Cooling Emissions and Policy Synthesis Report:

Benefits of cooling efficiency and the Kigali Amendment

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FOREWORD

Efficient and climate friendly cooling is a crucial piece of the climate and sustainable development puzzle. We need cooling to protect vulnerable populations from heatwaves, keep vaccines viable and food fresh, and workforces productive. It is essential for equity and development, especially as climate change raises global temperatures. The global pandemic has emphasized just how important cooling is to society, with many stuck indoors in hot climates during lockdowns and global cooling infrastructure essential to storing and delivering an eventual vaccine. There is, however, a catch.

There are an estimated 3.6 billion cooling appliances in use globally today, and that number is growing by up to 10 devices every second. This growth is set to increase the sector's greenhouse gas emissions dramatically, further warming the planet. Air conditioners are a double burden. In most cases, they use hydrofluorocarbons (HFCs), extremely potent greenhouse gases, and require significant energy to run. Without policy intervention, direct and indirect emissions from air conditioning and refrigeration are projected to rise 90 per cent above 2017 levels by the year 2050.

This report lays out ways to resolve this dilemma by delivering efficient and climate friendly cooling for all – in particular by rapidly phasing down hydrofluorocarbons in the cooling sector and delivering cooling more efficiently through more efficient equipment and more efficient buildings.

This report tells us there are many actions we can take to get cooling right. The Montreal Protocol's Kigali Amendment to phase down HFC refrigerants. Proven policies such as minimum energy performance standards. National Cooling Action Plans. The integration of efficient cooling into enhanced Nationally Determined Contributions of the Paris Agreement. Transformative initiatives like the Cool Coalition. Moving on all of these offers us a chance to slow global warming, improve the lives of hundreds of millions of people, and realize huge financial savings. As nations invest in COVID-19 recovery, they need to ensure that they use their money wisely to reduce climate change, protect nature and reduce risks of further pandemics. Backing sustainable cooling can help to achieve all of these goals."

We hope this report will help to raise awareness about one of the most critical and often neglected climate and development issues of our time. For policy makers, industry leaders and the general public, we hope it serves as an important guide to the role cooling can play in delivering on our climate and sustainable development goals. We need to seize this three-in-one cooling opportunity. And we need to do it now.

Inger Andersen

Executive Director of the
UN Environment Programme
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Box A:

THE IMPACT OF COVID-19 ON COOLING, AND THE ROLE OF ECONOMIC RECOVERY PACKAGES

The novel coronavirus (Covid-19) pandemic has created an extraordinary global health and economic crisis. Beyond the immediate impact on health, the current crisis has major implications for global economies, energy use and CO_2 emissions. The economy could decline by 6% in 2020, whilst energy demand which declined by 3.8% in the first quarter of 2020, could fall by 6% by the end of 2020 (IEA 2020a). Global energy-related CO_2 emissions could fall by 8% in 2020. This global economic downturn will also have an impact on investment in energy systems, including efficient climate-friendly cooling. For example, it is expected that investment in efficiency in buildings will fall by over 10% in 2020 (IEA, 2020b).

Unprecedented action and leadership from governments, companies and real-world decision makers will be required to put the world on an economic recovery path, to boost the economy to retain and create new jobs, whilst at the same time generating the conditions for achieving sustainable and affordable cooling. The use of sustainable economic recovery packages has been proposed by many countries including the European Commission, and many international organisations such as the International Monetary Fund and the World Bank (WB 2020, IMF 2020, IEA 2020c). The IEA's Sustainable Recovery plan suggests that an additional USD 1 trillion of spending over the next three years, could increase GDP by 3.5%, put global CO_2 emission on a declining path, and create several million jobs. Spending on improving the efficiency of buildings for example, could generate between 9 and 30 jobs per million USD invested, noticeably higher than the number of jobs generated from spending elsewhere in the energy sector (IEA 2020c).

More specifically for cooling, the K-CEP program has identified six high-impact opportunities where efficient, climate-friendly cooling could generate jobs, raise economic output and reduce emissions (E3G-K-CEP 2020). These are:

1. Conditional bailouts for hard-hit sectors that support sustainable cooling. Funds to bail out hard-hit sectors should by tied to the adoption of climate-friendly cooling solutions.

2. Rebates and incentives to promote cooling efficiency in the built environment, increasing demand for efficient appliances and climate-friendly cooling technologies will create jobs and also induce spending from lower energy bills.

3. Policy design to address resilient and responsive cold chain logistics for healthcare and food security. A growth in cooling is needed for food and medical supplies, will improve health outcomes, reduce food and vaccine loss, and also build capacity to respond to future shocks.

4. Supporting measures to encourage implementation of cooling retrofits and passive technologies. Retrofitting of buildings with better cooling features are low-capital investments which are labour intensive.

5. Expanding financing models to meet cooling needs. Funding can be used to promote and also support initial capital investment now to realise future savings.

6. Public and private financing investment in R&D for cooling. Grants and loans will sustain future innovation and deliver future improvements, offering innovators a competitive advantage.

The timing of impact of the different recovery measures will vary. For example, cooling system maintenance and painting roofs with reflective paint will increase employment in a relatively short period (in the order of months), whilst investing in more efficient equipment and buildings will take longer.

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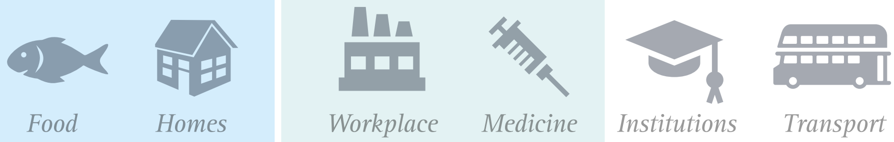

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GLOSSARY AND ACRONYMS

AC air conditioning

Banks Ozone-depleting or high-GWP chemicals contained within refrigerators, air conditioners, and other cooling equipment, as well as in chemical stockpiles and foams.

Baseline In the context of climate-related pathways, baseline scenarios refer to scenarios that assume that no mitigation policies or measures will be implemented beyond those that are already in force or are planned to be adopted.

Black carbon The substance formed through the incomplete combustion of fossil fuels, biofuels, and biomass. Black carbon contributes to warming by absorbing heat in the atmosphere and by reducing albedo when deposited on snow and ice.

Buyers clubs A buyers club, either public or private, pools members' collective buying power, enabling them to make purchases of higher performing or quality at lower prices, or to purchase goods that might be difficult to purchase in small amounts.

Carbon dioxide equivalent (CO_2e) For a given amount of a greenhouse gas other than CO_2, it is the amount of CO_2 that would have the same global warming impact over a certain time period. In this report, all CO_2e is according to 100-yr Global Warming Potential.

Carbon intensity The amount of CO_2 released per unit of another variable such as gross domestic product or energy produced.

CCAC Climate and Clean Air Coalition

CFC chlorofluorocarbon – CFCs are major ozone depleting substances phased out by the Montreal Protocol. Many CFCs are also potent greenhouse gases.

CO_2 carbon dioxide

Cold chain The supply chain needed to maintain a low temperature range, consisting of production, storage, and distribution activities. Proper cold chain preserves, extends, and ensures the shelf-life of products.

Cooling Cooling refers to any human activity, design or technology that dissipates or reduces temperatures and contributes to achieving: (i) reasonable thermal comfort for people, or (ii) preservation of products and produce (medicines, food, etc.), and (iii) effective and efficient processes (for example data centres, industrial or agricultural production and mining). Sustainable - or „clean" - cooling refers to cooling that uses climate friendly refrigerants and without other environmental damage including climate impact, in line with the objectives of the Paris Agreement on Climate Change and the Montreal Protocol. Access to clean and affordable cooling is necessary to help deliver our societal, economic and health goals.

Cooling equipment Stationary air conditioning (AC and other space conditioning for comfort); refrigeration (cooling to preserve food, goods, medicines, equipment); and mobile air conditioning and refrigerated transport.

CSPF Cooling Seasonal Performance Factor

EE energy efficiency

ESI Energy Savings Insurance

GHG greenhouse gas

GDP gross domestic product

$GtCO_2$ gigatons of CO_2

$GtCO_2$e gigatons of CO_2 equivalent

GW gigawatts

GWP global warming potential – An index representing the relative effectiveness of different gases in absorbing outgoing infrared radiation, over a given time period, relative to CO_2, which has a GWP of 1.

HC hydrocarbon

HCFC hydrochlorofluorocarbon – chemicals that deplete the ozone layer, but have less potency compared to CFCs. Many HCFCs are potent greenhouse gases.

HFC hydrofluorocarbon – chemicals that do not deplete the ozone layer and have been used as substitutes for CFCs and HCFCs. Many HFCs are potent greenhouse gases.

HFO hydrofluoroolefin

High-ambient temperature Conditions (or countries experiencing conditions) with a peak monthly average temperature above 35 °C for at least two months per year over consecutive years.

IEA International Energy Agency

IPCC Intergovernmental Panel on Climate Change – the United Nations body tasked with assessing the science related to climate change.

ISO International Organization for Standardization

K-CEP Kigali Cooling Efficiency Program

Kigali Amendment An amendment to the Montreal Protocol that aims to phase-down the production and consumption of HFCs.

LBNL Lawrence Berkeley National Laboratory

Leapfrogging The ability of developing countries to bypass intermediate technologies, like HFCs, and transition instead to advanced clean technologies.

MAC mobile air conditioning

MEPS minimum energy performance standard

MtCO$_2$e million tons carbon dioxide equivalent

Nationally Determined Contribution A submissions by a Party to the Paris Agreement representing that Party's efforts to meet the agreement's temperature goals.

ODS ozone-depleting substance

OzonAction A UN Environment body that works to strengthen the capacity of governments and industry in developing countries to meet their obligations under the Montreal Protocol.

Paris Agreement An international agreement under the United Nations Framework Convention on Climate Change (UNFCCC) that aims to hold the increase in the global average temperature to well below 2°C above pre-industrial levels, aiming for 1.5°C.

Peak demand The highest electricity demand occurring within a given period on an electric grid.

PM$_{2.5}$ fine particulate matter (2.5 micrometres is one 400th of a millimetre).

RAC Depending on usage, either "refrigeration and air conditioning," or "room air conditioning," which generally includes lower capacity window or unducted split units designed to cool one room.

RACHP refrigeration, air conditioning, and heat pump

Radiative Forcing A measure of how a substance influences the energy balance of Earth. The higher the value, the more it adds to a globally averaged surface temperature increase.

SAP Scientific Assessment Panel – The Montreal Protocol panel to assess the status of the depletion of the ozone layer and related atmospheric science issues.

Secondary loop A refrigeration system that incorporates two different refrigerants to provide cooling, which can provide for more safety and efficiency. The primary loop uses a direct expansion design and a compressor to circulate the refrigerant.

Space cooling Cooling that encompasses many forms of comfort cooling, including air conditioning, fans, and evaporative cooling.

SDGs Sustainable Development Goals – The 17 global goals for development for all countries established by the United Nations.

SEforALL Sustainable Energy for All

SO$_2$ sulphur dioxide

TEAP Technology and Economic Assessment Panel – The Montreal Protocol panel to assess technical information related to alternative technologies to eliminate the use of Ozone Depleting Substances.

TWh terawatt-hour; billion kilowatt-hours

UNEP United Nations Environment Programme

UNFCCC United Nations Framework Convention on Climate Change

Urban heat island The relative warmth of a city compared with surrounding rural areas, often higher in the city due to changes in runoff, effects on heat retention, and changes in surface albedo.

USD United States dollar

WMO World Meteorological Organization

KEY FINDINGS

Action under the Kigali Amendment to the Montreal Protocol on Substances that Destroy the Ozone Layer (Montreal Protocol) will phase-down the production and use of hydrofluorocarbons (HFCs) and could avoid up to 0.4°C of global warming by 2100.

In a warming world, prosperity and civilization depend more on access to cooling.[i] The growing demand for cooling will contribute significantly to climate change. This is from both the emissions of HFCs and other refrigerants and CO_2 and black carbon emissions from the mostly fossil fuel-based energy powering air conditioners and other cooling equipment. These emissions are particularly dominant during periods of peak power demand, which are increasingly determined by demand for air conditioning. As the climate warms, the growing demand for cooling is creating more warming in a destructive feedback loop.

By combining energy efficiency improvements with the transition away from super-polluting refrigerants, the world could avoid cumulative greenhouse gas emissions of up to 210-460 gigatonnes of carbon dioxide equivalent ($GtCO_2e$) over the next four decades, depending on future rates of decarbonisation. This is roughly equal to 4-8 years of total annual global greenhouse gas emissions, based on 2018 levels.

i Cooling refers to any human activity, design or technology that dissipates or reduces temperatures and contributes to achieving: (i) reasonable thermal comfort for people, or (ii) preservation of products and produce (medicines, food, etc.), and (iii) effective and efficient processes (for example data centres, industrial or agricultural production and mining). Sustainable - or „clean" - cooling refers to cooling that uses climate-friendly refrigerants and without other environmental damage including climate impact, in line with the objectives of the Paris Agreement on Climate Change and the Montreal Protocol. Clean cooling necessarily must be accessible and affordable to help deliver our societal, economic and health goals.

There are many policy options and approaches to seize these benefits, including:

1 International cooperation through universal ratification and implementation of the Kigali Amendment and global initiatives for efficient, climate-friendly cooling, such as the Biarritz Pledge for Fast Action on Efficient Cooling;

2 Development and implementation of National Cooling Action Plans that integrate policies otherwise addressed separately, accelerate the transition to low-GWP and high-efficiency cooling, identify opportunities to incorporate efficient cooling into the enhanced Nationally Determined Contributions of the Paris Agreement on Climate Change, and serve as the basis for climate finance;

3 Development and implementation of Minimum Energy Performance Standards (MEPS) and energy efficiency labelling to improve equipment efficiency as part of the transition to low-GWP cooling, using regional cooperation and the adoption of common standards and efficiency tiers where possible;

4 Promotion of building codes and system-wide and not-in-kind considerations to reduce demand for refrigerants and mechanical cooling, including integration of district and community cooling into urban planning, and measures such as improved building design, green roofs, and tree shading;

5 Aggregation of demand for sustainable cooling technologies through public procurement and buyers' clubs;

6 Programmes to reduce peak demand, including incentives to purchase efficient cooling equipment and use thermal energy storage;

7 Technician training to improve installation and servicing practices and facilitate adoption of new technologies;

8 Anti-environmental dumping campaigns to transform markets and avoid the burden of obsolete and inefficient cooling technologies;

9 Increase public and private financing to accelerate the HFC phase-down, promote leapfrogging and enhance energy-efficiency;

10 Sustainable cold-chains to both reduce food loss – a major contributor to greenhouse gas emissions – and reduce emissions from cold chains.

01

INTRODUCTION

Record temperature highs across the world, increasing climate impacts, and the vast body of science pointing to the economic and social disaster that climate change could bring call for urgent and strong action to cut greenhouse gas emissions. So far, this has not emerged. The UN Environment Programme (UNEP) Emissions Gap Report 2019 indicates that current efforts on mitigation put the world on track for a temperature rise of over 3°C (UNEP 2019a). To keep humanity safe, we need to rapidly bend the curve and enhance our mitigation actions. This Synthesis Report aims to provide information to decision makers on the sizable mitigation and development potential of efficient cooling, a traditional blind spot in climate and development policy.

To limit temperature rise to 2°C while making best efforts to restrict it to 1.5°C, as called for in the Paris Agreement, policymakers need to take advantage of viable solutions to strengthen their Nationally Determined Contributions under the Paris Agreement. One such solution with significant potential and many co-benefits lies in reducing the growing climate impact of the cooling sector. In this report, the cooling sector means both stationary and mobile space cooling and refrigeration, which are essential for food, health, thermal comfort and productivity, and industrial and commercial purposes (see Table 1.1).

Table 1.1: Refrigeration and Air Conditioning Applications and Technologies

	Thermal comfort		Removing heat and maintaining stable temperatures for industrial and commercial purposes		Maintaining stable temperatures for food and medicine transport and preservation	
Application	**Mobile Air Conditioning**	**Space Cooling**	**Industrial Refrigeration**	**Commercial Refrigeration**	**Transport Refrigeration**	**Domestic Refrigeration**
	Cooling in passenger cars, commercial vehicles, buses, trains, planes etc.	Indirect district cooling and room air conditioning or fans for human comfort and safety in buildings	Used on farms, and in food processing (including marine) and pharmaceutical factories and product distribution centres	Used in supermarkets, restaurants and other retail premises, e.g. display cabinets and cold rooms	Movement of goods over land and sea, preserving their safety and quality, and extending shelf life	Safe storage of food and extension of its shelf life
Technology	Mobile ACs	Heat pumps; Unitary ACs; AC chillers	Industrial refrigeration equipment	Commercial refrigeration equipment	Transport refrigeration units (TRUs) including shipping containers	Domestic refrigerators

A warming world will increase the need for access to cooling, including for over one billion people who face serious risks because they lack cooling services – like the "cold chain" necessary to ensure food safety, refrigeration for vaccines, and ensuring comfort and productivity in homes, institutions and workplaces (SEforALL 2019). An estimated 3.6 billion cooling appliances are in use. One estimate suggests that if cooling is provided for all who need it – and not just those who can afford it – there would be a need for up to 14 billion cooling appliances by 2050 (University of Birmingham 2018).

The growing demand for cooling will increase global warming – from emissions of hydrofluorocarbons (HFCs) used in cooling equipment, and from CO_2 and black carbon emissions from the mostly fossil fuel-based energy currently powering cooling. A transition to climate friendly and energy-efficient cooling, however, would avoid these emissions and allow an increase in cooling access that would contribute substantially to the Sustainable Development Goals (SDGs).

There are many ways to make this transition happen, particularly by building on the work of the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer. The Kigali Amendment, ratified by 91 nations as of December 2019 (United Nations Treaty Collection 2019), requires the phase-down of HFCs, potent greenhouse gases with a global warming potential (GWP) thousands of times that of CO_2 in some cases. The implementation of the Kigali Amendment provides the opportunity to improve the energy efficiency of cooling equipment at the same time. Integrating refrigerant change and energy efficiency offers an excellent opportunity for quick and cost-effective emission reductions.

Box 1.1:

Efficient Cooling Contributes to the Sustainable Development Goals

Increasing access to efficient cooling that uses low-GWP refrigerants will contribute to most of the 17 Sustainable Development Goals (SDGs). For example, sustainable cold chains increase incomes for farmers and fishers (SDG1) by providing them with access to markets and reducing post-harvest losses. Cold chains are critical to ending hunger and malnutrition (SDG2). Unbroken cold chains that deliver universal access to vaccines and medicines are necessary to ensure healthy lives and promote well-being (SDG3).

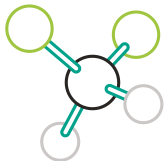
Managing thermal comfort is necessary for safe, resilient, and sustainable cities (SDG11), while providing affordable, sustainable modern energy (SDG7) is made more challenging by the additional demand for cooling services. Climate targets are also put at risk (SDG13).

This report aims to provide policymakers and practitioners with a non-technical summary of recent research on the topic and provide policy options to accelerate action. It focuses on the following questions:

- **What is the climate mitigation impact of the HFC phase-down? What are the current uses of HFCs and what are their substitutes?**
- **What is the status of cooling energy efficiency and its potential for improvement?**
- **What technologies are available to hasten the transition to climate friendly and energy-efficient cooling?**
- **What policies and measures can countries apply to unlock the multiple benefits of climate friendly and energy-efficient cooling?**

HFC EMISSIONS FROM THE COOLING SECTOR AND OPPORTUNITIES FOR MITIGATION

Phasing-down hydrofluorocarbons (HFCs) can avoid up to 0.4°C of global warming this century. Cooling-related sectors account for around 86% of HFC use in CO_2e. Low global warming potential alternatives are already available, and the transition is technically and economically feasible.



The phase-out of ozone-depleting substances (ODSs), such as chlorofluorocarbons (CFCs), under the Montreal Protocol led to the introduction of replacement compounds, including hydrochlorofluorocarbons (HCFCs) and later hydrofluorocarbons (HFCs). While HFCs do not deplete stratospheric ozone, many of these replacements are powerful greenhouse gases.

Scientists first alerted the parties to the Montreal Protocol to expected large growth in HFC emissions in 2009 based on projections of HFC use in the developed and developing world (Velders et al. 2009). The response was the eventual adoption of the Kigali Amendment to the Montreal Protocol, which targets the phase-down of a subset of the HFCs with the highest global warming potentials in the coming decades (United Nations Treaty Collection 2019).

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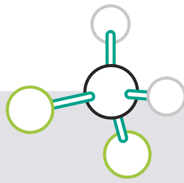

Box 2.1:

The Kigali Amendment to the Montreal Protocol

The Kigali Amendment entered into force on 1 January 2019, and its initial schedule will achieve over an 80% reduction in projected HFC production and consumption by 2047. As with previous refrigerant transitions, the Montreal Protocol is playing the dominant role in driving a transparent and organized global market transition away from HFCs through a stepwise phasedown. Most developed countries began reducing HFC use in 2019, whereas a majority of developing countries will freeze consumption and production in 2024 and begin the phasedown five years later. Other developing countries, including some susceptible to high ambient temperatures will freeze at 2028 and begin to phase down in 2032.

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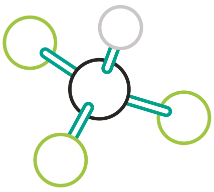
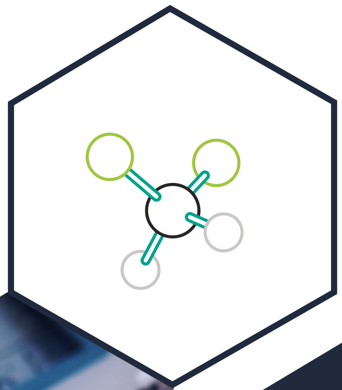
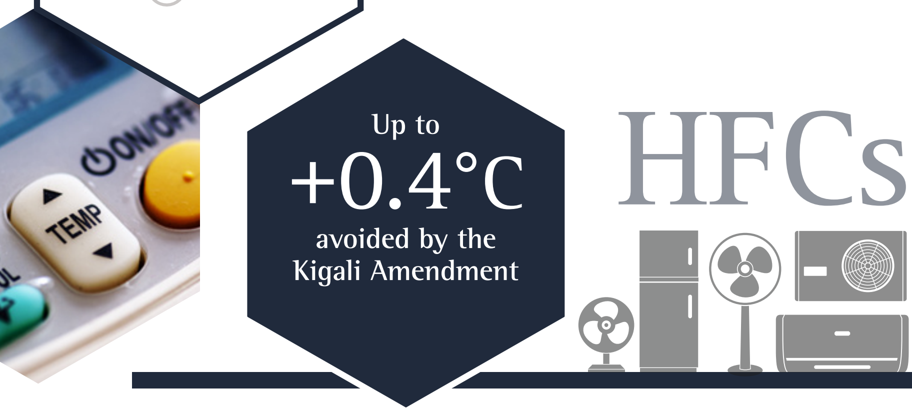


The role of HFCs in climate change is described in a chapter in the 2018 Scientific Assessment of Ozone Depletion (WMO et al. 2018), produced by the Montreal Protocol's Scientific Assessment Panel (SAP) under the auspices of the World Meteorological Organization (WMO), UNEP, National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Adminstration (NASA). Assessment reports from the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol address the technical and economic feasibility of the HFC phase-down in manufacturing, service, and recycling or destruction at end of product life. Findings of these assessment reports, as well as other studies, are summarized below.

Without the Kigali Amendment, HFC emissions are projected to raise global temperatures by 0.3-0.5°C by 2100. If the Kigali Amendment is implemented, however, the contribution of HFCs to global temperatures is predicted to peak by 2060 and be only 0.06°C by 2100 (WMO et al. 2018). This difference of up to 0.4ºC is substantial in the context of the Paris Agreement goal to limit warming to well below 2°C above pre-industrial levels, while aiming for no more than 1.5°C.





Additional warming, approaching 0.06°C, could be avoided with a faster phase-down schedule, which would be consistent with the "start and strengthen" history of past amendments and adjustments to the Montreal Protocol (WMO et al. 2018). This could be achieved with a more extensive replacement of HFCs with commercially available low-GWP alternatives.

A complete elimination of production of HFCs starting in 2020, and their substitution with low-GWP alternatives, would avoid an estimated cumulative 53 $GtCO_2e$ during 2020–2060, in addition to the reductions expected from the implementation of the Kigali Amendment (WMO et al. 2018). Greenhouse gas emissions can also be reduced by recycling or destroying ODSs and HFCs at the end of products' lives.

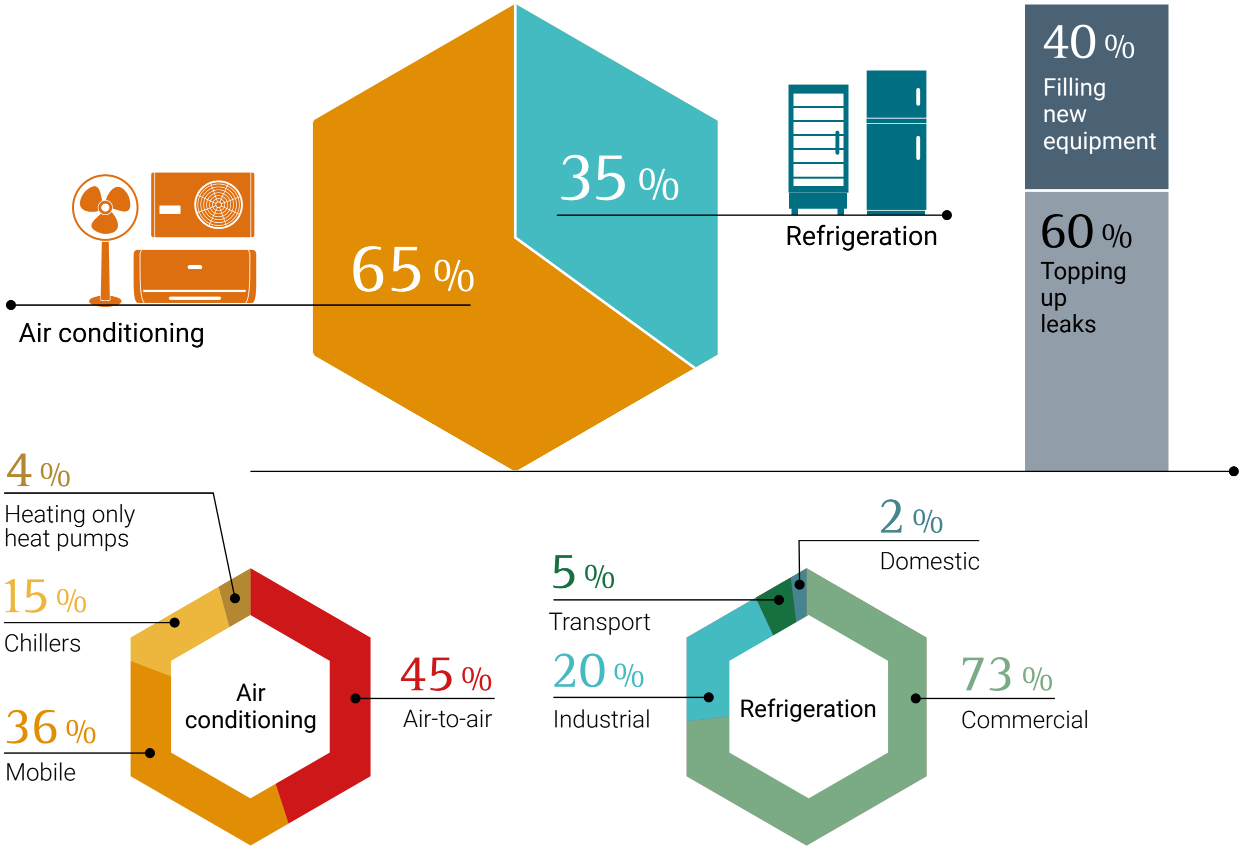
Opportunities for reducing HFC emissions

The vast majority of HFC consumption is in the cooling sector, comprising refrigeration, air conditioning and heat pumps (RACHP) in both mobile and stationary applications. These sectors accounted for 86% of the GWP-weighted share of global HFC consumption in 2012 (UNEP 2015c). More than half of the total HFC consumption for RACHP comes from emissions during the servicing of installed equipment (UNEP 2015c). An estimated 65% of GWP-weighted HFC consumption comes from air conditioning (with mobile air conditioning accounting for 36%) and 35% from refrigeration, as shown in Figure 2.1 (UNEP 2015c).

Assuming that cooling sectors continue to account for 86% of the GWP-weighted share of global HFC consumption, the cumulative direct emissions from these sectors without the Kigali Amendment could reach 78 to 90 $GtCO_2e$ by 2050, and as much as 216 to 350 $GtCO_2e$ by 2100 (WMO et al., 2018).

The global RACHP market relies on approximately 16 pure HFCs and 30 blends, with GWPs ranging from under 100 to close to 15,000. The weighted GWP average is 2,200 (UNEP 2015c). HFC-134a, the most widely used high-GWP HFC refrigerant (Myhre et al. 2013), has a GWP of 1360 (see Table 2.1 below). To give just

Figure 2.1: Global HFC use as share of total on GWP-weighted basis for stationary and mobile refrigeration, air conditioning, and heat pump sectors in 2012.



Source: UNEP 2015c

one example of a potential replacement, some hydrofluoroolefins (HFOs) have GWPs in the low single digits. In well over half of RACHP applications, lower-GWP alternatives are fully mature and commercialized and have an increasing market share. However, availability and usability among the different regions vary. The commonly used high-GWP refrigerants and their lower-GWP alternatives are listed in Table 2.1.

Cost, safety and performance are major considerations in refrigerant selection. Hazards related to particular refrigerants include toxicity, combustion/flammability/decomposition, and pressure. HFCs are popular refrigerants because of their relatively high safety performance, a standard not always easily achieved with commercially available alternatives for all applications.

Table 2.1: Refrigeration and Air Conditioning Markets and Lower GWP Alternatives[ii]

Market sector	High GWP HFC in common use (GWP)	Examples of lower GWP alternatives (GWP)
Domestic refrigerators	HFC-134a (1360)	→ HC-600a (<<1)
Small split room air-conditioning	R-410A (2100)	→ HFC-32 (704) → HC-290 (<1)
Water chillers for air-conditioning	HFC-134a (1360)	→ HFO-1234ze (<1) → HFO-1233zd (1) → R-514A (NA)
Food retail systems	R-404A (4200)	→ R-744 (1) → R-448A (1400) → R-449A (1400)
Mobile air-conditioning	HFC-134a (1360)	→ HFO-1234yf (<1) → HFC-152a (148) → R-744 (1)

ii Source: UNEP (2018) OzonAction Kigali Fact Sheet 19 – Phase-down Strategy: Impact of Gas Choices. Global warming potentials for 100-year time horizons (GWP-100) are WMO et al. 2018 values updated with the most recent analysis. Some GWPs in the table may differ from the official metrics for controlled substances reported in the Montreal Protocol Handbook (UNEP 2019e) due to consideration of recent experimental data, methods of analysis, and/or assessment recommendations.

A principal use of HFCs is in the mobile air conditioning (MAC) sector. MAC-related HFC emissions accounted for an estimated 170 million tonnes of CO_2e ($MtCO_2e$) emissions in 2013, or about one third of GWP-weighted global HFC emissions (Montzka et al. 2015). These emissions are expected to rise given rapid growth in vehicle ownership in hot countries. Transitioning to refrigerants with a GWP under 150 could provide global annual savings of 150–200 $MtCO_2e$ per year (Blumberg et al. 2019). Several low-GWP refrigerant alternatives are commercially available or under development, including HFO-1234yf, CO_2, and HFC-152a used in secondary-loop designs that achieve higher energy efficiency overall (Blumberg et al. 2019). HFO-1234yf is the predominant low-GWP refrigerant. It was used in over 70 million vehicles as of the end of 2018 (Taddonio, Sherman and Andersen 2019).

In addition to ensuring compliance with the Montreal Protocol's control measures, there are other strategies that could avoid additional HFC production/consumption and emissions:

- Reducing demand for refrigerants and mechanical cooling through improved buildings, better urban design, and nature-based approaches such as green roofs;
- Promoting use of not-in-kind cooling systems, including magnetocaloric refrigeration, absorption cooling that uses excess heat from industry or wastewater treatment, district cooling, and evaporative cooling (EIA 2015, Roberts 2017);
- Using lower GWP alternatives in new equipment, and where necessary for safety, using alternative designs such as secondary loops to isolate flammable refrigerants from occupied spaces;
- Reducing HFC refrigerant leaks through better design, manufacturing, and servicing; (WMO et al. 2018);
- Recovering and reclaiming or destroying banks of ODS and HFC refrigerants from products that have reached the end of their life. Currently, there is rarely funding nor incentive to do so and hence danger of leakage from storage tanks and discarded equipment;
- Using lower and zero GWP alternatives in retrofit of existing equipment, where appropriate;
- Training technicians for best service practices, including safe handling of inflammable refrigerants and proper installation for optimal efficiency and performance (AHAM 2017, UNEP 2015b);
- Replacing older and used refrigeration and AC equipment;
- Reducing HFC consumption in mobile air conditioning; and
- Halting the HCFC-22 feedstock emissions and the unwanted HFC-23 emissions from the production of HCFC-22 feedstocks, and otherwise destroying HFC-23.[iii]

iii HFC-23 represents 17% of forcing from HFCs in 2016, has the longest lifetime and highest GWP, and accounted for the second largest radiative forcing of all individual HFCs and other F-gases (WMO et al. 2018).

ENERGY-RELATED EMISSIONS FROM THE COOLING SECTOR AND OPPORTUNITIES FOR MITIGATION

The world can avoid 210-460 $GtCO_2e$ over the next four decades through efficiency improvements and refrigerant transition. This is equivalent to roughly 4–8 years of global greenhouse gas emissions, based on 2018 levels.

Demand for cooling is growing

Global energy demand for air conditioning in buildings more than tripled between 1990 and 2016, from about 600 Terawatt hours (TWh) to 2,000 TWh (IEA 2018a). This is equivalent to the total electricity consumed in Japan and India in 2016 (Enerdata 2019). In China alone, demand grew 68 times between 1990 and 2016 (IEA 2018a). In 2018, the global stock of equipment for air conditioning, refrigeration, and mobile cooling was projected to account for 3.4% of the world's total final energy demand (University of Birmingham 2018). The demand for space cooling is expected to triple by 2050 (IEA 2018a). If we take into account demand needed to deliver on the SDGs, growth will be much higher. This is because space cooling and refrigeration needs for agricultural cold chains, health, and other development needs are significantly underestimated in current income-based projections. Even today, over 1.1 billion people are at significant risk from lack of cooling, which makes it harder to escape poverty, keep children healthy, vaccines stable, food fresh, and economies productive (SEforALL 2018, SEforALL 2019).

Meanwhile, the rate of electricity demand increase in buildings was five times faster than improvements in the carbon intensity of the power sector between 2000 and 2018 (IEA 2019c), driven by space cooling as the fastest growing use of energy in buildings (IEA 2018a). Air conditioning contributes 50-80% of peak demand in hot climates (Khalfallah et al. 2016), and peak power is usually the most carbon intensive, polluting and costly – straining electricity grids, household, and national budgets (IEA 2018a). Over 100 gigawatts (GW) of space cooling capacity in buildings was added in 2017, outpacing the record 94 GW of solar generation capacity additions that year (Sachar, Campbell, Kalanki 2018). This shows that a net-zero electricity system may not be achieved without controlling growth in cooling.

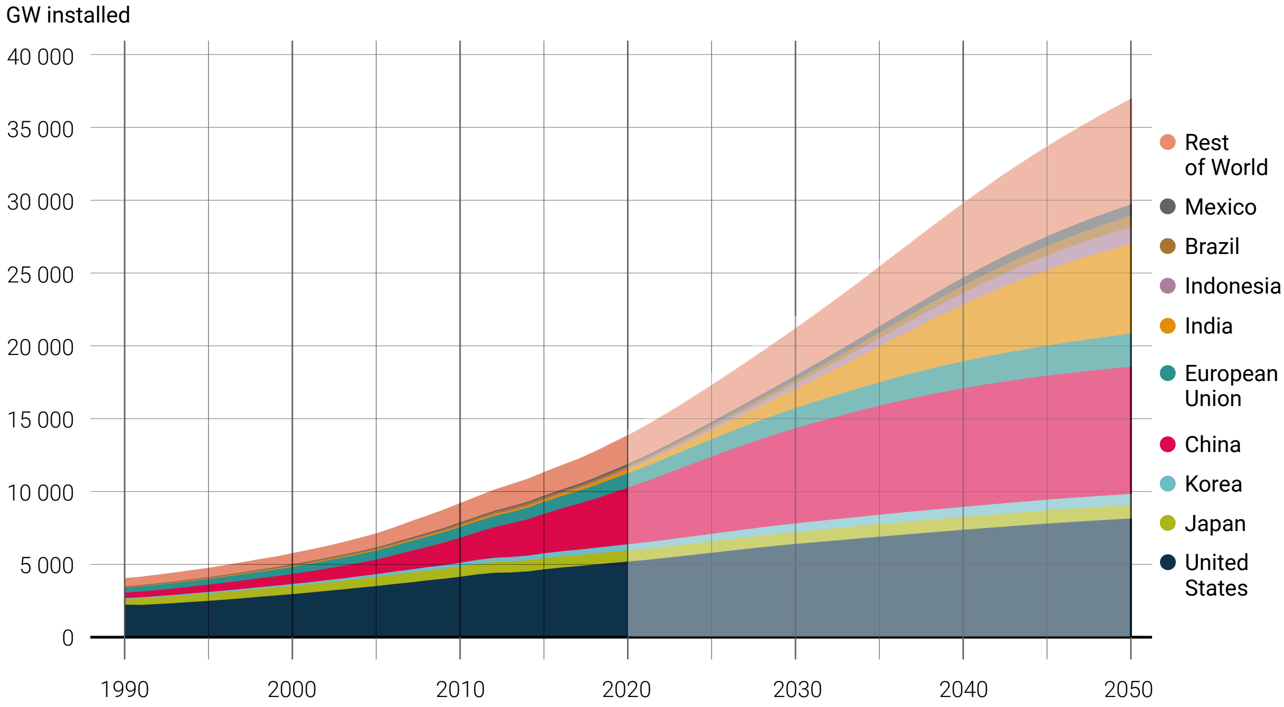
In 2018 the global cooling equipment stock (for air conditioning, refrigeration, and transport) is estimated to consume around **3,900** TWh/year globally of electricity.

This is approximately **17%** of the world's total demand for electricity.

Air conditioning accounts for the largest share and currently consumes approximately **2,000** TWh/year

...a number that is projected to triple by 2050.

Figure 3.1. Cooling capacity projections for residential and commercial air conditioning in baseline scenario of IEA Future of Cooling (2018a).



Note that global electricity generation capacity in 2016 was about 6,690 TW (IEA 2018b).

Moreover, demand for space cooling may grow faster than expected. The projected growth in residential and commercial space cooling capacity from 11,670 GW in 2016 to over 36,500 GW in 2050 (Figure 3.1) will leave substantial cooling needs unmet. Air conditioner ownership, in particular, rises very rapidly with income in countries with hot and humid climates, where cooling is essential for people to live and work in comfort (IEA 2018a). Demand in India, for example, has outpaced annual GDP growth, which has fluctuated between 5 and 8% since 2010 (World Bank 2018). Production of room air conditioners has been growing at 13% per year since 2010 and demand for air conditioners is expected to grow by 11–15% per year over 2017-2027 period (India, Ministry of Environment, Forest and Climate Change 2019).

This rapidly growing demand for space cooling also reflects increasing population and wealth, urbanization and warming cities amidst falling costs to purchase an air conditioner. More than half of the world's population is concentrated in cities. By 2050, it will be more than two-thirds of the population (UN DESA 2018). The urban heat island effect – due to traffic, air conditioning, heating, and heat-absorbing surfaces – can make cities hotter than the surrounding countryside by around 3°C or more on hot days and up to 12°C more in the evenings (US EPA 2008). Up to 10% of urban demand for electricity may be used to compensate for the heat island effect) (Akbari, Pomerantz, Taha 2001).

This wide-ranging demand in growth for cooling means that reducing the emissions profile of the sector is crucial to the goals of the Paris Agreement.

➜ Transitioning to high efficiency cooling can more than double the climate mitigation effects of the HFC phase-down, while also delivering economic, health, and development benefits.

Refrigerant conversions driven by the Montreal Protocol have already catalyzed significant improvements in the energy efficiency of refrigeration and AC systems – up to 60% in some subsectors (Shende 2009). Lessons learned from past transitions show that manufacturers who invested in improving the efficiency of their products as part of redesign for the CFC and HCFC transitions benefited from policies to improve the energy efficiency of cooling equipment that resulted in reductions in lifecycle costs to consumers, drove high-volume sales, and even reduced first costs (IGSD 2017). While similar improvements are expected under an HFC phase-down, more-deliberate policy efforts can drive even greater efficiency improvements.

Increase
Efficiency

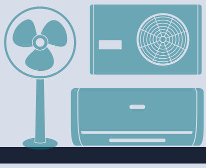
Emission reduction potential

In general, it is difficult to estimate GHG emission reduction potential precisely from increased energy efficiency because avoided emissions depend heavily on the assumptions made about the decarbonization rate of the global economy (including its electricity system) due to other mitigation efforts. A number of key studies offer insights into the potential enhancements available (Dreyfus et al. 2020). According to these studies, the world can avoid the equivalent of up to 210-460 $GtCO_2e$ (roughly equal to 4-8 years of global emissions at 2018 levels) (UNEP 2019b) over the coming four decades through efficiency improvements and the refrigerant transition (Shah et al. 2019), depending on future rates of decarbonization.[v] This would require that, starting in 2030, all stationary air conditioning and refrigeration equipment were replaced with the highest-efficiency and climate friendly refrigerants typical of the best technologies available in 2018.[vi] Three-quarters of the avoided emissions would come from energy efficiency – equivalent to an average 40% efficiency improvement. This study does not consider the additional equipment and power that would be needed to meet a “cooling for all” policy, which would add further to the potential.

v. Although this is implausible it illustrates the importance of improving energy efficiency in the cooling sector. The high end of the range assumes no additional decarbonization of electricity generation beyond 2015 emission factors (Shah et al. 2019).

vi Note that this scenario implies a faster HFC phase-down than the Kigali Amendment phase-down schedule.

Mobile Air Conditioning (MAC) for cars, vans, buses and trucks emit around 420 $MtCO_2e$ of greenhouse gases per year (approximately 70% from fossil fuel combustion and 30% from refrigerants). This is projected to rise to 1.3 $GtCO_2e$ in 2050 without further policy action. However, despite large additions of new vehicles between now and 2050, annual climate emissions could fall by 20% from today's levels as a result of improved efficiency and a shift to low-GWP refrigerants (IEA 2019). The global car industry began a move from HFC-134a to HFO-1234yf in 2013, initially driven by legislation in the EU that banned new mobile air-conditioning in cars if the GWP exceeded 150. Tens of millions of cars used HFO-1234yf by the end 2017 (UNEP 2017b, IEA 2019a).



Cooling benefits

Cooling enhances comfort, increases worker productivity and students' ability to focus, and enables economic activities requiring cooling such as high-end manufacturing, operation of data centers, research and development.

Inefficient cooling is costly to households, the economy, and public finances. The IEA estimates that doubling the energy efficiency of air conditioning by 2050 would reduce the need for 1,300 gigawatts of additional generation capacity to meet peak demand, the equivalent of all the coal-fired power generation capacity in China and India in 2018. In most countries and regions, the avoided capacity would be in the form of avoided coal and natural gas plants (IEA 2018a). Worldwide, doubling the energy efficiency of air conditioners could save up to USD 2.9 trillion by 2050 in reduced generation, transmission and distribution costs alone (IEA 2018a).

Reducing food waste and loss

Access to cooling can also reduce food loss and waste, boosting food security and reducing associated emissions. The Food and Agriculture Organization of the United Nations (FAO) estimates that food losses and waste cause up to 8% of total greenhouse gas emissions, and cost up to USD 2.6 trillion per year, including USD 700 billion of environmental costs and USD 900 billion of social costs (FAO 2013). Meanwhile, in 2018, 821.6 million people worldwide were undernourished (FAO et al. 2018).

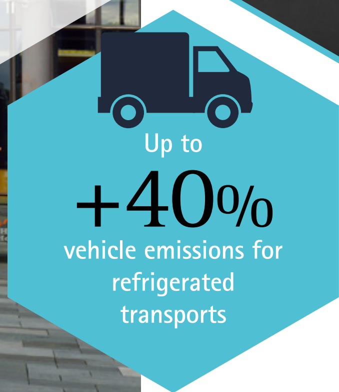
The lack of adequate cold chains is responsible for about 9% of lost production of perishable foods in developed countries and 23% in developing countries (International Institute of Refrigeration, 2009). Project Drawdown estimates that reduced food loss and waste brought about by consumer behaviour change and improved cold chains and agricultural practices would avoid 93.7 $GtCO_2e$ of emissions between 2020 and 2050. The potential impact of improved cold chains alone could account for 19-21 $GtCO_2e$ of these avoided emissions (Project Drawdown 2017).

Air quality benefits

Air conditioning and refrigeration equipment can increase air pollution through increased demand for electricity. In 2015, power plant emissions due to space cooling accounted for 9% of sulphur dioxide (SO_2), and 8% of nitrogen oxides (NOx) and particulate matter ($PM_{2.5}$) emissions (IEA 2018a). These emissions could cause up to 9% of all air pollution-linked premature deaths by 2050 (Abel et al. 2018). Air quality benefits increase substantially when cooling sector efficiency is combined with electricity decarbonization. Doubling air conditioner efficiency together with halving the global average carbon intensity of electricity generation, for example, could avoid up to 85% of global SO_2 emissions between 2015 and 2050 compared to a baseline scenario (IEA 2018a).

Mobile air conditioning is also a substantial and growing contributor to air pollution emissions. The World Health Organization estimates that road transportation is responsible for up to 50% of particulate matter emissions in Organisation for Economic Co-operation and Development (OECD) countries. Worldwide, MAC systems account for 3-7% of total fuel use for light-duty vehicles but can reach up to 40% in hot, humid climates (Chaney et al. 2007).

On-road diesel transport is responsible for nearly 20% of all black carbon emissions globally, and refrigerated transport can increase vehicle emissions by as much as 40% (Stellingwerf et al. 2018). Refrigerated transport efficiency can also be increased by improving insulation and mechanical efficiency of refrigeration units, and optimizing delivery, loading and offloading processes.



→ Opportunities for reducing emissions from the cooling sector while meeting cooling needs

Achieving the benefits described above requires an understanding of the opportunities for reducing energy-related emissions from each cooling sector.

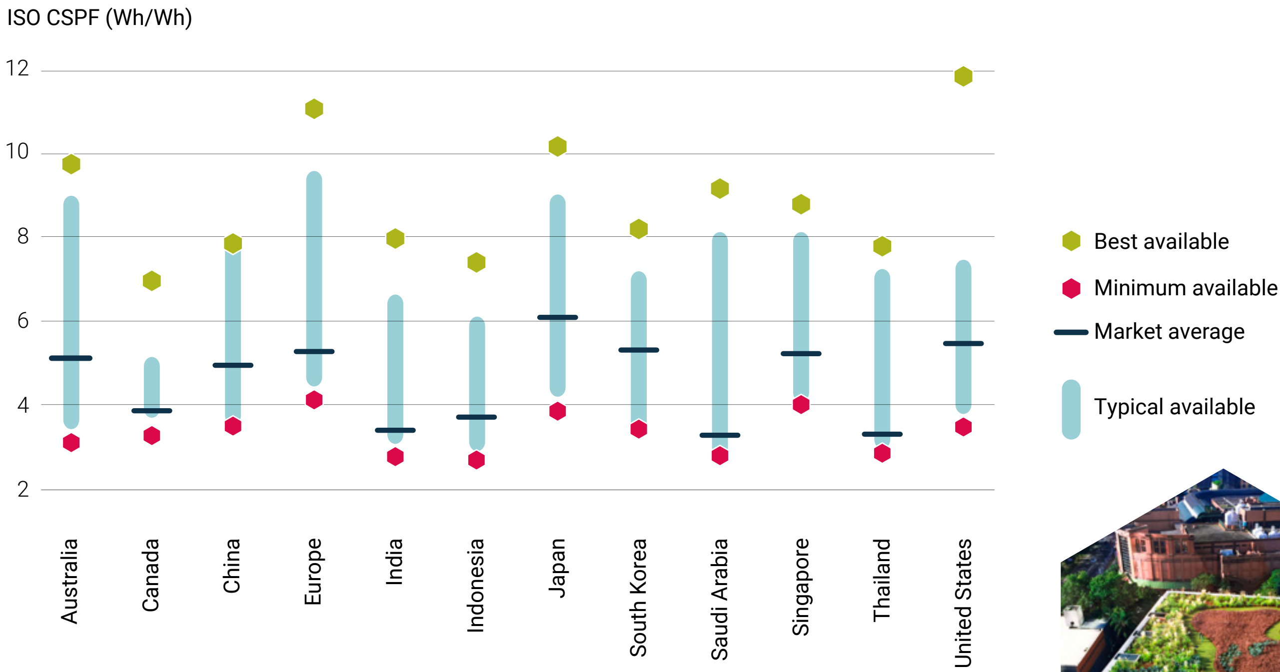
Space cooling opportunities

There are a number of strategies for reducing energy-related emissions from space cooling. These fall into two broad categories:

1 **Improve the energy efficiency of space cooling equipment.**

- Move to best available technology. Most air conditioners sold are 2-3 times less efficient than the best available on the market (see Figure 3.2).
- Improve installation of new equipment and monitoring and maintenance of existing equipment. This could deliver electricity savings of up to 20% (700 TWh annually), leading to emissions savings of up to 0.5 $GtCO_2e$ per year (K-CEP et al. 2018).
- Adopt district cooling and system approaches. By connecting multiple buildings, district cooling systems can safely manage alternative refrigerants and target much higher primary energy efficiencies through improved operation and use of local renewable energy sources, free cooling (from natural cooling sources such as rivers, lakes, seawater, etc.) and waste heat (Gang 2016, Roberts 2017). Properly designed district cooling systems can benefit from larger chiller systems that can be up to three times as efficient as smaller individual units (UNEP 2015b), reduce peak power requirements (Kombarji and Moussalli 2019), and use not-in-kind technologies including vapour absorption systems, natural heat sinks, heat pumps, and thermal storage (EIA 2019, Roberts 2017, IRENA 2017).

Figure 3.2. Efficiency of available residential ACs in selected countries/regions.



Efficiency estimated in ISO Cooling Seasonal Performance Factor (CSPF) based on IEA data converted to common metric using relationships in Park et al. (2020).

2 Reduce Demand

2 Reduce demand for cooling through improved building design and construction, management, shifts in user behaviour, and use of green and more reflective surfaces.

- New construction offers the best opportunity for building design optimization, including orientation and window placement to reduce the heat entering a building (IEA 2013). Improvements in the energy efficiency of building envelopes – components of a building's structure such as insulation, walls, roofs and windows – could reduce energy for cooling in hot climates by 10 to 40% (IEA 2013).
- Low- and no-cost building energy management practices can further reduce energy demand. These include best practices for operations and maintenance, such as replacing filters monthly, cleaning coils and keeping vents clear from obstruction, as blocked vents alone can increase energy use by over 25%.
- Use of metering systems, for example brought by district cooling systems, make building end-users aware of cooling consumed monthly, thus leading to better management of their internal cooling systems.

Reduce 2 Demand

- Simple measures such as adjustments in thermal comfort levels and better ventilation, along with more active measures such as choosing part-time, part-space equipment rather than centralized cooling equipment, could reduce energy demand by up to 80% (Zhou, Yan and Shi 2017). India has issued guidelines to encourage increasing temperature set points to 24°C in commercial buildings, which can save 20% in annual energy consumption compared to a 20°C set point (India, Ministry of Environment, Forest and Climate Change 2019).

- Making roof surfaces and pavements more reflective and increasing vegetation cover helps to counteract the effects of urban heat islands. On a typical sunny summer afternoon, a clean white roof that reflects 80% of sunlight will stay about 30°C (55°F) cooler than a grey roof that reflects only 20% of sunlight (LBNL n.d.). The IEA estimates that well-designed cities could save 25% of the energy used for heating and cooling (IEA 2018a).

Refrigeration opportunities

- The energy use of refrigerating appliances can be improved by 50-60% by using the best technologies on the market compared to average units in countries with existing energy efficiency policies (Shah et al. 2019). Developing countries could attain energy savings of more than 60% by discouraging dumping of inefficient equipment in their markets and adopting measures such as minimum energy performance standards (UNEP 2017).

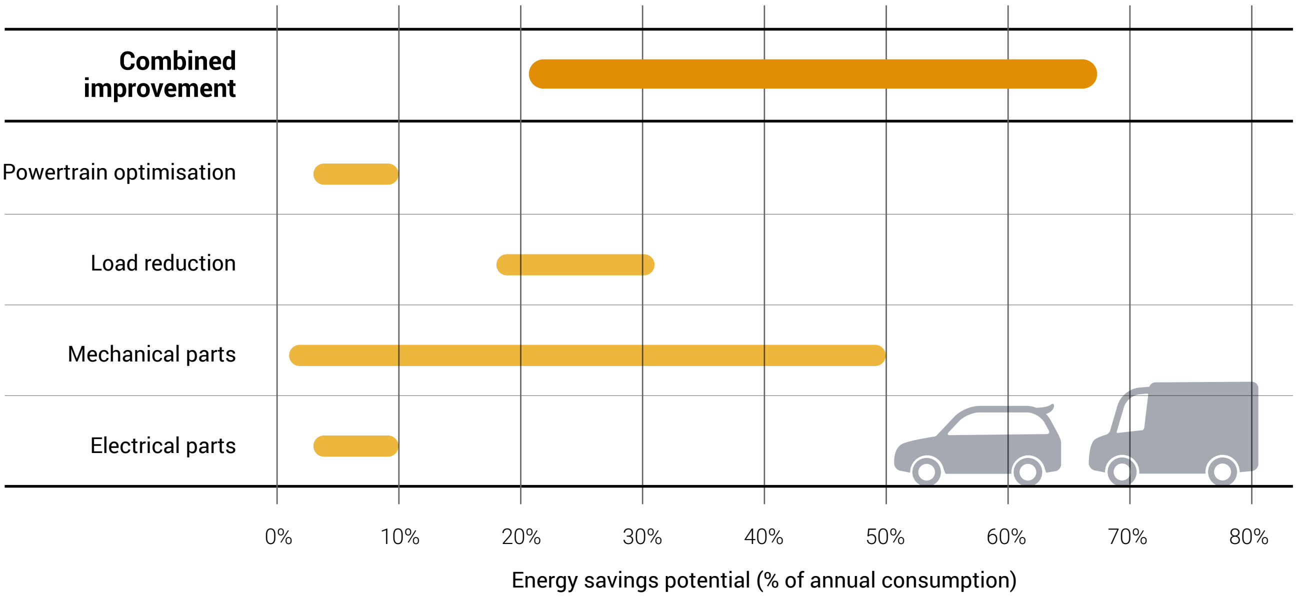
- Supermarkets can improve the energy efficiency of their refrigeration systems by 15-77%, depending on type of system in use (Shah et al. 2019). Demonstration projects of low-GWP alternatives to HFCs presented by the Climate and Clean Air Coalition (CCAC) calculated energy savings of 15% to 30% and CO_2 reductions of 60% to 85% for refrigeration in commercial food stores (CCAC 2014).

Energy efficiency potential
in supermarkets
15-77%
depending on type of system

Mobile cooling opportunities

- Studies suggest potential energy efficiency improvements of 55-63% in Mobile Air Conditioning efficiency (Figure 3.3) (IEA 2019b). Innovative technologies like secondary loop MACs allow a greater choice of affordable low-GWP refrigerants while reducing charge size and leak rates, which save consumers money on service and fuel (Blumberg et al 2019).

Figure 3.3. Efficiency improvement potential of MAC in cars and vans (IEA 2019b).



Doubling the efficiency of air cooling would reduce the need for

1,300 GW by 2050

POLICIES AND RECOMMENDATIONS

Policies and financing strategies can promote fast HFC phase-down in parallel with improvements in energy efficiency of cooling equipment, and hence are key to realizing the emissions reduction potential in the cooling sector. The billions of ACs, refrigerators and air-conditioned vehicles that will be produced to meet the growing demand for cooling have not yet been designed or manufactured. Equally, much of the building stock in which this equipment will be used is yet to be built or is expected to be refurbished (IEA 2019c).

There is, therefore, a large opportunity to shift the future of cooling by changing the trajectory of the technologies, solutions and behaviours that drive cooling demand and determine its impacts.

There are well-proven policies for capturing the climate and development benefits of sustainable cooling. Maximizing the climate and development benefits of the Kigali Amendment will require coordination with energy efficiency policies to integrate cooling efficiency technologies into broader frameworks.

A comprehensive approach to cooling policy, with efficient and smart use of public finances, can create the conditions to realize the full climate and development benefits of the mandatory refrigerant transition. National and local governments play a key role in the demand for cooling. Public authorities can encourage manufacturers to develop energy-efficient technologies and impose stringent building codes alongside implementation of policies to achieve the HCFC phase-out and HFC phase-down mandated by the Montreal Protocol. This requires good coordination among different ministries or regulatory agencies to ensure effective compliance regimes.

International cooperation remains essential

Continuing international cooperation is essential to deliver fully on the climate mitigation potential of the transition to low-GWP and energy-efficient cooling. Countries can ratify the Kigali Amendment and join one of many international initiatives to accelerate action. Initiatives include the Cool Coalition – which offers a platform for governments, private sector, and civil society to promote the transition to efficient, clean cooling – and the Efficient Cooling Initiative of the Climate and Clean Air Coalition, a ministerial-level effort with more than 100 partners, including 65 countries and international and regional finance institutions (CCAC 2019).

National Cooling Action Plans can help integrate policies that are addressed separately, and accelerate the transition to low-GWP and high-efficiency cooling

National Cooling Action Plans enable policy makers to send market signals and create favourable conditions for a streamlined transformation that provides investment security to producers and end-users, while maximizing preparation for anticipated future requirements (UNEP 2019c).

Good plans need to account for national circumstances, including vulnerable populations, current and projected demand, corresponding energy use, economic drivers, and the current state of

Box 4.1:
Example of International Action

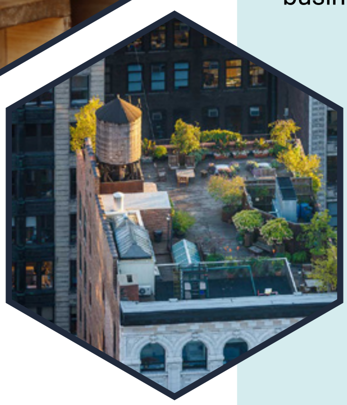
The **Cool Coalition** is a global network connecting over 100 partners from the private sector, government, cities, international organizations, finance, academia and civil society. It is supporting National Cooling Plans, Minimum Energy Performance Standards (MEPS) and labels, the scaling up of finance, technology pilots, innovative products, district cooling, cooling-as-a-service agreements, nature based solutions, cool and green roofs, cooling audits, knowledge resources and services (UNEP 2019c).

The **Kigali Cooling Efficiency Program** (K-CEP) is a philanthropic collaboration that to date has provided USD 60 million of support to international organizations, governments and the private sector to scale up efficient clean cooling.

Heads of state and governments backed cooling efficiency through the **Biarritz Pledge for Fast Action on Efficient Cooling**, launched at the August 2019 G7 Summit in Biarritz (French President's Office 2019).

The **World Bank Sustainable Cooling Initiative** is integrating efficient and climate-friendly cooling into its country engagements and investments. The World Bank Group is developing a "Global Roadmap towards Sustainable Cooling by 2050". Its Montreal Protocol Unit and Energy Sector Management Assistance Program (ESMAP) have together established a dedicated cross-sectoral technical assistance window, the Efficient and Clean Cooling Program to support client countries with affordable, efficient clean cooling solutions.

The **International Finance Corporation** (IFC) has established a **Sustainable Cooling Innovation Program**, which uses IFC's TechEmerge platform to support companies in developing countries to find and adopt innovative sustainable cooling solutions and business models.



the market in terms of product availability and pricing (IEA 2018a). This is important for communicating expectations to the cooling value chain on refrigerant choice and energy performance. National plans can include other policies discussed in this chapter, as well as up-front incentives and regulations to drive the market, alongside longer-term signals. This can help lower barriers for first-movers.

National Cooling Action Plans – such as those adopted in China (China NDRC 2019), India (India, MoEFCC 2019), and Rwanda (Rwanda, Ministry of Environment 2019) – combine high-level policy ambition with strategies addressing the entire value chain, including identifying potential governance gaps (for example, lack of effective monitoring, validation, reporting, and enforcement), loop-holes or exemptions in regulatory measures, capacity building needs such as training for equipment maintenance and customs officials, and finance issues such as the need for manufacturer access to credit lines and assistance to consumers to overcome resistance to higher first costs of energy saving equipment.

Governments can use National Cooling Action Plans to identify opportunities for incorporating efficient cooling into the enhanced Nationally Determined Contributions of the Paris Agreement on Climate Change. Cities also have an important role to play in promoting efficient and climate-friendly cooling, through urban heat mitigation plans, building codes and zoning, and urban planning for green spaces (UNEP 2019b).

Minimum Energy Performance Standards (MEPS) are key for improving equipment efficiency as part of the transition to low-GWP cooling

MEPS are highly effective tools to increase the energy efficiency of standardized mass-manufactured equipment such as refrigerators and air conditioners (Sonnenschein et al 2017). These policies are part of a toolbox that can be complemented by labelling schemes as well as up-front incentives such as consumer rebates and industry tax relief (IGSD 2017).

Labelling programmes promote the sale of energy-efficient cooling technologies. Consumers can make informed decisions based on a variety of indicators, such as the amount of cooling the unit can produce and expected operating costs. With developments in performance, labelling programmes are best designed to account for future improvements and provide for regular upgrades of the labels. A policy guide on market transformation for refrigerating appliances and ACs covering these issues has been prepared by UNEP under the U4E programme (United for Efficiency 2019d).

Regional cooperation and the adoption of common standards and efficiency tiers, such as the model regulation guidelines for energy-efficient and climate-friendly refrigerating appliances developed by UNEP's U4E programme (UNEP 2019d), would enable manufacturers to capitalize on scale and drive down costs while

MEPS are highly effective

increasing availability of efficient and lower-GWP cooling equipment (UNEP TEAP 2019). Furthermore, policymakers can give their markets a clear policy trajectory, such as Japan has done with its Top Runner programme, and increase investor confidence that there will be a market for higher-efficiency products by setting longer-term targets for energy efficiency alongside the HFC phase-down (UNEP TEAP 2019).

Similar mandatory regulations can be used for transport cooling. For example, Mobile Air Conditioning (MAC) fuel efficiency can be addressed directly by incorporating MAC use in vehicle fuel efficiency test cycles, or indirectly through the use of off-cycle credits. At the same time, GWP limits can also be set for such equipment, as is already done in the EU. Trucks can also be equipped with battery powered air conditioners for cabin comfort that avoid the need for engine idling.

MEPS and energy efficiency programs need to be coordinated with safety standards and technical requirements for low-GWP alternatives to achieve a transition to efficient and climate-friendly cooling. Implementation of life cycle performance metrics is a good integration tool to ensure all the elements of cooling are considered. These should be combined with the continued development and introduction of technical and safety standards for low-GWP HFC alternatives, as well as training and capacity building for relevant stakeholders.

Building codes and system-wide and not-in-kind considerations to reduce demand for refrigerant and mechanical cooling

Demand for cooling in buildings has steadily risen, and currently accounts for nearly one fifth of total building electricity use (IEA 2018a). An estimated 130 billion square meters of new building construction is expected over the next 20 years. The first step is to reduce the need for cooling through improved building design, construction, retrofitting, and operation. Once a building has been constructed, the amount of cooling required for thermal comfort gets locked-in. There is an urgent need for effective building codes that mandate cooling efficiency (IEA 2018a).

Energy efficiency in buildings should not be considered in isolation, but as an integrated approach that combines demand side efficiency (at the consumer end) with cooling supply side efficiency to minimize greenhouse gas emissions. Accounting, labelling and standards that prioritize building-level efficiencies over full energy-system efficiency can stand as a barrier to using not-in-kind alternatives. These include evaporative cooling, vapor absorption systems, deep lake and seawater cooling systems, tidal and other cooling systems in a district cooling configuration, which do not use conventional refrigerants such as HCFCs, HFCs and HCs (Roberts 2017, BPIE 2018).

District cooling systems are most viable in high-density and mixed-use areas. Integrating cooling into urban land-use and infrastructure planning and mapping can allow a city to designate areas or zones that have favorable conditions for district cooling development and promote siting of buildings there through appropriate policies. Local resources including excess heat, natural cooling, renewable assets (geothermal and solar) and concentrations of cooling demand can be the basis for zoning (Connolly et al. 2013; Persson et al. 2012). Cities ranging from Stockholm to Tokyo are using land-use planning policies to require developers to assess the opportunities for cost-effective modern district cooling or to identify a cheaper next-available sustainable cooling option before attaining a building permit.

Aggregating demand through public procurement and buyers' clubs can speed adoption and reduce the cost of super-efficient refrigeration and air conditioning equipment

Public procurement and private buyers' clubs pool the state's or private members' collective buying power to make purchases of large quantities of products at lower prices than would be available independently, while simultaneously demanding newer, energy-efficient, and higher-quality models (Andersen et al. 2018). The strategic use of this consumer power is a key transformation tool to address what otherwise could be higher initial costs of super-efficient air conditioners and other equipment, and can help next-generation technologies penetrate the market faster.

Energy service companies are one mechanism for financing bulk procurement programs. For example, India has launched bulk public procurement that aims to deliver ACs that are comparably priced with average efficiency units, but over 40% more efficient, perform at high ambient temperatures, are reliable over wide operating voltage range, and are backed up by five years of additional warranty (Energy Efficiency Services Limited [EESL] n.d.). Bulk procurement through private buyers' clubs and partnerships are underway in Morocco for room ACs and in Brazil for manufacture and promotion of inverter AC technology (IGSD & OzonAction 2018).

Utility regulation can reduce peak demand and offer incentives to purchase efficient cooling equipment and thermal storage technologies

Decisions by consumers whether to buy efficient cooling equipment and how to operate the equipment has a significant impact on electric utilities. Consequently, various strategies have been used by utilities to promote the purchase of efficient cooling equipment and to limit demand for electricity during peak periods. These include charging higher prices for electricity during peak periods, offering subsidies for the purchase of more efficient systems, and encouraging large-scale utilization of thermal storage (ice or chilled water) as in district energy, and information or awareness campaigns. Governments can require utilities and other actors to improve energy efficiency and reduce energy consumption. The use of Energy Efficiency Obligations (EEOs) have been used in many countries to finance and drive the uptake of energy efficiency. This includes financing of replacement programmes to remove inefficient technology and accelerate the adoption of high energy performance technologies, and provide for capture and recycling of refrigerants.

Finance
with Energy Efficiency Obligations

With the advent of digital technologies, it is now possible for utilities to directly control cooling equipment in order to cap consumption during peak periods, usually in return for some financial reward for consumers. Cooling capacity can also be adjusted to the availability of on-site electricity production, a concept used in China to match operation of air conditioning units with the power available from solar panels (IEA 2019d).

Skilled technicians are key to proper installation and servicing of equipment, and to the rapid adoption of new technologies

Governments and industry have common interests in attracting, retaining, and upskilling technicians in the cooling sector to adapt to fast technological developments and maximize associated environmental and economic benefits. Poor installation, such as stacking or clustering condensers to create mini "heat islands" or insufficient maintenance practices can significantly reduce performance and lifetime of equipment (Games 2019). Improved installation and servicing practices to reduce refrigerant charge and leakage will maintain energy performance of equipment and lower the cost of ownership through less frequent service (UNEP 2010). This is a particular challenge in many developing countries which lack trained service personnel, a gap now being addressed by some climate funds such as the IKI Green Cooling Initiative.

Effective anti-environmental dumping campaigns can transform markets

Inefficient cooling equipment that is dumped in markets in developing countries and transitioning economies undermines national and local efforts to manage energy, environment, health and climate goals, including achieving the SDGs.

Specific regulations can avoid environmental dumping. Parties to the Montreal Protocol have employed this practice, which involves exercising the right to know information about the product before consenting to its import (Maldives, Ministry of Environment 2016). Requiring imported appliances to include information on energy performance and climate impact can be a powerful step toward achieving the Kigali Amendment's climate benefits. In this regard, it is important to ensure effective compliance with labels on imported equipment that indicate low-GWP and energy-efficient technologies. Additional strategies for eliminating unwanted dumping are described in a legal and policy "toolkit" (Andersen et al. 2018).



Financing can accelerate the HFC phase-down and energy-efficiency improvements

Funding can complement labelling and standards programmes and speed up the transition to low-GWP refrigerants and energy-efficient equipment and help capture the USD 2.9 trillion of savings in generation, transmission and distribution costs identified by the IEA (2018a). In addition to support for the HFC transition from the Multilateral Fund of the Montreal Protocol, there are international (including multilateral development banks) (Hawkins 2019), national, and private financing mechanisms that could support the energy efficiency transition. These include traditional tools such as funds provided through national budgets, fee-generating product registration schemes, and electricity tariffs (Hossain 2018).

Other mechanisms include equity, commercial or concessional loans, guarantees and risk-sharing facilities, technical assistance grants, market-based instruments, and fiscal incentives or penalties (Deason et al. 2016). Business models that treat cooling as a service allow the private sector to work with both the public and private sectors in phasing down HFCs while improving efficiency (UNEP 2015a, IFC 2016). Green mortgages developed with support from the International Finance Corporation are supporting residential developments incorporating passive design and energy-efficient refrigerators in Mexico (Menes 2019).

USD 2.9 trillion
of savings in generation, transmission and distribution costs

A current challenge is the absence of coordination between funding from the Multilateral Fund for refrigerant replacement and funding for energy efficiency from the Green Climate Fund, Global Environment Facility, and other climate funds (NRDC 2019). This is inefficient and potentially costly if cooling systems are optimized for one objective at a time, requiring multiple changes in equipment. A recent promising development is GCF consideration of a concept for support of a co-ordinated program supporting refrigerant replace-ment and efficiency improvements for appliances in Costa Rica, Indonesia, and Ghana; if approved the project could be a model for replication (GCF 2019).

Commercial or concessional loans in certain markets are mobilized using revolving funds such as the Energy Efficiency Revolving Fund in Indonesia, whose initial fund size in 2003 was THB 2 billion (USD 63 million) and reached USD 261 million by September 2010, including USD 27.5 million allocated for renewable energy projects (K-CEP 2018a).

The development of innovative financing, such as cooling-as-a-service (K-CEP 2018b, BASE 2019) and utility "on-bill" financing for efficient equipment can support the transition to low-GWP and energy-efficient cooling. Much of the investment required to achieve the transition could be self-funded by purchasers or as part of loans for new equipment. Private finance can step in, but governments also have a role to facilitate investment opportunities, for instance de-risking and enabling new business models such as energy service

agreements or energy performance contracting (provisions that link payments to performance and thus reduce perceived risks to buyers) via energy service companies.

Insurance packages that de-risk initial operations by providing standardized insurance scheme contracts catalyze initial adoption in countries looking to leapfrog legacy systems. For example, the Energy Savings Insurance (ESI) scheme provides steady credit lines by partnering with national development banks to develop standardized structures in Latin America. The ESI aims to work in other countries and attract USD 10-100 billion in investments between now and 2030 and provide annual emissions reductions of 20-200 $MtCO_2$ (K-CEP 2018a).

Furthermore, tracking and benchmarking access to sustainable cooling finance, which is still lacking, should be a clear focus of governments and financial institutions (SEforALL 2018).

Sustainable cold-chains can both reduce food loss – a major contributor to greenhouse gas emissions – and reduce emissions from cold chains

Improving access to energy-efficient and climate-friendly refrigeration through enhanced cold chains would further deliver economic, environmental, and health benefits through reduced food loss and waste. A key challenge is to deliver sustainable cold chain equipment, logistics, and business models that simultaneously reduce food loss and minimize climate emissions, while economically empowering small farmers and fishers (Peters et al. 2019). The International Solar Alliance (ISA) launched the Solar Cooling Initiative to increase usage of solar and solar-hybrid linked cold-chain and cooling systems (ISA 2019). One promising approach is the creation of "cooling hubs" – aggregating demands to address the needs of rural farmers and fishers for cold chains, other local community needs, and access to medicines (Ogden 2019).

Reduce food loss and GHG emissions

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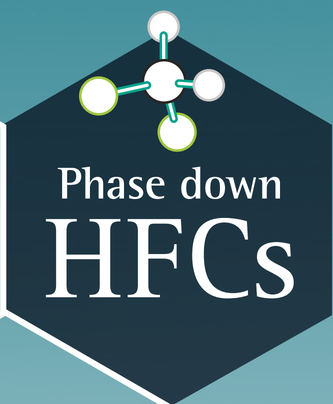

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