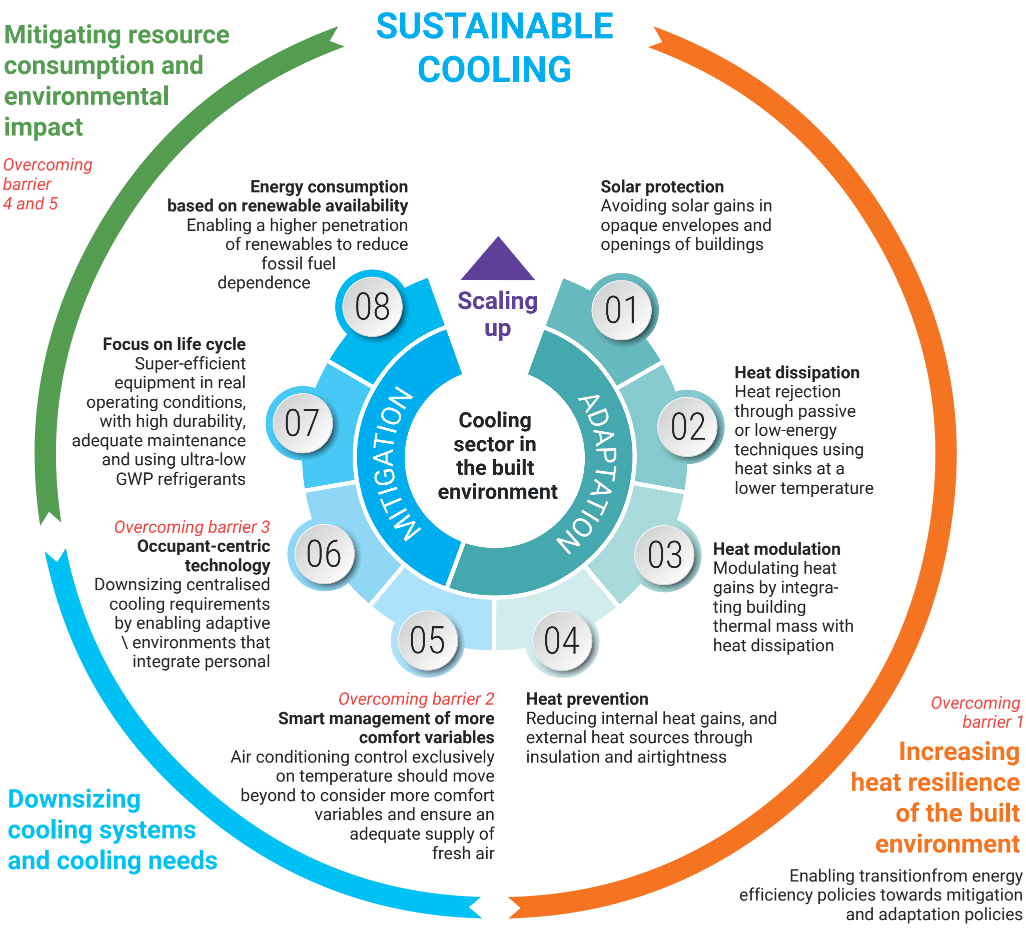
Source: Adapted from Lizana et al. 2022

A sequential policy approach that reduces the need for space cooling and minimizes overall impact

It is important for space cooling policies to promote sustainable cooling and heat resilience in a manner that downsizes cooling systems and cooling needs, decreases resource consumption and minimizes the environmental impact of cooling. A sequential approach would begin with a focus on adaptation and increasing heat resilience, through solar protection, heat dissipation, modulation and prevention. Next, it would focus on downsizing cooling systems and needs through smart management of more comfort variables and occupant-centric technology. Then, it would focus on mitigating resource consumption and environmental impact, equipment life cycle and grid decarbonization. Figure 4-5 demonstrates these steps.

Marunouchi, Tokyo
Photo: yoshi0511/shutterstock

Figure 4-5: Recommended action steps to address the barriers to sustainable space cooling



Source: Lizana et al. 2022

Vinnitsa, Ukraine
Photo: BONDART PHOTOGRAPHY/shutterstock

05 Refrigeration and cold chains

A robust and sustainable cold chain that can deliver nutrition and healthcare, and transform livelihoods and economies, requires a systems approach that integrates solutions to reduce energy consumption and uses energy-efficient technologies with low-GWP refrigerants.

Overall, food cold chains are responsible for around 4 per cent of total global GHG emissions, including emissions from cold chain technologies and from food loss and waste due to lack of refrigeration (IIR 2021). Emissions from cold chain equipment itself are set to rise significantly as new cooling-related infrastructures become available in developing countries.

Aggregating cooling demands within and/or across sectors can help to optimize system performance and resource use and can facilitate bundling of revenues and end-user applications to increase socio-economic benefits. To develop resilient, sustainable and equitable cold chains, governments should adopt a future-oriented approach, focusing on cost-effective, equitable pathways with minimal environmental impact.

Nipomo, CA, USA
Photo: Tim Mossholder/unsplash.com

A variety of technology innovations can be advanced to ensure a more sustainable cold chain.

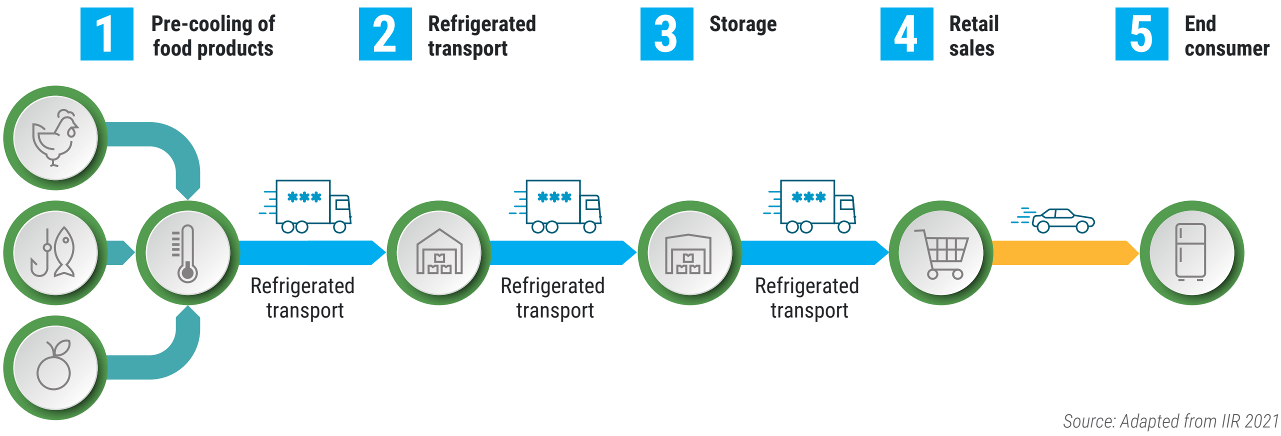
5.1 Sustainable cold chains

A cold chain is an uninterrupted system of temperature-controlled transport and storage of refrigerated products between upstream producers and final consumers, designed to maintain the quality and safety of these products. The cold chain can be best defined as: "The series of actions and equipment applied to maintain a product within a specified low-temperature range from harvest/production to consumption, including farming/fishing, food processing, cold storage, transportation, food services, and domestic uses, as well as specialized products like medicinal products and vaccines" (UNEP OzonAction 2020a).

The food cold chain sector plays a crucial role in managing the world's food systems from production to consumption, or "from farm to fork." Sustainable cold chains ensure that this is being done in an environmentally responsible and economically viable manner while minimizing waste and energy consumption. The cold chain is essential for maintaining the quality and safety of food products from production or manufacturing to consumption, especially when they require specific temperature ranges to prevent spoilage, contamination or degradation.

The cold chain consists of five stages, as shown in Figure 5-1:

Figure 5-1: The food cold chain as an example of a typical cold chain



Source: Adapted from IIR 2021

1 Pre-cooling and food processing: This corresponds to the first cooling of food products, such as just after harvest for agricultural products. Multiple processes and types of equipment are used in the pre-cooling process.

2 Refrigerated transport: This corresponds to the transport under optimal temperature conditions of refrigerated products. Refrigerated transport can occur several times in the chronology of the cold chain.

3 Storage: As with the refrigerated transport stage, cold storage can occur several times in the cold chain.

4 Retail: This corresponds to the distribution of refrigerated and frozen products in supermarkets and other sales outlets as well as storage equipment in the food service industry. Types of equipment include refrigerated display cases and freezers.

5 Final consumer: This is the stage of cold storage of the products in the refrigerator and/or freezer of the final consumer. Types of equipment include residential refrigerators and freezers.

The key principles and practices associated with a sustainable cold chain include:

- **Energy efficiency improvements:** considering both equipment energy efficiency and load reduction through the entire cold chain. Relevant measures include the use of advanced insulation materials, energy-efficient refrigeration systems and smart temperature monitoring.

- **Renewable energy integration:** integrating renewable energy with the cold chain to improve reliability and efficiency and to reduce GHG emissions and environmental impact. Proven examples include off-grid refrigeration equipment.

- **Transition towards low-GWP refrigerants:** accelerating the transition towards environmentally friendly alternative refrigerants that have lower GWP.

- **Reduced food loss and waste:** minimizing food and product losses at every stage of the cold chain – from production to distribution – by improving handling, packaging and monitoring processes.

- **Optimization of transport:** Utilizing efficient transport methods and routes to reduce the carbon footprint of transporting temperature-sensitive products, including using electric or hybrid vehicles and optimizing loading to maximize capacity.

- **Technology and data:** Leveraging technology and data-driven solutions to monitor and control temperature and humidity levels, ensuring that products are stored and transported within the required conditions.

- **Sustainable packaging:** Using eco-friendly and recyclable packaging materials to reduce waste and environmental impact.

- **Government and industry collaboration:** Encouraging collaboration between governments, industries and stakeholders to develop and enforce regulations and standards that promote sustainability in the cold chain.

- **Training and education:** Providing training and education to all stakeholders, including producers, transporters, and retailers, to raise awareness and improve best practices in the cold chain.

Photo: olrat/shutterstock

Bandoli, GA, India
Photo: Ishay Botbol/pexels.com

5.2 System-based strategies to advance sustainable cold chains

Cold chains are critical infrastructure that underpin the delivery of multiple developmental goals and targets, from food and health security to poverty reduction. Ineffective cold chains result in up to 30 per cent more waste in the perishable foodstuff chain and in an additional 1 billion tons of CO_2e emissions (IIR 2021). The lack of reliable cold chains reduces the income of an estimated 470 million farmers worldwide by up to 15 per cent (UNEP and FAO 2022). Moreover, inadequate cold storage and transport in developing economies hinders universal vaccine access and contributes to more than 1.5 million preventable deaths annually; it also results in an estimated US$34.1 billion annual financial cost due to vaccine wastage from temperature exposure (UNEP Ozone Secretariat 2021).

A holistic approach – covering various activities from source to consumption (Figure 5-2) – demands a review of the system-wide outcomes of the cold chain, from protecting the quantity, quality, nutritional value and safety of the food/product to preventing waste. It also requires evaluating the energy loads and the total environmental impact by breaking down each supply chain activity along the cold chain. This includes not just the provision of cooling, but also components such as packaging, sorting and grading, inventory and asset management, mobility and waste management – all of which require attention from an energy and resource use perspective.

Addressing the cold chain while focusing on reducing energy consumption and environmental impact requires an integrated approach that links solutions to reduce cooling load, use energy-efficient and renewable technologies and enable low-GWP refrigerants. Key policies and practices that have been identified towards advancing sustainable cold chains include the following:

- improve the standards for cold chain refrigeration that reduce cooling loads;
- improve the efficiency of cooling equipment through best practice specifications (for use in tenders for new equipment) including through MEPS and energy labels, aggregation of cooling services through community cooling hubs or similar in lieu of diffuse refrigeration, procurement programmes and procurement specification guidance, financial support and demand-side management;
- improve the operating efficiency of equipment through training for end users and for refrigeration technicians on optimal operations and maintenance practices;
- minimize direct emissions from refrigerants by adopting policies to increase the rate of phase down of high-GWP refrigerants beyond the current requirements in the Kigali Amendment (see chapter 6); and
- decarbonize the electric grid at a faster rate to ensure that it is fully decarbonized by 2050.

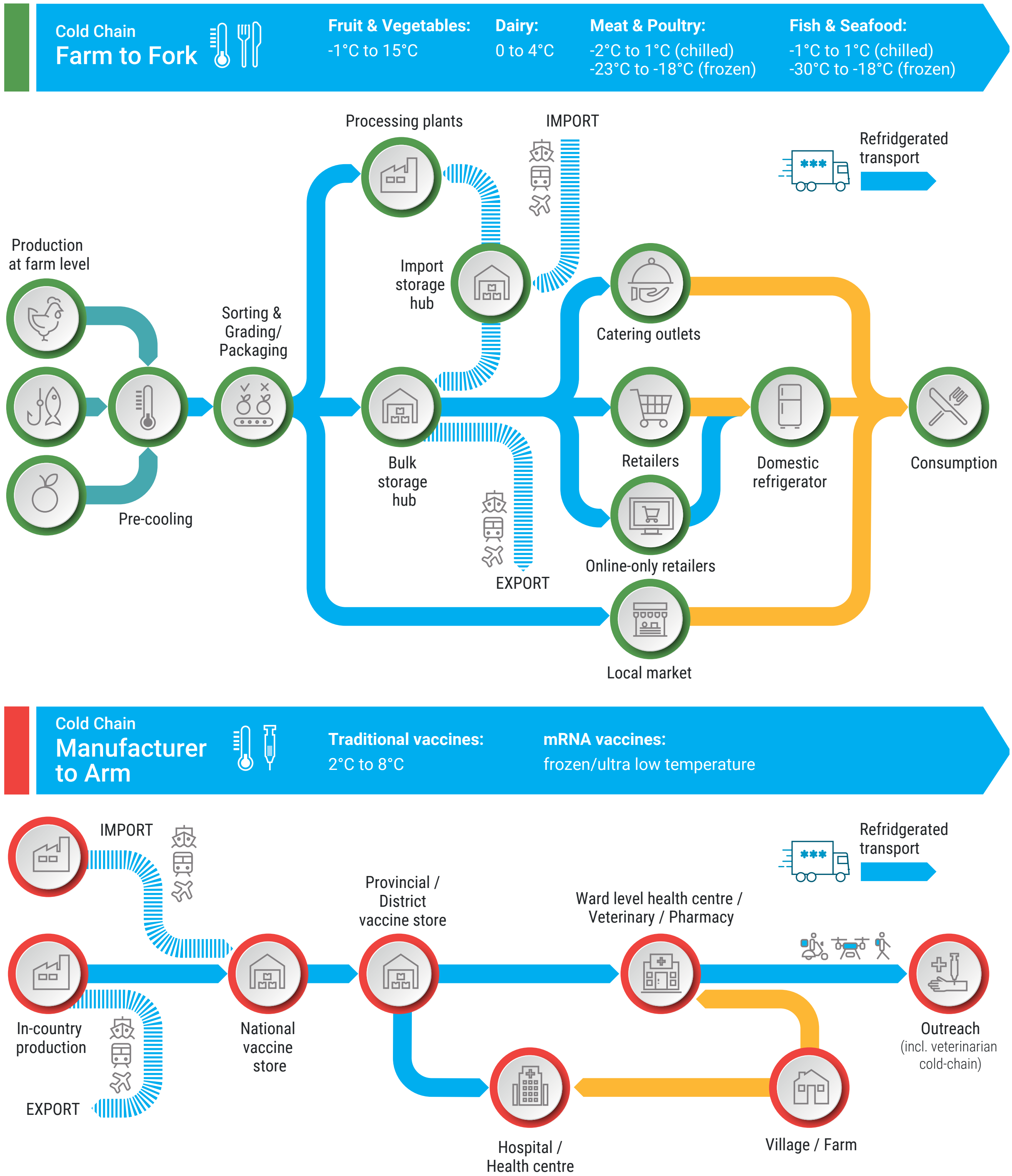
470

million farmers worldwide lack access to a reliable cold chain

Seoul, South Korea
Photo: Grace Lim/unsplash.com

Banda Aceh, Indonesia
Photo: FREDOGRAPHY.ID/shutterstock

Figure 5-2: Typical cold chain flow from farm to fork, and from vaccine manufacturer to arm



Source: UNEP Ozone Secretariat 2023b

Exploiting multi-sectoral synergies by creating cold chains that provide integrated food supply, agricultural and healthcare services

In developing economies, incentives for cold chain provision often focus on a single component of the overall system – typically, cold-storage facilities. This disregards essential connectivity that includes multiple static and mobile elements of cooling, as well as the energy system, roads, ports (sea, air) and other critical infrastructure that underpins the cold chain. Likewise, attempts to establish vaccine cold chains are often focused on the individual fridge, rather than on management of the entire chain of cooling from point of manufacture through to dose recipient.

At the systems level, multi-sectoral synergies can be exploited by creating cold chains that provide integrated services, for example, across food supply and agriculture as well as health. In countries with gaps in energy access and unmet cooling demand, interventions at the nexus of energy and cold chain development may help accelerate efforts to deliver rural access to modern energy services for all cooling needs for agriculture and health care.

Photo: Mat Napo/unsplash.com

Aggregating cooling demand

Aggregating cooling demands within and/or across sectors can help to optimize system performance and resource use and can facilitate bundling of revenues across sectors and end-user applications to increase socio-economic benefits. For example, the societal needs of farming communities that rely on temperature-controlled pack-houses/aggregation hubs , which typically include energy-intensive cooling equipment, can be better met by a cooling system that aggregates cooling demand to create system efficiencies.

Such system-level approaches also enable development of the most cost-effective transition pathway to a smarter, decarbonized and resilient energy system. This enables improved cross-sectoral cohesion, potentially lowering the investment cost and reducing the risks such as overbuilding or underutilizing the deployed capacity.

Future-oriented approach

To develop resilient, sustainable and equitable cold chains, governments should adopt an approach that focuses on cost-effective, equitable pathways with minimal environmental impact. Understanding societal changes in demographics, climate, food production, consumption patterns, social norms, technologies and innovations will impact the requirements for cold chain infrastructure. Current technologies may struggle to operate in a future world with higher temperatures and heat waves. Three tools that can help are: horizon scanning to identify drivers affecting future cold chain provision; examining return on investment to quantify and monetize impacts; and developing a Cold-Chain Security Index to support governments with a dynamic, quantitative and qualitative decision-making and resilience tool.

Cold chain security

is essential for modern healthcare

5.3 Technology innovation in refrigeration and cold chains

Diverse innovations in passive cold storage have emerged in recent years. Evaporative cooling methods include clay-in-clay passively cooled rooms, zero-energy cooling chambers (sand and bricks) and the use of charcoal-filled walls in non-refrigerated rooms (Makule, Dimoso and Tassou 2022). The zero-energy cool chamber (ZECC) is being used in India at the community level (SEforALL 2018). Evaporative cooling systems perform best in hot and arid regions such as the African Sahel, where most people live in rural areas with limited or unaffordable access to electricity (Rehman *et al.* 2020). Evaporative cooling can slow the deterioration of fruit and vegetables, although it cannot achieve the recommended temperatures for conserving animal products and some plant-based products.

During 2016-2021, the MIT D-Lab Evaporative Cooling for Vegetable Preservation group led a project in Mali that trained 39 people in proper vegetable storage, evaporative cooling principles and best practices using clay pot coolers, leading to the sale of nearly 2,000 of the coolers (MIT D-Lab 2022). In India, the domestically produced Mitticool refrigerator is made entirely from clay and is designed to store vegetables, fruits, milk and cooled water. Its refrigeration effect depends on ambient temperature and humidity, with the lowest storage temperature achieved being 4.5°C in summer (Engineering for Change n.d.; Patel *et al.* 2021). In Africa, the Zeer pot, a low-cost refrigeration device that uses natural evaporative cooling, has been tested in Sudan, Nigeria and Gambia (SEforALL 2018).

Photo: Sabrina Bracher/shutterstock

Some of the other technology innovations being used in refrigeration and the cold chain are summarized below.

- **Pre-cooling.** Studies have shown that with pre-cooling, post-harvest losses of commercial fruits and vegetables could be reduced from 25-30 per cent down to 5-10 per cent (Elansari, Fenton and Callahan 2019). However, smallholder farmers and aggregators often lack access to energy, equipment and finance to do this. Globally, innovative methods and equipment are needed to enable pre-cooling and related approaches in remote locations that lack a stable electricity grid (UNEP and FAO 2022). In Colombia, the coffee company Buencafé relies on large-scale freeze-drying technology to preserve the coffee's quality and has made significant advancements in energy efficiency. Between 2015 and 2018, Buencafé was able to reduce its energy consumption per kilogram of freeze-dried coffee from 40 kWh to 34 kWh (UNEP and FAO 2022).

- **Digitalization.** Innovative technologies are emerging that rely on machine learning, artificial intelligence and the Internet of Things to provide a digital blueprint of cold chain equipment and their operation. Through data-driven insight and analysis, cold chain operators can optimize routes, exploit unused capacity and develop more efficient maintenance schedules (Garcia and de Souza 2023). Studies have found that smart controller design could achieve up to 4.5 per cent energy savings (Kapici, Kutluay and Izadi-zamanabadi 2022). However, smart refrigerators using the Internet of Things are costlier to produce and service, thus limiting their market share (UNEP Ozone Secretariat 2023b).

- **Waste heat recovery.** There are opportunities for end users and suppliers to share infrastructure and to benefit from energy that would otherwise be wasted. One example is using the waste heat from a supermarket refrigeration system to provide domestic heating or hot water via a district heating system. In Denmark, 20 SuperBrugsen supermarkets in Høruphav are reducing their environmental impact through heat recovery from the refrigeration system to satisfy the heating needs of the stores and sending the surplus heat to the district heating network. The supermarkets were able to supply heat to 16 standard homes in the region, reducing their CO_2 emissions by 34 per cent (Euroheat & Power 2017).

Scaling of super-efficient equipment. Stronger policies are needed to improve the uptake of newer, more efficient technologies, to support wide-scale adoption (UNEP Ozone Secretariat 2019). In the last decade, the use of improved compressor and control technologies has led to a 65 per cent reduction in the energy consumption of domestic refrigerators and freezers (IIR 2019; Kapici, Kutluay and Izadi-zamanabadi 2022). In addition, novel components and alternative technologies – including phase-change materials and solar direct-drive refrigerators – have the potential to improve performance, enabling further reductions in energy use.

Phase-change materials (PCMs). PCMs can store substantial amounts of energy and release or absorb it as heat, thereby increasing the efficiency of the refrigeration circuit (Sidik *et al.* 2018; Riffat *et al.* 2022). Because they offer good temperature homogeneity and stability, energy storage with PCMs could be used in refrigerated transport – either stand alone or in combination with a vapour compression system (Maiorino, Petruzziello and Aprea 2021; Minetto 2022). Compared with conventional refrigerators, studies found that placing PCMs in separate places in a refrigerator decreased energy use and reduced temperature fluctuations (Ilangovan *et al.* 2022).

Photo: Service Communication et Media, MSANP, Sept. 2020

Photo: Paul Einerhand/unsplash.com

Solar direct-drive refrigerators. These are designed for rural areas without electricity and are connected to solar photovoltaic panels, operating without batteries (Efficiency for Access Coalition 2022). They freeze cold storage materials and use stored energy to maintain cold temperatures for up to four days, using water or non-toxic salts as PCMs (World Health Organization [WHO] and UNICEF 2017; CLASP and SEforALL 2021). In the Solomon Islands, the donation of solar-powered freezers to a group of rural women in the fishing sector enabled cold storage for fish and other perishable food, allowing the women to expand their product offerings and to generate extra income to cover the freezers' expenses (UNEP and FAO 2022).

Other technologies such as Stirling cycle, absorption, adsorption cycles, thermoelectric and magnetic are being developed to improve efficiency. However, these technologies are not yet competitive on a cost or efficiency basis with conventional vapour compression technology for mass-produced domestic refrigerators.

Additional technology innovations in the cold chain are related to the transition to natural and ultra-low GWP refrigerants, especially in combination with energy efficiency measures. The benefits of this approach are discussed in chapter 6.

“Improve the efficiency of cooling equipment through best practice specifications (for use in tenders for new equipment) including through MEPS and energy labels, aggregation of cooling services through community cooling hubs or similar in lieu of diffuse refrigeration, procurement programmes and procurement specification guidance, financial support and demand-side management.”

Norrtalje, Sweden
Photo: Emelie Lundman/shutterstock

06 Path towards low-emission refrigerants

The Kigali Amendment to the Montreal Protocol has provided the signal to mobilize the refrigeration and air-conditioning sector to transition towards low-GWP refrigerants. This momentum can be leveraged to enhance innovations and a faster phase down of high-GWP refrigerants, alongside higher energy efficiency and better refrigerant management.

The transition to next-generation refrigerant technologies can be accelerated by implementing codes, standards and regulations, as well as training programmes for technicians. Life-cycle refrigerant management can be improved through new programmes to reduce leaks and increase recovery at end-of-life. Integrating the refrigerant transition with energy efficiency measures is necessary to maximize synergies.

Annex 10 provides a high-level summary of national policies and regulations related to the HFC phase down in some of the world's largest refrigerant producing and consuming economies. The pathways modelled in chapter 2 show that it is possible to achieve rates of HFC phase down that are faster than those required under the Kigali Amendment (see section 2.3).

6.1 Refrigerant phase down

Strengthening the Montreal Protocol to minimize opportunities for illegal refrigerant trade

The 2016 Kigali Amendment, which entered into force in 2019, widened the scope of the Montreal Protocol to phase down HFCs, which are substitutes for chlorofluorocarbons (CFCs) that do not deplete ozone but have high global warming potential. The quantities of refrigerants consumed globally can continue to grow, so long as the substitutes for HFCs have lower GWP. However, there remain exemptions for certain feedstocks and process agents, which creates opportunities for illegal trade in banned substances. The Montreal Protocol must be strengthened to close these loopholes.

6.2 Life-cycle management of refrigerants

Enhancing life-cycle refrigerant management through new and expanded programmes paired with financial incentives and robust monitoring and reporting requirements

Life-cycle management of refrigerants aims to avoid the emissions from refrigerant gases over the life cycle of cooling equipment, including during installation, operation, servicing and end-of-life (Figure 6-1). This, together with an accelerated HFC phase down, can avoid up to 90 billion tons of CO_2e globally by the end of the 21st century, beyond the reductions expected through the Kigali Amendment.

Figure 6-1: Life-cycle stages of refrigerant gases

Life-cycle management of refrigerant gases involves:

- designing and manufacturing equipment to minimize refrigerant charge size and reduce the potential for leaks from fittings, hoses and connections;
- preventing leakages during installation, servicing and operation of cooling equipment
- discouraging refrigerant venting and increasing recovery of refrigerant at the end-of-life of equipment; and
- recycling/reclaiming gases for re-use or destroying recovered refrigerants.

Life-cycle refrigerant management can be enhanced through new and expanded programmes to reduce leaks and increase refrigerant recovery, reclamation, and destruction, paired with financial incentives and robust monitoring and reporting requirements. In some countries, dedicated Infrastructure and systems have been established for collection, transport, aggregation and reclamation/destruction of the gases, as well as data recording and monitoring of the initiatives. In 2022, a good practice portfolio for life-cycle management of fluorocarbons was published by Japan and the Climate and Clean Air Coalition.

Further examples of life-cycle management initiatives taken by selected countries are provided in Annex 11.

6.3 Transition towards alternative refrigerants

Accelerating the transition through enabling codes, standards, regulations, purchasing specifications and training programmes

Most of the refrigerants in wide use today are hundreds to thousands of times more damaging to the atmosphere than CO_2. For example, R-404A, a common blend used in refrigeration, has a high GWP of 3,922. Alternative refrigerants with much lower GWPs are available for all cooling applications, and can greatly reduce the GHG emissions resulting from leakage and/or spillage during use and end-of-life disposal. The transition to low- or no-GWP refrigerants is already under way (see Annex 5); however, it can be accelerated by assuring that enabling codes, standards, regulations, purchasing specifications and training programmes for servicing technicians are in place.

The most mature markets for low-GWP refrigerant alternatives are residential cold chains and mobile air conditioning, followed by food retail and food service refrigeration. There is significant progress towards using ultra-low-GWP refrigerants in sectors such as residential refrigerators, sealed retail and food service, large retail, chillers and industrial applications. Progress is slower for air-to-air air conditioning and heat pumps, with medium-GWP options now available and much development work focused on lower-GWP alternatives.

Drivers and barriers in the transition

The Kigali Amendment has provided the signal to mobilize the cooling sector to transition towards low-GWP refrigerants. Regulatory and financial incentives, as well as public pilots and research and development, have played a key role in scaling the market for these alternatives. in some cases, the transition has not impacted consumer costs and has even delivered savings in the form of reduced energy consumption. This is because refrigerants historically account for less than 1 per cent of the purchase, operating and maintenance cost of equipment (JMS Consulting and Inforum 2018).

Even so, barriers continue to impede the shift to more sustainable refrigerants. They include limited funding, lack of standards and regulations, inadequate training and insufficient coordination and cooperation, as well as operational challenges such as flammability, toxicity and high pressure that could result in safety risks if not handled properly. A few of the barriers influencing the market status of alternative refrigerants are summarized below (UNEP Ozone Secretariat 2022b):

- **Access, safety and environmental concerns related to low-GWP refrigerant technology remains the major hindrance to wide-scale adoption of alternative refrigerants.** Accessibility challenges include the lack of availability of low-GWP products and components in some locations, the high price of some patented hydrofluro-olefin (HFO) blends, and outdated building codes that slow the transition to alternatives. Because HFCs are controlled under the Kigali Amendment, prices have increased in some markets where supply is constrained, creating incentives for illegal smuggling and trade in regulated refrigerants.
- **Because most ultra-low-, low- and medium-GWP refrigerants have different flammability classes, the cooling sector continues to update the relevant safety standards to enable their use.** Recent updates included reducing the restrictions on flammable refrigerants and increasing the allowable charge limits for these refrigerants used in self-contained cooling applications. As these alternatives get tested, reviewed, and approved, industry transitioning to these depends on the pace of change of the standards and permissible usage limits.
- **New environmental challenges have emerged for synthetic HFCs and HFOs.** For example, trifluoroacetic acid, a decomposition product of some HFC and HFO refrigerants, as well as refrigerants that contain at least one fully fluorinated methyl (CF3-) or methylene (-CF2-) carbon atom (without any hydrogen, chlorine, bromine or iodine attached to it) are included in the definition from the Organisation for Economic Co-operation and Development (OECD) of per-and poly-fluoroalkyl substances (PFAS), synthetic chemicals that can be highly persistent and toxic. This definition does not include R-32 (a common medium-GWP alternative used in air conditioners and heat pumps), HFC-152a, HFO-1132 and HFO-1123.

European updates based on the region's own definition of PFAS may impact applications in the cooling sector in some countries due to the restriction on transitional refrigerants and HFOs limiting refrigerant options (IIR 2022a; Cooling Post 2023; European Commission 2023; European Parliament 2023; IIR 2023a; Refrigeration Developments and Testing Ltd. 2023).

Phasing down HFCs

plus life cycle management can avoid up to 90 billion tons of CO_2e globally by the end of the 21st century

Le Mans, FRANCE
Photo: Kerckweb/ shutterstock

At this stage, different country and industry groups have varying views on the definition of PFAS, its impact on the ecosystem as well as the overall implementation of the Montreal Protocol, its destruction, and alternatives to it. In October 2023, at the 35th Meeting of Parties (MOP35) to the Montreal Protocol, it was decided that the environmental, scientific, and technology and economic assessment panels constituted within the agreement will be assessing and evaluating various issues related to PFAS to be presented to the Parties for their review in 2026.

6.4 Synergies between energy efficiency and the refrigerant phase down

Integrating the refrigerant transition with energy efficiency and building decarbonization programmes and appliance efficiency standards, labels and promotion programmes

The HFC phase down is focused on the direct GHG emissions from refrigerant use. However, the indirect GHG emissions related to the energy consumed by equipment in the cooling sector are equally or more impactful to climate change. Indirect emissions can be greatly reduced through improved equipment energy efficiency, reduced demand using high-performance buildings and cold chain, and reduced carbon intensity of the electricity sector.

Although the Kigali Amendment itself does not regulate energy efficiency, at the request of countries the Montreal Protocol is negotiating decisions to support a transition towards greater efficiency while lowering the use of high-GWP refrigerants (UNEP Ozone Secretariat 2021a; UNEP Ozone Secretariat 2019; UNEP Ozone Secretariat 2017).

Future phase down of HFCs through the Kigali Amendment can mitigate global warming by 0.3°C to 0.5°C. Synchronous improvements in the energy efficiency of cooling equipment could double this climate benefit. Equipment that uses low- and medium-GWP refrigerants with enhanced energy efficiency is available in all sectors but is not necessarily accessible in all countries. Increasingly, larger supermarkets and other commercial cold chain users are piloting the use of ultra-low GWP refrigerants alongside other efficiency measures, resulting in large energy savings as well as direct emission reduction (see Annex 12).

So far, very few countries have aligned their transition to low-GWP refrigerants to their use of MEPS. Although MEPS and low-GWP refrigerants belong to two different policy areas – one related to energy, the other to chemical management and climate – implementing these measures in tandem can bring great benefit. These include synergies for service sector training, consumer awareness, technology research and development (R&D), streamlining financing regulations and policy, and enhancing product lifespan to reduce embodied emissions.

Avepozo, Togo
Photo: Africanway/istockphoto

Some jurisdictions of the European Union link MEPS with GWP refrigerants (EU-China Energy Cooperation Platform 2022), and recent proposals in the region to amend F-gas regulations emphasize energy efficiency-first principles in the transition to low-GWP and natural refrigerants (European Union 2009; European Commission 2022a). These proposals to control fluorinated and ozone-depleting gases could lead to a reduction of 490 million tons of CO_2e in the European Union by 2050 (European Commission 2022b).

In Kenya, the National Cooling Action Plan evaluated that if the country's MEPS were to only allow equipment with HFC-32 or HC-290 (medium- and low-GWP refrigerants) from 2025 onwards, Kenya could save 3.1 million tons of CO_2e emissions to 2050 (14 per cent of its annual emissions in 2021) (Government of Kenya 2022). Similarly, Rwanda's project on Enabling Deployment of Energy-Efficient and Climate-Friendly Cooling aims to enhance access to space cooling and cold chains using low-GWP refrigerants and energy-efficient technologies. It targets reducing energy bills by US$40 million by 2030 by enhancing stakeholder capacities, developing MEPS implementation frameworks, increasing investments, raising consumer awareness and institutionalizing enforcement and monitoring (UNEP U4E 2021e; Green Climate Fund 2022; UNEP U4E 2023b).

Mbale, Uganda
Photo: Stephen Butler/shutterstock

Challenges in implementation persist, as with Bangladesh's draft Standard & Labelling of Appliance Regulations, which call for the use of ultra-low GWP HC-290 for air conditioners with less than 1.5-ton capacity and for low-GWP conversion of production lines for higher-capacity air conditioners. So far, key elements have not been sufficiently and suitably prepared, such as the method for energy efficiency measurement, the energy efficiency verification system and the energy efficiency testing laboratory. Implementation requires international and national prioritization (Bangladesh, Sustainable and Renewable Energy Development 2020; Gesellschaft für Internationale Zusammenarbeit [GIZ] 2021).

Operationalizing synergies between the HFC phase down and energy efficiency

A common policy framework, coordination among national ozone units and national energy and climate authorities, and a focus on energy efficiency and the decarbonization of electricity can lead to substantial reductions in GHG emissions between now and 2050. The World Bank has developed numerous case studies highlighting ways to operationalize the synergies between the HFC phase down and energy efficiency in different countries (Box 6-1). There have also been efforts to link the refrigerant transition to the energy efficiency obligations of utilities (Box 6.2). Realizing the HFC phase down and energy efficiency goals in tandem, within the same equipment and/or cooling system and supported by consistent policies, is essential to save costs, accelerate the refrigerant transition, roll out efficiency improvements, obtain financial support and meet global climate goals.

Kenya
could save 3.1 million tons of CO_2e emissions up to 2050 by enforcing MEPS that allow only medium- and low-GWP-refrigerants

Box 6-1:
Case study: Operationalizing synergies between the HFC phase down and energy efficiency in different countries

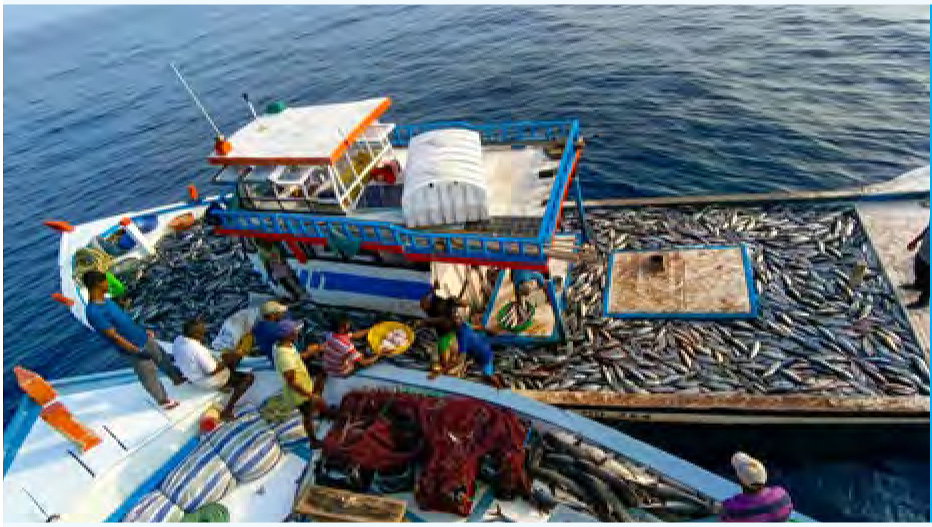
The World Bank, with support from the Government of the United Kingdom of Great Britain and Northern Ireland, conducted case studies on how to operationalize synergies between the HFC phase down and energy efficiency in the cooling sectors of several countries, including through analysing policies and developing solutions for the cold chain and buildings sectors. The project increased the capacity to implement sustainable cooling solutions; supported the development of policies, regulations and standards on energy efficiency and cooling in buildings (including through NCAPs and Kigali Implementation Plans); and investigated financing options, including through green bond markets (cooling bonds).

In Pakistan, the project identified inefficiencies in fishing operations, processing, cooling, storage, and transport of seafood and fish products. The study found that most ice factories still use ammonia cooling technology with zero direct GHG emissions (but inefficiently) and recommended keeping and upgrading this technology to save electricity. Opportunities to make the fisheries sector more sustainable included right sizing the supply chain, introducing energy-efficient technologies and practices, modernizing the ammonia-based ice-making technology and avoiding the use of HFC-based solutions. The study proposed a plan for modernizing the sector and advised the NCAP process.

In India, the project produced a comprehensive GHG inventory for the seafood cold chains, conducted extensive stakeholder consultations, and recommended upgrades to technologies and business models. The project found large potential to expand the seafood value chain and developed knowledge and plans on how to achieve that. An energy audit demonstrated that investing in solutions that combine energy efficiency and the use of zero ozone-depleting and low/zero-GWP refrigerants can save energy and costs. In West Bengal, the project developed pilot proposals to save energy by moving cold chain transport from congested roads to inland waterways. However, because low/zero-GWP refrigerants are not yet available in West Bengal and face legal barriers, HFC blends were recommended as transitional refrigerants while market barriers are being addressed.

In Costa Rica, the Dominican Republic and El Salvador, the project assisted the governments with analysis and recommendations for improved building energy efficiency codes for construction, insulation and cooling. To facilitate implementation and enforcement, the project recommended "packages" of technologies that meet the new standards and from which builders can pick. In Costa Rica and El Salvador, the project demonstrated substantial economic and climate benefits resulting from enhanced energy performance standards for air conditioners and refrigerators.

Agatti, Lakshadweep, India
Photo: Mohijaz/shutterstock



India

has worked on a comprehensive GHG inventory for seafood cold chains

Box 6-2:
Linking the refrigerant transition to the energy efficiency obligations of utilities

Governments are increasingly establishing goals to reduce GHG emissions from buildings, often by promoting heat pumps and other refrigerant-using devices to replace natural gas appliances. However, professionals charged with reducing emissions in buildings are increasingly realizing that, in addition to examining the emissions associated with electricity or fuel use, it is important to track and manage refrigerant leakage (California Energy Commission 2021). Ensuring that low-GWP refrigerants are prioritized in energy efficiency incentive programmes can help unlock additional funding to assist with the phase down of high-GWP refrigerants.

The laws, regulations and evaluation tools being created in a handful of North American states could be adapted for use elsewhere. For example, the 2018 California Cooling Act authorized the California Public Utilities Commission (CPUC) to develop a strategy to promote low-GWP refrigerants in equipment funded by energy efficiency programmes that it oversees (California State Legislature 2018). The CPUC responded by 1) requiring efficiency programme administrators to use a new refrigerant calculator to evaluate refrigerant GHG impacts and the avoided costs from reducing refrigerant emissions; 2) updating its evaluation tools, such as the Cost Effectiveness Tool, to include refrigerants; and 3) requiring utilities and efficiency programme administrators to seek out all cost-effective opportunities to mitigate refrigerant emissions starting in 2022.

The state of Washington similarly passed a bill encouraging utilities to address refrigerants (House Bill 1050 of 2021; Washington State Legislature 2021). Such laws are significant because they can unlock funding to manage refrigerant emissions and address refrigerant banks while promoting energy-efficient equipment. They can also potentially increase the cost effectiveness of utility energy efficiency programmes in areas where energy regulators have a dual mandate of increasing efficiency and reducing emissions from buildings, a win-win for both.

It is important that those most in need can access climate-friendly technologies and avoid environmentally harmful dumping of inefficient and obsolete technologies (CLASP and IGSD 2020). To support implementation of energy efficiency improvements alongside the refrigerant transition, steps can be taken to expand public funding, mobilize private capital and develop needs-based funding models. Such action requires coordinated and holistic attention by both the public and private sectors.

"A common policy framework, coordination among national ozone units and national energy and climate authorities, can lead to substantial reductions in GHG emissions between now and 2050."

Photo: l i g h t p o e t/shutterstock

“Proper risk management frameworks are needed to bring finance towards sustainable cooling projects and products. Technology, operational performance and ESG risks are particularly important when assessing cooling investment risks.”

Photo: Romolo Tavani/shutterstock

07 Financing for sustainable cooling

A step-change in public, industry, philanthropic, and international finance, as well as technical assistance, is needed to pilot and scale various approaches dedicated to financing sustainable cooling. Although business models and finance instruments exist to tackle upfront cost barriers, they have yet to be deployed at scale. Proper risk management frameworks and access to reliable market data are required to unlock and redirect finance towards sustainable cooling projects and products.

Greater clarity to de-risk, size the financing market and identify funding gaps for sustainable cooling would present a better business case to attract required investments. Already, a variety of financial instruments can be leveraged to finance cooling for innovation and early adopters. These include business models for affordability and life-cycle management that promote market growth, as well as emerging financial instruments such as public and blended finance mechanisms, risk sharing and guarantee facilities, and cooling bonds.

The low penetration of cooling services in developing countries, which is at an inflection point to increase substantially, provides the dual benefit of scaling up cooling finance while achieving development and environmental targets. Financing greater cooling access via sustainable technologies is always more cost effective than financing a transition from inefficient to efficient technologies.

Key recommendations include systematically tracking cooling finance and its impacts as the market grows; incorporating sustainable cooling into the environmental, social and governance (ESG) safeguards for multilateral development banks; financing residential, non-residential and cold chain stakeholders; and strengthening the role of efficiency and sustainability standards (such as MEPS) in cooling financing decisions.

7.1 Streamlining and overcoming challenges to scale financing

Many opportunities and challenges exist for financing sustainable cooling across sectors, end users and business models. This includes options for accelerating financing, with a focus on risk and reward considerations; considering market factors such as sectors, end-use customers, institutional capacities, and business models; as well as regulatory frameworks and geographical, economic and political factors. (For an overview, see GIZ 2019).

Finance for sustainable cooling must go beyond grants and other non-repayable funding, even if these are fundamental to create better conditions. Multilateral development banks can contribute greatly to scale up financing for sustainable cooling, but the potential for more investment avenues is yet to be unlocked. Proper risk management frameworks are needed to bring finance towards sustainable cooling projects and products. Technology, operational performance and ESG risks are particularly important when assessing cooling investment risks.

For example, residential consumers accessing finance would be inspected for their ability to pay, and intermediaries such as providers of “cooling as a service” (CaaS) would get enhanced scrutiny of their business model, financial abilities and previous experience. Meanwhile, manufacturers would face additional scrutiny over technology risk environmental, social and governance (ESG standards) and market assessments for technology sales.

Technology, operational performance and ESG risks are particularly important when assessing cooling investment risks. Solving the financing problem is not simply a matter of applying more money. It is about unlocking funding through risk management, re-directing funding from unsustainable to sustainable technology, and making financing available to vulnerable groups that need it most. Where funding is required, a range of instruments can be used, ranging from grants to risk sharing.

Numerous organizations provide support for managing risks and unlocking available financing. This includes efforts by UNEP and CLASP to support voluntary and regulatory standards for appliances, by the International Finance Corporation (IFC) and others to develop new building codes, by the Clean Cooling Collaborative to strategically programme funds, and by the German-funded CoolUp programme to address project preparation. Unfortunately, such programmes remain limited and have not been implemented at scale (Nain and Bhasin 2022).

Along with risk assessment, access to reliable market data is a requirement for the design of financing programmes. Lack of clarity about the size of the financing market and funding gaps for sustainable cooling make it challenging to support the business case required to attract investments across sectors, stages and geographies. No formal tabulation of funds dedicated for sustainable cooling is available – such funding is often a subset of larger projects and is not defined or reported consistently. However, even with the limited data available, it is apparent that the financing needs are orders of magnitude greater than recent investment. Moreover, barring significant new initiatives, the shortfall will increase as warming continues and as temperature extremes occur more frequently.

7.2 Mapping the financing landscape for cooling

Finance is needed for work on the enabling environment for sustainable cooling (such as technical assistance or capacity-building projects, including vocational training for the installation and maintenance of cooling systems), as well as for the implementation of (typically larger) investments. Programmes to scale up investment often combine the two. For example, the IFC's Market Accelerator for Green Construction programme combines the EDGE green buildings certification programme and the Climate Assessment for Financial Institutions with risk sharing instruments that enable local financial institutions to develop a climate strategy and green building lending programmes (IFC n.d.a).

Financial leverage for the enabling environment and implementation is critical to scale up investments and to reach a tipping point, after which the rest of the market will follow. For example, with the size of the market for refrigeration and air conditioning estimated at US$135 billion (Economist Intelligence Unit 2019), a 25 per cent tipping point would require US$33.75 billion in investment. By leveraging public and private funds in diverse ways (grants, loans, risk sharing instruments, plus the impact of technical assistance), it will often be possible to achieve such investment level with more modest donor support.

135
billion USD
is the estimated market size for refrigeration and airconditioning

Funding for product innovation

There is broad consensus about the need for more innovative cooling technologies, which require support for innovation – research and development, and acceleration – as well as growth capital for innovators. Notable examples of programmes addressing innovation are the IFC TechEmerge sustainable cooling programme, the Mission Innovation heating/cooling working group, Ashden Foundation Fund Fair Cooling Fund, the Global Cooling Prize (launched by RMI, the Government of India's Department of Science and Technology, and Mission Innovation in 2018) and the Million Cool Roofs Challenge (launched by the Clean Cooling Collaborative in 2019) (IFC n.d.a; Ashden n.d.; Global Cooling Prize n.d.). The TechEmerge experience to date suggests that much greater investment in early-stage research and development and product innovation is required to bring high-quality disruptive products to market (IFC n.d.).

Companies such as Daikin, Danfoss, Godrej, Gree and Trane are championing themselves as leaders on sustainable cooling by investing heavily in product development. For example, Trane created Operation Possible as an internal crowd-sourced innovation programme and selected fighting food loss and hunger as its first challenge in 2021. One solution developed was a cooling cart to reduce food loss for street vendors in developing countries (Trane Technologies 2022). To further incentivize disruptive innovations, existing or new firms and entrepreneurs need to be attracted through a combination of larger funding for seed capital and venture capital.

Funding for scale-up

Moving beyond innovation and early adopters of new technologies to the scale-up in investment in these technologies shifts the focus to finding investors willing to support the commercial application of new technologies and business models. A further objective at this stage is to find ways to bring down production costs to make the technology more affordable. One example is using public procurement schemes such as those piloted by Energy Efficiency Services Limited (EESL) in India, making the most efficient systems available to end users at prices comparable to conventional technologies (World Bank 2021a).

Concessional funding and investment instruments

Concessional funding can be used to support soft costs as well as investment instruments such as capital buy-downs, risk capital in guarantee structures or as part of a blended project financing structure. Traditionally, concessional finance has come from public sources. However, philanthropic capital played a key role in putting cooling on the map with the 2017 launch of the Kigali Cooling Efficiency Program (re-branded as the Clean Cooling Collaborative), with initial financing of US$51 million.

The Productive Use Appliance Financing Facility, launched by CLASP and Nithio, is offering procurement subsidies, capacity-building grants, consumer financing and advisory support to develop credit systems for the uptake of high quality and energy efficient appliances, including cold rooms and refrigerators (CLASP 2022; VeraSol 2023). The facility aims to lower appliance costs for end users through bulk procurement and by providing finance for distributors to sell their products on credit across Africa.

Accra, Ghana
Photo: Nataly Reinc/ shutterstock

Funding
for Innovation is required to develop and accelerate disruptive technologies.

Photo: I AM NIKOM/shutterstock

4 billion USD
for 9,321 approved projects across 144 developing countries have been provided by the MLF as of 2023.

Funding the phase down of HFC refrigerants with improvements in energy efficiency

The Kigali Amendment to the Montreal Protocol aims to phase down the production and use of HFC refrigerants, and the Multilateral Fund (MLF) provides grant funding to enable developing country compliance and to support early action. As seen in chapter 2, the emission mitigation benefits increase dramatically when the transition of refrigerants is accompanied by measures to enhance the energy efficiency of cooling equipment. While the importance of promoting energy efficiency when replacing HFCs is increasingly recognized within the purview of the Kigali Amendment, the dedicated financing facility, the MLF, has been focused on refrigerant replacement and avoiding an increase in energy requirements.

The MLF was requested to consider funding (through additional resource mobilization from relevant financing institutions) projects for maintaining or enhancing the energy efficiency of low-and zero-GWP replacement technologies and equipment, when phasing down HFCs. The focus is both on the supply side and the servicing sector. In December 2022, it was decided to establish a funding window of US$20 million for pilot projects for energy efficiency while phasing down HFCs, with the possibility of augmenting this funding at a future meeting.

As of 2023, the MLF had provided cumulative grant funding of US$4 billion for 9,321 approved projects (more than 85 per cent of them completed) across 144 developing countries. The funding has also aimed to establish national ozone offices, build their capacities and provide technical assistance – including for developing regulatory frameworks, advancing energy-efficient technologies, training servicing sector technicians and supporting cooperation with customs officers.

Although cooling has traditionally been considered a (sub)component of other financing efforts, it is increasingly being acknowledged as a stand-alone topic worthy of attracting dedicated development finance. The success of the World Bank's Efficient Clean Cooling Program enabled the development of the World Bank Cooling Facility, one of the world's first initiatives to focus on helping countries develop low-carbon and inclusive cooling solutions. The facility mobilized US$157 million from the Green Climate Fund (GCF) and will channel this concessional climate finance to co-finance World Bank-financed operations in nine countries across refrigeration and cold chains in agriculture and health as well as space cooling (ESMAP 2021). Funds mobilized from the GCF are expected to leverage an additional US$723 million in World Bank financing, reduce CO_2 emissions by an estimated 16.2 million tons and support countries' climate adaptation efforts (ESMAP 2021).

7.3 Emerging business models and instruments to scale financing

Innovative business models and financing

Cold chain equipment costs are high compared with the affluence level of potential users in developing countries, limiting their participation in supply chains for food and healthcare products. New finance and business models are needed to make sustainable cold chains affordable, distribute risks and costs fairly and overcome investor concerns. These models could enable smallholder farmers or local entrepreneurs to buy equipment, reduce payback periods and lower upfront costs.

Examples of implementing innovative sustainable refrigerators to provide affordable and reliable cooling to households and small businesses include Promethean Power Systems in India and KoolBoks and SureChill in Africa. Promethean Power Systems installed thermal storage milk chilling hubs for subsistence and larger farmers, training community hub operators to pay farmers based on milk quality (Thaker and Tripathi 2019). KoolBoks and SureChill's pay-as-you-go (PAYG) and cooling-as-a-service (CaaS) offerings provide financing models and manage payments to enable the use of solar-powered fridges of up to 400 litres and 65 litres, respectively, to be rented at an affordable price without commitment, allowing customers to keep the fridge for as long as they need it.

Rome, Italy
Photo: Lenush/ shutterstock

Equitable access to cold chains

Support with access to financing and business models needs to be targeted directly to female agricultural producers, as women may not have the same level of market information as men. In Mozambique, efforts to provide rural farmers with access to agricultural value chains showed an increase of overall crop production between 2020 to 2021 (World Bank 2022b). However, the beneficiaries of a matching grant scheme were mainly men, with female smallholder farmers accounting for only 13 to 14 per cent of beneficiaries. Under a similar matching grant for the fisheries sector, women represented only 29 per cent of recipients, typically receiving less funding than male counterparts.

To overcome this barrier, governments must play a fundamental role in ensuring equitable access to cold chains, particularly in developing countries where vulnerable groups lack a compelling business case for private sector investments. Overcoming this challenge requires a step-change approach, where governments partner in developing critical infrastructure, unlocking investments in high-risk areas for social, economic and environmental benefits. The public-private-community partnership model aims to promote inclusive, equitable and sustainable development in cold chain operations by shifting the focus from direct cash returns to community involvement and rigorous assessment of cooling needs.

Governments
must ensure equitable access to cold chains in developing countries where vulnerable groups lack a compelling business case for private sector investments.

Business models for affordability and life-cycle management that promote market growth

In developed economies, private customers may have access to savings for cash transactions or easy credit, while in less affluent economies, upfront costs and affordability are significant barriers to investment. Following are some of the business models designed to address affordability, quality control, warranties, maintenance, after-sales service, etc., to ensure market growth and sustainability.

- Businesses operating leasing-type models – including PAYG (IRENA 2020) and CaaS (BASE 2022) – as well as on-bill financing and on-wage financing,[7] need to have access to sufficient capital and financing to build inventory, provide training, pay staff, etc.

- Bulk procurement has been used by both public agencies (World Bank 2021a) and private organizations (Andersen and Carvalho 2018) for the sale, service and maintenance of stand-alone cold storage appliances and cooling devices, including room air conditioners and fans (Box 7-1). In Morocco, multiple banking institutions participated in a pilot "buyers' club" for super-efficient air conditioners. Such pooled procurement initiatives can reduce transaction costs, incentivize production and send powerful market signals.

7 On-bill financing is a financing mechanism where the cost of energy-efficient improvements or upgrades is added to the utility bill of the consumer. On-wage financing is a mechanism where the cost of energy-efficient appliances or upgrades is incorporated into an individual's salary or wage payments.

Box 7-1:
Case study: Bulk procurement in India

The Super-Efficient Air Conditioning Programme was created by Energy Efficiency Services Limited (EESL) to provide affordable, efficient air conditioning in India. The programme involved a tender for 100,000 super-efficient 1.5 refrigeration-ton ISEER 5.2 variable-speed room air conditioners for residential and non-residential use. Manufacturers (including Daikin, Godrej and Panasonic) developed high-efficiency air conditioners for sale at half their original cost, transforming the market. EESL contracted 60,000 units to Panasonic, while Godrej contracted 40,000 units; 40 per cent of the products used lower-GWP refrigerants.

Source: EESL 2021; Kigali Cooling Efficiency Programme 2018.

Delhi, India
Photo: Abhishek Sah Photography/shutterstock

40%
of the products used lower-GWP refrigerants in EESL's bulk procurement programme in India

- In an energy service company (ESCO) financing model, the financier makes direct investments into an ESCO, which enters an energy performance contract (EPC) with the client. The ESCO guarantees energy and monetary savings, carries the performance risk of the technology, and is responsible for making payments to the financier.

- In a variation referred to as a "Super ESCO," an entity established by a government or via a public-private partnership functions as an intermediary between the government, facility owners and ESCOs to coordinate the implementation of energy efficiency projects (Rahman, Hakim and Turrini 2020). In February 2022, the African Development Bank approved the Africa Super ESCO Acceleration Program with the objective of catalysing private sector investments in energy efficiency.

- The energy savings insurance (ESI) model developed by the Swiss not-for-profit foundation BASE aims to unlock the energy efficiency potential of small and medium enterprises by combining financial and non-financial elements to reduce investment risks (BASE n.d.). Successfully implemented in Colombia and Mexico, it is among the most promising instruments to mobilize private sector investments in energy efficiency.

- In Dubai, Empower is an end-to-end service provider that builds, owns and operates district cooling plants and distribution networks. Based on a public-private partnership model, Empower has become the world's largest publicly listed district cooling company.

Emerging financial instruments to enable cooling access

Financial markets need to disinvest from inefficient and unsustainable cooling technologies to unlock funds for sustainable approaches. Financing instruments that can accelerate the scale-up and deployment of new technologies include the following:

- **Public and blended finance mechanisms.** Such finance involves "combining concessional funds from donors and philanthropic sources with commercial funds from private investors and development finance institutions (DFIs) to de-risk high-impact projects in priority areas" (IEA and IFC 2023). It is critical for creating an enabling environment for the cooling sector to overcome local market barriers and develop at scale. A 2023 Independent Evaluation Group report assessing 408 World Bank Group demand-side energy efficiency projects concluded that: "Successful scale-up was possible when (i) countries had robust policy environments, (ii) clients received strong advisory and analytical work, (iii) the Bank Group targeted large greenhouse gas-emitting entities such as state-owned enterprises, (iv) the interventions used de-risking instruments, and (v) clients benefited from cumulative engagements" (World Bank 2023a)[8].

8 An additional example is a Green Climate Fund project promoting energy-efficient equipment in El Salvador through an insurance scheme developed by the Inter-American Development Bank, https://www.greenclimate.fund/projects/fp009.

Advanced market commitments. "Pull" financing interventions such as volume guarantees can help accelerate market access to advanced cooling technology. Under these agreements, large funders (philanthropic or/and private) commit to cover any shortfall in demand in exchange for negotiated pricing arrangements. Such mechanisms have been historically implemented in the health space to transform markets for key vaccines and have more recently been deployed to kick-start innovation for carbon-removal technology.

Results-based financing. This revolves around the provision of funding to a project or portfolio of projects where the concessionality is subject to pre-agreed outputs and outcomes and independently verifiable performance (World Bank 2019). It has rarely been deployed for cooling, except for the Sustainable Energy for All Universal Energy Facility, which has two firms proposing support for off-grid refrigerators.

Conventional equity and loans. Although concessional financing mechanisms have a significant role to play in accelerating the uptake of new technologies, there are still many projects that can be financed through conventional financing instruments. Examples include the IFC's US$5.4 million equity investment in an India-based provider, Snowman Logistics, to dramatically reduce food waste; and ECOFRIDGES, which provides conventional loans with improved lending terms with participating vendors for the promotion of certified cooling appliances.

Risk sharing and guarantee facilities. A risk sharing facility is a blended finance instrument in which a development finance institution, often with support from a third-party donor, agrees to share the risk of loan defaults on a portfolio of projects with defined characteristics, such as energy efficiency and renewable energy, and potentially sustainable cooling. Such instruments facilitate lending to smaller companies or consumers by bundling transactions and risk sharing. Payment guarantees can take various forms, for example energy savings insurance (ESI) surety bonds provided by third-party providers to guarantee clients of promised energy savings during a specified period. Another example is cold storage rooms with payment guarantees integrated into CaaS pricing that offer farmers confidence in revenue generation.

Cooling bonds. The World Bank uses its AAA bond rating to raise funds from international capital markets for sustainability objectives (World Bank 2023b). This has included green bonds (Box 7-2), blue bonds, and bonds for protection of forests and biodiversity. The eligibility criteria for green bonds include some sustainable cooling measures, such as projects that reduce net energy consumption in buildings, reduce food loss or waste, and improve energy efficiency in data centres.

Photo: Wanan Wanan/shutterstock

Cooling bonds

can be based used for projects that reduce net energy consumption in buildings, reduce food loss or waste, and improve energy efficiency in data centers.

Box 7-2:

Case study: Green mortgages for the construction sector in Colombia

Colombia has the maximum offerings of green mortgages for the construction sector in Latin America. These have supported developers and end users through better rates, encouraging the construction and use of sustainable housing. Between 2016 and 2021, the IFC bought green bonds and provided loans of US$504,000 towards green buildings in Colombia. This supported the development of more than 157,000 certified housing units across the country, a majority of which are low-income and affordable housing.

More than 20 per cent of new construction floor space built in Colombia between 2021 and 2023 is certified, representing a cumulative private sector investment of more than US$11.5 billion. This flow in investment – and resulting impact – was created as a result of financial instruments (green bonds) dedicated to the sector (construction) being accessible across different financing institutions. Policy frameworks such as the Green Building Code and tax incentive structures were used to encourage private sector engagement and investments..

Source: World Bank 2023b.

San Andres Island, Colombia
Photo: Benoit Daoust/shutterstock

7.4 Challenges to scaling up investment in sustainable cooling

Some of the most significant challenges to scaling up and mainstreaming investment in sustainable cooling include:

- **Lack of reliable market data.** Data on cooling equipment demand and supply are a cornerstone of efforts to scale up adoption of innovative technologies.

- **Lack of attention to cooling decision making within a larger project.** For example, temperature control is a major consideration for effective delivery of vaccines, but is only one of many problems confronting public health officials. The result is that finance for cooling is often addressed as a secondary consideration or a sub-project within a broader investment context, instead of being seen a key enabler for achieving a range of SDGs.

- **Difficulty in developing a pipeline of investible projects.** Reasons for this include the lack of quality experience and documented results; of funding and technical assistance for project preparation; and of data availability on potential energy savings required to make investment decisions (Clean Cooling Collaborative 2022). Capacity-building and on-boarding banks in new markets also requires dedicated effort and resources.

- **Insufficient engagement and buy-in from senior management of financial institutions, to ensure internal coordination and collaboration to catalyse finance.** Demonstrating the business case for cooling investments can be challenging due to uncertainty about the size of the market and the lack of examples and data, resulting in difficult and lengthy investment decisions (Clean Cooling Collaborative 2022). The frequently small ticket size of purchases further impedes investments, as processing large volumes of small-sized individual projects implies expensive transaction costs[9].

9 One response by the IFC and other multilateral development banks has been to aggregate small projects into larger investment programmes, such as on energy efficiency financing, with partial risk guarantees through commercial lenders.

Lack of access to reliable electricity and the lack of affordability of air-conditioning equipment for low-income households. On-bill financing, which can be an effective solution for households and small and medium enterprises, remains a challenge in developing countries where there are ongoing struggles with blackouts/brownouts and strained utility balance sheets. For rental housing, landlords may hesitate to invest in energy-efficient cooling systems since tenants typically pay the electricity bills.

Afar, Ethiopia
Photo: JohnRobert/shutterstock

7.5 Recommendations for scaling sustainable cooling financing

Opportunities and challenges for financing solutions exist across and within key market segments such as buildings and districts, households, small and medium enterprises, and cold chain systems. The following recommendations are important to effectively scale up financing of sustainable cooling going forward and support near-zero emissions from cooling.

Incorporate sustainable cooling into the environmental, social and governance (ESG) safeguards for multilateral development banks

Multilateral development banks can systematically screen their pipeline and client portfolios to identify new financing opportunities (recognizing that cooling is often a component of a larger project) and develop innovative financing instruments where appropriate. Creating dedicated cooling funds can start with a review of the portfolios and pipelines of financial institutions to identify investment opportunities and create dedicated funding instruments to catalyse a scale-up of investment. For example, a proposal by the independent climate change think tank E3G builds on the approach of the World Bank's Green Climate Fund cooling facility to create a dedicated fund to support technical assistance as well as financial and risk-mitigation instruments.

Systematically track cooling finance and its impacts as the market grows

Estimating the sizes of the different market segments that comprise cooling and monitoring their growth would facilitate financing but is complicated for several reasons, including the continued absence of a systematic process for defining and tracking sustainable cooling finance. Tracking metrics – such as the value of funding provided, value of financial instruments, value of financing leveraged, value of sales, as well as measures of non-financial impact such as energy savings and CO_2 emission reductions and impacts on end users – will be hugely beneficial, including for risk assessment. A first step is identifying an appropriate institution to take on such a tracking role.

Direct wholesale finance for sustainable cooling in large real estate projects and in district cooling

The global construction market is expected to reach US$14.4 trillion in 2030 (Statista 2022). Ensuring that sustainable cooling technology is incorporated in new construction and retrofits is crucial. Voluntary standards that are more ambitious than building codes can be an influential tool to re-direct finance to more efficient solutions. Independent certification of building standards is also a strong approach to validate expected lower energy costs, supporting clients' ability to repay loans. Examples include the fund manager Actis, which has adopted the IFC's EDGE Green Building standards for all sites and has sustainability guidelines applicable to all of the fund's property investments.

District cooling is another significant opportunity for large, concentrated and mixed-use cooling demand, such as in a business district with office buildings, entertainment venues, shopping centres, and high-rise residential and hospitality buildings. Making such projects creditworthy requires an enabling environment to mitigate project risks. Incorporating district cooling in urban local government plans, updating building codes to enable it, specifying energy efficiency requirements for buildings and monitoring these requirements regularly are important for project success.

In the United Arab Emirates, cities such as Abu Dhabi and Dubai have strong regulations balancing the interests of district cooling companies and consumers. The IFC and the district cooling utility provider, Tabreed Asia, invested US$100 million in an equity facility to support up to US$400 million total investment in district cooling projects. Tabreed Asia is also investing in cooling infrastructure and CaaS in India with an investment of around US$3.6 million for a 30-year period.

Provide retail finance for cooling for households and small and medium enterprises

Most consumers will adopt efficient and sustainable cooling technologies if monetary benefits are certain, match the additional cost and are incentivized by financing to smooth out such costs over time. Compliance with updated minimum performance standards and incentives modelled on precedents from solar energy programmes are highly relevant.

For example, the Refrigerators and Air Conditioners Initiative (ECOFRIDGES) of the Economic Community of West African States (ECOWAS) is a joint initiative of the governments of Ghana and Senegal, UNEP and the BASE Foundation that provides consumers with financing based on improved lending terms and no-risk repayment for lenders and appliance retailers. As of June 2023, ECOFRIDGES GO sold 3,304 new certified refrigerators and air conditioners and unlocked 18.2 million Ghanaian cedi (US$1.6 million) in finance, enabling more households to access energy-efficient cooling appliances. This has saved a substantial 27,172 megawatt-hours of energy (UNEP Ozone Secretariat 2023c).

Government procurement of cooling appliances should similarly purchase best available technology, and incentives for efficient cooling should be made available for retrofit of existing equipment.

Finance the cold chain through public private partnerships and protect smallholder farmers in developing countries with seed financing

Financing for agricultural cold chains and ensuring that smallholder farmers receive an equitable return is nascent. Implementing a comprehensive cold chain system requires significant investment in infrastructure, technology and training, as well as coordinating multiple parties responsible for each stage. Challenges in doing so include high upfront investment costs in infrastructure, refrigerated transport and temperature monitoring systems.

The Global Cold Chain Alliance (GCCA) estimates that building a basic cold storage facility costs between US$100 and US$300 per cubic metre (GCCA 2019), creating a significant barrier to entry for small-scale farmers and businesses in emerging markets. Suppliers in emerging economies also struggle to allocate sufficient funds to cover ongoing operational expenses, particularly in the absence of reliable electricity supply and limited financial resources (United Nations Industrial Development Organization 2013). Investors and financial institutions thereby perceive the cold chain sector in developing countries as high risk due to factors such as weak regulatory frameworks, inadequate infrastructure and volatile market conditions.

Examples of financing in such contexts include the Asian Development Bank's Supply Chain Finance Program, which provides financing to small and medium enterprises involved in the agricultural supply chain, including the cold chain. Solar-powered cold storage facilities in Kenya, Nigeria, India and the Philippines are implemented to reduce energy costs and unreliable electricity supply. These facilities use renewable energy and design standardization, operating with a CaaS business model, to improve payback, affordability and sustainability and to promote a circular economy.

In another example, BASE and Empa developed a CaaS initiative that digitalizes inventory management and allows operators to remotely monitor cold room temperature, occupancy and finances. This reduces food loss and increases food security. Farmers can track crop quality in real-time, enabling informed decisions on selling and market prices. The SET Alliance aims to enhance the benefits of the CaaS initiative through engagement with technology partners and financial institutions[10].

In addition, governments play a fundamental role in mitigating investment risk for cold chains by treating cold chains as critical public infrastructure and partnering with the private sector to unlock investments – particularly in high-risk areas – for social, economic and environmental benefits.

Strengthen the role of MEPS, efficiency and sustainability standards in cooling financing decisions

In the absence of efficiency and sustainability standards, increased financing of inefficient and polluting cooling technologies will contribute to further global warming and increase the stock of stranded cooling assets. Efficiency and sustainability standards should be agreed on and incorporated into all cooling financing instruments going forward. Environmental and social performance standards of development finance institutions could be modified to ensure screening for sustainable cooling options.

Studies have found that MEPS do not necessarily lead to a higher purchase price for consumers over the long term, and there is an accelerated decline in the life-cycle cost following implementation (UNEP Ozone Secretariat 2019). Financial mechanisms and incentives, such as tax breaks and rebates, can be used to address the higher upfront costs of efficient and climate-friendly products.

10 See https://set-alliance.org.

In Thailand, the Electricity Generating Authority of Thailand offered interest-free loans to help consumers cover the higher initial cost of 4- and 5-star air conditioners. Shop owners who sold 5-star air conditioners also received refunds. Consumers who bought these air conditioners were given no interest loans from participating banks in the amount of 5,000 and 10,000 baht (around US$125 and US$250), respectively. Because of this, Thailand's labelling programme not only helped strengthen the local air-conditioning business and raise the market share of the most effective air conditioners, but also 5-star units are now exported to Australia, Indonesia and Sri Lanka (Sulyma *et al.* 2000).

Other mechanisms include on-bill financing, on-wage financing, utility obligations and bulk purchasing programmes, as highlighted in resources such as the Manual of Financing Mechanisms and Business Models for Energy Efficiency and the Sustainable Public Procurement Toolkit (UNEP U4E 2019a; UNEP U4E n.d.c). The report *Lessons Learned from* ECOFRIDGES *and the* Rwanda Cooling Initiative's Financial Mechanisms offers excellent insights from recent private finance-focused projects that support consumer adoption of efficient and climate-friendly fridges.

Validate consumer-financing interventions through pilots

To address initial hesitancy over alternative financing models, stakeholders should explore opportunities to conduct initial small-scale pilot studies. Funders may be more open to supporting feasibility pilots that require less resources, support proof-of-concept and help build momentum for expanded financing facilities. Such initiatives provide an opportunity to address key operational challenges, familiarize stakeholders (e.g. power distribution companies) with cooling-related dynamics and enable financing mechanisms to be tailored to national contexts. It is also important for governments to lead by example and invest in retrofit of existing cooling systems.

“In the absence of efficiency and sustainability standards, increased financing of inefficient and polluting cooling technologies will contribute to further global warming and increase the stock of stranded cooling assets.”

Margao, Goa, India
Photo: balajisrinivasan/shutterstock

08 Recommended steps to support the pathway to near-zero emissions from cooling

Achieving near-zero emissions from cooling by 2050 is possible through a series of measures, as outlined in chapter 2. These include the adoption of passive cooling technologies, adopting highest possible equipment efficiency, accelerating the phase down of high GWP refrigerants, transitioning towards electric vehicles and decarbonizing the electric grid. Chapter 3 identified that most countries have at least one national-level policy that is critical to driving the cooling sector to near-zero emissions. However, synergistic integration is lacking among these policies and other enabling activities related to space cooling, cold chains, the refrigerant transition and finance for sustainable cooling, as noted in chapters 4 to 7.

Moving forward, it is important to consider an integrated cooling policy framework for implementation that accounts for cooling emissions and their role in countries' Nationally Determined Contributions (NDCs) under the Paris Agreement. A promising example is the pioneering work of Viet Nam, where a national-level decree was established to coordinate varying aspects of the cooling sector among the different government stakeholders (Box 3-4).

8.1 Recommended policy actions

Table 8-1: Recommended policy actions

Ambition area	Scope	Enforcement	Key scalers / Ecosystem policies / Finance	Status and 2030 tracker
Passive cooling				
▶ Enhance and strongly enforce building energy codes that account for passive cooling. ▶ Build industry confidence, skills and capacity to scale passive cooling. ▶ Build consumer confidence and knowledge base to scale demand for passive cooling.	▶ Focus building policies on variables beyond energy efficiency, including passive design, low-GWP refrigerants, and meeting the thermal comfort needs of occupants. ▶ Provide support to sub-national governments and cities to adapt and incorporate codes into local planning requirements and to scale implementation and track progress. ▶ Develop standards for key passive cooling technologies and materials (e.g. cool paints, insulation, clothing insulation, etc.) ▶ Preferentially link appliance efficiencies and refrigerant standards in building energy codes, with an emphasis on load reduction via passive measures.	▶ Mandate and regularly update codes where voluntary over a period of time. ▶ Ensure that new building construction and significant building retrofits comply with the latest building energy codes. ▶ Support skilling and capacity-building of energy auditors, certifiers, construction industry, supply chains and sub-national planning officials. ▶ Enhance the capacity of sub-national and local governments to scale enforcement and track progress.	▶ Provide planning incentives (such as more floor space, faster approvals, fiscal incentives) for code compliance and certification. ▶ Use public procurement to demonstrate and mainstream passive cooling in public buildings and social housing. ▶ Finance instruments and models like green mortgages, micro-loans for self-build housing, dedicated green construction financing with banks. ▶ Enhance public financing for self-built homes to include passive cooling beyond building energy code standards. ▶ Encourage and remove barriers to ESCO market.	▶ Building energy codes at the national level are present in only 80 countries (41 per cent) and are mandatory in 56; only 49 countries include cool and reflective surfaces. **2030 tracker:** ▶ National model building energy codes that incorporate market appropriate measures such as passive cooling (shading, ventilation, orientation, etc.), energy efficiency and low-GWP refrigerant strategies for new and refurbished buildings. ▶ Implementation of building energy codes and their updates across countries and sub-nationally. ▶ Public procurement policies and guidance for low-GWP and high-efficiency cooling technologies.

Table 8-1: Recommended policy actions (continued)

Ambition area	Scope	Enforcement	Key scalers / Ecosystem policies / Finance	Status and 2030 tracker
Urban action				
▶ Empower cities through knowledge, technologies, tools, capacity, finances and skills to plan for and take comprehensive action on cooling and extreme heat assessments. ▶ Quantify and monitor benefits from heat resilient planning, nature-based solutions on GHG savings to create case studies for large-scale replication.	▶ Apply heat-resilient urban design including shelters and access for the vulnerable, scaled building code enforcement, and higher levels of green and blue space integrated into city planning. ▶ Support heat-wave preparedness and coordination for early warning systems; targeted support programmes to the urban poor and vulnerable (children, elderly, outdoor workers, etc.). ▶ Enable passive cooling at scale through urban design (shading, nature-based solutions, ventilated corridors), public buildings, public procurement of high-efficiency and low-GWP equipment, district cooling.	▶ Increase capacities and resources for integrating heat adaptation and cooling demand mitigation in urban planning and code enforcement for new greenfield spaces and in existing areas. ▶ Provide a clear city mandate and designate officials' and departmental responsibility for coordinated action on heat. ▶ Create urban indicator frameworks for improved quality of life (shelter, health impacts, productivity, etc.) and climate mitigation from cooling emissions tracked by urban ministries and reported under NCAPs, national adaptation plans, net-zero strategies, etc.	▶ Update national and sub-national planning guidelines for urban masterplans to incorporate heat-resilient urban design, higher levels of accessible passive cooling solutions including nature-based approaches (green space, trees, water bodies), and where appropriate district cooling. ▶ Adopt national adaptation plans incorporating city action on heat; climate mitigation plans including reducing urban cooling demand, local Climate and Heat Action Plans; and urban heat island effect studies. ▶ Create city mandates for integrated urban design across different postcodes. ▶ Provide enhanced national funding for cities that prioritize heat adaptation and mitigation from cooling emissions. ▶ Provide planning and fiscal incentives to drive sustainable cooling.	**2030 tracker:** ▶ Sustainable cooling in an existing climate, energy or health strategy or development of a Heat Action Plan. ▶ Increased area, accessibility and quality of nature-based solutions such as green and blue spaces in urban areas. ▶ Public procurement of low-GWP and high-efficiency cooling technologies in government buildings. ▶ Improved outdoor comfort, air quality and reduced GHG emissions from the city.
High efficiency and low-GWP equipment				
▶ Gradually phase out sales and use of low energy efficiency and high-GWP cooling equipment from the market using regularly updated standards. ▶ Build market demand for higher-efficiency and low-GWP equipment through know-how, economic benefits, and accessibility of the supply chain.	▶ Update, implement and enforce MEPS and appliance labelling policies that help phase out low energy efficiency and high-GWP cooling equipment. ▶ Align MEPS with the switch to low-GWP refrigerants, considering regional and global MEPS harmonization. ▶ Develop policies and regional/global agreements to prevent product dumping and the prolonged use of obsolete appliances in secondary markets. ▶ Create locally specific awareness and promote information on the socio-economic benefits, incentives and accessibility of using high efficiency and low GWP equipment, even beyond MEPS.	▶ Implement robust monitoring, verification and enforcement to ensure compliance with regularly updated efficiency and labelling standards. ▶ Follow model regulations, for example UNEP U4E to harmonize standards across countries. ▶ Implement import bans on second-hand products and have international cooperation to prevent dumping. ▶ Enhance local level technical capacity and capabilities to ensure adequate testing of products and enforcement.	▶ Provide trainings for service technicians for ensuring high quality and accessible installation and servicing practices. ▶ Create financing instruments and incentives, including low-interest loans, tax rebates, on-bill or on-wage financing. ▶ Develop targeted finance instruments (including microfinance and leasing) for low-income populations. ▶ Support consumer awareness and campaigns. ▶ Support buyers' clubs and bulk procurement; public procurement in public buildings and social housing. ▶ Provide rebate programmes for the take back of used products when purchasing a new efficient model. ▶ Provide incentives for industry and supply chains to ensure that the average equipment in the market is high efficiency and low GWP.	▶ 115 countries have national-level MEPs for cooling and refrigeration. **2030 tracker:** ▶ Increased market penetration of highly efficient low-GWP air-conditioning equipment and innovative technologies. ▶ MEPS and routine increases in ambition, with efforts for global harmonization. ▶ Updating and tracking of national and sub-national public procurement policies and guidance.

Table 8-1: Recommended policy actions (continued)

Ambition area	Scope	Enforcement	Key scalers / Ecosystem policies / Finance	Status and 2030 tracker
HFC phase down				
▶ Deliver a faster HFC phase down ahead of the Kigali timetable through integration of refrigerant and energy efficiency regulations and programmes and enhanced life-cycle management.	▶ Develop codes and standards for low-GWP refrigerants and integrate energy efficiency and low-GWP standards. ▶ Regulate servicing and end-of-life of equipment to minimize refrigerant leakage, encourage refrigerant reclamation and recycling, and support destruction. ▶ Enhance life-cycle refrigerant management by pairing with financial incentives and robust monitoring and reporting requirements. ▶ Promote and incentivize industry to move to low-GWP refrigerants with clear policy signalling.	▶ Develop and offer customised trainings for serving sector officials for refrigerant life-cycle management. ▶ Safeguard the market from illegal refrigerant trade (domestic and international). ▶ Enact robust monitoring and reporting requirements for servicing and refrigerant recovery, reclamation and destruction. ▶ Strengthen the Montreal Protocol to further reduce illegal trade in banned substances. ▶ Promote the supply chain of low-GWP refrigerants and the integrated of energy efficiency with low-GWP refrigerants.	▶ Establish Kigali Implementation Plans with monitoring of effective implementation. ▶ Enhance research, development and innovations for low GWP alternatives and supporting technologies. ▶ Support service trainings and compliance with high-quality servicing practices for equipment. ▶ Work with industry to develop a robust supply chain to accelerate the transition to low-GWP options beyond Kigali compliance.	▶ More than 150 countries have ratified the Kigali Amendment's action on HFC phase down. **2030 tracker:** ▶ Ratification of the Kigali Amendment by 2024 (if not already ratified). ▶ Robust action through the Montreal Protocol Multilateral Fund for early action to reduce HFC consumption and to promote improved energy efficiency for the HCFC phase out and HFC phase down. ▶ Life-cycle management of HCFCs and HFCs. ▶ Implementation of Kigali Implementation Plans.
Cold chain				
▶ Expand food and health cold chains equitably and including as a development priority. ▶ Enhance efficiency and use of low-GWP refrigerants and renewable/non-fossil fuel energy. ▶ Exploit multi-sectoral synergies across agricultural and health cold chains.	▶ Develop sustainable design codes and guidelines for cold chain refrigeration components (e.g. cold storage, packhouses etc.) that incorporate passive cooling design, MEPS and low-GWP refrigerants. ▶ Ensure equitable access to cold chains by partnering in developing critical infrastructure, e.g. through public-private-community partnership models.	▶ Establish tracking for reports on food loss. ▶ Enhance mapping of the full cold chain to enhance capacity at the weak links. ▶ Implement and enforce minimum efficiency standards, passive design, and low-GWP refrigerants. ▶ Support monitoring and enforcement to prevent illegal imports of equipment.	▶ Quantify and benchmark energy use and emissions in the cold chain so as to annually improve effectiveness. ▶ Develop a cold chain needs assessment linked to NCAPs, including strategy and delivery of implementation with designated agencies and departmental coordination. ▶ Provide financial assistance and capacity support for cold chain accessibility and robustness. ▶ Build necessary skills, and where applicable develop large-scale demonstrators and test business models such as CaaS and participative models with farmer and stakeholder groups.	**2030 tracker:** ▶ Published NCAPs incorporating cold chain development, mitigation and adaptation strategies. ▶ MEPS covering cold chain components including low-GWP refrigeration. ▶ Collaborative research, innovation, and deployment activities at the local and international level such as renewable energy-based cooling solutions in rural, remote, off-grid locations.

8.2 Recommended enabling activities

Adopting an integrated approach to planning and regulatory frameworks will be instrumental in ensuring the effective implementation of a transition to sustainable cooling that 1) enables equitable access to cooling and opportunities; 2) creates resilience, jobs and increased capacity; 3) supports national decarbonization efforts; and 4) unlocks capital and financing opportunities – all while supporting the simultaneous goals of adopting energy efficiency, low-GWP refrigerants and passive cooling measures.

Streamline cooling policies using National Cooling Action Plans (NCAPs), Heat Action Plans and other cross-sectoral integrated approaches.

- Work across multiple government stakeholders to coordinate MEPS, building codes and refrigerant actions.
- Enhance access to sustainable space cooling for populations.
- Identify current cooling energy consumption and emissions and future energy needs.
- Develop Heat Action Plans, urban heat island mapping, and heat adaptation and mitigation plans; evaluate different scenarios; and coordinate implementation among relevant parties.
- Establish synergies across policy strategies and ministries to achieve near-zero emissions from cooling.

Training and capacity building across multiple stakeholders are important to ensure that successful transition towards sustainable cooling.

Establish goals for the decarbonization of cooling.

- Embed cooling actions in Nationally Determined Contributions (NDCs) towards reducing emissions under the Paris Agreement, and in other national climate and net-zero strategies.
- Decarbonize the food cold chain by providing technical and non-technical tools and solutions to reduce GHG emissions.

Improve availability of and access to sustainable cooling technologies.

- Support supply chain readiness by focusing on the entire supply chain, enabling local small and medium enterprises to adopt new technologies through research support, collaboration with multinational firms and capacity-building mechanisms.
- Engage in regional cooperation and harmonize policies to enable economies of scale.
- Support and promote the market availability of resilient technologies that can operate either off-grid or with unstable electricity supply.
- Support the implementation of nature-based solutions in hot spots of urban areas to reduce health-related illness for vulnerable populations.

Support training and capacity-building within the cooling sector.

- Establish and link to regional multi-disciplinary centres for sustainable cooling and cold chain development and incorporate cooling and extreme heat under existing centres, such as on urban planning, disaster management and building design.
- Develop training materials and capacity-building programmes for technicians, urban planners, auditors, architects, engineers, farmer groups, the health sector, building certifiers, banks and finance institutions and the legal sector.
- Establish programmes to support the capacity-building of small and medium enterprises in cooling and allied sectors to ensure supply chain robustness and an optimized, innovative transition towards sustainable cooling.

Raise awareness among retailers and consumers of the benefits of sustainable cooling.

- Promote dissemination of the most-efficient technologies, including through minimum energy performance standards (MEPS) and policies that support innovation and scale.
- Prioritize the sale and use of energy-efficient air conditioners with more-efficient variable-speed compressors over fixed-speed compressor units.
- For non-residential space cooling, support the dissemination and scaling of more-efficient variable refrigerant flow systems that have the potential to provide both heating and cooling.
- Create consumer education campaigns that encourage the selection and use of energy-efficient and low-GWP equipment, highlight the benefits of considering the full life-cycle cost of equipment and support actions to minimize the operating costs of equipment.
- Encourage consumers to use the services of trained and certified technicians and to adopt preventive maintenance.

Raise awareness

amongst consumers about the need to adopt sustainable cooling equipment and practices.

Prioritize and support the engagement of women in advancing sustainable cooling.

- Increase and strengthen the employment of women as part of the labour force in the refrigeration, air-conditioning and heat pump sectors, including jobs related to the manufacturing and installation of equipment.
- Encourage women to pursue education and job opportunities in the maintenance and servicing sector for cooling equipment.

Scale up innovative business models and financing for sustainable cooling.

- Invest in district cooling to enable greater efficiencies, cost reductions and economies of scale.
- Expand public funding, mobilize private capital and develop needs-based funding models to support implementation of energy efficiency improvements alongside the refrigerant transition.
- Support innovative business models and financing to make sustainable cold chains affordable, distribute risks and costs fairly, and overcome investor concerns.
- Incorporate sustainable cooling into the environmental, social and governance (ESG) safeguards for multilateral development banks, investment funds and pension funds.
- Systematically track cooling finance and its impacts as the market grows.
- Direct wholesale finance for sustainable cooling in large real estate projects and in district cooling.
- Provide retail finance for cooling for households and small and medium enterprises.
- Finance the cold chain and protect smallholder farmers in developing countries with "seed financing."
- Strengthen the role of MEPS, efficiency and sustainability standards in cooling financing decisions.

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