The Economist INTELLIGENCE UNIT

The Cooling Imperative
Forecasting the size and source of future cooling demand

A report by The Economist Intelligence Unit

Sponsored by KIGALI COOLING EFFICIENCY PROGRAM

Contents

Foreword

The Cooling Imperative: Forecasting the size and source of future cooling demand is an Economist Intelligence Unit (EIU) report that has been commissioned by the Kigali Cooling Efficiency Program (K-CEP). The findings are based on an extensive literature review, expert interview programme and econometric modelling exercise conducted by The EIU between June and October 2019. The EIU bears sole responsibility for the content of this report. The findings and views expressed do not necessarily reflect the views of K-CEP.

We would like to extend our gratitude to Dan Hamza-Goodacre, K-CEP Executive Director, for his invaluable advice and guidance throughout the project.

The report was produced by a team of researchers, writers, editors and graphic designers, including:
Conor Griffin – Project director
Diana Hindle Fisher – Project manager
Syedah Ailia Haider – Researcher
Eve Labalme – Researcher
Devika Saini – Researcher
Sara Constantino – Contributing economist
Vidhi Garg – Economist
Mrigansh Jain – Economist
Sahil Raaj Kapur – Economist
Adam Green – Contributing author
Gareth Owen – Graphic designer

Interviewees
Our thanks are due to the following people for their time and insights:
Andrea Voigt, European Partnership for Energy & the Environment, Director General
Ray Gluckman, Gluckman Consulting, Consultant
Scott Nicholson, National Renewable Energy Laboratory, Chemical Engineering Researcher
Jonas Hamann, Danfoss Cooling, Communication and Public Affairs Advisor
Jenny Chu, The Climate Group, Head of Energy Productivity Initiatives
Iain Campbell, Rocky Mountain Institute, Senior Fellow and Managing Director
Roberto Peixoto, United Nations Environment Programme Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (UNEP RTOC), Co-Chair
Walid Chakroun, ASHRAE Publishing and Education Council, Vice President
Eric Gibbs, CLASP, Chief Policy & Analysis Officer
Alex Hillbrand, Natural Resources Defense Council (NRDC), HFC Expert, Climate & Clean Energy and International Programs
Prima Madan, Natural Resources Defense Council (NRDC), Lead: Energy Efficiency and Cooling
Clotilde Rossi di Schio, Sustainable Energy for All, Policy Team Specialist

Ben Hartley, Sustainable Energy for All, Energy Efficiency Expert
Glenn Pearce-Oroz, Sustainable Energy for All, Director of Policy and Programs
Stephen Andersen, Institute for Governance and Sustainable Development (IGSD), Director of Research
Nihar Shah, Lawrence Berkeley National Laboratory (LBNL), Co-Leader of Emerging Economies Research Program
James Wolf, Energy and Environmental Consultant
Sonia Medina, Children's Investment Fund Foundation (CIFF), Executive Director
Yelena Ortega, Children's Investment Fund Foundation (CIFF), Analyst
Thomas Motmans, Basel Agency for Sustainable Energy (BASE), Sustainable Energy Finance Specialist
Dario Abramskiehn, Climate Policy Initiative (CPI), Senior Analyst
Toby Peters, University of Birmingham, Professor in Cold Economy
Shubhashis Dey, Shakti Sustainable Energy Foundation, Manager & Program Lead, Energy Efficiency (Industry, Buildings and Cooling)
Jiang Lin, Lawrence Berkeley National Laboratory (LBNL), Nat Simons Presidential Chair in China Energy Policy
Corey Rosenbusch, Global Cold Chain Alliance (GCCA), President and Chief Executive Officer
Alice McKinnon, Global Cold Chain Alliance (GCCA), Director of Membership & International Programs
Todd Washam, Air Conditioning Contractors of America (ACCA), Vice President, Public Policy & Industry Relations
James Walters, Air Conditioning, Heating, and Refrigeration Institute (AHRI), Senior Director, International Affairs
Hilde Dhont, Daikin Europe, Senior Manager
Randal Newton, Ingersoll Rand, Vice President (Enterprise Engineering)
Clay Nesler, Johnson Controls, Vice President, Global Energy and Sustainability
Talbot Gee, Heating, Air-conditioning & Refrigeration Distributors International (HARDI), Chief Executive Officer
Guitze Messina, Heating, Air-conditioning & Refrigeration Distributors International (HARDI) Mexico, Executive Director
Carl Hunter, Jade Mountain & Anse Chastanet Hotel and Spa, Property Manager
Cliff Majersik, Institute for Market Transformation, Director of Market Transformation
Lisa Bate, World Green Building Council, Chair of the Board of Directors
Alan Fogarty, Cundall, Sustainability Partner
Cristina Gamboa, World Green Building Council, Chief Executive Officer
Ahmed Kamal, Majid Al Futtaim, Corporate Communications Manager
Tony Cupido, Mohawk College, Research Chair, Sustainability
Spencer Wood, Humber Institute of Technology and Advanced Learning, Director Facilities Management
Anirban Ghosh, Mahindra Group, Chief Sustainability Officer
Satish Kumar, Alliance for an Energy Efficient Economy (AEEE), President and Executive Director

For any enquiries about the report please contact:
Diana Hindle Fisher
The Economist Intelligence Unit
London | United Kingdom
E: dianahindlefisher@eiu.com
Tel: + 44 (0)20 7576 8368

About the Economist Intelligence Unit

The Economist Intelligence Unit (EIU) is the research arm of The Economist Group, publisher of The Economist. As the world's leading provider of country intelligence, it helps governments, institutions and businesses by providing timely, reliable and impartial analysis of economic and development strategies. Through its public policy practice, The EIU provides evidence-based research for policymakers and stakeholders seeking measureable outcomes, in fields ranging from gender and finance to energy and technology. It conducts research through interviews, regulatory analysis, quantitative modelling and forecasting, and displays the results via interactive data visualisation tools. Through a global network of more than 650 analysts and contributors, The EIU continuously assesses and forecasts political, economic and business conditions in more than 200 countries. For more information, visit www.eiu.com

About the Kigali Cooling Efficiency Program (K-CEP)

The Kigali Cooling Efficiency Program (K-CEP) is a philanthropic collaboration launched in 2017 to support the Kigali Amendment to the Montreal Protocol and the transition to efficient, climate-friendly cooling solutions for all. K-CEP works in over 50 countries in support of ambitious action by governments, businesses and civil society. K-CEP's program office, the Efficiency Cooling Office, is housed at the ClimateWorks Foundation in San Francisco.

Executive Summary

- The market for cooling – refrigeration and air conditioning (AC) – is substantial. It is already larger than that for solar photovoltaic (PV) panels, wind turbines and lithium batteries. It is also on a rapid growth trend, driven by climate change, urbanisation and income growth.
- Based on a new econometric model, we estimate that **4.8bn** new units of cooling equipment will be sold globally between 2019 and 2030 and that annual sales will hit **460m units**, up from **336m** unit sales in 2018. As a guiding estimate, this could mean that the total market value could reach almost US$170bn in 2030, up from $135bn in 2018. In an absolute sense, China will drive demand. However, the relative pace of growth will be faster elsewhere - for example in India and Indonesia.
- This uptick in demand for cooling must be met if countries are to meet the Sustainable Development Goals (SDGs). This is because cooling offers critical and diverse benefits, including curbing systemic food loss; preventing heatstroke and spoiled vaccines and medication; improving childrens' learning and employee productivity; and reducing systemic inequalities – a lack of cooling disproportionately hurts women, minorities and the poor.
- However, current cooling technologies and practices are also a substantial and growing contributor to climate change. Most cooling devices are a *direct* source of emissions owing to their use and leakage of hydrochlorofluorocarbon (HCFC) or hydrofluorocarbon (HFC) refrigerants. The devices also contribute emissions *indirectly* as they typically run, often very inefficiently, on fossil fuel-based power.
- If the world is to scale up access to cooling without exacerbating current levels of emissions, policymakers, companies and individuals must transition to more efficient climate-friendly models. First, they must take steps to *reduce* the need for cooling – for example, through better building design and behaviour change. Second, they must *shift* to forms of cooling with lower emissions – for example, by replacing HFCs with climate-friendly alternatives. Third, they must *improve* the efficiency of cooling, by deploying new technologies and harnessing waste thermal resources. Finally, they must *protect* those most vulnerable to a lack of cooling – for example, through more inclusive business models.
- Individuals are the largest source of cooling demand. In 2018 *domestic* refrigeration and *residential* AC accounted for **62%** of total cooling demand. However, across the eight sub-sectors of cooling that we analyse, the *industrial* and *transport* refrigeration sectors will grow the fastest out to 2030. This means that businesses are playing a growing role in driving cooling demand. With this in mind, we conclude our report with emerging examples of best practice across industries, such as hotels using *passive cooling* design, supermarkets reselling the excess heat that they generate through refrigeration, and data centres using "free cooling" provided by colder climates.

1. Introduction

Some innovations stand as symbols of modernity and economic transformation, from the shipping container and the internal combustion engine, to the computer and the barcode. Cooling technologies – specifically, air conditioning (AC) and refrigeration – surely stand among them. Our ability to manipulate temperature has changed nearly every aspect of our lives, from how we transport food and medicines to our ability to create and maintain critical assets such as data centres and energy facilities.

Demand for cooling is on a rapid growth curve. In part, this is a byproduct of economic development. As households reach a certain income threshold, they seek out modern conveniences like refrigeration and AC, especially in hot summer conditions. Urbanisation also drives demand for cooling because cities, where the majority of the world's population now live, tend to trap heat. Rising temperatures caused by climate change are further stoking demand.

Meeting current and future cooling demand sustainably will require innovative approaches – and fast. Affordable cooling is critical to societal well-being, but the direct and indirect emissions from current devices are a substantial and growing contributor to climate change. Without radical improvement to product design, behaviour change, policymaking, and greater engagement from industries, increased cooling demand will exacerbate climate change even as it tries to mitigate its effects.

This report is based on expert interviews, an extensive literature review, and a new econometric model for cooling demand. It quantifies the need to transition to more efficient, climate-friendly cooling, and maps out what such a transition could look like.

- In section 1, we explain what cooling is, who uses it, and how.
- In section 2, we quantify current cooling demand and forecast how it will grow by 2030 – globally and in six key markets.
- In section 3, in highlighting cooling's diverse economic and societal benefits, we explain why the gap between cooling demand and supply must be closed.
- In section 4, we highlight the environmental cost of current cooling models and explain how to shift to more efficient, climate-friendly approaches.
- In section 5, we highlight the sectors and companies that need to shift their approach to cooling and provide best practice examples.

1. What is cooling and who uses it?

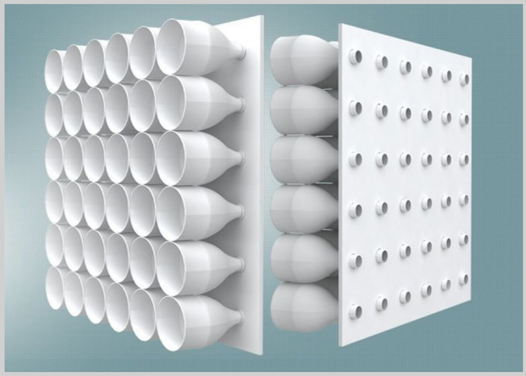
Refrigeration and AC are the primary forms of cooling in use today.[1] Refrigeration describes systems that remove heat and keep physical goods (including liquids) at fixed temperatures in confined facilities. Outside the home, refrigeration systems are critical inputs in chemical facilities and processes, and for medical technologies, such as imaging and scanning, that require careful temperature control.

AC describes the systems that control ambient temperature, or the temperature of the surrounding air, for the benefit of people in the home, in the workplace, and on the move. In buildings, AC may be provided by small fixed units or by large centralised "chillers" which generate and transport chilled water to remove heat. Room air conditioners (RACs), typically mounted on windows, constitute approximately 70% of ACs in use today.[2]

One size doesn't fit all

Most cooling studies focus on the mass-manufactured AC and refrigeration units that are most commonly purchased across the world. However, a diverse range of local cooling solutions exist. For example, individuals in heat-intensive occupations, such as firefighters, wear "cooling vests" equipped with *phase change* materials that absorb and release heat.[3] Across the world, people deploy a range of local innovations to manage heat, from basic fans to terracotta clay tube structures.[4]

Case study: Local needs, local solutions


Source: Inhabitat

Owing to inconsistent, expensive or non-existent electricity supply, traditional AC systems are often not viable in deprived areas such as slums. However, other types of AC systems exist.[5] Invented by Ashis Paul to tackle the stifling summer heat in rural Bangladesh, the EcoCooler is inspired by how humans purse their lips to blow air out of their mouths.

To construct the device, Paul and his colleagues inserted plastic bottles with their bottoms cut off into a window-sized board with holes drilled into it. The wider part of the bottle catches the wind and funnels it into the building. The change in air pressure that occurs when the air travels from the wider part of the bottle through the bottleneck has a cooling effect. Without requiring any electricity, and using easily accessible materials, the device has the potential to lower indoor temperatures by 5°C.

Who uses cooling, and how?

The goal of cooling extends far beyond ensuring thermal comfort and keeping food and medicine safe. A diverse range of individuals and organisations use many types of cooling device, from small RACs used to cool individual rooms; all-in-one heating and cooling systems for homes, known as packaged units; and chillers that cool whole buildings and industrial processes. In this report, we analyse and forecast **four types of AC** use:

- **Residential:** AC in peoples' homes;
- **Commercial:** AC in large commercial spaces, such as supermarkets, hypermarkets, offices and hotels;

- **Industrial:** AC in manufacturing facilities, workshops, warehouses, and laboratories (including for both food and medicines);
- **Mobile:** AC in cars and buses.

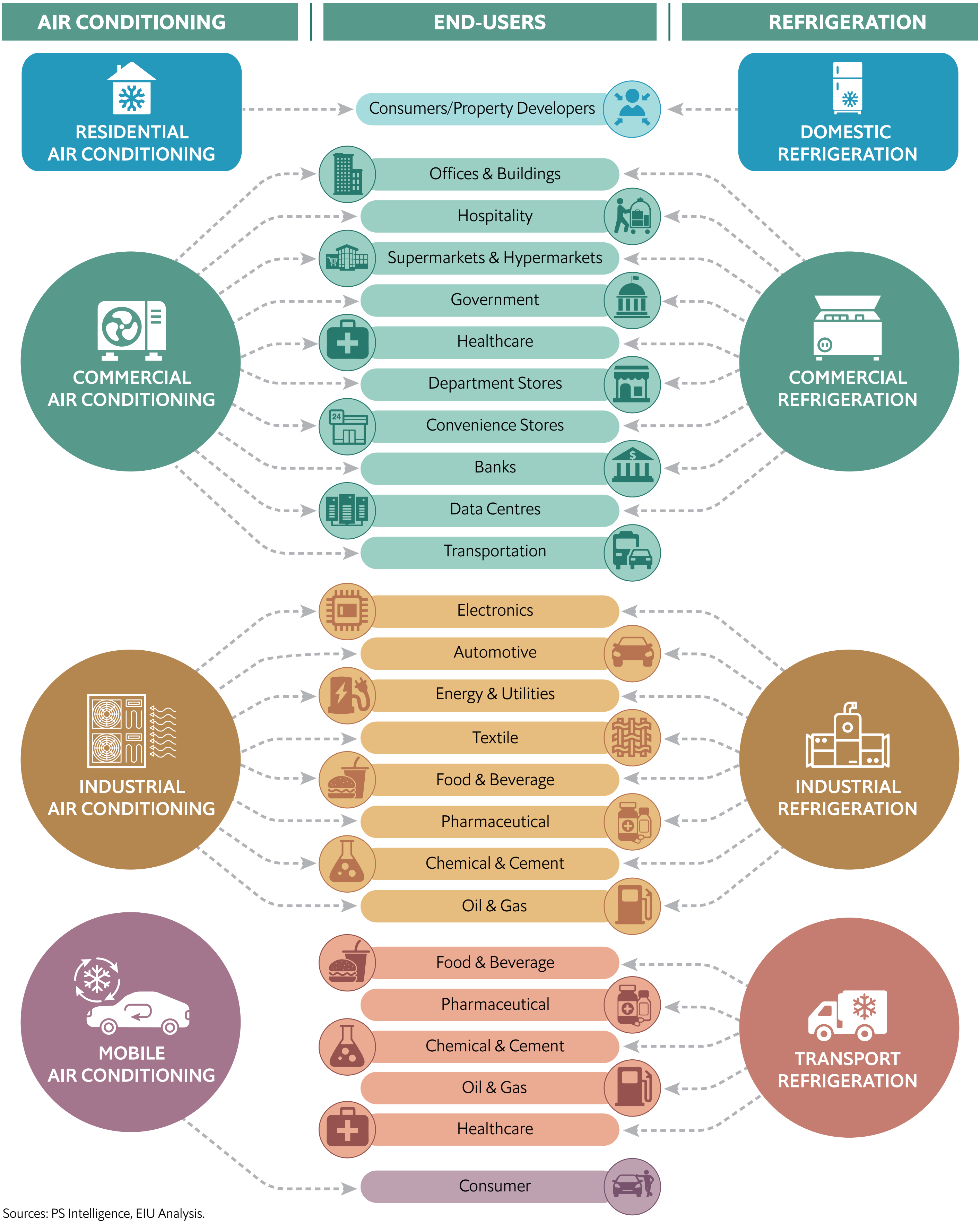
We also analyse and forecast **four types of refrigeration** use

- **Domestic:** Home refrigerators and freezers;
- **Commercial:** Refrigerators and freezers in supermarkets, stores and restaurants;
- **Industrial:** Refrigeration for cold storage and for specific industrial processes, such as the environmental testing of products in manufacturing plants, and the processing of foods such as cheese;
- **Transport:** Refrigeration to prevent spoilage of products en route to consumers, including fresh foods and pharmaceuticals.

Across these four end-user sectors, refrigeration devices range from traditional fridge-freezers found in the home; walk-in coolers found in restaurants; and “reefers” – refrigerated shipping containers used in transportation.

Where does demand for cooling come from?

End-users of cooling



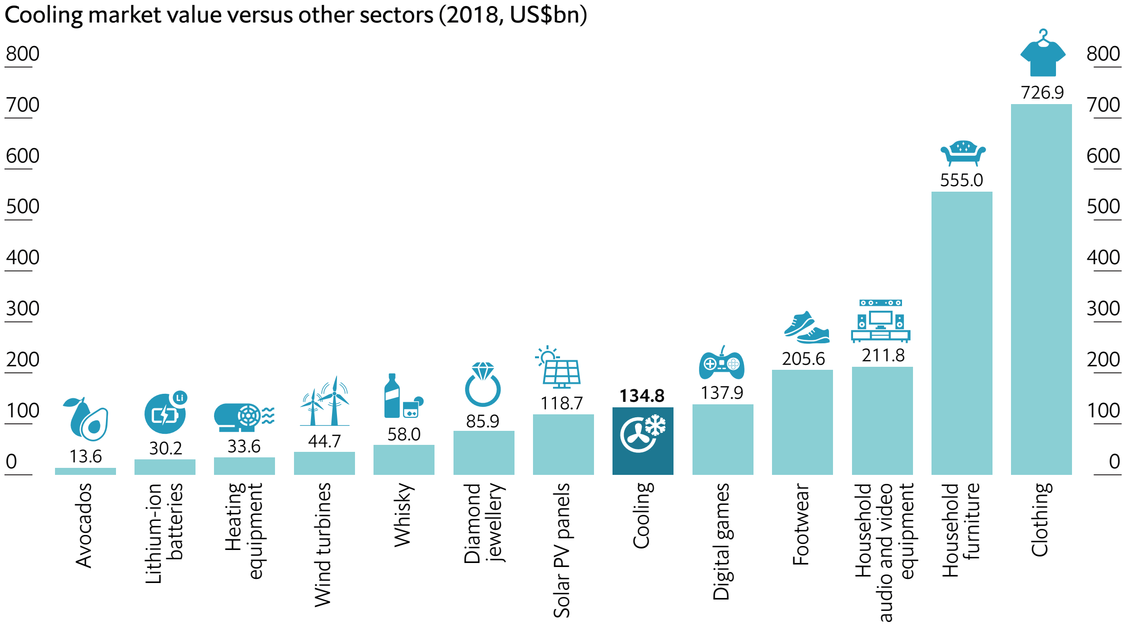
Sources: PS Intelligence, EIU Analysis.

2. Forecasting global and national cooling demand to 2030

Owing to the pervasive importance of cooling, the industry that produces and maintains cooling equipment is already a sizeable global sector. In 2018 its market value was estimated at US$135bn – greater than diamond jewellery and solar photovoltaic (PV) panels. The cooling market is set to grow dramatically in the next 10–15 years, as the cumulative effects of climate change, urbanisation and income growth accelerate. In this report, we estimate that annual global unit sales will grow from 336m in 2018 to 460m by 2030. As a guiding estimate, this could mean that the annual market value reaches almost US$170bn (see modelling results, below).

Cooling in comparison

Cooling market value versus other sectors (2018, US$bn)



Source: EIU; Clean Cooling Landscape Assessment; Transparency Market Research; Grand View Research; Alrosa; Newzoo; Power Technology; Allied Market Research

Climate change: Adapting to a warmer world

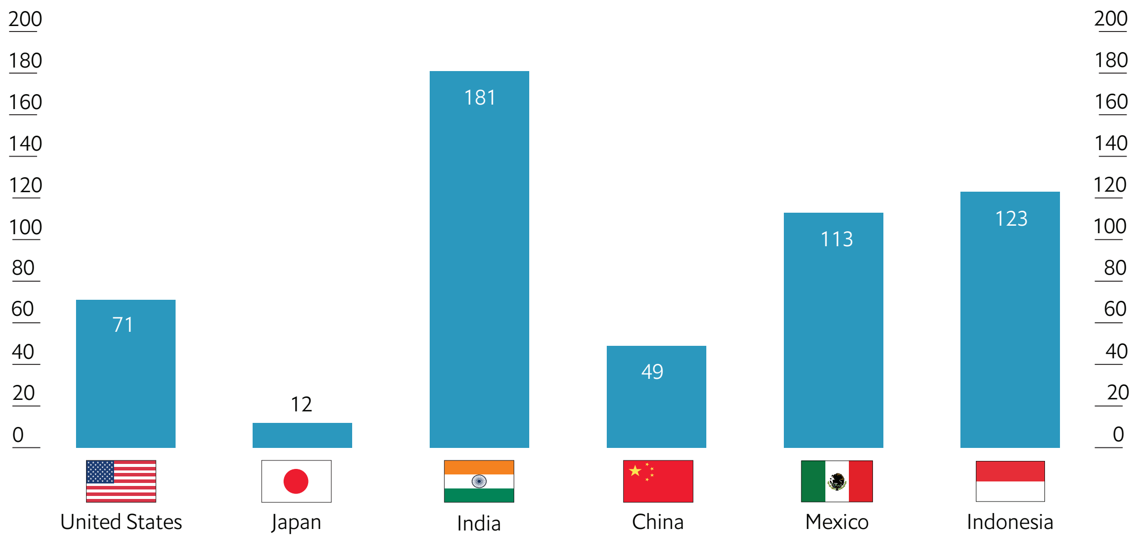
Signatories to the Paris Agreement aim to limit global warming to well below 2°C above pre-industrial levels, and ideally to no more than 1.5°C. However, a lack of ambitious policies to curb emissions among large emitters means that the world on track for temperature increases of more than 3°C by 2100, and up to 4.8°C under the worst-case scenarios.[6] Against this backdrop, the number of hot days is projected to increase in most regions, with demand for cooling rising accordingly.[7] The Intergovernmental Panel on Climate Change (IPCC) predicts that global energy demand from residential AC[8] will grow 33-fold between 2000 to 2100, mostly from developing countries. A quarter of this growth will be driven by the effects of climate change.[9] Actual demand growth may well provide higher again, as the IPCC's estimates are lower than other sources such as the IEA.[10]

Populous cities in already hot regions could see temperature shifts of multiple degrees. According to one study's "best-case" scenario, Jakarta's average July temperature is projected to hit 27.5°C by 2100, an increase of 1.8°C from 1900.[11] Ahmedabad in India, which is trying to save lives by implementing a Heat Action Plan,[12] will see an increase of 1.6°C, to 30.4°C. Under the study's "worst-case" scenarios, Jakarta and Ahmedabad's average July temperatures would both rise by 4.5°C, to 30.2°C and 33.3°C respectively.[13] Moreover, average temperatures do not reveal the full picture as they hide extreme heat events. For instance, Cambridge University Botanic Garden recorded the UK's highest-ever temperature of 38.7°C in July 2019[14] - even though the country's average temperature that month was just 16.4°C.[15]

Cooling demand is also likely to grow in more temperate climates. Indeed, perhaps surprisingly, some colder regions could be more detrimentally affected by rising temperatures than hotter regions, because they have not traditionally prepared for hot days and heatwaves. One US-based study found higher mortality among elderly citizens in cool regions experiencing temperatures above 29°C (85°F) than in hotter regions, due to a lack of adaptation.[16] The authors argue that regions typically invest in measures to adapt to the temperatures they face most frequently – whether hot or cold. In the UK, for instance, building practices have traditionally focused on ensuring reliable winter heating and access to high levels of sunlight. To cope with high summer temperatures, buildings have traditionally relied on ventilation – the intentional introduction of outdoor air into a space – which is less effective during heatwaves. With heatwaves becoming more prevalent in the UK and the rest of Europe, demand for cooling is likely to grow. Such trends are already visible. In 2019 Currys PC World reported that fan sales in the UK jumped by 200% during the July heatwave.[17]

Turning up the heat

Total number of days >35°C (2080-2099) under high emissions scenario



Source: Climate Impact Lab (2019).

Urbanisation: The growth of heat islands

A second core driver of global cooling demand is urbanisation. More than half the global population now lives in urban areas and this will rise to almost 70% by 2050, adding another 2.5bn urban dwellers to the global total.[18] Three countries – India, China and Nigeria – will account for 35% of urban population growth out to 2050.[19] The urbanisation rate (the proportion of a country's population that lives in urban areas) will continue to increase across the six countries we analyse in this report – US, China, India, Japan, Indonesia and Mexico. However, while the overall urban population will continue to grow, year-on-year growth in the urban population will begin to decelerate in the coming decade. For example, annual growth in China's urban population will slow to an average of 0.9% over 2018–30, down from an average of 2.5% over 2010–18. In some markets, this could restrain year-on-year growth in cooling demand compared with recent decades.

Cities raise temperatures by trapping heat and preventing its dissipation into the lower atmosphere. As vegetation is paved over and vertical urban structures erected, vital processes of ventilation and heat dispersion, known as "evaporative cooling", are obstructed. Cities also produce their own heat, such as warm pollutants ejected from vehicle fumes and industrial activities, which becomes concentrated, confined by buildings and urban structures.

The result is microclimates known as *urban heat islands* (UHI). Typically, the annual air temperature of a city with more than 1m people can be between 1 and 3°C warmer than its surrounding areas.[20] Developed-world cities with UHI dynamics include London,[21] Paris, New York and Las Vegas.[22] Low- and middle-income countries suffer acutely. Studies suggest that UHI effects in Delhi have increased temperatures by up to 6°C.[23] A study of four African cities (Lagos, Nairobi, Addis Ababa and Lusaka) found that those with a higher proportion of artificial surfaces like roads and pavements were between 3 and 4°C warmer, highlighting the importance of green spaces for cooling.[24] Similarly, studies in Bandar Lampung in Indonesia show that surrounding areas have higher air moisture and lower temperatures due to vegetation land cover.[25]

Income growth: Escaping poverty, buying fridges

Rising incomes will be the third core driver of global cooling demand. Nihar Shah, Co-Leader of Emerging Economies Research Program at the Lawrence Berkeley National Laboratory (LBNL), believes that income thresholds are a better indicator for forecasting future cooling demand than GDP per capita, because at certain income points consumers shift their buying from daily needs to durable goods and convenience. According to Shah, fridges are the first of the two cooling technologies that consumers typically look to purchase, followed by AC.

Academic studies support this claim. One project, drawing on microdata from Mexico, shows a combination of climate and income dynamics driving AC adoption decisions. In the past two decades, China's burgeoning middle classes have sent demand for cooling soaring, with rates of refrigerator ownership among urban households rising from 7% to 95% between 1995 and 2007.[26] Similar dynamics look set to play out across Asia Pacific in the coming decade, with the region's middle class forecast to more than double by 2030 to 3.5bn people, or 65% of the world's total.[27]

Beyond enabling households to buy fridges and AC, income growth indirectly increases cooling demand by stimulating the development of modern retail stores and accompanying supply chains.

Income growth also prompts demand for cooling-hungry products such as cars, medicine and data centres. As Toby Peters, Professor in Cold Economy at the University of Birmingham, notes: "We're talking about an extra billion or more cars on the road globally by 2050. If these cars are electric, as hoped for in policy statements, in countries such as India, these electric cars will likely be cheap, short-range, uninsulated cars. We will see significant cooling demand just to make the cars safe to occupy."

While the middle class will continue to expand, income growth will decelerate in some markets over the coming decade, which could restrain some new cooling purchases. In China, for example, The EIU forecasts that real personal disposable income per head will grow at 7.2% per year, on average, from 2018–30, compared with 11.2% over 2010–18.[28]

How to quantify and forecast cooling demand out to 2030?

In this report, we forecast what climate change, urbanisation and income growth, as well as other growth drivers, will mean for cooling demand out to 2030. We forecast global cooling demand, as well as demand in six priority countries: China, India, Indonesia, Japan and Mexico and the US. While many countries have an interesting cooling story to tell, our selection of these six markets was informed by a desire to capture major sources of current and future cooling demand, prominent supplier countries, and countries that are somewhat representative of others in their region, as well as other factors such as data availability.

To build a new forecasting model, we first confirmed the *variables* to forecast. Forecasting overall cooling demand can mask diverse trends that are occurring at the sub-sector level. As a result, we decided to also forecast demand for eight priority cooling sub-sectors: residential, commercial, industrial and mobile AC, as well as domestic, commercial, industrial and transport refrigeration.

We forecast *unit sales* as our measure of cooling demand, as opposed to other metrics such as cooling *energy use* or cooling-related *emissions*. Unit sales provide a clear indication of the total amount of cooling equipment that is going to be purchased in the coming 12 years – equipment that policymakers and businesses need to ensure becomes more efficient and climate-friendly (see Section 4). Unit sales also provide a clear signal about where exactly demand is coming from; for example, the sale of a walk-in cooler to a supermarket can be more easily recorded than the energy used by the cooler or the emissions created by a supermarket's cooling requirements. However, unit sales should not be confused with cooling *stocks* (i.e. all cooling devices currently in use in a country). Rather, unit sales are new devices coming on the market every year, in addition to existing stocks. We also considered forecasting the *market value* of demand, but this would have required analysing price separately from unit sales, and the availability of robust price data across markets is limited.

On page 11, we provide a guiding estimate of the total market value of cooling, based on assumptions about equipment prices from the Green Cooling Initiative (GCI), Toby Peter's Clean Cooling Landscape Assessment and our understanding of price dynamics for electronic appliances. We did not derive this market value from our new forecasting model, which is only used to estimate unit sales.

To build our forecast model, we first obtained historical data on unit sales for mobile AC and domestic refrigeration for over 100 countries from the Green Cooling Initiative (GCI).[29] For the remaining six cooling sub-sectors, we used data for 30 countries from Prescient & Strategic (P&S) Intelligence.[30] Together, these 30 countries accounted for 84% of global GDP in 2018. They also show the necessary diversity across key variables that is required to build a robust forecast model. Historical estimates for cooling unit sales vary by source.

After obtaining and validating our historical data, we began an exercise to identify the primary future *drivers* of cooling demand across the eight sub-sectors. To do so, we carried out a literature review of close to 100 global and national studies and consulted with a range of leading cooling experts. Based on our findings, we produced a framework of the primary drivers by sub-sector (see table below). We then carried out a data audit to identify available datasets on each driver.

To qualify for inclusion in our model, the dataset had to be publicly available, or accessible through The EIU's proprietary databases. The dataset also had to have robust and comparable *historical* and *forecast* data to 2030 available across a sufficient number of countries. We found that while historical data exists for many drivers, forecast data to 2030 was extremely limited. Moreover, finding consistent historical and forecast data for even the six priority countries was challenging. We therefore relied heavily on The EIU's proprietary macroeconomic and industry data (for which forecasts exist) as well as proxy datasets for certain variables.

Priority drivers of cooling demand and data availability

Priority demand drivers (selection)

Forecast variables									
Residential AC	Number of households	Income	Urbanisation	Temperature and heatwaves	Electricity access	Electricity prices	Real estate sector	Availability of affordable ACs	Consumer perceptions of AC
Commercial AC	Population	GDP	Urbanisation	Temperature and heatwaves	Commercial sector access to electricity	Electricity prices	Real estate sector	Hospitality sector	
Industrial AC	Population	GDP	Industrial Production	Food and beverage sector	Pharmaceutical sector	Industrial sector access to electricity	Industrial sector		
Mobile AC	Number of households	Income	Auto demand						
Domestic refrigeration	Number of households	Income	Urbanisation	Electricity Access	Electricity prices				
Commercial refrigeration	Population	GDP	Urbanisation	Commercial sector access to electricity	Electricity prices	Supermarket sector	Hospitality sector		
Industrial refrigeration	Population	GDP	Industrial production	Food and beverage sector	Pharmaceutical sector	Industrial sector access to electricity	Chemicals sector		
Transport refrigeration	Population	GDP	Sales of commercial road vehicles	Food and beverage sector	Pharmaceutical sector	Transport sector access to electricity	Sales of rail, marine and air transport	Logistics industry	

Key:			
	Data available	Proxy data available	Insufficient data available

Modelling approach

Following the literature review, expert consultation and data audit, we decided to use **panel data regressions**[31] to forecast unit sales of cooling equipment.[32] This approach allowed us to draw on approximately ten years of historical time series data to investigate the relationship between the demand drivers and the forecast variables noted above, across more than 30 countries. We then used the findings to forecast future unit sales (i.e. demand).

Panel data regression is not the only approach to forecasting cooling demand. We also considered **S-Curve modelling**, which forecasts future sales based on expectations about the number of households that will reach a specific income threshold where cooling purchases are estimated to occur (see box, below). We also considered **forecasting energy demand** from the residential, commercial and industrial sectors, and then splitting out cooling demand from these forecasts. However, reliable data for the proportion of energy demand that comes from cooling, across different countries, is very limited. Finally, we considered a bottom-up approach of **estimating the market size of key cooling vendors** in major markets, and aggregating these estimates into overall demand estimates. However, while the AC market is fairly consolidated, the refrigeration market is not. This makes such an aggregation exercise challenging, as does accounting for market leaks and trade.

Before running the panel regression models, we divided our set of countries into low- and high-income groups because both are at different stages of cooling demand and so the relative impact of each driver is different. To produce forecasts for *global* unit sales, we made assumptions about the share of global demand accounted for by the number of countries that we were forecasting, and used this assumption to forecast overall global demand.[33]

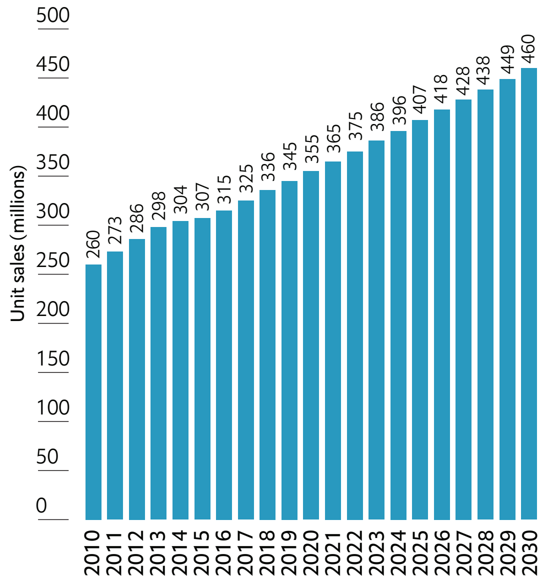
To understand the source of our demand forecasts by country, we also used P&S data on the breakdown of cooling demand across different end-users – today, and out to 2030. We used this data to assess which end-user sectors are driving current demand in each of our six priority countries, and which end-user sectors will drive demand growth out to 2030.

Our forecasts: 4.8bn new cooling units sold between 2019 and 2030

Globally, by 2030, 460m new units of cooling equipment will be sold every year, compared with just 260m unit sales in 2010 and 336m in 2018. China, the US and India are by far the three largest markets – accounting for 49% of total sales in 2030. In 2024, India will overtake the US as a source of cooling demand, with 38.8m unit sales. Across the six markets, India and Indonesia are growing the fastest, albeit from lower bases than the US and China. Domestic refrigeration, residential AC and mobile AC will make up over 90% of unit sales in India and Indonesia in 2030. However, the fastest growth sector for both countries will be transport refrigeration which will grow at around 14% per year from 2018 to 2030.[34]

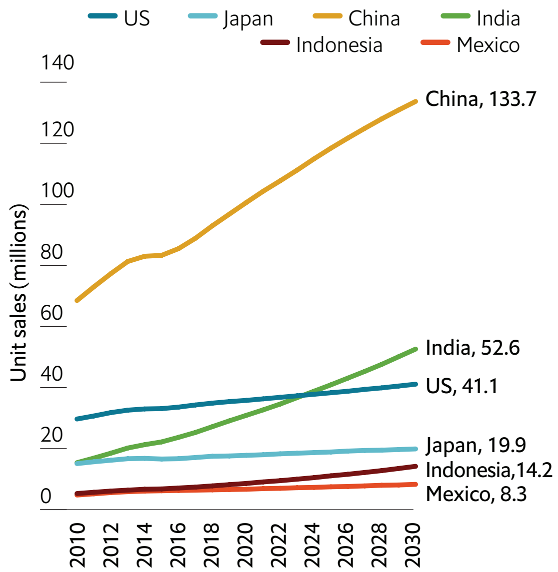
In 2018 domestic refrigeration, residential AC and mobile AC accounted for **92%** of total annual cooling sales. The three sub-sectors will remain dominant in 2030 – accounting for **91%** of total demand. However, across the eight sub-sectors, the industrial and transport refrigeration sectors will grow the fastest out to 2030, mainly due to expected growth in industrial production and *cold chain* capacity – a process used to manage the temperature of perishable products, such as food and vaccines, across the supply chain.[35]

Global annual cooling sales (2010-2030)



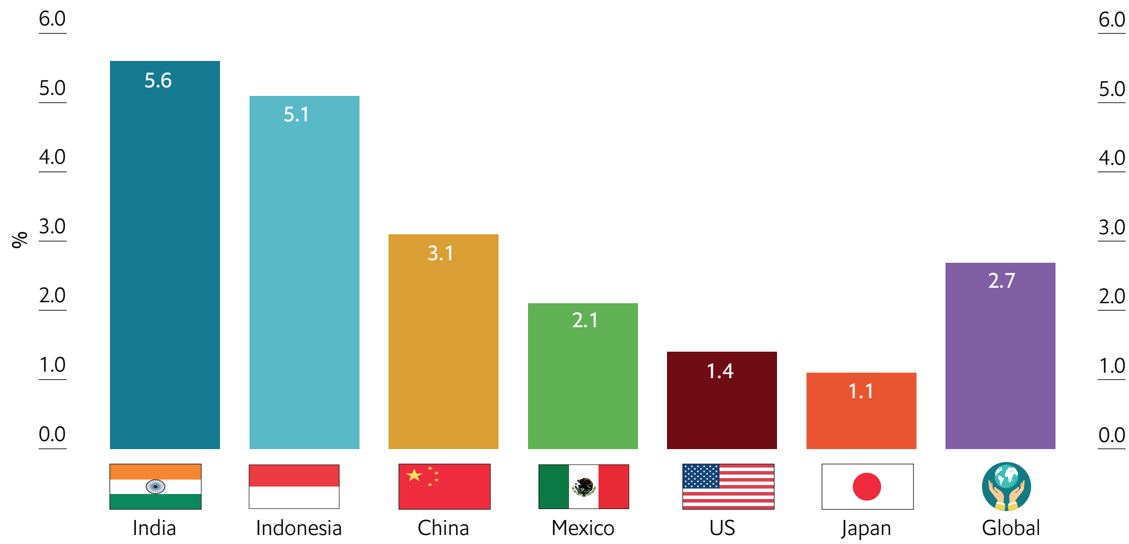
Source: P&S Intelligence, Green Cooling Initiative, EIU analysis.

Annual cooling sales (2010-2030)



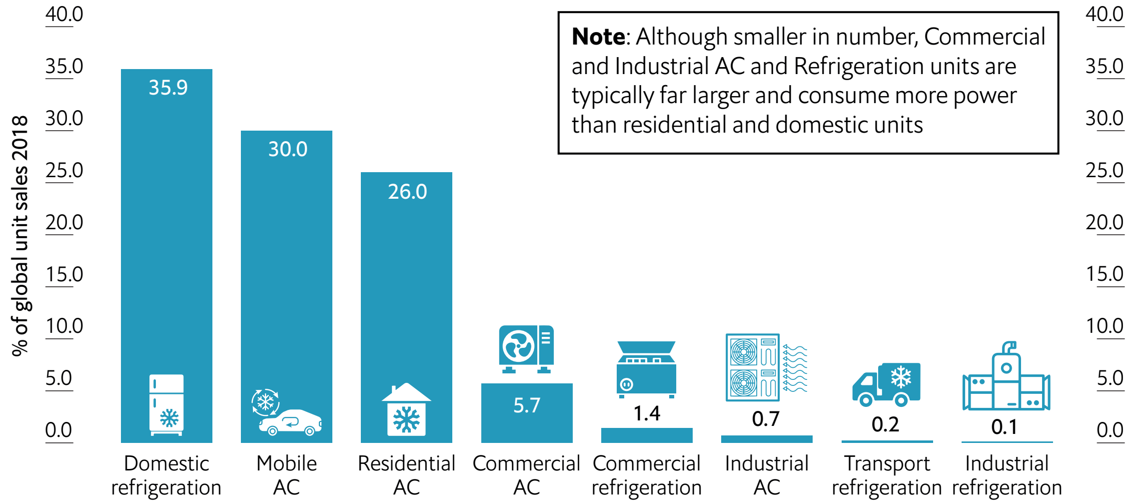
Source: P&S Intelligence, Green Cooling Initiative, EIU analysis

Cooling sales: Average annual growth rate (2018-2030) (a)



(a) As measured by compound annual growth rates
Source: EIU analysis

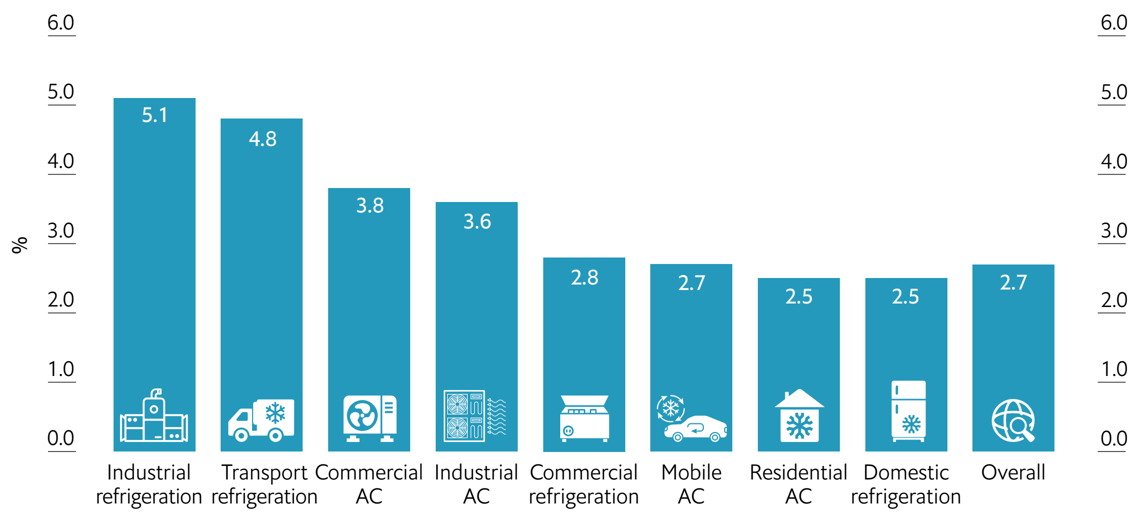
Sub-sector sales as a percentage of total sales (2018)



Source: P&S Intelligence, Green Cooling Initiative, EIU analysis.

This means that businesses will play an increasing role in driving demand for cooling sales out to 2030, in addition to the important role they already play in the residential and mobile AC sectors (as real estate developers and automobile manufacturers). This highlights the imperative of business shifting to more efficient, climate-friendly cooling models (see Section 5). The primary business users of cooling differ by country, and sub-sector. For example, in the US, the food and beverage sector is the primary user of industrial AC, whereas in China it is the electronics sector. Offices and buildings were the largest user of commercial AC across all six countries in 2018. However, by 2030 the hospitality sector will be the largest user in the US, China, Japan and Mexico. (See Country Cooling Profiles in the Appendix for more details.)

Cooling sales: Average annual growth rate by sub-sector (2018-2030) (a)



(a) As measured by compound annual growth rates.
Source: EIU analysis.

Do our forecasts underestimate cooling demand?

Different sources provide different forecasts for cooling demand, and in particular for *residential* cooling demand (AC and refrigeration). For example, the India Cooling Action Plan forecasts that room AC sales will grow 11–15% per year for the next ten years and 8-12% in the following ten years, compared with our forecasts of 8% for residential AC demand out to 2030.[36] It is possible that our forecasts for residential AC and refrigeration are underestimates. It is also possible that other forecasts are overestimates. If our forecasts are underestimates, this may arise in four ways:

1. Panel regression vs S-Curve modelling

Panel regression offers several advantages when forecasting overall cooling demand. It allows us to leverage EIU industry data and account for the diverse predictors of cooling demand, while being easily interpretable with less reliance on subjective assumptions than other modelling approaches.

However, as with any modelling approach, it also has limitations. In particular, it assumes a log-linear model – that is, it assumes that the relationship between the *explanatory variable* (e.g. disposable income) and the *dependent variable* (e.g. residential AC unit sales) is linear and constant. Research shows that the societal adoption of certain technologies, including cooling devices, may follow a curve that more closely resembles an "S" shape – initially growing slowly before rapidly expanding once a certain income threshold is reached, before slowing again as the market reaches saturation.

S-curve modelling, whereby forecasts are based on the outlook for disposable income and income distribution and assumptions about the "thresholds" at which demand starts growing exponentially, could potentially result in higher forecasts for residential cooling demand.[37] However, S-Curve modelling also has limitations. It emphasises income as the driver of cooling demand (at the expense of other variables); requires long time series of income and cooling sales data in order to "map" the "correct" S-curve; and requires the estimate of country-specific "thresholds" (as the curve in one country may look different to that in another).

2. Capturing dramatic or unprecedented changes

Almost all forecast models are based, to a degree, on what has happened in the past. Some, such as panel regression, draw *explicitly* on historical data to create the forecasting model. Other models use assumptions that, at the very least, draw *implicitly* on past data. By definition, these models may fail to account for future scenarios that are *unprecedented* – for example, a scenario where certain demand drivers increase exponentially, or converge, to result in unforeseen levels of demand for cooling. For cooling, if temperatures increase dramatically, or if heatwaves become considerably more common, this is unlikely to be fully captured in our forecasting model and so our residential AC forecasts could be underestimates. This is particularly the case in locations where heatwaves have been uncommon, or if "feedback loops" start to kick in – for example, if urbanisation continues to grow and the UHI effect becomes more extreme.

3. Historical data

While different sources provide different *forecasts* for cooling demand, they also provide different estimates for *historical* demand. For example, data from P&S Intelligence on unit residential AC sales in India is for the most part lower – both in absolute terms and in annual growth rate terms –

than historical data from other sources, such as the Alliance for an Energy Efficient Economy (AEEE) and the India Cooling Action Plan. As our forecasts for residential AC are based on P&S Intelligence historical data, they are also lower than some other forecasts.[38] However, P&S Intelligence estimates are more in line with other sources, such as The Japan Refrigeration and Air Conditioning Industry Association.

In the case of India, following in-depth conversations with the AEEE, the lead knowledge partner for the India Cooling Action Plan, we made some adjustments to the P&S historical data estimates for residential AC for India. These adjustments were based on a review of the historical data used in the AEEE's analysis, which was endorsed by the government of India.[39] However, if our core historical datasets across the 30 countries contain underestimates, this could in turn feed into forecasts that are underestimated.

4. Income forecasts

One of the advantages of our panel regression approach is that it can draw on The EIU's proprietary forecasts for different driver variables – including personal disposable income per head and urban population. For certain variables, The EIU's forecasts are more conservative than some other sources and typically more conservative than governments' own forecasts. One example is India. Currently The EIU is forecasting disposable income growth per head of 7.0% per year out to 2030, and real GDP growth of 5.6% per year. While relatively high in comparison to other countries, these forecasts are lower than the government's own forecasts.

Due to methodology issues, The EIU believes that the Indian government has likely been over-stating broader economic growth by 2–2.5% in recent years. In reality, real GDP growth has likely been closer to 5–6% in recent years than the oft-reported 7–8%.[40] In addition, recent quarters have shown evidence of a worrying economic contraction. The obstacles to unlocking further economic growth in India are many, from complex labour and land laws to higher rates of non-performing loans at banks. Such challenges explain why India is unlikely to follow a similar growth story to that seen in China in recent years – either in terms of cooling or broader economic growth. However, if India – or indeed other countries – is to grow faster than The EIU expects, our forecasts for cooling demand are likely to be underestimates.

Future research priorities

As organisations, policymakers and business executives across the world try to understand the *scale* and *nature* of future cooling demand, this report has highlighted topics that would benefit from new research.

Additional research could focus on **cooling scenarios**. As evidenced by the diverse range of forecasts that exist, relying on a single forecast for cooling demand is challenging. Given the relatively high rate of uncertainty in the outlook for core demand drivers, and how they will intersect, it would be useful to create scenarios to capture "alternative futures", with different outlooks for income, temperature and policy, for instance, in order to explore how cooling demand could evolve.

Future reports have the potential to **expand the national model to other countries**. This report assesses six priority countries. However, cooling demand is evolving in many markets and may be driven by local contextual factors. For example, heatwaves in Europe have led to some sharp increases in AC sales in recent years.[41] The dynamics around cooling demand in Europe are very different to those in the markets assessed in this report and would benefit from new research.

A new study could **compare modelling approaches**. As noted above, there is a variety of approaches to modelling cooling demand, each with its own strengths and weaknesses. Few reports compare the outlook from different modelling approaches. Such a comparison could provide crucial context as policymakers and businesses look to respond to evolving cooling demand.

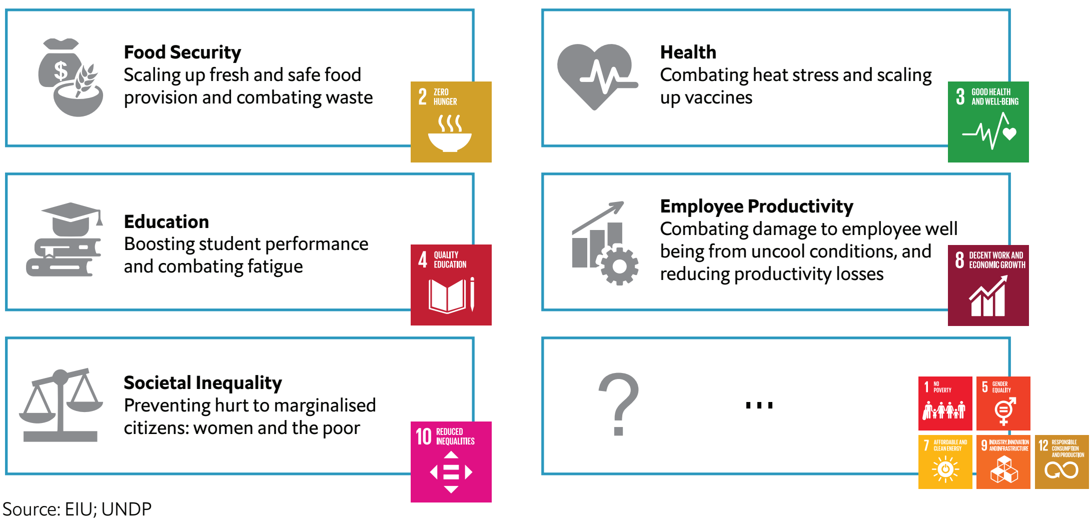
Finally, new research is needed to **assess the emissions from each end-user sector**. This report highlights those end-user sectors that are driving unit sales. Data permitting, future research could focus on the energy used for cooling by each end-user sector.

3. Why the world must close the cooling gap

The growing demand for cooling that our forecasts highlight must be met – and quickly. The uptick in cooling demand will come on top of an already substantial "cooling gap". Precise estimates of the number of people and organisations that require cooling yet lack affordable and reliable access to it are unavailable. However, an estimated 470m people in poor rural areas lack access to safe food and medicines due to inadequate electricity and refrigeration. An estimated 630m people in hot, poor urban slums have little or no access to cooling due to inadequate power supplies.[42]

Unless more reliable and cost-efficient cooling is made available, along with supporting (low-emission) power supplies, the effects will be detrimental. In the absence of cooling, high temperatures are not merely uncomfortable, they directly affect human health, national productivity and societal well-being, in diverse and underappreciated ways. As explained below, scaling up affordable access to cooling will thus be critical if countries are to meet the Sustainable Development Goals (SDGs), particularly in the areas of food security, health, education, employee productivity and inequality.

Making sustainability cool
How cooling will help achieve priority SDG goals



Source: EIU; UNDP

Food Security: Combatting waste and ensuring fresh food

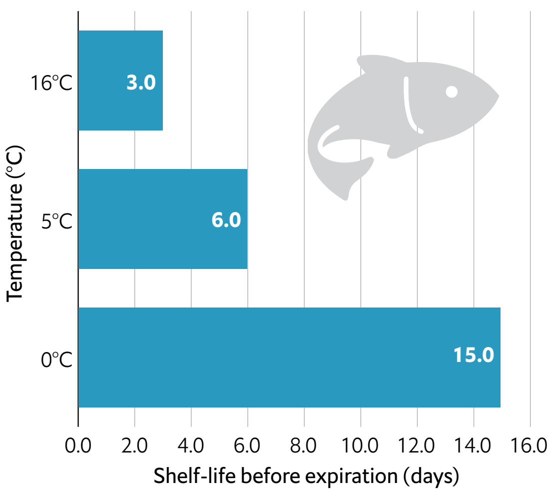
The global food system is grossly inefficient. Roughly one third of the food produced for human consumption – approximately 1.3bn tonnes per year – is lost or wasted, partly due to temperature-related spoilage.[43] At the same time, over 820m people, or one in nine, suffer from hunger and this number has been increasing since 2015.[44] Population growth and rising incomes are heaping pressure on the global food system to produce more, even as arable land and fresh water supplies are exhausted. Rising temperatures and shifting precipitation are also making seasons and crop selection less reliable, while marine fisheries are in decline due to ocean acidification, pollution and overfishing.

Cold chains, which include "packhouses" where produce is sorted and processed and field heat is removed,[45] distribution hubs, and refrigerated transport could radically reduce food waste. However, in many countries such cold chains are either absent or exist in isolation, notes Professor Peters. This dearth of integrated cold storage and transport helps lead to the loss of 200m tonnes of food annually – or 14% of the total global supply.[46] Halving this waste could feed an extra 1bn people.[47] Indeed, as Corey Rosenbusch, President & CEO of the Global Cold Chain Alliance (GCCA) notes, more than enough food is already being produced to feed everyone on the planet. "The main challenge," he says, "is spreading knowledge and encouraging the implementation of best practices in cold chain processing, storage, and distribution across the globe, with appropriate investments in cold chain infrastructure."

There are clear opportunities for cold chain implementation across countries, and sectors. Estimates suggest that India has less than 15% of the refrigerated trucks that the country needs and less than 1% of the packhouses.[48] As a result, just 4% of India's food moves through the cold chain (compared with 70% in the UK and 10% worldwide), and 40% of certain harvested crops are discarded before reaching the consumer.[49] Quick gains are possible. One project in Punjab and Bangalore found that the introduction of cold chains reduced citrus food wastage by 75% and raised farm gate profits tenfold.[50]

Apart from increasing local food security, cold chains provide farmers with the market connectivity they need to sell further afield and support farm incomes by enabling them to store their produce and sell it at more optimal prices – particularly during a supply glut. In an economic sense, this becomes particularly important in a context like India, where agriculture employs almost half of the workforce, or more than 250m people.[52] Being able to store produce is particularly important for individuals who earn their livelihood from fishing, of which there are an estimated 59.6m globally. Increased temperatures accelerate the proliferation of harmful bacteria that live on the skin, gills and intestines of fish, which in turn can cause serious food poisoning. While fresh fish can be stored for ten days at 0°C, they last just a few hours in the heat (see graphic below).[52][53]

Cold is gold
The effect of chilling on the shelf-life of fish

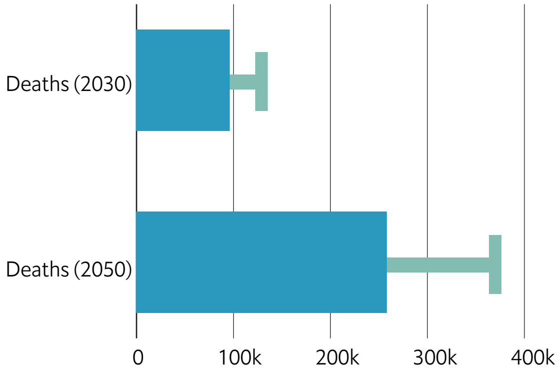


Source: Bord Lascaigh Mhara (Irish Sea Fisheries Boards)

Health: Preventing heat stroke, accidents and damaged vaccines

People's "thermal comfort threshold" – the temperature at which they are physiologically comfortable – varies according to factors such as age, health and gender. Discomfort typically starts to be felt as temperatures exceed 25°C, with increasingly serious effects beyond 35°C.[54] Temperatures above 37°C can produce cardiac failure, heat exhaustion, dehydration and kidney failure. When body temperatures exceed 39°C, acute heat disorders such as heatstroke can occur. Above 40.6°C, life-threatening severe hyperpyrexia can develop.[55] In the absence of cooling, heatwaves today kill an estimated 12,000 people every year. Owing to the effects of climate change, the World Health Organisation (WHO)

Perishing projections
Climate-change attributable, heat-related deaths annually, without adaptation



Source: WHO (2014)

forecasts that deaths will rise to 92,000 by 2030, and 255,000 by 2050.[56] The young, elderly and those with physical or mental illness are most vulnerable, as are those in social isolation or poor housing.[57]

In addition to direct heat stress, heat compromises health in multiple ways. Long-distance truck drivers, for instance, face a higher risk of road accidents than their counterparts with AC. In India, drivers routinely become dehydrated as they do not stop regularly enough for refreshment, notes Dr Stephen Andersen, Director of Research at the Institute for Governance and Sustainable Development (IGSD). Construction and machinery employees are also at greater risk if they are working in extreme heat. In the absence of refrigeration, high temperatures ruin medicines and vaccines. The WHO estimates that more than half of freeze-dried vaccines, and 25% of liquid vaccines, are wasted every year due to intermittent power supplies and a lack of effective cooling.[58]

Education: Learning, concentration, energy and performance

Children are more cognitively affected by high temperatures than adults.[59] Studies on the interaction between the thermal environment and learning have been conducted for decades. A 1974 study argued that an air temperature of 20-23°C (68–74°F) was ideal for learning, especially for reading and mathematics.[60] A wave of recent research supports the claim. A 2018 study of 10m students taking exams in the US suggested that every 0.56°C (1°F) increase in school–year temperature reduced the amount learned by students by nearly 1%, but that AC could partly offset the negative impacts.[61]

A lack of AC also increases student absences due to temporary school closures or parents opting not to send their children to school if lengthy travel is required.[62] Without cooling, heat can also cause illness and discomfort due to a lack of ventilation on hot days, or due to spoiled food and water-borne illness. A small 2010 Cameroon-based study among children aged 12–16 years in public secondary schools found a sharp increase in the incidence of headaches, fatigue and discomfort on hot days[63].

Minority students and those from low-income backgrounds, who already tend to have weaker educational outcomes, are disproportionately affected by a lack of cooling, partly because of a reduced ability to study comfortably, at home.[64] Children in developing countries and low-income communities are also more likely to be withdrawn from school if high temperatures impede their parents' ability to work, particularly in sectors such as agriculture, fishing and manual labour which take place primarily outside, often with little or no temperature protection.

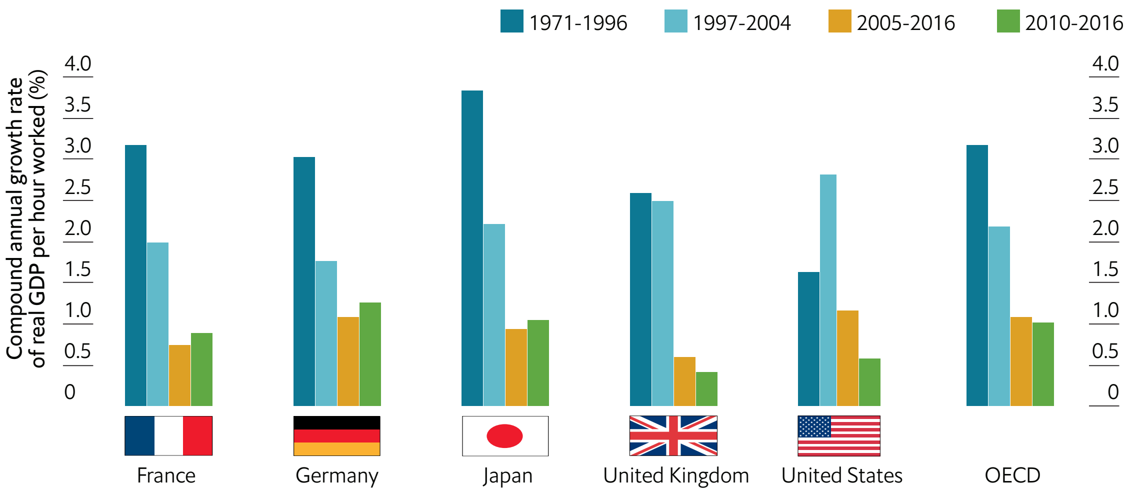
Employee Productivity

More than a decade since the Great Recession, labour productivity growth remains near historical lows. The outlook is little better. A recent 50-year forecast for the UK predicts productivity growth of just

1.8%, far below historical trends[65]. In emerging markets, productivity growth slowed from an average of 4% in 2000–07 to 3.2% in 2008–15, and in China from 8.1% to 6.2%.[66]

A slowdown

Labour productivity has been falling across countries



Sources: OECD; Oxford University.

Against a backdrop of falling birth rates and ageing populations, increasing employee productivity will be crucial to raising wages and improving living standards. In a similar vein to education outcomes, thermal conditions affect employees' work performance and productivity *directly*, by impacting cognition, engagement, mood and comfort, as well as *indirectly*, through absenteeism. One meta-analysis of studies across 30 countries found that 30% of individuals who work under heat stress report productivity losses.[67] The International Labour Organisation (ILO) has warned that a mere 1.5°C increase in global temperature by the end of the century – well below current expectations – would result in the loss of 2.2% of working hours, or 80m jobs by 2030, at an equivalent cost of $2.4trn.[68]

Tropical and emerging economies face particular threats. In India, The EIU expects average annual labour productivity growth of just 3.6% in the decade out to 2028 – far below what is needed to meet the country's ambitious economic growth objectives. Scaling up access to cooling could help to narrow the gap. In a 2016 study of 442 workers from 18 workplaces across the country, 57% reported productivity losses due to heat stress, including from fatigue, sickness and absenteeism.[69] The challenge is particularly acute in sectors such as informal manufacturing which are often based outside or in stifling informal structures. Across Southeast Asia, the ILO estimates that rising temperatures caused a loss of 3.1% of working hours in 2015.[70] In Thailand, one study found that workers in construction and ceramics became up to 60% less productive depending on heat exposure levels.[71]

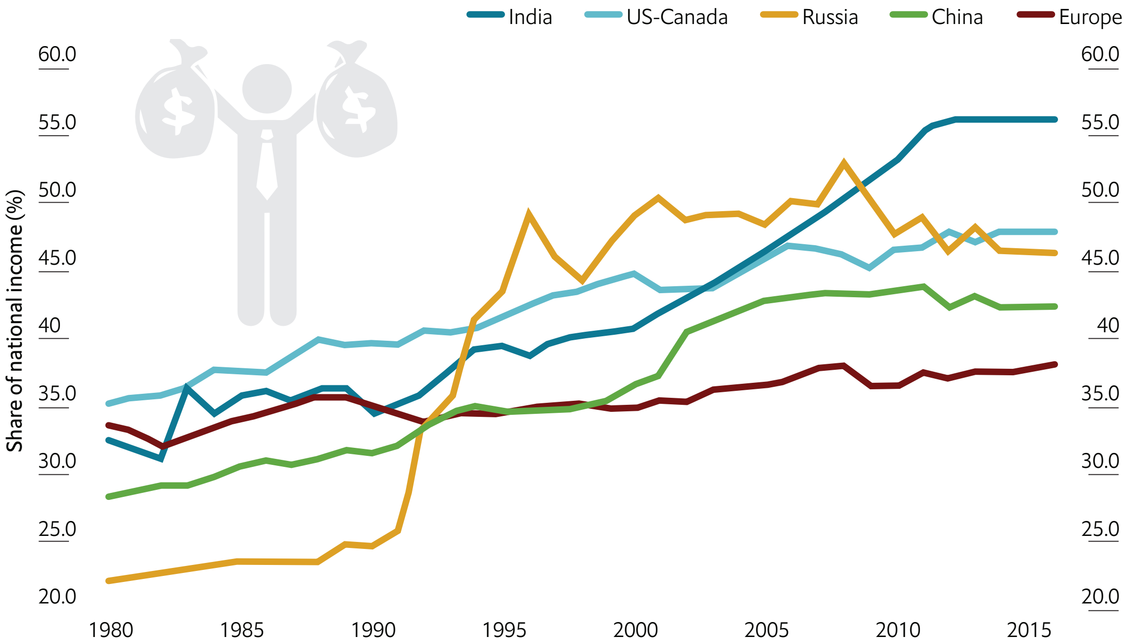
Employee comfort will only become more important to national competitiveness as countries shift towards more knowledge-driven digital economies, and where employee productivity will be an increasingly significant differentiator of organisational performance.[72] Digital economies will also rely heavily on data centres, which require a delicate temperature balance. Reliable and cost-effective access to cooling will therefore be central to future-proofing economies.

Inequality: Women, children and the poor

As with productivity growth, inequality stands as one of the most vexing challenges facing economists and policymakers across the world, given its role as a growing driver of political polarisation and internal conflict. With respect to income inequality, the last 35 years have seen a gradual narrowing of incomes *between* countries, but a consistent rise in inequality *within* countries (class-based inequality). Although most of the world's most unequal countries are still found in the developing world, the recent increase in class-based inequality has also been evident in Europe, North America, and East Asia where the share of national income secured by the top 10% of the population has risen for three decades, although at different magnitudes.

The rich getting richer

Top 10% income shares across the world, 1980-2016



Source: World Inequality Lab.

Alongside income and wealth inequalities, policymakers are trying to narrow the interrelated "inequalities of opportunities" that marginalised groups across the world face due to factors over which they have no control, such as gender or race. Cooling is an underappreciated aspect of this story. High temperatures, without cooling, are not felt equally by all. The costs fall disproportionately on women, children, and the poor.

Climate change will disproportionately affect people in developing and emerging economies in both tropical and arid climate zones.[73] According to Eric Gibbs, Chief Policy & Analysis Officer at CLASP, unless thermal comfort becomes the norm, which is highly unlikely given that less than 10% of the population in these countries currently have access to AC, temperature increases in areas that are already hot will reduce standards of living and could drive migration as people who have the means to do so begin to relocate to cooler climates. Within low- and middle-income countries, women are disproportionately affected by the lack of AC, as they often spend more time than men in the home, and in the hottest part of the home – the kitchen – as they continue to overwhelmingly manage cooking and food preparation.[74]

Low-income people as a whole are more likely to work outside in industries such as agriculture, informal manufacturing, construction, or street trade, which are more exposed to the effects of heatwaves. Those on the lowest incomes are also more vulnerable to sickness from food spoilage due to lack of access to modern food retail outlets and home refrigeration. Within countries, the *urban* poor are more vulnerable to heatwaves due to substandard housing and less access to green spaces, while people in remote regions are more likely to be affected by temperature-compromised medicines, such as vaccines.

Sustainable Energy for All has identified three populations who face cooling risks: the rural poor, the urban poor, and lower-middle income people on the verge of buying potentially inefficient cooling devices. The rural and urban poor face serious and immediate health and safety risks due to a lack of access to cooling. Meanwhile, the third group could contribute to a dramatic rise in energy demand and emissions because their purchasing options are limited, causing them to favour devices that are currently inefficient (see below). For all groups, a critical variable is the access to affordable electricity, even in wealthy countries. One US-based survey found that, of people reporting heat-related health symptoms, the majority could not afford to use AC because of electricity costs.[75]

4. How to make cooling efficient and climate-friendly

Scaling up affordable cooling access will be critical to achieving the SDGs. However, current cooling technologies and practices are also a substantial and growing contributor to climate change. Most cooling devices are a *direct* source of emissions, owing to their use and leakage of hydrochlorofluorocarbons (HCFC) or hydrofluorocarbon (HFC) refrigerants. The devices also contribute emissions *indirectly* as they typically run, often very inefficiently, on fossil fuel-based power. In 2016, the US Department of Energy estimated that direct emissions from stationary AC systems account for approximately 25% of their annual CO_2-equivalent emissions, while indirect emissions account for approximately 75%.[76] If the world is to scale up access to cooling without exacerbating current levels of emissions, a transition to more efficient climate-friendly cooling is needed. This transition will require action from policymakers, companies and individuals.

Direct impact: The scourge of HCFCs and HFCs

Most cooling devices use refrigerant gases that can be emitted during manufacturing, operation, and disposal. Refrigerant leakage can happen "24 hours a day, whether the equipment is on or off," notes Ray Gluckman, a refrigeration and climate change mitigation expert. Under the provisions of the Montreal Protocol on Substances that Deplete the Ozone Layer, ozone-depleting chemicals are being progressively phased out. Chlorofluorocarbons (CFCs) have been phased out globally since 2010. HCFCs, which are less ozone-depleting than CFCs, were adopted as "transitional substitutes" and are in the process of being replaced by HFCs. However, both HCFCs and HFCs are extremely powerful global-warming gases. HFCs are now the fastest-growing category of greenhouse gas, and are tens to thousands of times more potent than CO_2, as measured by their global-warming potential (GWP), a metric which quantifies the mass of heat a gas traps in the atmosphere, up to a specific time horizon (typically 20, 50 or 100 years), relative to CO_2 which is standardised to 1. GWP is a critical metric because it highlights how the impact of a gas on the climate is not defined solely by its quantity.[77]

Common coolers

The most commonly used refrigerants in room air conditioners

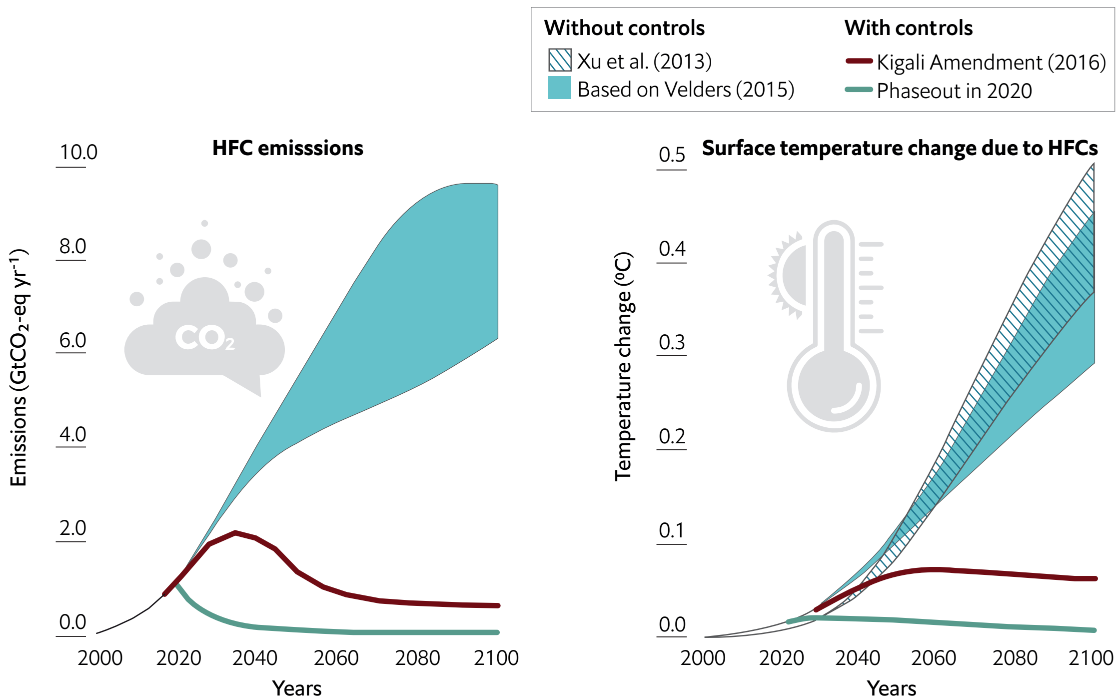
Type	Refrigerant	GWP 100 years
HCFC	R-22	1,760
HFC blends	R-410A	1,900
	R-407C	1,600

Source: Lawrence Berkeley National Laboratory

HFCs are "some of the most potent" greenhouse gases in use today, notes Sonia Medina and Yelena Ortega from the Children's Investment Fund Foundation (CIFF), and are used across many cooling appliances and systems. When other forms of heat pump[78] are included alongside AC and refrigeration, together they account for 79% of HFC consumption, rising to 86% when measured in GWP-weighted tonnes of CO_2 equivalent (as the devices require HFCs with a higher-than-average GWP). Of this HFC consumption, 65% is for AC and 35% is for refrigeration.[79] The growth in HFC use is leading to an increase in surface air temperature, which in turn requires further cooling and therefore HFC leakage (see graphic).

Up, up and away

HFC and temperature growth forecast due to cooling (with and without controls)



Source: World Meteorological Organization, United Nations Environment Programme, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, European Commission, Xu et al (2013), Velders (2015).

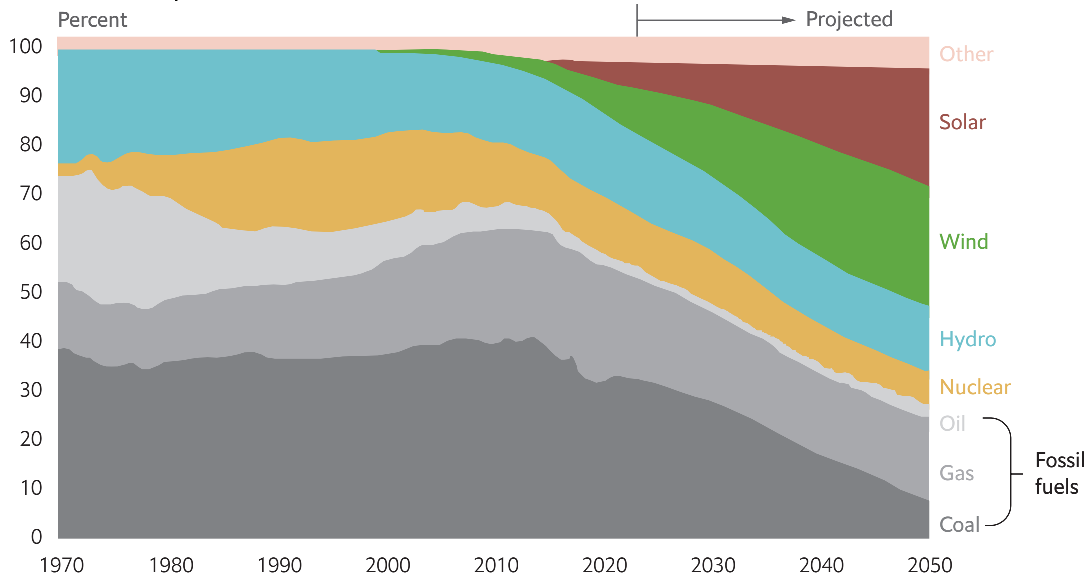
Indirect impact: Fossil fuel-hungry

Most cooling systems are powered by electricity, so increased usage – in intensity or length – increases demand on power grids. Between 1990 and 2018, the use of energy for *space cooling* – the cooling of buildings and spaces – more than tripled globally. Since the world's electricity mix remains dominated by fossil fuels (see chart below), cooling use increases CO2 emissions. Past estimates suggest that 16% of power consumed in the UK is used to keep offices, food, cars, medicines, homes and scientific instruments cool. Globally, refrigeration and AC are estimated to cause around 7–10% of global CO2 emissions – three times more than aviation and shipping combined.[80] Cooling also contributes to the release of other noxious gases. In the US, emissions of nitrogen oxide and sulfur dioxide from power plants increases by over 3% for each 1°C increase in daily temperatures due to rising power demand from AC systems. These gases can have significant detrimental impacts on health.[81]

Led by countries such as Indonesia, it is estimated that 2.3bn lower/middle-income people are at an income level near which they will begin buying cheap but inefficient cooling devices.[82][83] Buildings to accommodate this expanding urban "carbon captive" population are also installing AC of variable quality. In India, notes Eric Gibbs, "70% of building stock is not yet built, and we've seen a massive construction boom nationwide, with high rises from Mumbai to Delhi to Calcutta. Cooling units in these buildings are often lower cost and less efficient." As a result, cooling is forecast to almost double its energy consumption by 2050, to ~7,500 TWh annually, compared with 3,900 TWh in 2018.[84] Indonesia, a populous Asian economy with a hot climate, is forecast to add 20 GW of power demand between

Powering the world

Global electricity mix until 2050



Source: Stratfor; Bloomberg New Energy Finance; International Energy Agency

2015 and 2030, driven by AC adoption.[85] According to Stephen Andersen, some of these forecasts may even be underestimates if they do not adequately account for the UHI effect and improper installation and service of ACs.

Ray Gluckman believes that low- and middle-income countries seeking to close the cooling gap could undermine emissions targets and face a higher financial bill by using inefficient equipment. For example, many African countries will require huge growth in AC and refrigeration if they are to improve living standards. If inefficient, energy-guzzling equipment is installed because it is cheap, more power stations will have to be built in order to increase the capacity of electricity transmission and distribution networks, and meet that increased energy demand, resulting in the electricity company ultimately having to pay more.

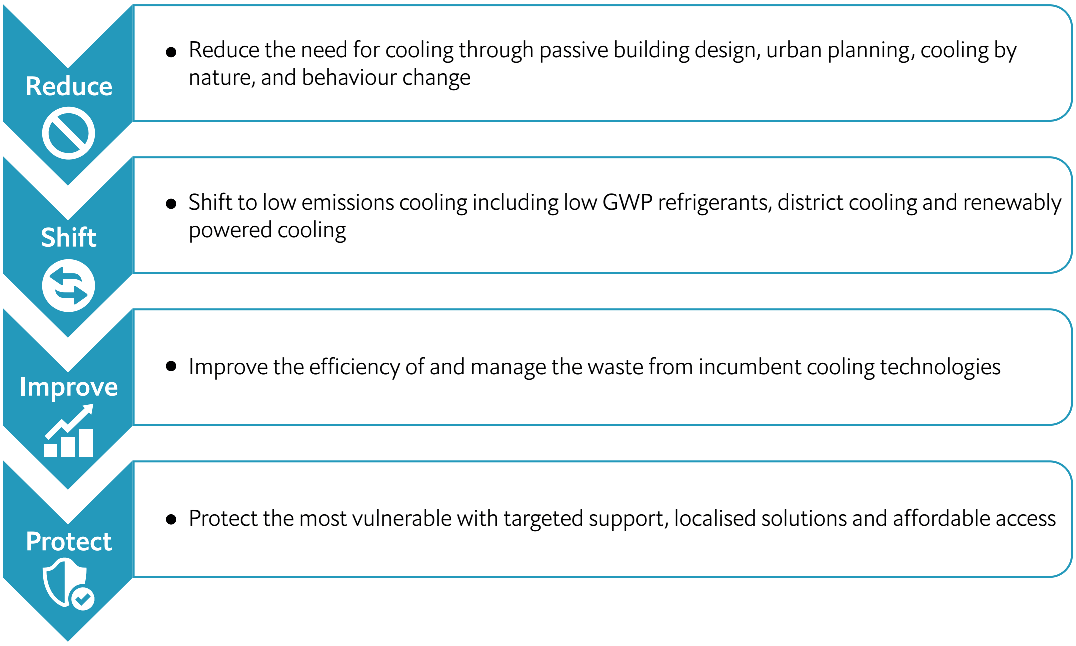
Moving to efficient, climate-friendly cooling

To close the cooling gap and meet future demand without dramatically increasing emissions, a multi-pronged strategy is required that combines efficient technologies, energy "stewardship", a shift to lower-impact gases, and smarter use of design, architecture and urban planning. This strategy can be divided into four components: **reduce, shift, improve** and **protect**.

1. Reduce the need for cooling: *Building design, urban planning and behaviour change*

As noted by Sonia Medina, populations in countries with hot climates have long constructed buildings with an eye on managing temperatures. *Passive building design* uses layout, materials and form to accentuate ventilation to reduce temperature. This is in sharp contrast to many modern building trends, such as using glass in skyscrapers which traps heat by inviting sunlight in, just as a greenhouse does.

Buildings can also reduce wasteful cooling by using sensors and smart systems for temperature control when and where it is needed. Mitsubishi's customised heating unit, the 3D i-See Sensor,



Source: The Economist Intelligence Unit

analyses room temperature to detect hot and cold spots. It then calculates how many people are present in order to target cooling and heating more precisely.[86] Installation choices can also reduce a building's energy use. For instance, placing condensers in a hot area will diminish their effectiveness.[87] Ray Gluckman notes that "if you locate them poorly, say in a sunny spot where air doesn't flow, you can create massive extra energy use."

At the city level, urban designers can reduce cooling demand by protecting and restoring green spaces, constructing shaded street infrastructure, installing "green roofs" (partially covered with vegetation) on buildings, and replacing or coating heat-trapping materials like asphalt with alternatives such as reflective paint, tiles and sheet coverings.[88] Senior Fellow and Managing Director at the Rocky Mountain Institute, Iain Campbell points out that efforts to tackle urban pollution can also have welcome effects, as polluted air outside incentivises people to close windows, thereby reducing indoor ventilation. Improving air quality could mitigate this effect.

Building designers and urban planners can take steps to reduce the need for cooling. But much will rest on organisations and individuals becoming more sensitive to their harmful cooling use and changing their behaviour. This is especially the case for heavy-use sectors such as supermarkets, and those whose decisions influence the broader population's cooling use, such as real estate developers and shopping centres. For instance, LED lighting for display illumination, which emits less heat, remains underused across many industries. Energy and environmental consultant James Wolf argues that too many decision-makers still do not consider climate a priority when it comes to cooling equipment, or have misperceptions such as that more energy-efficient equipment has a shorter lifespan. He also argues that leasing structures influence behaviour; users who pay a flat fee for energy, rather than paying based on metering, have little incentive to change their practices.

2. Shift to low-emissions cooling: *Low GWP gases, district cooling and decarbonised energy systems*

Replacing the worst-offending HFCs with lower-impact options like HFC blends, and next-generation options such as hydrofluoroolefins (HFOs) could dramatically reduce the emissions damage of cooling. Perhaps surprisingly, the transition could even involve greater use of hydrocarbons and CO2 which are far less harmful to the atmosphere than HFCs. Equipment providers can also use naturally occurring refrigerants like ammonia and propane.

Some proposed alternatives to HFCs are flammable and bring safety concerns that require additional measures and improved training for servicing technicians. However, there are energy-efficient, lower-GWP alternatives that are mature and commercialised and are taking an increasing market share in many cooling sectors. For example, about 65% of the 100m domestic refrigerators produced globally in 2018 used hydrocarbons.[89] Lower-GWP alternatives and hydrocarbons have also become a safe alternative refrigerant in room ACs in India and China.[90][91] Globally, new mobile AC systems in passenger vehicles are increasingly shifting to low-GWP alternatives.[92] In the commercial and industrial sectors, hydrocarbon and CO2-based systems have also been introduced in applications like vending machines and supermarket refrigeration, and ammonia has become a popular replacement for HFC R404A in the food and beverage industry.[93]

Another way to reduce cooling emissions is to shift to more innovative approaches. District cooling involves the centralised production and delivery of cooling. As it relies on very large chillers, it has the potential to cool multiple times more efficiently than more traditional models.[94] A 2015 review of three cases in Hong Kong found that district cooling used less energy at lower operational costs.[95] According to Jonas Hamann, Communication and Public Affairs Advisor at Danfoss Cooling, buildings using district cooling in Copenhagen can reduce their costs by up to 40% while reducing their CO2 emissions by approximately 70%. The approach is increasingly in vogue in China, India and the Middle East, and is supported by initiatives like UNEP's District Cooling in Cities project. Hamann explains that it can be implemented on a wide scale, but also in a smaller context, such as in a hospital. It is currently being trialled by a variety of stakeholders including individual building owners, supermarkets, real estate developers and urban planners.

Replacing HFCs with cleaner alternatives, and shifting to district cooling, will not address all the *indirect* effects of cooling on the climate. Transitioning to affordable low- or zero-carbon energy is crucial to ensuring that future cooling use does not further increase CO2 emissions. It will doubtless be a complex and long-term process requiring a diverse range of policy action. Designing renewable power systems for cooling also poses specific technical challenges. For example, solar will be a crucial renewable power source in many developing tropical countries where cooling needs will be greatest. The IEA estimates that solar in India is expected to grow to up to 1,000GW of installed capacity by 2050.[96] The extra capacity means that at the sunniest time of day, more power will be generated than is needed. However, solar cannot satisfy certain high-demand periods such as in the evenings when UHI effects keep cities hot and cooling is most needed. Solar is also ill-suited to continuous temperature control, such as in supermarkets. Energy storage innovation, including thermal energy storage, will thus be critical.

3. Improve the efficiencies of technologies: New appliances and re-using waste

The efficiency of cooling devices is improving. For example, *Variable speed drives* enable appliances to maintain a steadier room temperature, resulting in more efficient and quieter operation. *Electronic expansion values* improve control over the flow of refrigerants. Innovation over the past 30 years has provided a steady flow of improvements to compressor, fan, motor, and heat exchanger designs, increasing efficiency and lowering costs.

According to Ray Gluckman, "in the US, over the last 30 years, energy used by new domestic refrigerators has more or less halved, but the equipment cost, in real terms, has come down, not gone up. Over time, energy efficiency improvements to devices often get absorbed into the price and the consumer doesn't pay that much for it up front, and saves a lot on electricity costs." More accurate data is increasingly showing the difference that such efficiency improvements can make to the bottom line. Nihar Shah, for instance, studying regions including Indonesia, Brazil and India, argues that seasonal data metrics show the savings of variable-speed versus fixed-speed AC. Such efficiencies can lead to dramatic reductions in the energy needed to power cooling. One study found that shifting the forecasted 2030 global stock of room ACs towards more efficient models, using cleaner gases, would be equivalent to 1,000 fewer peak power plants at 500 MW each. In China, the shift would save power equivalent to that produced by more than eight of the country's massive Three Gorges Dam.[97]

More innovative devices will continue to emerge. A team of researchers at the University of California and SRI International are working on a cooling device that uses polymer material.[98] In an experiment to assess the cooling of a battery, the team found that after five seconds of running the cooling device, the battery's temperature fell by 8°C, compared with just 3°C in 50 seconds when using more traditional air cooling. The technology has a low GWP as it does not use damaging coolants or refrigerants. The device is slim and flexible, with the potential to be integrated into smartphones and tablets, as well as personalised wearable cooling devices such as in a hat or the sole of a shoe, which the team is now working on.[99]

In addition to new and more innovative technologies, better management of existing devices could allow for the "re-use" of cooling, leading to a boost in overall efficiency. For example, liquified natural gas (LNG) – the conversion of gas to liquid to facilitate transportation – requires extremely low temperatures. This "cold energy" can be harnessed by nearby industrial users, as has been done for decades in Japan.[100] According to one estimate, such "cold energy utilisation" globally represents less than 1% of its potential and could deliver nearly 12 GW of energy per annum if scaled up.[101] In 2014, the wasted cold energy from the LNG imports of seven EU countries could have supported the cooling demand for 210,000 refrigerated vehicles, around one fifth of the EU fleet. In addition to reusing wasted cold energy, there is potential to harness the waste heat that LNG liquefaction plants produce.[102]

Better management of equipment disposal at the end of the life cycle could also reduce emissions and waste. Around 90% of refrigerant emissions occur when refrigerators and AC units are disposed of and leakage spikes due to dumping or damage. More careful disposal and storage, and re-use or destruction of refrigerant gases, could reduce these emissions substantially.[103]

4. Protect the most vulnerable: Targeted support, localised solutions and affordable access

A lack of cooling disproportionately affects the vulnerable, such as those on low incomes, the elderly and those in social isolation. An effective response needs to prioritise their protection, particularly from the most extreme consequences of the cooling gap, such as during heatwaves and to ensure access to critical vaccines. To do so, policymakers and businesses will need to work alongside leading NGOs. For example, GAVI, the Vaccine Alliance, could spearhead efforts to use refrigeration to reduce vaccine wastage in an environmentally friendly way.

When it comes to vulnerable groups, responses must be rapid and flexible. In Paris, during the July 2019 heatwaves, the government quickly opened up air-conditioned rooms in public spaces, such as town halls. In Ahmedabad in India, the government reduced employees' working hours during the hottest parts of the day and introduced heat alert systems to better communicate information about upcoming extreme heat days to the public.

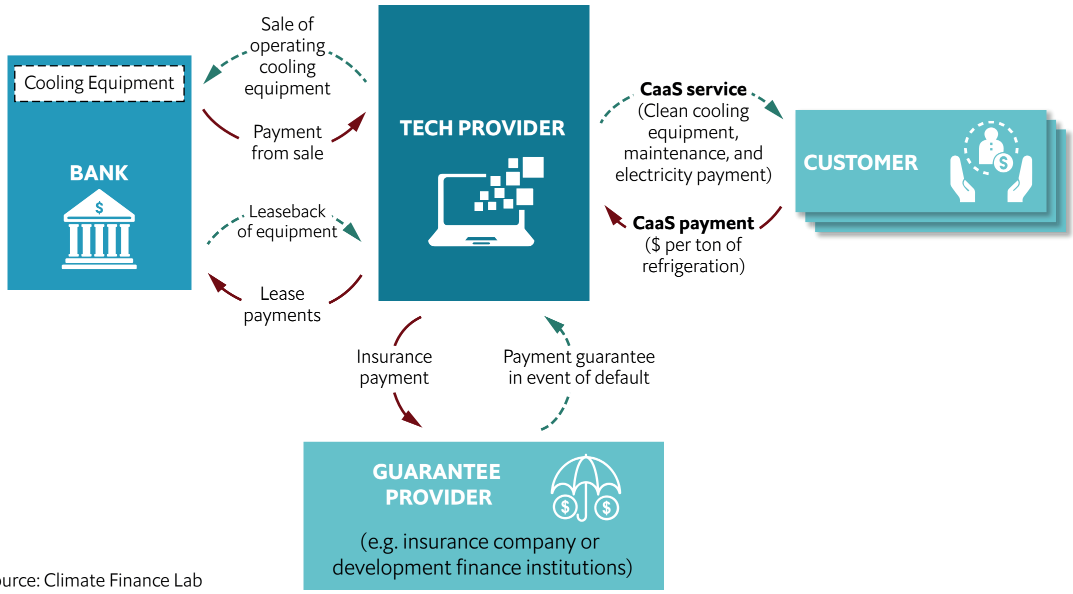
Solutions must also be locally relevant. For example, in 2014, almost 30% of the world's urban population lived in slums. Certain policies, such as revising building codes, will not have a huge impact in these areas, but simple practices such as installing window shutters or awnings that block sunlight can prove critical. Another priority is roofing. In many slums, roofs are made of corrugated tin which can quickly overheat in summer. In contrast, a cool roof uses light-coloured, reflective paint or a sheet covering or tiles. As a result, it absorbs minimal heat, reflects light and has the potential to reduce inside temperatures by 20%. To scale up access to cool roof materials, the Million Cool Roofs Challenge awards grants to teams that can deploy cool roof materials in the most sustainable way.

Finally, cooling – and the power on which it runs – must be made more affordable and reliable. Bulk procurement by governments, or by "buyers clubs" of private companies or citizens, can help lower AC installation and distribution costs. A set of actors including the IGSD and UN Environment have recently published a Buyers Club Handbook to provide advice to new and prospective clubs. New business models can also make cooling more affordable. For example, Cooling as a Service (CaaS) allows customers to pay for the cooling they use instead of buying and maintaining equipment. Proponents of this approach have set up implementation models in Jamaica and the Dominican Republic.

According to Sustainable Energy for All, "(CaaS) could be a good model for decreasing upfront costs, allowing people to access higher-efficiency devices via regular instalments." Presently the opportunities provided by CAAS are more appropriate for businesses, but similar "pay-as-you-go" models have been successful in overcoming financial barriers to energy access at the individual and household level. Even when applied to the private sector, CAAS can have positive knock-on effects on lower-income households. For example, in the Dominican Republic, refrigeration and AC account for approximately half of electricity consumption in the hotel sector, one of the country's main employers, which means that substantial cost savings could have positive knock-on effects on employment.[104]

Role models

The Cooling-as-a-service (CaaS) business model



Source: Climate Finance Lab

The role of policy: Phase-outs, agreements, codes and incentives

Policymakers will play a critical role in enabling the transition to the efficient, climate-friendly model of cooling outlined above. At a national level, some countries are looking to add impetus for action by putting in place ambitious plans and targets. The India Cooling Action Plan (ICAP), finalised in 2019, is an early example.[105] Bringing together multiple diverse stakeholders, ICAP is targeting reductions of 20–25% in overall cooling demand, 25–40% in cooling energy requirements, and 25–30% in refrigerant demand by 2037–38. It also aims to train and certify 100,000 technicians and boost cooling research. According to Satish Kumar, President and Executive Director of the AEEE, the principal research partner for ICAP, the government of India will need to be assertive in the short term if such targets are to remain viable and to avoid ICAP becoming just a well-intentioned plan. As Mr Kumar notes, given the cross-sectoral nature of cooling, "an inter-ministerial approach, that avoids siloed thinking, will be key to ensuring that India meet the ICAP targets."

When it comes to meeting such targets, policymakers have a number of options. They have phased out harmful gases in the past, as evidenced by the Montreal Protocol's successful efforts to phase out the production of ozone-depleting substances – the most successful multilateral climate agreement to date.[106] Efforts are under way to achieve similar success with HFCs. The 2016 Kigali Amendment marks the next phase in the Montreal agenda, calling for a reduction in the production and consumption of HFCs with high GWP by more than 80% over the next 30 years. The Kigali Amendment entered into force on 1 January 2019, with ratifications by 88 Parties as of 24 October 2019.[107]

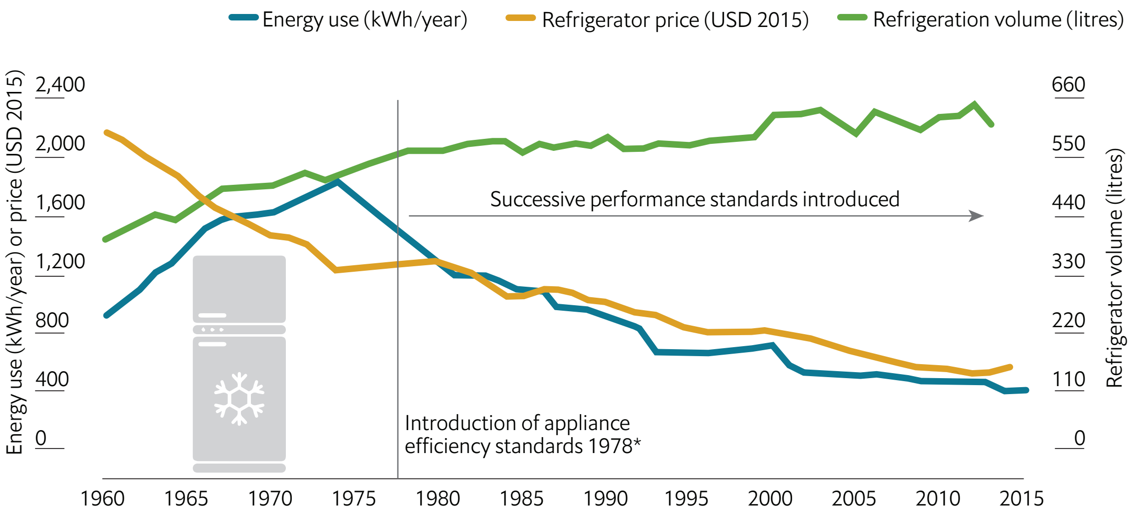
As large markets in Europe and Asia make the transition to energy-efficient and climate-friendly cooling products, they will drive investment and increase the availability of these globally traded products. While the agreement of major economies is critical, experts note that international agreements need not always include all countries. If a set of nations work together, they can provide an international "pull-through" effect – with other countries emulating them, or companies that comply with regulations in one market expanding their efficient products into other markets. The EU's F-gas regulations provide one example. Implemented in 2006, and strengthened in 2015, the regulations seek to control emissions from fluorinated greenhouse gases, known as F-gases, including HFCs. To date, the regulations have successfully limited the quantity of F-gases sold in the EU, banned the use of F-gases in new equipment where alternatives are available, and reduced F-gas emissions by requiring checks and servicing of equipment.[108]

While important and laudable achievements, HFC phase-outs must be conducted in an orderly way. The EU reforms have been criticised in one industry report for creating "market chaos", as evident in increased prices and equipment obsolescence, owing to a failure to allow sufficient time for the necessary innovation to smooth out transition costs.[109] Another challenge relates to the ability of smaller companies to comply with phase-outs. The Environmental Investigation Agency has noted that smaller European retailers, which are more vulnerable to price hikes and supply shortages, are trailing behind in their adoption of HFC-free technology.[110]

In addition to phase-outs, mandatory and voluntary green building codes and energy efficiency standards and labels can coordinate market development, drive up technology standards and boost the energy efficiency of cooling (although they are less relevant in slums and informal housing where construction tends not to comply with regulations).[111] While green building codes may increase construction costs, these costs can be outweighed in the long term by the operational savings from the improved energy efficiency of the building. One study in Indonesia, for instance, found that buildings that attained voluntary green certifications had utility costs that were 30–80% lower than those of

Price happy

The introduction of performance standards in 1978 in the US did not translate into higher prices



*The introduction of refrigerator performance standards in 1978 was at a state level in California. The standards were introduced at a national level in 1987.

Source: LBNL (2016), LBNL Analysis of AHAM (Association of Home Appliance Manufacturers) Fact Books, Rosenfeld (1999) and Bureau of Labor Statistics, Lawrence Berkeley National Laboratory, Berkeley.

standard buildings.[112] Driving up efficiency standards of appliances, however, can also be achieved even without significant increases in appliance costs as manufacturers optimise their production efficiency over time. This was seen in the US in recent decades, when the price of refrigerators decreased despite the introduction of appliance efficiency standards (see the chart below).

Alongside hard phase-outs and standards and codes, policymakers must ensure that they are incentivising a shift to climate-friendly cooling, and not merely incentivising the status quo. Fossil fuel subsidies are a glaring example of poor incentives. Estimating the total scale of these subsidies is notoriously difficult given their opaque nature and the lack of agreement over what exactly constitutes a subsidy. The OECD and the IEA conservatively estimate the total at just over US$370bn.[113] Other organisations include unlevied consumption and carbon taxes as a form of subsidy, and put the figure at closer to US$5.3trn (or 6.5% of global GDP)[114]. By contrast, renewable energy subsidies are relatively meagre, at approximately US$120bn. With regard to cooling, these subsidies keep fossil fuel-based energy costs artificially low. As a result, users waste more power on needless cooling and fail to scrutinise the performance efficiency of their cooling systems.

Governments can also incentivise a shift towards more efficient cooling equipment through financial incentives such as tax breaks, according to Todd Washam, Vice President of Public Policy & Industry Relations at the Air Conditioning Contractors of America.[115] Green procurement is another opportunity. Governments are major buyers of goods and services: public procurement in the EU reached almost €2trn in 2016, or 13.4% of the bloc's GDP.[116] In developing countries, the figure is typically closer to 30%.[117] Supporters of green procurement argue that, when selecting cooling suppliers, governments should incorporate environmentally friendly criteria into their traditional cost–benefit analysis. Governments can also act as a "lead buyer" for innovative products that are not yet commercially viable.

5. Which corporates should take action and how?

Policymakers, NGOs and citizens will all play critical roles in the transition to efficient, climate-friendly cooling. However, businesses will play an increasingly important role. Among the eight cooling sub-sectors analysed in this report, commercial and industrial AC and refrigeration, along with transport refrigeration, will grow the fastest out to 2030. As both producers *and* consumers of cooling, businesses must urgently shift to more efficient equipment, and use this equipment more judiciously.

Seizing the opportunity: Tackling misperceptions

In the past, private sector fears that phase-outs of inefficient technologies will hit their bottom line have often proven overblown. Refrigerant transitions, for instance, have not been onerously expensive as innovation and scale economies have brought down costs. The cost of refrigerants is also low when considered against the lifetime cost of equipment – typically, less than 0.75% of the total cost of ownership for a residential unit and less than 0.5% for a commercial unit.[118]

Given the long life cycle of cooling products, commercial buyers must be careful not to lock themselves into inefficient technologies that vendors are moving away from. As Ray Gluckman notes: "If you are building new systems using fixed-speed compressors and old-fashioned heat exchangers, while companies are moving forward with variable-speed compressors and micro-channel heat exchanger designs, you end up isolated, stuck using old technology. You've got to keep close to the leading edge."

The cooling transition provides new commercial horizons, rather than simply closing off existing technology pathways. For example, if the US is slow to ratify the Kigali Amendment, commentators suggest that the market for next-generation cooling products will simply move elsewhere. China, once a laggard in terms of frontier innovation, is a global leader and top investor in green energy technology. Globally, various companies are deploying innovative and best practice solutions across different industry sectors.

In this section, we analyse different commercial and industrial sectors that use cooling, explain how they use it and share case studies of companies who are leading the way in reducing the environmental impact of their cooling use. For each sector we also identify the largest companies in each country to shine a light on those who need to take action most urgently.[119] To identify the largest companies we used data on annual revenue, sourced from Orbis.

Residential: The push for green homes

In 2018, 26% of total global cooling demand came from the residential AC sector. As a result, property developers are under pressure to shift to more innovative approaches, such as *passive cooling*, which involves optimising building design in order to capture natural wind flows, accelerate the movement of air through spaces, and make use of building orientation and exterior shading.[120]

In Mexico, the need for climate-friendly homes is particularly pressing. The country is undergoing a rapid urban expansion and, due to a hot climate and poor building design, housing already accounts for 5% of greenhouse gas emissions.[121] Funded by the Inter-American Development Bank, the Latin American Investment Facility and the EU, the *EcoCasa* programme was set up in 2013. It aims to build 27,600 low-carbon houses and to provide 1,700 "green" mortgages in its first seven years. As of 2015, 15 housing developers, including Famoca and Sadasi, have participated in the programme. New buildings incorporate energy saving windows, efficient insulation in roofs and windows, and high-efficiency refrigerators.[122]

Residential: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
Invitation Home	Hefei Urban Construction Development	Omkar Realtors	UR Urban Organization	Total Bangun Persada	Urbanplan
American Homes for Rent	Guang Dong Roomme	Brij Gopal Construction Co.	Daito Kentaku Partners		Hacienda Los Pavorreales
JBG Smith			Daiwa Living		
Glenwood			Seikwa		
New Senior Investment Group			Asahi Kasei		

Source: Orbis

Offices and buildings: From retrofits to replacements

In 2018, the offices and buildings[123] sector was the leading end-user of cooling in each of the six countries analysed in this report.[124] By 2030, it will be overtaken in the US, China, Japan and Mexico by the hospitality sector. However, it will remain the leading source of cooling demand in India and Indonesia, owing to an expected uptick in commercial real estate. Offices and buildings use AC mainly to ensure the comfort, productivity and creativity of their employees (as described in Section 3). To boost cooling efficiency, innovative developers and building management teams are focused on retrofitting existing buildings and incorporating innovative design and technologies into new buildings.

A decade ago critics regularly pointed to the Empire State Building's high CO_2 emissions and utility costs as evidence of its energy inefficiency. In 2008, the building's owners partnered with the Clinton Climate Initiative, the New York State Energy Research and Development Authority (NYSERDA) and Rocky Mountain Institute, among others, on a US$500m retrofit. Improvements included better lighting, more efficient office equipment, renovating smaller chillers and installing the world's largest WiFi-enabled control system.[125] The result was an estimated cut of 38% in the building's annual energy use, with an associated US$4.4m in cost savings.[126] Indonesian real estate developers have begun to make similar, albeit smaller, retrofits. In 2017, the Pakuwon Group's real estate arm, which owns multiple skyscrapers, apartment blocks and malls across the country, replaced five chillers with high-efficiency models at its Tunjungan Plaza shopping centre.[127] In addition to boosting customer comfort, the retrofit cut electricity consumption by approximately 3.9m kWh/year.

Alongside retrofits, innovative new buildings are needed. Canada created a strategic investment fund to improve the quality of its dated third-level education infrastructure (the majority of which is more than 25 years old).[128] One recipient is Mohawk College which used a grant of C$20m (US$15.3m) to build the Joyce Centre for Partnership and Innovation.[129] To meet its goal of being a zero-carbon building, the centre uses triple-glazed windows and insulated concrete panels to create an airtight building envelope which prevents air leakage, along with heat pumps to provide efficient cooling. Owing to such measures, its energy use intensity is estimated to be one-twelfth of that of a traditional third-level institutional building in Canada.

Offices and buildings: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
ASB Capital Management	Vanke	DLF	Mitsui Fudosan	Lippo	Liverpool
CBRE	Evergrande	Pearls	Mitsubishi Estate	Ciputra Development	FIBRA Uno
JLL	Poly	Sobha	Kintetsu Railway Co.	Pakuwon Group	Citibanamex Inmuebles
RX Realty	Dalian Wanda Commercial Management	Godrej Properties	Tokyu Fudosan	Summarecon	Consorcio ARA
DRA Advisors	China Merchants Shekou Industrial Zone Holdings	Oberoi Property	Nomura Real Estate	Agung Podomoro Land	FIBRA Danhos
Realogy	Shimao Property	Sahara	Leopalace21 Corporation	Surya Semesta Internusa	Ruba
	Chongqing Longhu Development Co.	Unitech	Open House	Bintang Mitra Semestaraya	FIBRA Prologis

Source: Orbis

Hospitality: Keeping customers cool

In 2018, the hospitality sector, which includes hotels and food and drink establishments, was the second-highest user of cooling in all six countries analysed in this report, just behind offices and buildings.[130] By 2030, it is expected to be the leading end-user in the US, China, Japan and Mexico. Along with guest comfort, hotels and restaurants rely on cooling to keep food safe and to maintain pools and other amenities.

As cooling demand continues to grow, leading hotels are looking to retrofit their equipment. The Sun-n-Sand Hotel in Shirdi, Western India, used to rely on diesel-powered absorption chillers to provide AC. Partly owing to soaring diesel costs, they shifted to a new oil-free compressor, from Danfoss, that is both quieter (which guests appreciate) and more energy-efficient. According to the facility's manager, the shift has led to cost savings of 200,000–250,000 Indian Rupees per month (US$2,800–3,500). [131]

Other hotels are seeking to cut the demand for cooling altogether. As in much of the Caribbean, hospitality in St Lucia is a critical driver of economic growth. It accounts for approximately two-thirds of GDP and is the main source of foreign exchange and employment – in a country where one in five is unemployed.[132] With a competitive landscape, and a consistently warm climate throughout the year, the availability of cooling is a key determinant of a hotel's market share. However, much of St Lucia's AC stock is inefficient and the country lacks trained professionals to maintain it. Hotels must also grapple with unreliable power supply. As a result, some are seeking to reduce the need for cooling. The Jade Mountain Resort was designed to incorporate *passive cooling* approaches and much of the resort therefore does not require active cooling measures, meaning very few AC units on the premises.[133]

Hospitality: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
Starbucks	Jin Jiang International Hotels	Taj Hotels	Zensho	KFC Indonesia	Dream Resorts & Spas
US Foods	Dongfang Hotel	Club Mahindra	Skylark Group	Pizza Hut Indonesia	Alsea
Mariott	KFC China	Oberoi Hotels	Skylark Group	Aerowisata	CMR Brands
McDonald's	Starbucks China	McDonald's India	McDonald's Japan	Jakarta International Hotels & Development	Posadas Hotels
	Yum! Brands	Westlife	McDonald's Japan	Jakarta Setiabudi Internasional	El Pollo Loco
			Colowide	Dyandra	Posadas Hotels
			Yoshinoya	PSU Food Resources Solutions	

Source: Orbis

Supermarkets and hypermarkets: Closing doors and re-using cold

In 2018, the supermarkets and hypermarkets sector was the third-largest user of cooling[134] in each of the six countries analysed in this report[135] due to its thirst for refrigeration to provide safe fresh food and to minimise waste. This is expected to remain the case until 2030. Supermarkets have long been criticised for wasteful practices – notably a continued failure to fit doors to open-display refrigerators. In their defence, some point to evidence that such doors can reduce sales.[136] If such evidence is correct, it highlights the need for supermarkets to collectively take action.[137] Some are leading the way. Woolworths[138] has outlets across South Africa and Sub-Saharan Africa. In 2012, after conducting a customer survey, it decided to replace its open refrigerators with closed-door systems.[139] Despite the significant upfront cost, the initiative is expected to save up to US$10m over five–ten years. Since 2005, Woolworths South Africa has more than tripled its energy productivity owing to the addition of doors as well as other initiatives, such as replacing incandescent lighting with LEDs.

Other supermarkets are trying to recycle the excess heat generated from their refrigeration systems and provide it to neighbouring buildings. The Danish supermarket chain SuperBrugsen is one such energy supplier. In 2015, it installed technology in the town of Høruphav to recover heat from its cooling systems and supply it as heating to 16 private homes, through Sønderborg District Heating, a local heating provider.[140] In doing so, it joined 20 other Danish supermarkets that have recycled heat. It had previously cut emissions by 34%, and saved more than DKK200,000 (around US$30,000) annually, by re-using surplus heat within the supermarket. When Sønderborg shifted to supplying heat to homes it faced a significant upfront cost to install the technology. But given its resulting income gains, it estimated that it broke even after just 12 months.

Supermarkets and hypermarkets: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
Kroger	Yonghui Superstores	Big Basket	Aeon	Alfamart	Soriana
Albertsons	Wumart	Al-Sameer Exports	7 and i	Transmart - Carrefour Indonesia	Chedraui
Publix Supermarkets	Lianhua Supermarket Holdings	Umang Dairies	7-Eleven Japan	Hero Supermarket	La Comer
Safeway	Vanguard	Royal Canin	Lawson	Tigaraksa Satria	Prodea
Morrisons Groceries	Metro	KPN Farm Fresh	Life Corp.	Kino	7-Eleven Mexico
Whole Foods Market	Su Guo	Crane Group	United Super Markets Holdings	Super Indo	La Cosmopolitana
Supervalu	Auchan	Manjushree Group	Valor Holdings	Sang Hyang Seri	Nery's Queso

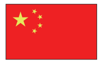
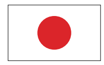
Source: Orbis

Food and beverage: From cold storage to climate-friendly alternatives to HFCs

The food and beverage sector is the leading source of cooling demand for industrial and transport refrigeration for all six countries analysed in this report. Producers use refrigeration during the manufacturing process, as well as to safely store their products. In India, the lack of refrigerated storage, such as packhouses, means that post-harvest losses can hit 40% within the first mile of transit.[141] It also means that farmers must sell their produce quickly, at market rates. During supply gluts, the inability to store products can have a detrimental effect on farmers' incomes. To address this challenge EcoZen Solutions, a startup based in Pune, has developed a portable cold storage box called Ecofrost. The box runs on solar power, rather than the grid, and so is unaffected by unreliable power supply. It is also portable, allowing a farmer to rent it to another farmer when it is not in use. According to EcoZen, farmers who used to sell their pomegranates for around 30 Indian Rupees each due to fear of spoilage can now store them for up to two months and sell at more than double this price.[142]

At the other end of the size scale is Coca-Cola – the world's largest soft drink manufacturer. The company has a vast network of vending machines and bottle coolers in millions of locations across the world. Traditionally, it relied on HFCs to keep the machines cool. In 2005 Coca-Cola Japan made the decision to start using climate-friendly alternatives and has since pledged to make all new cold drinks equipment HFC-free by 2020.[143] By the end of 2016, it had made more than 500,000 vending machines HFC-free.

Food and beverage: Large companies in priority markets

 US	 China	 India	 Japan	 Indonesia	 Mexico
Cargill	COFCO	KR Bakes	Asahi	Indofood	FEMSA
Pepsi	Yili	Shree Ashtvinayak Roller Flour Mills	Kirin	Charoen Pophand Indonesia	Bimbo
ADM	New Hope Group	Karnataka State Beverages	Suntory Spirits	Japfa	Coca-Cola FEMSA
Tyson	Kweichow Moutai	Adani Wilmar	Meiji	Mayora	Arca Contal
Coca-Cola	Mengniu	Amul	Suntory	FKS Multi Agro	Modelo
Kraft Heinz	Shuanghui	K P M Agro Food Products	Nipponham	CP Prima	Lala
Mondelez	Bailian Group	MP State Civil Supplies	Ajinomoto		Gruma

Source: Orbis

Automotive and transportation: Testing new cooling technology

Mobile AC accounted for 30% of global cooling sales in 2018 and will account for 31% in 2030. While individual consumers are the primary end-users of mobile AC, automotive companies produce, install and maintain the mobile air conditioning systems (MACs) that are found in cars, buses and other vehicles. Owing to how hot vehicles can get in direct sunlight, MACs are typically powerful devices, capable of cooling a small flat.[144] Automotive companies also use AC directly in their plants, workshops, and body shops. As a result, the automotive sector was the second-largest user of industrial AC in the US, China and Mexico in 2018. As with supermarkets, some manufacturers are taking steps to re-use the heat they generate through cooling. Mahindra & Mahindra[153] is India's largest vehicle producer and the world's largest tractor producer. With support from the Indian government, the company is deploying heat recovery called *trigeneration* across its manufacturing facilities. Under trigeneration electricity, (useful) heating and cooling are generated simultaneously, which the firm hopes will enable it to boost energy conversion efficiencies almost threefold.

Mahindra & Mahindra is also working with Energy Efficiency Services Limited (EESL), the Indian government's energy service company, to test novel "super-efficient" cooling technology in its plants. By acting as a launch customer, the company aims to support the entry of the technologies into the broader market. Mahindra & Mahindra is also testing *radiant cooling* in its newly built offices. The process, which uses cool surfaces to absorb heat, is significantly more efficient than conventional AC. In September 2019, Mahindra & Mahindra became one of the first companies to join The Climate Group's EP100 Cooling Challenge (see Appendix).[145]

Planes, trains, boats and their respective airports, stations and ports are also heavily reliant on cooling. Transportation (excluding automotive) was the fourth-largest end-user of commercial AC in all six countries in 2018.[146] The Channel Tunnel – the longest undersea tunnel in the world – is a notable example. In the absence of cooling, the heat produced from the high-speed trains would push temperatures for passengers above 35°C (95°F).[147] In 2016, Eurotunnel, the tunnel's operator, installed highly efficient large-capacity chillers from the firm Trane which uses low-GWP refrigerants. As a result, in 2017 Eurotunnel cut its energy consumption by 33%, saving around €500,000 (US$560,000).[148]

Automotive: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
Ford	Faw Volkswagen	Tata Motors	Toyota	Astra International	Nemak
GM	Saic Volkswagen	Tata	Nissan	Indomobil Group	Daimler Mexico
Fiat - Chrysler	Saic Motor	Mahindra Rise	Denso	Astra Otoparts	Kuo
Honeywell	Saic GM	Maruti Suzuki	Aisin Group	SMSM	Rassini
Honeywell UOP	BMW Brilliance	Samvardhana Motherson International	Suzuki	Indospring	Stant
Lear Corporation	Beijing Benz	Hyundai India	Mazda	Prima Alloy Steel	Fritec
PACCAR	Dongfeng Motor Company Limited (DFL)	Ashok Leyland	Subaru		Metalsa

Source: Orbis

Transportation: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
FedEx Trade Networks	Huayu Automotive Systems Co.	Air India	East Japan Railway Company	Garuda Indonesia	Aeromexico
United Parcel Service (UPS)	China Southern Airlines	IndiGo	Nippon Express	Jasamarga Indonesia Highway Corp.	Ferromex
FedEx	China Eastern Airlines	GMR Group	All Nippon Airways (ANA)	Kereta API	Volaris
American Airlines	China Railway Shanghai Group	SpiceJet	Central Japan Railway Company	GMF AeroAsia	Aleatica
Delta Airlines	SF Express	Devyani International	West Nippon Expressway Company	Angkasa Pura II	Interjet
United Airlines	Hainan Airlines	TVS Supply Chain Solutions	Yamato Holdings	Angkasa Pura Airports	Aeropuertos del Sureste
BNSF Railway	Beijing Railway Bureau	Go Air	West Japan Railway Company	Air Asia Indonesia	Grupo Aeroportuario del Pacífico

Source: Orbis

Electronics and data centres: Keeping computers cool

The *digital economy* does not describe a new industry. Rather it describes the transformation of products, services and processes, across all industries, by digital technologies such as cloud computing, mobile devices and machine learning. Partly owing to the rise of the digital economy, the electronics sector is the leading source of demand for industrial AC in China, India and Japan, and the fastest-growing user in both India and Mexico.

Computers and electronic devices rely on cooling to ensure that critical components, such as computer processing units (CPUs), do not overheat and malfunction. However these cooling systems are traditionally energy-intensive and use materials that are damaging to the environment. Like CPUs, data centres' components are also at risk of overheating and faltering, particularly under extreme environmental conditions. As a result, they rely heavily on cooling systems, both man-made and natural. As much of the digital economy rests on data, for commercial AC, data centres are the second-fastest-growing end-user in both China and Mexico, just behind hospitality. Data centres house computer, telecommunications and storage systems.

In 2012, technology giant Facebook began searching for a site in Europe to house the second phase of a large new data centre initiative. Coming under pressure to curb its energy use, it sought a source of cheap and green energy, as well as a cold climate that could provide "free cooling". It finally settled on on Luleå, a city of 75,000 inhabitants on the coast of northern Sweden.[149] Powered by locally generated hydroelectricity, the "ultra-efficient" centre utilises the naturally cool local air to reduce cooling demand. Such innovations are also possible in warmer climates. The sustainable engineering consultancy Cundall, which worked with Facebook, also partnered with Telefónica on the first Tier IV Leadership in Energy and Environmental Design (LEED) Gold certified project in Spain.[150] The data centre was designed to make use of free cooling 95% of the time. This is made possible even in hot Madrid when the outside air temperature is below 27°C and lower than the temperature inside, typically during the night and outside of the summer season. In addition, the air in Madrid is usually quite dry and so when the outside temperatures soar above 27°C, evaporative cooling using water is used to lower the temperature in the data centre. Only on very hot days and days of high humidity is mechanical cooling required, which amounts to only 5% of the year.

Other tech giants are also focussed on making their data centres more energy-efficient. In 2016, DeepMind, an Artificial Intelligence (AI) start-up acquired by Google, developed an AI-powered recommendation system to improve the energy efficiency of Google's data centres. The AI system has since taken direct control over Google data centres' cooling decisions. Every five minutes, the cloud-based AI pulls a snapshot of the cooling system from thousands of sensors and feeds it into a deep "neural network" - a model that identifies which potential actions will minimise energy consumption. Optimal actions computed by the AI are vetted against an internal list of safety constraints defined by Google's (human) data centre operators.[151]

Electronics: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
Apple	Foxconn	Samsung India	Hitachi	Multipolar	Mabe
GE	Huawei	LG India	Sony	PT Sat Nusapersada	Mitsubishi Mexico
Dell Technologies	Founder Group	Exidie	Panasonic	Nipress	
Intel	Shandong Heavy Industry Group	Siemens	Mitsubishi	Mahakam Media	
Cisco	TCL		Canon	Sentral Mitra Informatika	
	Oppo		Fujitsu		
			Toshiba		

Source: Orbis

Pharmaceutical and healthcare: Replacing refrigerants

Pharmaceutical companies are the second-fastest-growing user of industrial refrigeration in the US, China, India and Japan, and the fastest in Indonesia. Like food and drinks producers, pharmaceutical companies rely on cooling during the highly temperature-sensitive process of manufacturing antibiotics and medications, when many drugs must be consistently stored at between 2 and 8°C to prevent spoilage.[152]

In Indonesia, the 2012 HCFC Phase-Out Management Plan and the subsequent HFC phase-down under the Kigali Amendment mean that pharmaceutical companies are looking for HFC-free approaches. In 2018 PT Phapros, a local drug firm, installed two AICOOL chillers to cool rooms used in drug production, storage and cultivating bacteria. These chillers use the hydrocarbon-based refrigerant R290-propane, which is a natural refrigerant with a negligible GWP and excellent energy efficiency.[153] Owing to the shift, the firm's annual energy bill fell by approximately US$26,000 per year, and its annual greenhouse gas emissions fell by an estimated 356tCO2 per year.[154]

Healthcare institutions, particularly hospitals, are also major cooling users as they need to maintain patient comfort and wellbeing, protect medicines, vaccines and blood, and reduce potential sources of bacteria. Healthcare (excluding pharmaceuticals) is expected to be the fastest-growing user of commercial refrigeration in India between 2018 and 2030, and the second-fastest-growing user of commercial AC in India and the US. Globally, hospitals' cooling use is responsible for annual greenhouse gas emissions equivalent to approximately 365 metric tons of carbon, which in turn is equivalent to the emissions from over 75m cars or 110 coal-fired power plants.[155]

With such emissions in mind, in 2010 the Ladera Health Network, which includes 38 health institutions, in Colombia began its implementation of the Global Agenda for Green and Healthy Hospitals' (GGHH)[156] Energy Challenge. The challenge offers members a framework that allows them to assess their energy consumption, take measurable actions and conserve energy. Aspects of this challenge included replacing old AC systems with more efficient low-GWP models, and also making changes to the underlying building infrastructure to facilitate natural ventilation. In 2016 the Secretariat of Municipal Health of Cali decided to implement pilot renewable energy and energy efficiency projects, and provide financial support across more than 100 healthcare institutions, following the success of the work done by the Ladera Health Network.[157]

Pharmaceutical: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
McKesson	Sinopharm	Sun Pharma	Medipal	Kalbe Farma	Nadro
Amerisource Bergen	Shanghai Pharma	Aurobindo	Alfresa	Tempo Scan	Fanasa
Cardinal Health	Yangtze River Pharmaceutical Group	Lupin	Suzuken	Kimia Farma	Maypo
Johnson and Johnson	China National Accord Medicine Corporation	Cipla	Mediceo	Sido Muncul	Dimesa
Pfizer	Guangzhou Pharma Holdings	Dr Reddy's Laboratories	Takeda	Biofarma	Roche Mexico
Merck	Biocause Pharma	Mylan	Astellas Pharma	Millennium Pharmacon International	DSM
Abbvie	China National Medicines Corporation	Glenmark		MSD Indonesia	Birmex

Source: Orbis

Healthcare: Large companies in priority markets

US	China	India	Japan	Indonesia	Mexico
Humana	AIER Eye Hospital	Capgemini	Japanese Red Cross Society	Siloam Hospitals	ISSSTE
HCA	DIAN Diagnostics	Apollo Hospitals	National Hospital Organization (NHO)	Hermina Hospitals	IMSS
First Care	Tongji Medical College of Huazhong University of Science & Technology	Aster DM Healthcare	Saiseikai	Mitra Keluarga	Secretaria de Salud del Gobierno de Puebla
Tenet Health	Union Hospital of Tongji Medical College	Fortis Healthcare	Japan Community Healthcare Organization (JCHO)	Prodia	Medica Sur
Catholic Health Initiatives	Beijing Anzhen Hospital		Nichii Group	Omni Hospitals	Hospital Civil de Guadalajara
Dignity Health	Shandong Provincial Hospital		Tokushukai Medical Group	Pertamedika	Instituto Nacional de Ciencias Médicas y Nutrición
Community Health Systems	KingMed Diagnostics		ASO	Mayapada Hospital	

Source: Orbis

(i) Resources for *policymakers* to draw on

Research:

- AEEE: Research and advice on sustainable cooling in India[158]
- Cool Coalition: Cooling in a warming world[159]
- LBNL: Opportunities for Simultaneous Efficiency Improvement and Refrigerant Transition in Air Conditioning[160]
- Oxford University: "Future of Cooling" research programme[161]

Guides and tools:

- Cool Coalition: Government Action on Efficient, Climate-Friendly Cooling[162]
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH: Climate-friendly Refrigeration and Air Conditioning – A Key Mitigation Option for INDCs[163]
- United 4 Efficiency: Model regulation for energy-efficient and climate friendly air conditioners and refrigerators[164]
- United 4 Efficiency: Guidance note on what is a product registration system and why use one?[165]
- World Bank Energy Sector Management Assistance Program (ESMAP): Energy Efficient and Clean Cooling Program[166]

(ii) Resources for *businesses* to draw on

Research:

- The Climate Group: EP100 Progress and Insights Report[167]

Guides and tools:

- ASHRAE: Refrigeration Commissioning Guide for Commercial and Industrial Systems[168]
- The Carbon Trust: Heating, Ventilation and Air Conditioning (HVAC) Energy Efficiency guides[169]
- Cool Coalition: Business Action on Efficient, Climate-Friendly Cooling[170]
- Small Business Energy Initiative: Action Guide[171]
- University of Birmingham and Heriot Watt University: Investing in Clean Cooling[172]

(iii) Best practice initiatives and competitions

- Ashden Awards[173]
- BASE: Cooling as a Service Initiative[174]
- The Climate Group EP100 Cooling Challenge[175]

- The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants[176]
- Cool Coalition[177]
- District Energy in Cities Initiative[178]
- European Partnership for Energy & the Environment[179]
- The Global Cooling Prize[180]
- Kigali Cooling Efficiency Program[181]

(iv) Country cooling profiles: China, India, Indonesia, Japan, Mexico and the United States

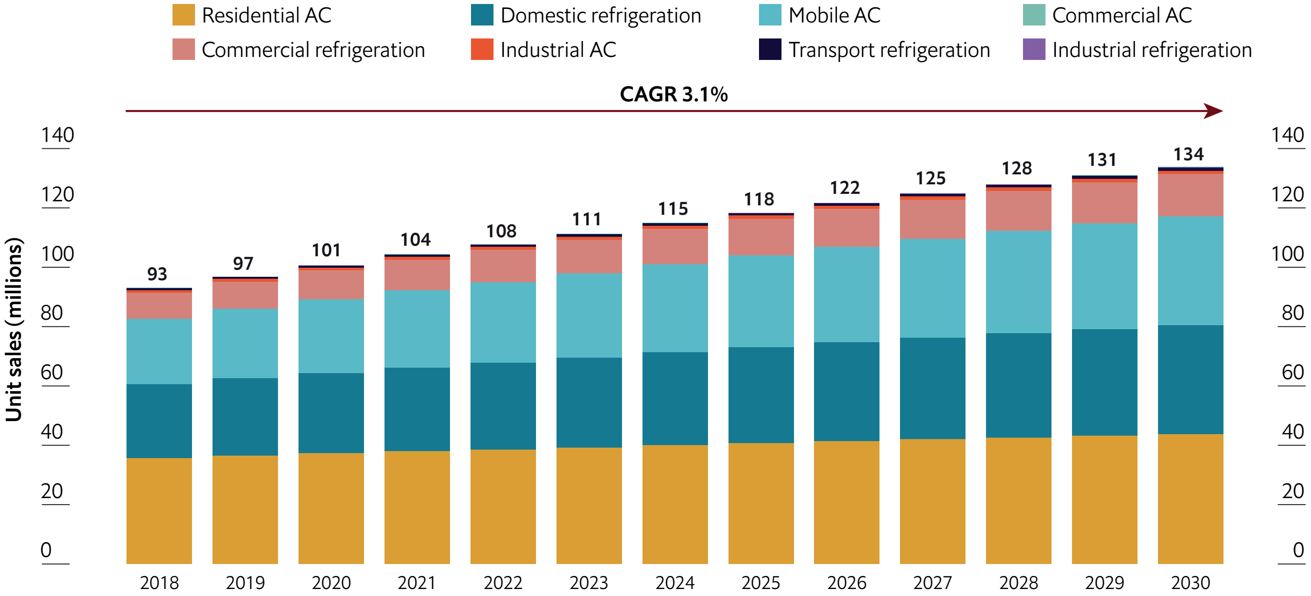
China

Annual cooling sales 2018: **93.0m**

Annual cooling sales 2030: **133.7m**

Compound annual growth rate (CAGR) 2018-2030: **3.1%**

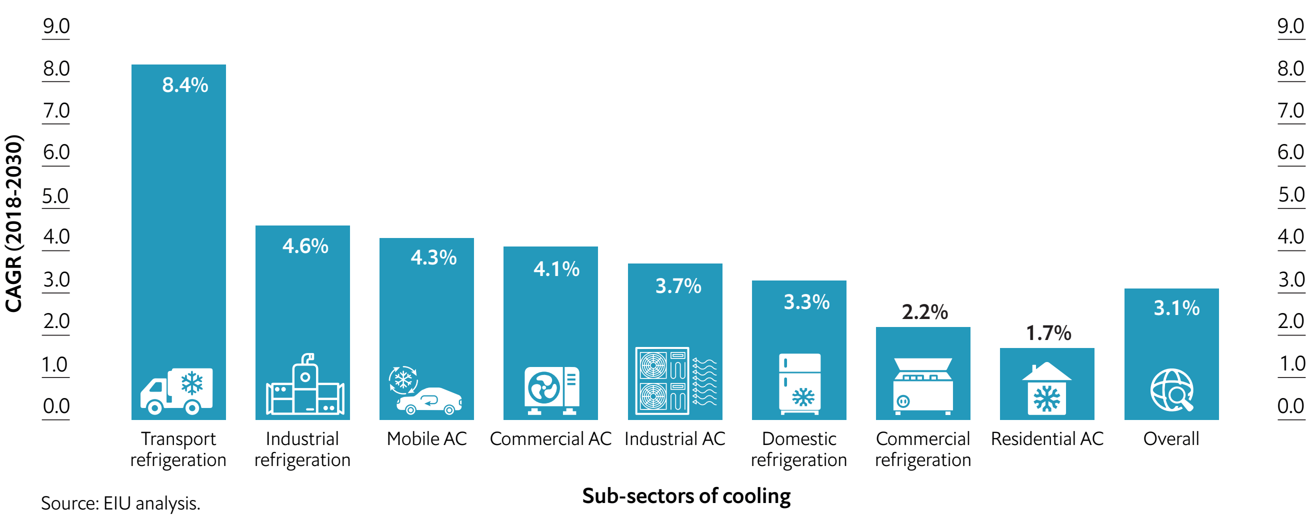
China: Annual cooling sales 2018-2030



Source: EIU analysis, P&S Intelligence, Green Cooling Initiative.

China: Sub-sectors growth to 2030

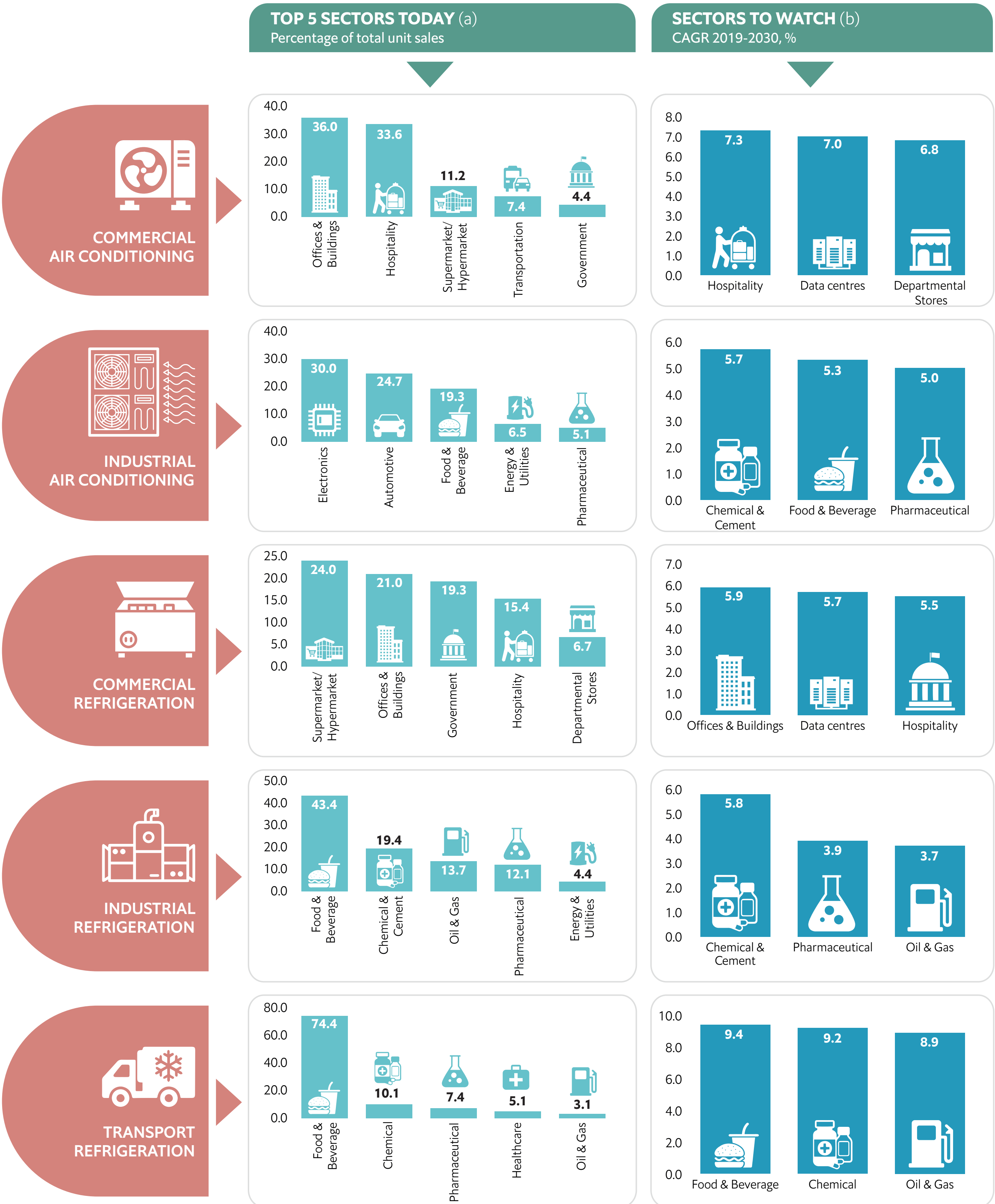
Compound annual growth rate (CAGR) 2018 to 2030



Source: EIU analysis.

China

Key end-user sectors today and sectors to watch



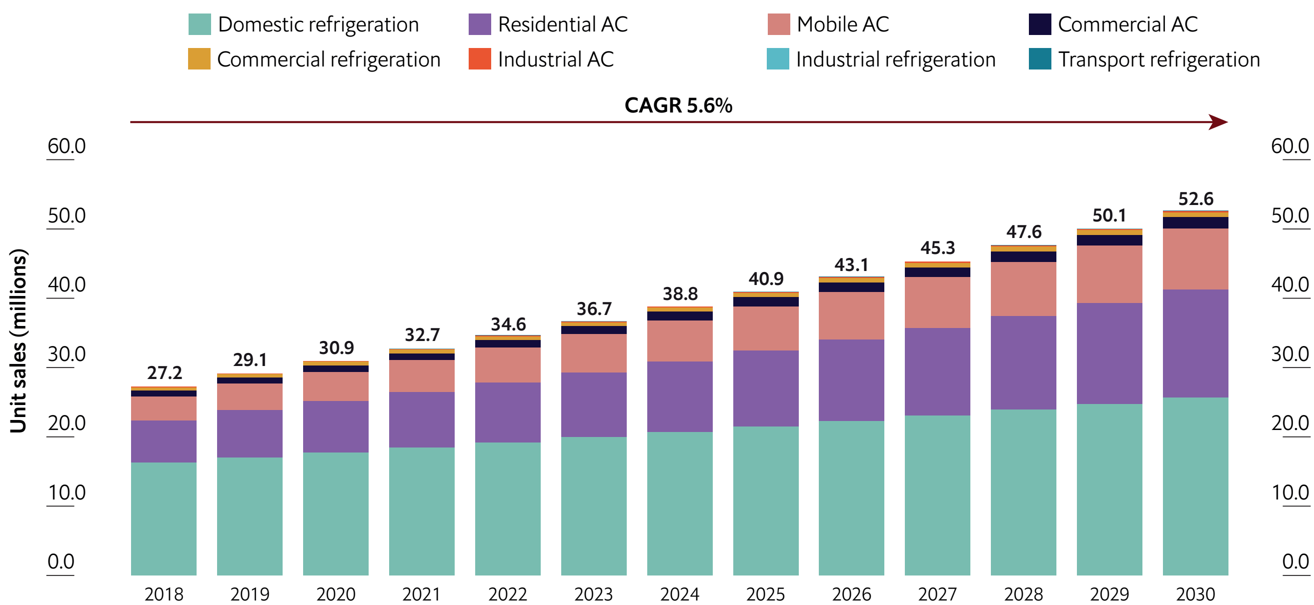
(a) 2018; (b) 2019-2030

Sources: PS Intelligence, EIU Analysis

India

Annual cooling sales 2018:	27.2m
Annual cooling sales 2030:	52.6m
Compound annual growth rate (CAGR) 2018-2030:	5.6%

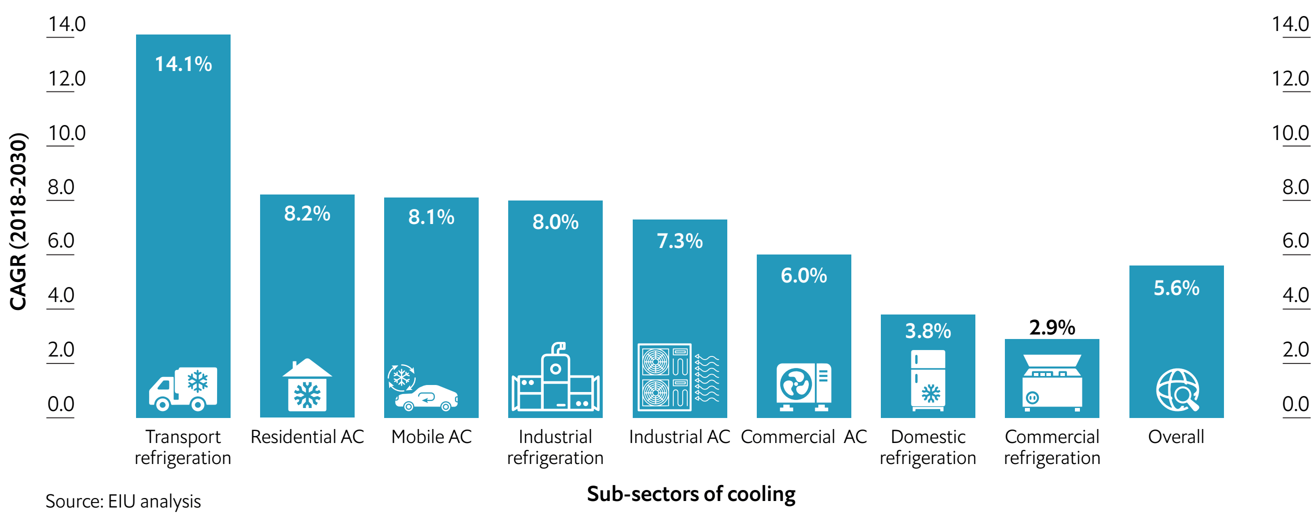
India: Annual cooling sales 2018-2030



Source: EIU analysis, P&S Intelligence, Green Cooling Initiative.

India: Sub-sectors growth to 2030

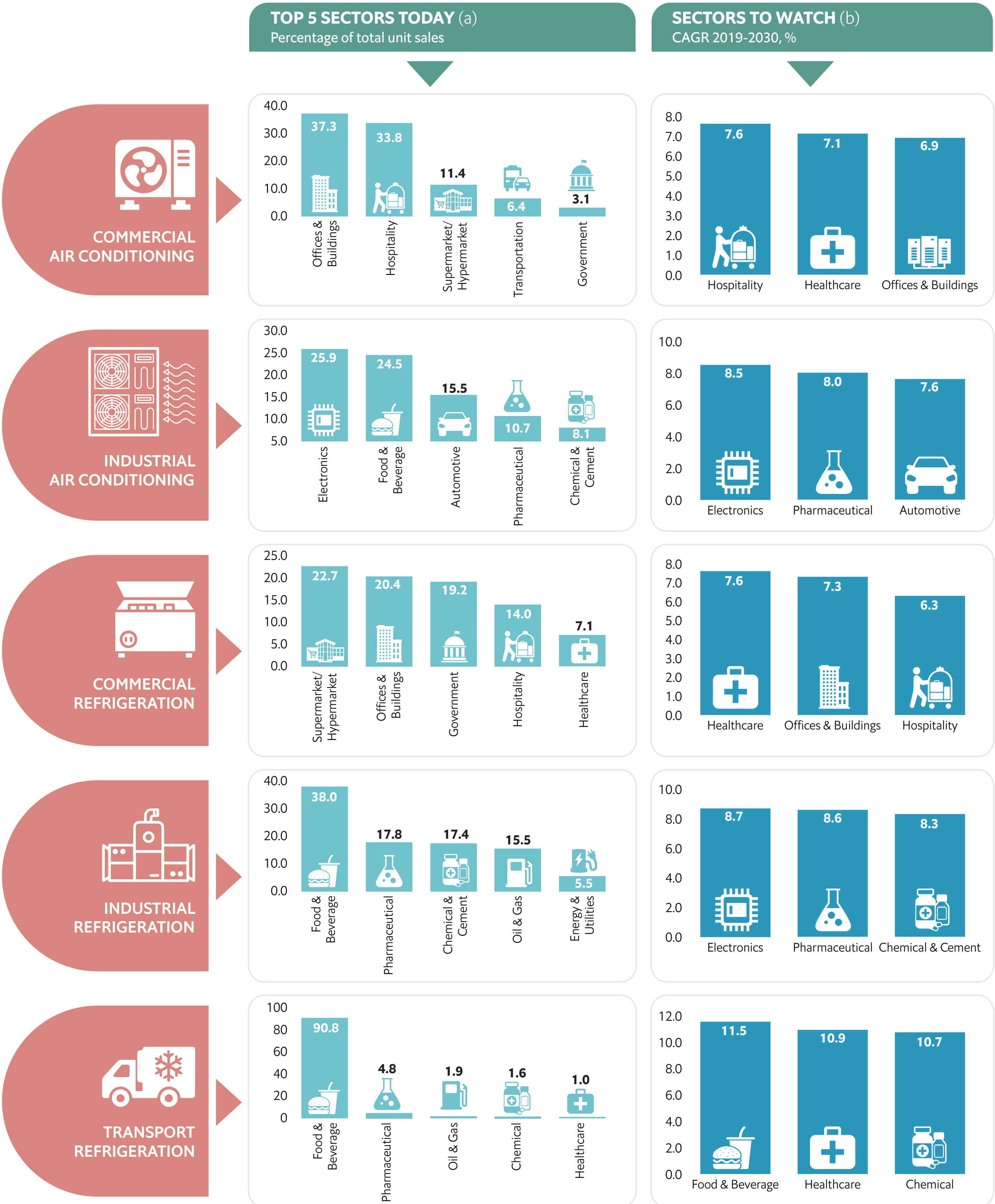
Compound annual growth rate (CAGR) 2018 to 2030



Source: EIU analysis

India

Key end-user sectors today and sectors to watch



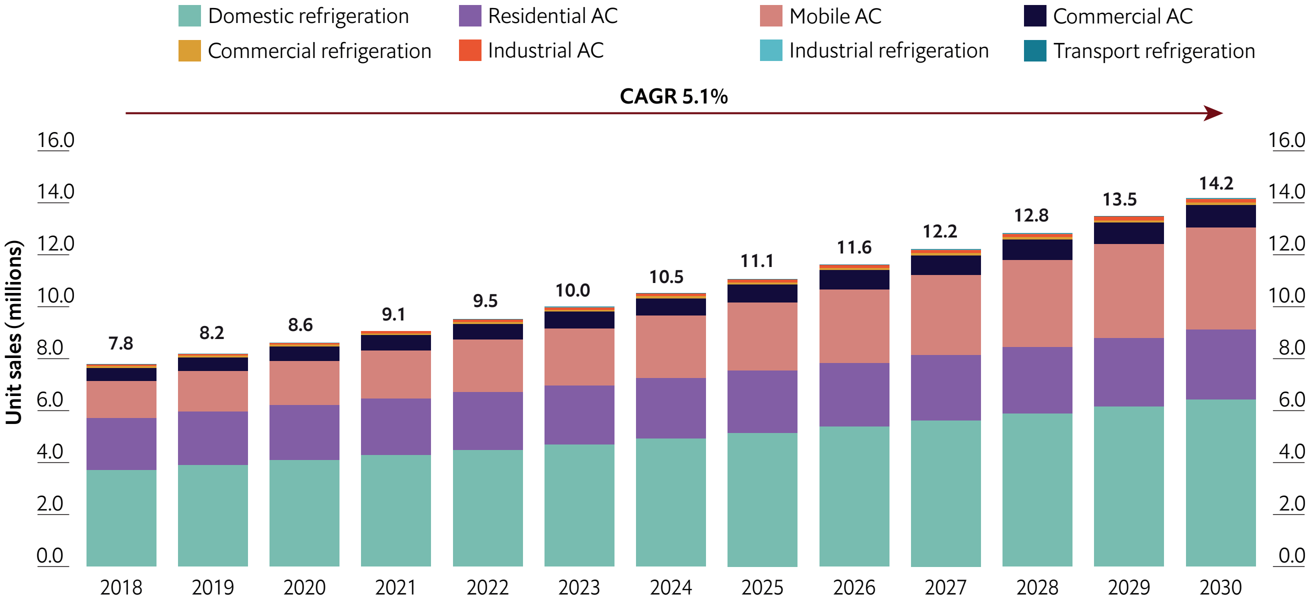
(a) 2018; (b) 2019-2030

Sources: PS Intelligence, EIU Analysis.

Indonesia

Annual cooling sales 2018:	**7.8m**
Annual cooling sales 2030:	**14.2m**
Compound annual growth rate (CAGR) 2018-2030:	**5.1%**

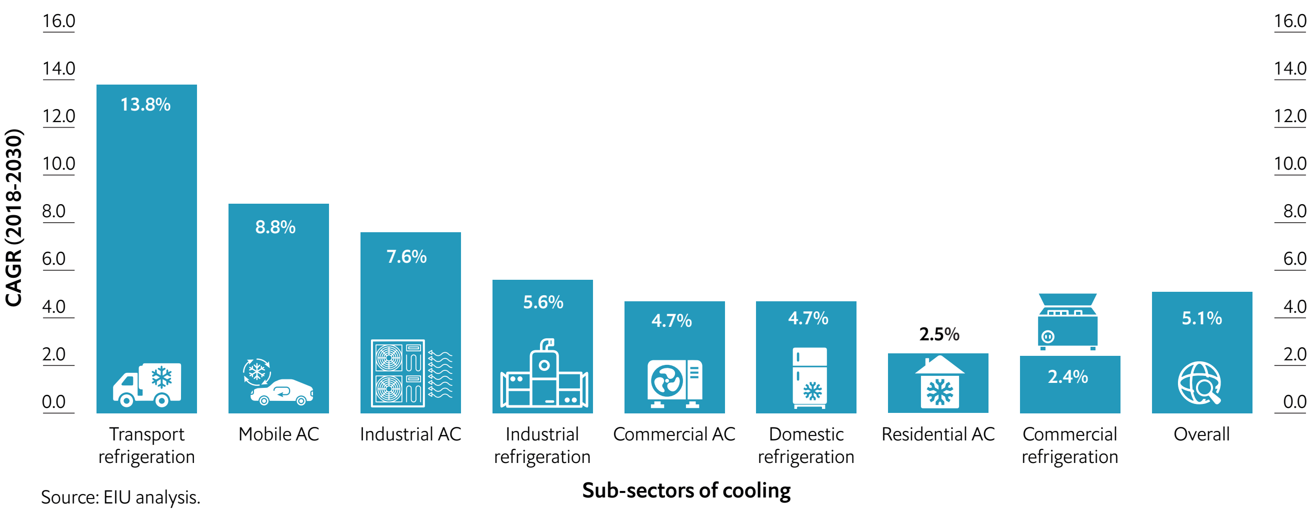
Indonesia: Cooling market size 2018-2030



Source: EIU analysis, P&S Intelligence, Green Cooling Initiative.

Indonesia: Sub-sectors growth to 2030

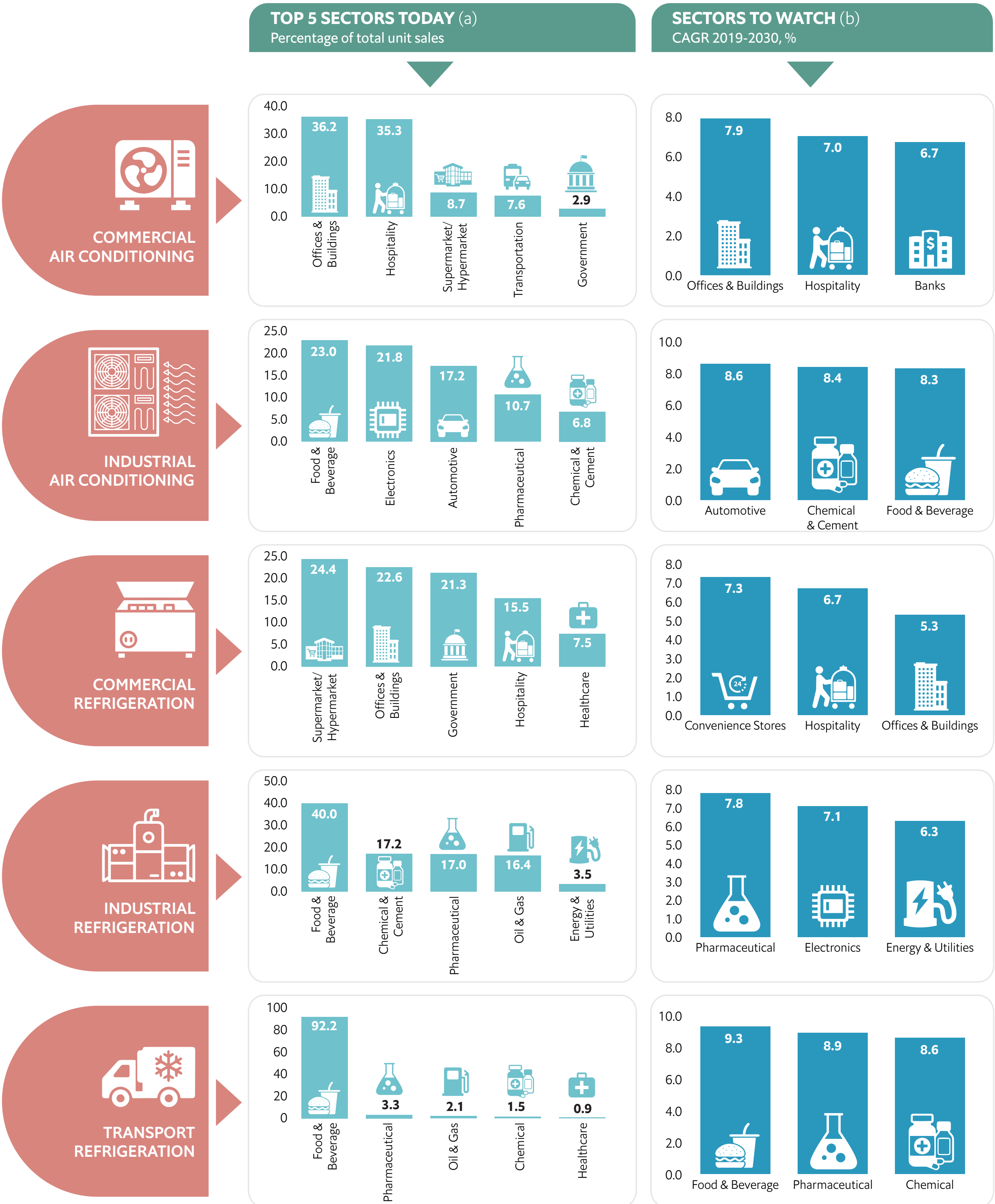
Compound annual growth rate (CAGR) for eight subsectors of cooling between 2018 to 2030



Source: EIU analysis.

Indonesia

Key end-user sectors today and sectors to watch



(a) 2018; (b) 2019-2030

Sources: PS Intelligence, EIU Analysis.

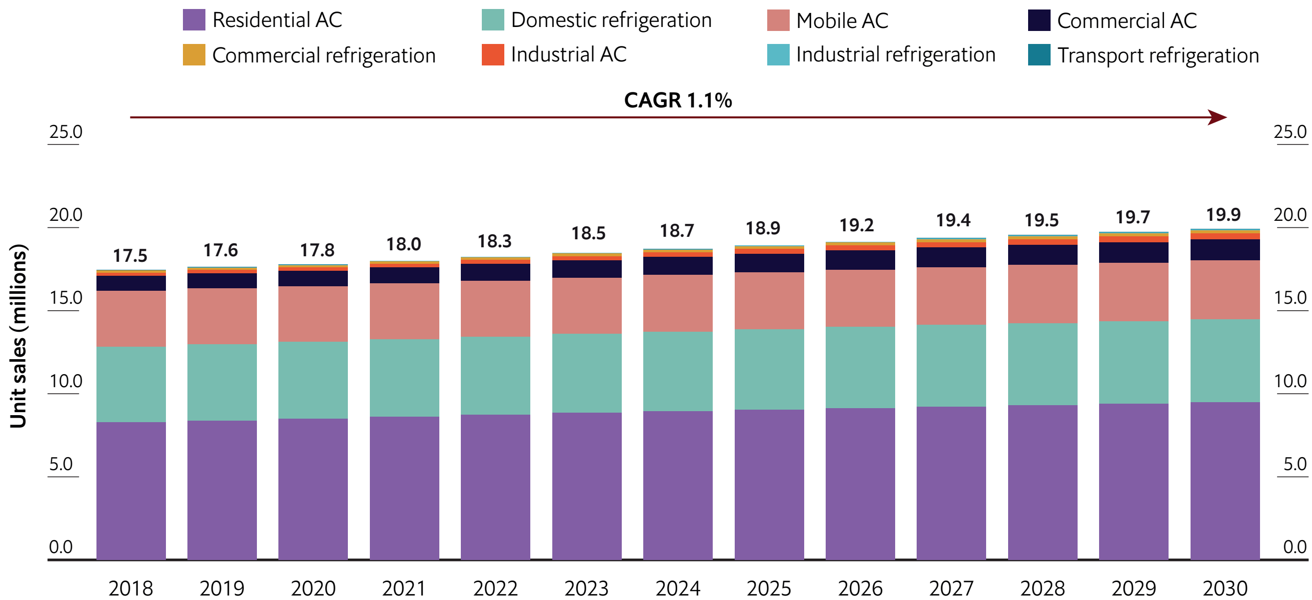
Japan

Annual cooling sales 2018: **17.5m**

Annual cooling sales 2030: **19.9m**

Compound annual growth rate (CAGR) 2018-2030: **1.1%**

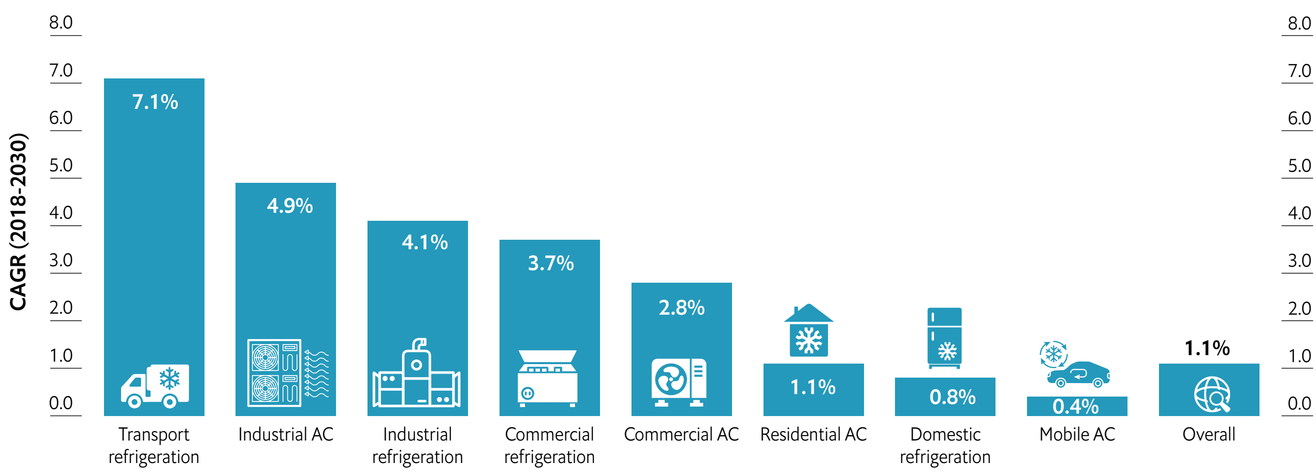
Japan: Cooling market size 2018-2030



Source: EIU analysis, P&S Intelligence, Green Cooling Initiative.

Japan: Sub-sectors growth to 2030

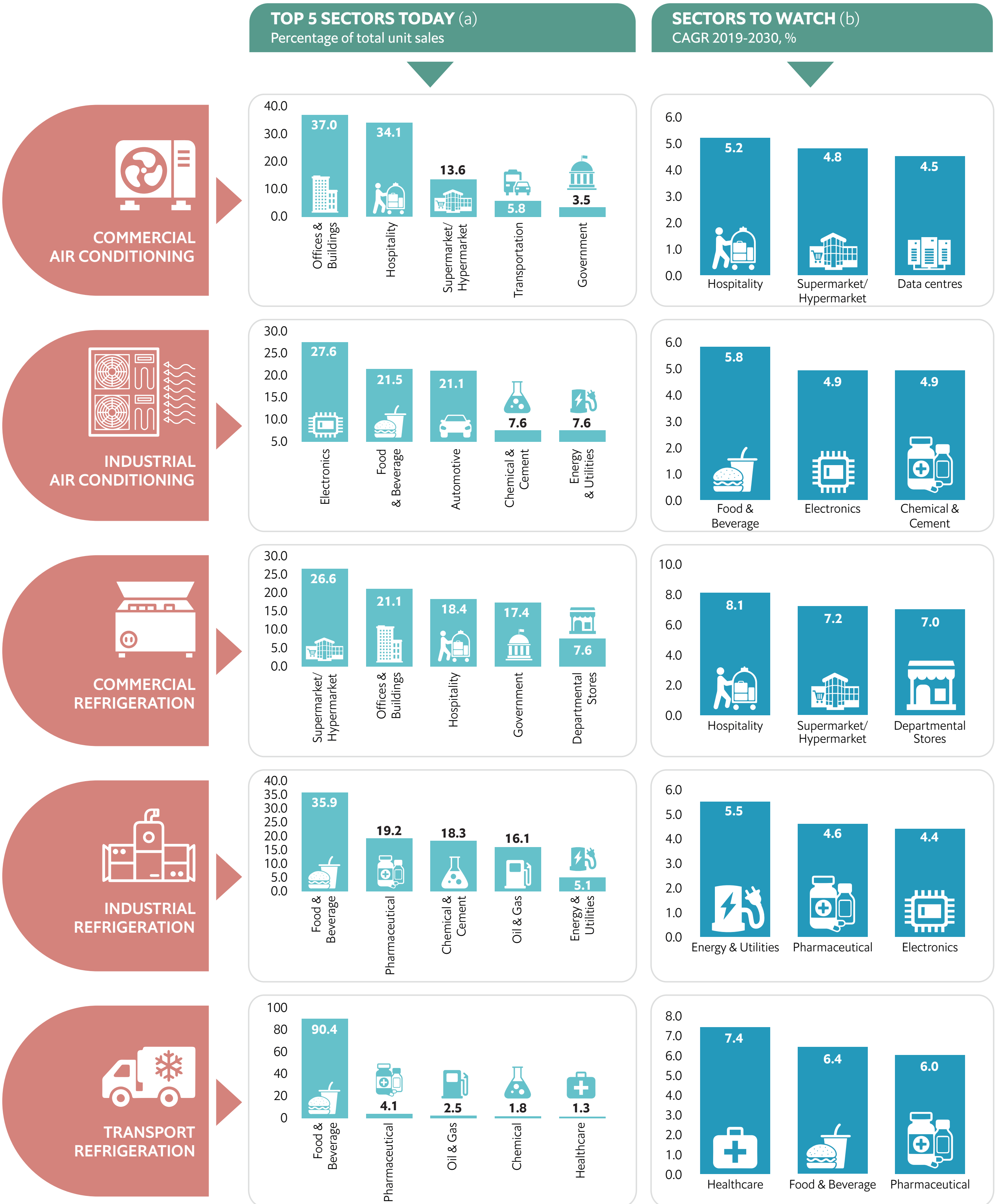
Compound annual growth rate (CAGR) for eight subsectors of cooling between 2018 to 2030



Source: EIU analysis.

Japan

Key end-user sectors today and sectors to watch



(a) 2018; (b) 2019-2030

Sources: PS Intelligence, EIU Analysis.

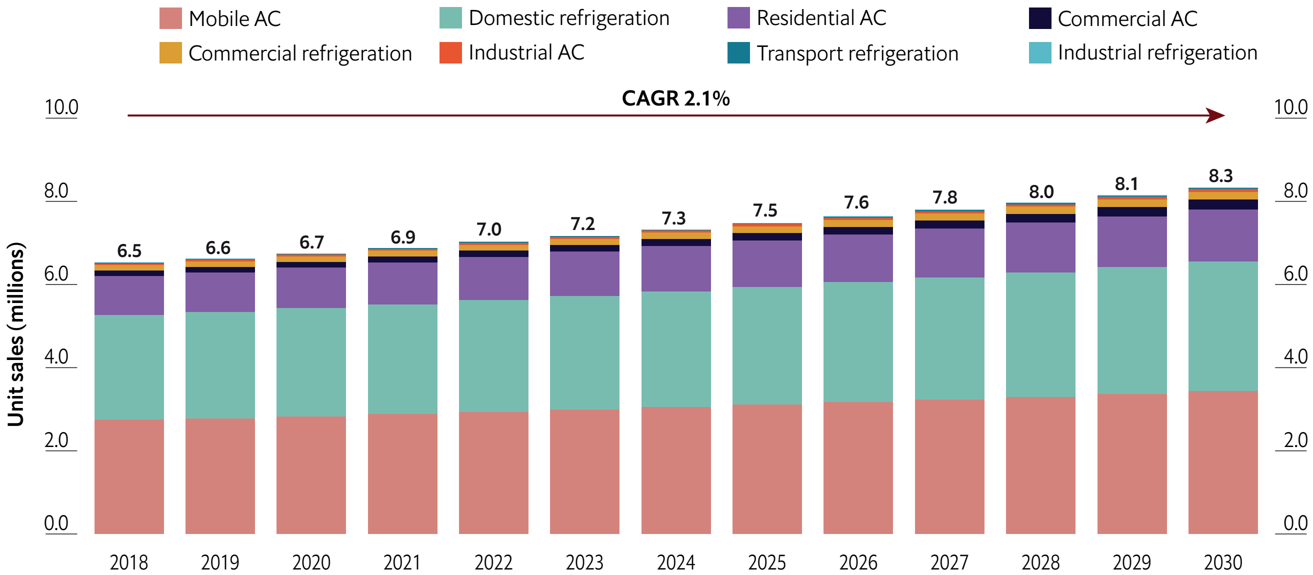
Mexico

Annual cooling sales 2018: **6.5m**

Annual cooling sales 2030: **8.3m**

Compound annual growth rate (CAGR) 2018-2030: **2.1%**

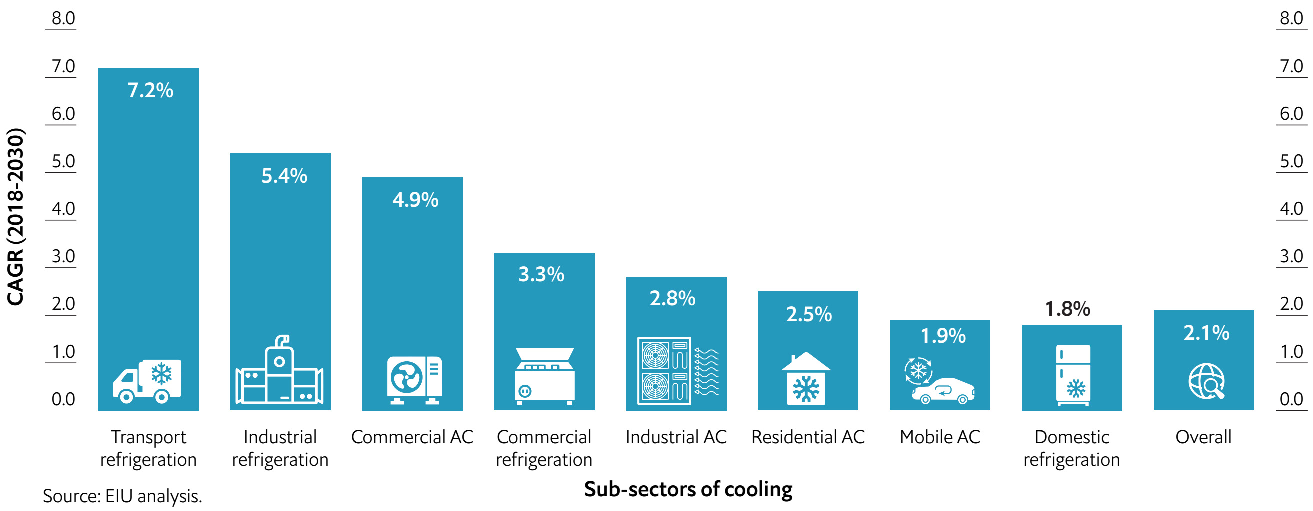
Mexico: Cooling market size 2018-2030



Source: EIU analysis, P&S Intelligence, Green Cooling Initiative.

Mexico: Sub-sectors growth to 2030

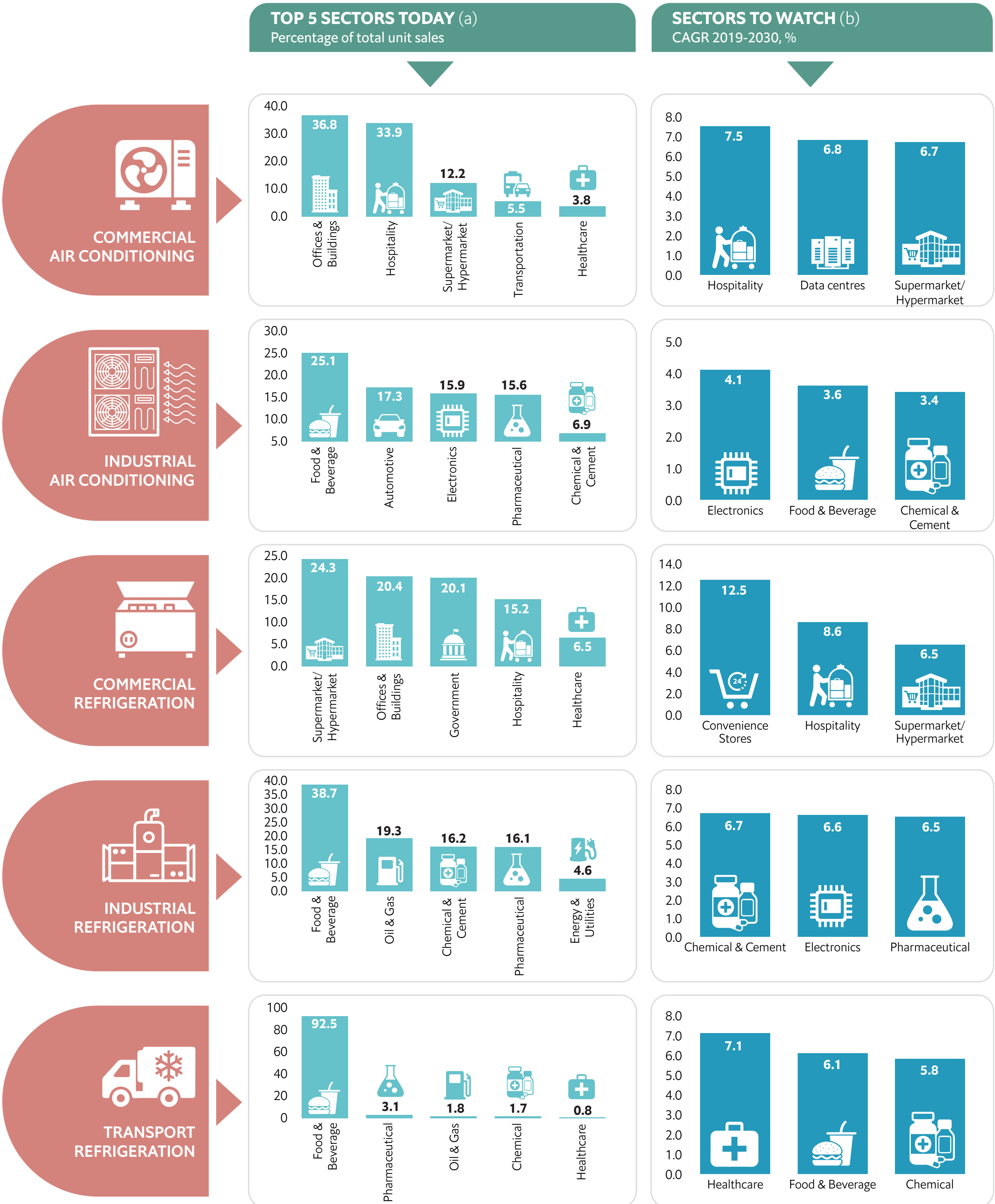
Compound annual growth rate (CAGR) for eight subsectors of cooling between 2018 to 2030



Source: EIU analysis.

Mexico

Key end-user sectors today and sectors to watch

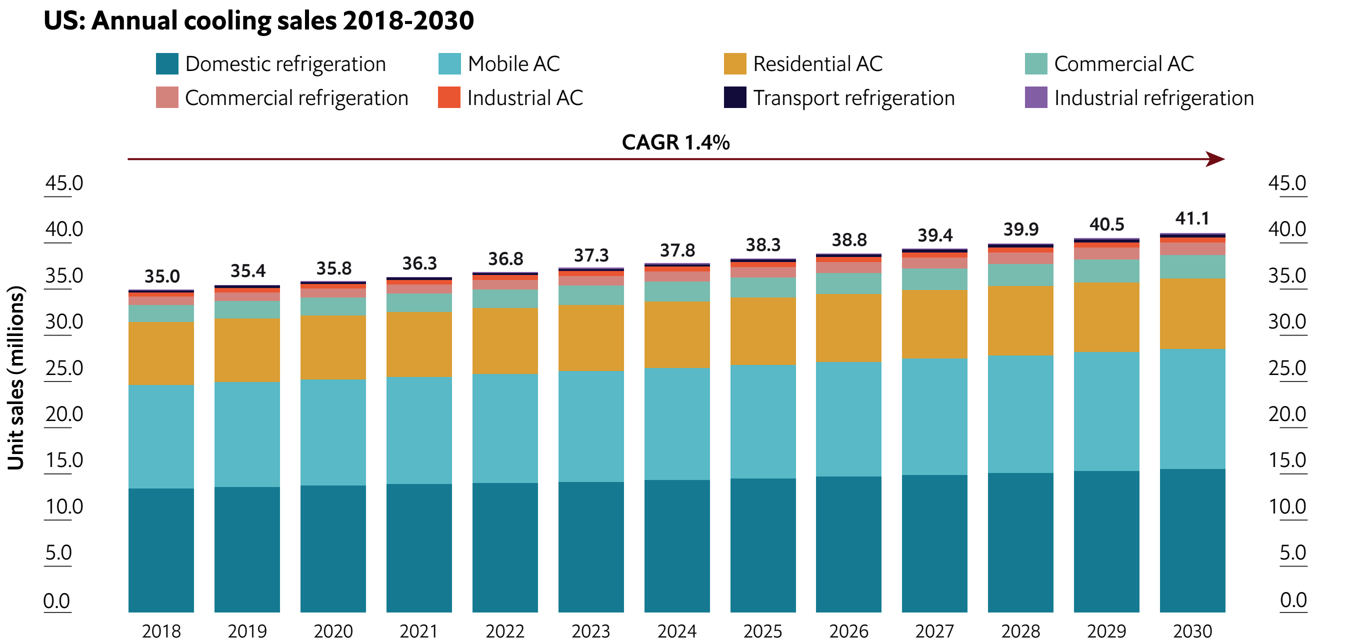


(a) 2018; (b) 2019-2030

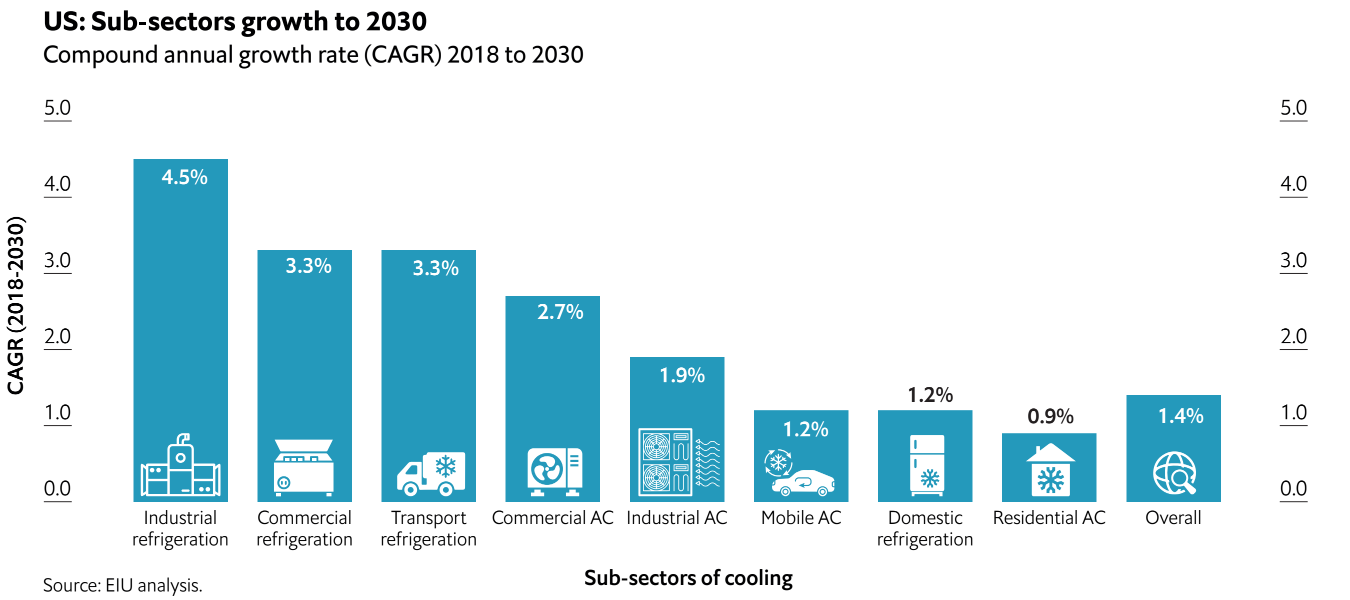
Sources: PS Intelligence, EIU Analysis.

United States

Annual cooling sales 2018:	34.9m
Annual cooling sales 2030:	41.1m
Compound annual growth rate (CAGR) 2018-2030:	1.4%



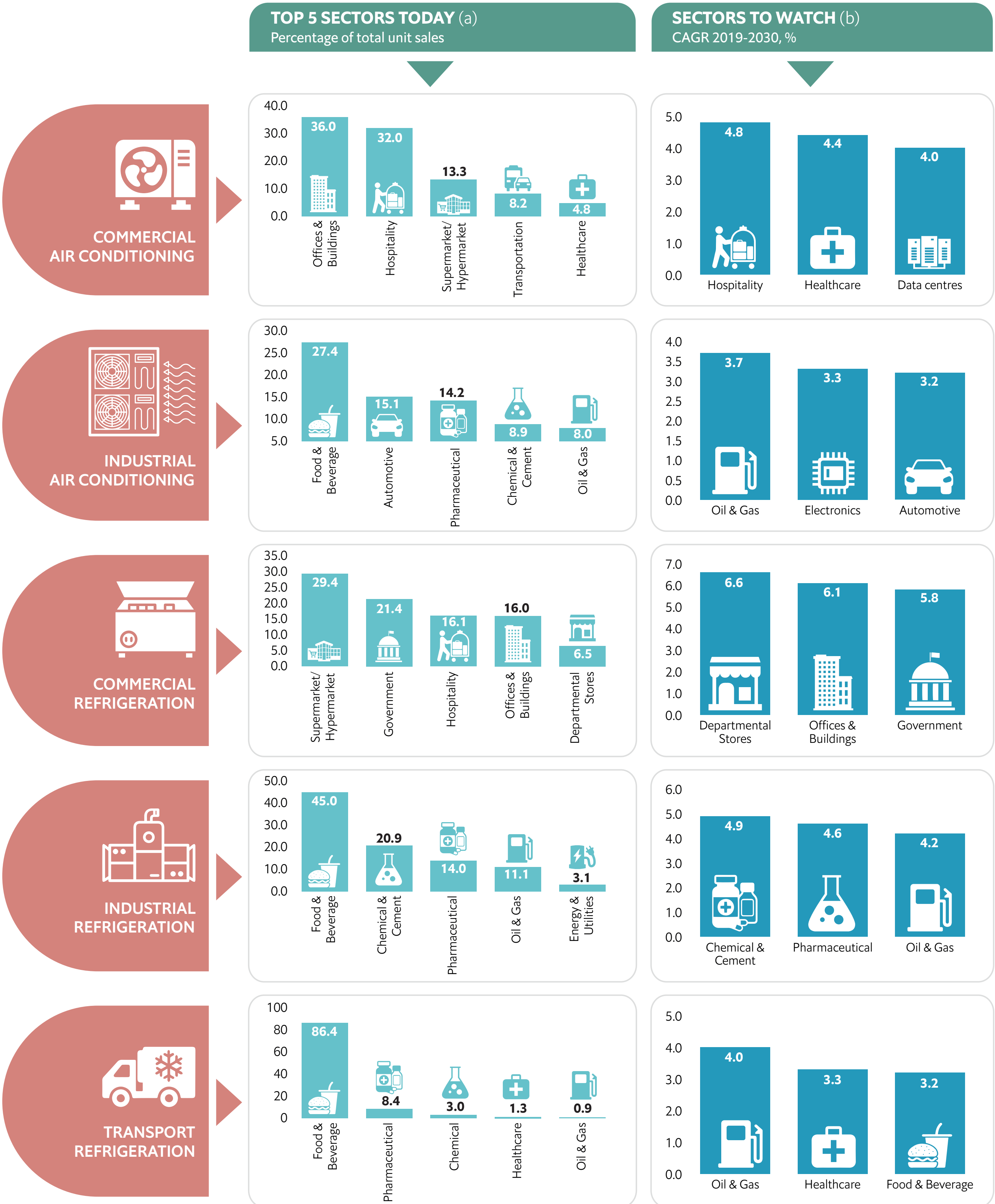
Source: EIU analysis, P&S Intelligence, Green Cooling Initiative.



Source: EIU analysis.

United States

Key end-user sectors today and sectors to watch



(a) 2018; (b) 2019-2030

Sources: PS Intelligence, EIU Analysis.

REFERENCE

1. Electric fans are also a common and cheap source of cooling, but are excluded from our definition in this report.
2. http://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf
3. https://www.ncbi.nlm.nih.gov/pubmed/22385303
4. https://materialdistrict.com/article/terracotta-cones-air-conditioning/
5. https://observers.france24.com/en/20160602-bangladesh-air-conditioner-plastic-bottles-technology
6. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf
7. https://www.ipcc.ch/sr15/chapter/spm/
8. Note: Covers stationary AC only.
9. https://archive.ipcc.ch/pdf/assessment-report/ar5/wg2/drafts/fd/WGIIAR5-Chap10_FGDall.pdf
10. https://www.sciencedirect.com/science/article/pii/S0301421508005168?via%3Dihub; https://www.iea.org/futureofcooling/
11. https://www.bbc.co.uk/news/resources/idt-985b9374-596e-4ae6-aa04-7fbcae4cb7ee
12. https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2018.pdf
13. https://www.bbc.co.uk/news/resources/idt-985b9374-596e-4ae6-aa04-7fbcae4cb7ee
14. https://www.bbc.co.uk/news/uk-49157898
15. https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2019/july-statistics
16. https://www.nber.org/papers/w23271.pdf
17. https://www.capgemini.com/gb-en/2019/08/heatwaves-hot-or-not-for-retailers/
18. https://data.worldbank.org/indicator/sp.urb.totl.in.zs; https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html
19. https://population.un.org/wup/Publications/Files/WUP2018-Highlights.pdf
20. https://www.nationalgeographic.org/encyclopedia/urban-heat-island/
21. https://www.sciencedirect.com/science/article/pii/S0378778811006293
22. https://www.climatecentral.org/news/urban-heat-islands-threaten-us-health-17919
23. https://www.sciencedirect.com/science/article/pii/S2210670717309769
24. https://www.mdpi.com/2072-4292/11/14/1645
25. https://pubs.iied.org/pdfs/10721IIED.pdf
26. https://www.birmingham.ac.uk/Documents/college-eps/energy/policy/Doing-Cold-Smarter-Report.pdf
27. https://www.brookings.edu/wp-content/uploads/2017/02/global_20170228_global-middle-class.pdf
28. Annual growth rates referred to here are compound annual growth rates, with real personal disposable income per head measured in US$.
29. https://www.green-cooling-initiative.org/country-data/#!unit-sales/domestic-refrigeration/absolute
30. https://www.psmarketresearch.com/aboutus
31. Panel data, also known as longitudinal data or cross-sectional time series data, is data that is derived from a (usually small) number of observations over time on a (usually large) number of cross-sectional units like individuals, households, firms, or countries (as in this case).
32. We recognise the diversity of equipment in the refrigeration and AC sectors. However, for simplicity we have aggregated the units of different types of equipment across refrigeration and AC, as other experts and institutes have in the past, such as the GCI, IEA and multiple commercial data providers.
33. We derived the assumptions about the share of global demand based on the proportion of GDP that the set of countries account for compared with global GDP in 2018 and out to 2030.
34. Calculated using compound annual growth rates.
35. https://www.gcca.org/about/about-cold-chain
36. Measured using compound annual growth rates. Note that due to differences in equipment coverage and sector breakdowns between our data and the India Cooling Action Plan these forecasts are not directly comparable.
37. Like for like papers using S-Curve modelling to forecast unit sales of cooling specifically were not found during the course of the research but Nihar Shah, Max Wei, Virginie Letschert and Amol Phadke's paper (https://ies.lbl.gov/sites/default/files/lbnl-1003671.pdf) shows an example of an S-curve approach to modelling AC stocks.
38. For example, the GCI's forecasts for ACs, which are based on data with higher historical growth rates. Note that the GCI focuses on all 'unitary' ACs.
39. Developed by the Ministry of Environment, Forest and Climate Change (MoEFCC) and Ozone Cell, with input from the AEEE. http://www.indiaenvironmentportal.org.in/files/file/DRAFT-India%20Cooling%20Action%20Plan.pdf

40. https://www.economist.com/special-report/2019/10/24/a-downturn-in-india-reveals-the-desperate-need-for-deeper-reform
41. https://www.washingtonpost.com/world/2019/06/28/europes-record-heatwave-is-changing-stubborn-minds-about-value-air-conditioning/
42. https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf
43. http://www.fao.org/save-food/resources/keyfindings/en/
44. http://www.fao.org/state-of-food-security-nutrition/en/
45. Field heat describes the difference in temperature between the temperature of the crop harvested and the optimal storage temperature of that product.
46. http://www.fao.org/3/ca6030en/ca6030en.pdf
47. https://www.birmingham.ac.uk/Documents/college-eps/energy/policy/Doing-Cold-Smarter-Report.pdf
48. https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/india-third-agricultural-revolution-birmingham-energy-institute.pdf
49. http://naturalleader.com/wp-content/uploads/2016/04/UTC-Nottingham-Report_3-30_FINAL.pdf
50. https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/india-third-agricultural-revolution-birmingham-energy-institute.pdf
51. https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/india-third-agricultural-revolution-birmingham-energy-institute.pdf
52. http://www.fao.org/state-of-fisheries-aquaculture
53. http://www.bim.ie/media/bim/content/downloads/BIM,Retailers,Guide, to,Cold,Chain, Management,for, Seafood_4.pdf
54. https://www.tandfonline.com/doi/abs/10.1080/09613218.2011.552703
55. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2998052/
56. https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf
57. https://www.who.int/sustainable-development/housing/health-risks/extreme-heat-cold/en/
58. https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf
59. http://www.ncef.org/content/research-report-effects-hvac-student-performance
60. https://eric.ed.gov/?id=EJ096100
61. This figure is an average, with the impact ratcheting up at the higher temperature bands. Compared with school days with temperatures in the 60s (°F), each additional day with a temperature in the 90s (°F) reduced achievement by one-sixth of a percent of a year's worth of learning. A day above 100 (°F) has an effect up to 50% larger. https://scholar.harvard.edu/files/joshuagoodman/files/w24639.pdf
62. http://www.ncef.org/content/research-report-effects-hvac-student-performance
63. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2998052/pdf/GHA-3-5610.pdf
64. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2998052/pdf/GHA-3-5610.pdf
65. https://cdn.obr.uk/FSR-July-2018-1.pdf
66. https://www.oxfordmartin.ox.ac.uk/downloads/Productivity%20Paradox%20Report.pdf
67. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(18)30237-7/fulltext
68. https://sdg.iisd.org/news/ilo-warns-of-work-related-heat-stress-causing-job-and-productivity-losses/
69. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4730480/
70. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_711919.pdf
71. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3001853/
72. https://www.nber.org/papers/w22962; https://www.isiaq.org/docs/papers/272.pdf
73. https://advances.sciencemag.org/content/4/5/eaar5809
74. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5854721/
75. https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf
76. https://www.energy.gov/sites/prod/files/2016/07/f33/The%20Future%20of%20AC%20Report%20-%20Full%20Report_0.pdf
77. http://wedocs.unep.org/bitstream/handle/20.500.11822/8014/-HFCs_%20A%20Critical%20Link%20in%20Protecting%20%20Climate%20and%20the%20Ozone%20Layer-20111072.pdf; https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/2018OzoneAssessment.pdf
78. Devices used to move heat from cool spaces to warmer spaces.
79. http://www.gluckmanconsulting.com/wp-content/uploads/2015/04/FS-2-Overview-of-HFC-Markets-final-rev1-.pdf

80. http://www.c2es.org/document/greenhouse-gas-emissions-from-aviation-and-marine-transportation-mitigation-potential-and-policies/

81. https://journals.ametsoc.org/doi/full/10.1175/WCAS-D-16-0125.1; https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1002599

82. https://www.seforall.org/sites/default/files/SEforALL_CoolingForAll-Report.pdf

83. https://www.seforall.org/news/building-markets-for-sustainable-cooling-technology-in-indonesia

84. https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018-clean-cold-report.pdf; https://www.seforall.org/news/new-chilling-prospects-report-shows-lack-of-cooling-access-threatens-health-prosperity-and-the

85. https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2019/9-improving-energy-efficiency-in-ict-appliances-and-products/accelerating-cooling-efficiency-in-indonesia/; https://eta.lbl.gov/publications/baseline-evaluation-policy

86. http://www.mitsubishi-electric.co.nz/heatpump/3D-i-See-Sensor.aspx

87. Heat exchangers work by transferring heat across mediums, such as coolants being pumped into hot coils and pipes or, in cooling, a refrigerant which absorbs heat from a medium and evaporates.

88. https://www.mdpi.com/2073-4433/10/5/282; https://www.energy.gov/energysaver/design/energy-efficient-home-design/cool-roofs

89. https://www.oekorecherche.de/sites/default/files/publikationen/giz_side_event_greenfreeze_brochure.pdf

90. http://hydrocarbons21.com/articles/8892/godrej_launches_new_hc_air_conditioners;

91. http://hydrocarbons21.com/articles/9129/chinese_companies_report_sales_of_nearly_160_000_propane_room_acs

92. https://saemobilus.sae.org/content/2019-01-0909

93. https://ec.europa.eu/clima/policies/f-gas/alternatives_en

94. https://www.sciencedirect.com/topics/engineering/district-cooling-system; https://www.sciencedirect.com/science/article/abs/pii/S0306261914011635

95. https://core.ac.uk/download/pdf/82270543.pdf

96. https://webstore.iea.org/the-future-of-cooling

97. https://ies.lbl.gov/sites/default/files/lbnl-1003671.pdf

98. https://science.sciencemag.org/content/sci/357/6356/1130.full.pdf

99. https://www.sri.com/sites/default/files/brochures/sri_delta_coolingboot_2017_datasheet.pdf

100. https://setis.ec.europa.eu/system/files/integrated_set-plan/bham_input_action6_0.pdf; https://www.birmingham.ac.uk/Documents/college-eps/energy/policy/Doing-Cold-Smarter-Report.pdf

101. https://eprints.qut.edu.au/115095/

102. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.822.5611&rep=rep1&type=pdf

103. https://www.drawdown.org/solutions/materials/refrigerant-management

104. Developed by the Ministry of Environment, Forest and Climate Change (MoEFCC) and Ozone Cell, with input from the AEEE. http://www.indiaenvironmentportal.org.in/files/file/DRAFT-India%20Cooling%20Action%20Plan.pdf

105. https://www.scmp.com/business/article/2040177/why-montreal-protocol-most-successful-climate-agreement-ever

106. https://treaties.un.org/doc/Publication/MTDSG/Volume%20II/Chapter%20XXVII/XXVII-2-f.en.pdf

107. https://ec.europa.eu/clima/policies/f-gas/legislation_en

108. http://www.alliancepolicy.org/site/usermedia/application/5/consumer_costs_final_inforumjms_20181110.pdf

109. https://eia-international.org/wp-content/uploads/Chilling-Facts-VII-FINAL-1.pdf

110. https://www.seforall.org/sites/default/files/gather-content/SEforALL_CoolingForAll-Report.pdf

111. https://www.worldgbc.org/news-media/green-buildings-yield-30-80-lower-utility-costs-compared-standard-buildings-finds-gbc

112. https://www.carbonbrief.org/oecd-fossil-fuel-subsidies-373-billion-2015

113. https://www.sciencedirect.com/science/article/abs/pii/S0305750X16304867

114. Note: ACCA supports programmes that encourage the correct installation of highly efficient systems as a way to ensure that consumers see the benefits of their investments and that taxpayer resources are used appropriately.

115. http://trade.ec.europa.eu/doclib/docs/2018/september/tradoc_157319.pdf

116. http://www3.weforum.org/docs/Environment_Team/40049_Shaping_Future_Environment_Natural_Resource_Security_report_2018.pdf

117. http://www.alliancepolicy.org/site/usermedia/application/5/consumer_costs_final_inforumjms_20181110.pdf

118. This list is not exhaustive and does not analyse the actual cooling use of these companies. It is simply a list of some of the largest companies by revenue for that sector, in each country. Company consumer names are used.

119. https://www.iea.org/publications/freepublications/publication/Building2013_free.pdf

120. https://ec.europa.eu/europeaid/blending/ecocasa-programme_en; https://unfccc.int/climate-action/momentum-for-change/financing-for-climate-friendly/mexico-financing-sustainable-housing
121. https://www.ashden.org/winners/ecocasa#continue; https://www.passivehouse-international.org/index.php?page_id=482; https://europa.eu/capacity4dev/public-environment-climate/blog/ecocasa-and-mexico%E2%80%99s-green-all-housing-recovery
122. Includes retailers (not supermarkets/hypermarkets and other non-residential buildings).
123. Excluding individual consumers, who are the leading end-users of residential AC, domestic refrigeration and mobile AC.
124. https://www.virgin.com/entrepreneur/why-going-green-was-important-empire-state-building
125. https://www.esbnyc.com/sites/default/files/ESBOverviewDeck.pdf
126. https://www.seforall.org/news/building-markets-for-sustainable-cooling-technology-in-indonesia
127. https://www.ic.gc.ca/eic/site/051.nsf/eng/home
128. https://www.newswire.ca/news-releases/minister-tassi-marks-completion-of-project-to-improve-facilities-at-mohawk-college-692854401.html
129. This excludes consumers themselves who are considered the end-user for the residential AC, domestic refrigeration and mobile AC sectors.
130. https://www.danfoss.com/en/service-and-support/case-studies/dcs/hotel-with-chiller-retrofit/
131. https://www.stats.gov.lc/
132. https://www.jademountain.com/about_us/environment.html
133. This excludes consumers themselves who are considered the end-user for the residential AC, domestic refrigeration and mobile AC sectors.
134. Behind Offices & Buildings at the top of the list and Hospitality in second place.
135. https://www.coolingpost.com/features/study-sees-fridge-doors-sales-barrier/
136. https://www.coolingpost.com/features/study-sees-fridge-doors-sales-barrier/
137. Woolworths is an EP100 member and this intervention was a part of its effort to double energy productivity.
138. https://www.theclimategroup.org/sites/default/files/ep100_annual_report_final.pdf
139. https://www.euroheat.org/news/local-residents-stay-warm-thanks-supermarkets-cooling-system/
140. https://shaktifoundation.in/wp-content/uploads/2019/04/Cold-Chains-in-India-Report-Final-Web.pdf
141. https://www.ecozensolutions.com/innovation/micro-cold-storage
142. https://issuu.com/shecco/docs/aaunz1611/63
143. https://www.green-cooling-initiative.org/refrigeration-sectors/mobile-air-conditioning/
144. Mahindra & Mahindra is an EP100 member.
145. https://www.theclimategroup.org/news/playing-it-cool-major-companies-take-climate-friendly-cooling-challenge
146. We have not quantified the use of ACs in planes, metros and trains, but our research identified case studies of good practice, detailed here.
147. https://company.ingersollrand.com/content/dam/ir-corp/documents/sustainabilitysupplement/IR_2018_ESGReport.pdf; https://www.eurotunnel.com/uk/build/
148. https://www.trane.com/commercial/north-america/us/en/about-us/newsroom/press-releases/worlds-longest-undersea-tunnel-stays-cool.html
149. https://cundall.com/Projects/Facebook-Lule%C3%A5.aspx
150. https://cundall.com/Projects/Telef%C3%B3nica.aspx
151. https://deepmind.com/blog/article/safety-first-ai-autonomous-data-centre-cooling-and-industrial-control
152. https://www.contractpharma.com/issues/2012-05/view_features/temperature-sensitive-pharma-concerns/
153. https://www.danfoss.com/en-gb/about-danfoss/our-businesses/cooling/refrigerants-and-energy-efficiency/refrigerants-for-lowering-the-gwp/hydrocarbons/
154. https://issuu.com/shecco/docs/1809_aasia
155. https://www.k-cep.org/wp-content/uploads/2018/10/Kigali_CEP_GlobalHospital Cooling_102418.pdf
156. GGHH is a network of 1,200 hospitals and healthcare facilities across 60 countries which works to reduce member institutions' environmental footprint and promote public and environmental health.
157. https://www.greenhospitals.net/wp-content/uploads/2018/03/Secretar%C3%ADa-de-Salud-P%C3%BAblica-Cali-Colombia.pdf
158. https://www.aeee.in/space-cooling/
159. http://coolcoalition.org/cooling-in-a-warming-world-opportunities-for-delivering-efficient-and-climate-friendly-cooling-for-all/

160. https://ies.lbl.gov/publications/opportunities-simultaneous-efficiency
161. https://www.oxfordmartin.ox.ac.uk/future-of-cooling/
162. https://www.k-cep.org/wp-content/uploads/2019/07/Cool_Coalition_National_Government_Guidance_Note.pdf
163. https://www.transparency-partnership.net/sites/default/files/rac-sector-and-indcs-eng-final-web.pdf
164. https://united4efficiency.org/resources/model-regulation-guidelines-for-energy-efficient-and-climate-friendly-air-conditioners/
165. https://united4efficiency.org/resources/guidance-note-on-what-is-a-product-registration-system-and-why-use-one-1-4/
166. https://www.esmap.org/cooling
167. https://www.theclimategroup.org/sites/default/files/ep100_annual_report_final.pdf
168. https://www.ashrae.org/technical-resources/bookstore/refrigeration-commissioning-guide-free-download
169. https://www.carbontrust.com/resources/guides/energy-efficiency/heating-ventilation-and-air-conditioning-hvac/#guides
170. https://www.k-cep.org/wp-content/uploads/2019/07/Cool_Coalition_Business_Guidance_Note.pdf
171. https://www.imt.org/wp-content/uploads/2018/08/Small-Business-Energy-Initative-Action-Guide.pdf
172. https://www.clean-cooling.ac.uk/investing-in-clean-cooling
173. https://www.ashden.org/
174. http://energy-base.org/project/cooling-as-a-service/
175. https://www.theclimategroup.org/news/playing-it-cool-major-companies-take-climate-friendly-cooling-challenge
176. https://www.ccacoalition.org/en
177. http://coolcoalition.org/
178. http://www.districtenergyinitiative.org/
179. https://www.epeeglobal.org/about-us/
180. https://globalcoolingprize.org/
181. https://www.k-cep.org/

The Economist INTELLIGENCE UNIT

LONDON
20 Cabot Square
London
E14 4QW
United Kingdom
Tel: +44 (0) 20 7576 8181
Email: london@eiu.com

NEW YORK
750 Third Avenue
5th Floor
New York, NY 10017
United States
Tel: + 1 212 698 9717
Email: americas@eiu.com

HONG KONG
1301 Cityplaza Four
12 Taikoo Wan Road
Taikoo Shing
Hong Kong
Tel: + 852 2802 7288
Email: asia@eiu.com