

China's Cooling Imperative

A report by The Economist Intelligence Unit



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Foreword

China's Cooling Imperative is an Economist Intelligence Unit (EIU) report, commissioned by the Kigali Cooling Efficiency Program (K-CEP). The findings are based on an extensive literature review, an expert interview programme and a modelling exercise conducted by The EIU between January and March 2020. The EIU bears sole responsibility for the content of this report. The findings and views do not necessarily reflect the views of K-CEP.

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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 measurable 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, please 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 programme office, the Efficiency Cooling Office, is housed at the ClimateWorks Foundation in San Francisco.

Executive summary

Cooling is a major contributor to climate change, accounting for at least 9% of greenhouse gas emissions globally. China is the world's largest producer of cooling equipment. 70% of the world's air conditioners are made in and exported from China. China is also the world's leading user of household cooling equipment, accounting for 22% of installed household air conditioning units and 18% of the world's residential refrigerators.

As a consequence, China is the world leader in emissions from cooling, comprising roughly one third of global cooling emissions. As rapid urbanisation and economic development continues, The Economist Intelligence Unit expects that cooling emissions could grow to 2,005 Mt by 2030, representing a 48% increase over 2019 levels.

Yet China has a major opportunity to substantially reduce and even arrest that growth, limiting China's emissions to 1,417Mt per year in 2030 or 29% lower than the baseline scenario. In this report, The EIU assesses the main policy levers available to the Chinese government for greening the cooling sector and quantifies the impact on future greenhouse gas emissions. These scenarios are (all annual emissions savings are relative to Current Trends, an extrapolation of historical data through to 2030):

- *Demand Reduction*, where consumer awareness campaigns help to reduce the use of cooling equipment across residential, commercial, industrial and mobile sectors in the period to 2030 (annual emissions savings of 2%, meaning annual emissions in year 2030 are 2% lower than in Current Trends).
- *Efficiency Boost*, where energy efficiency standards go beyond the targets of China's national cooling plan, resulting in higher adoption of high-efficiency equipment (annual emissions savings of 8%, meaning annual emissions in year 2030 are 8% lower than in Current Trends).
- *Green Safety*, where the safety issues associated with more environmentally friendly refrigerants are resolved, facilitating a faster transition away from fluorinated gases (annual emissions savings of 19%, meaning annual emissions in year 2030 are 19% lower than in Current Trends).
- *Windfall*, where the combined impacts of steps taken in the Demand Reduction, Efficiency Boost and Green Safety scenarios demonstrate the vast potential of pulling all of these policy levers (annual emissions savings of 29%, meaning annual emissions in year 2030 are 29% lower than in Current Trends).

Greening the cooling sector will have substantial economic benefits for China in an era of significant disruption and business uncertainty. The consumer awareness campaigns in Demand Reduction could yield savings of US\$40bn over ten years. The energy efficiency standards of Efficiency Boost would have an even larger impact, freeing up US\$141bn in energy savings to reinvest in the economy. The combined impact of demand and efficiency savings, represented in *Windfall*, is US\$177bn—a significant benefit to the Chinese economy.

Exports would grow, too. With higher energy efficiency and refrigerant standards, China's cooling producers could expand their share of the global cooling equipment market by 4-5 percentage points, particularly in markets where their success has been limited such as Europe. The result is US\$1.4bn in

new exports per year, representing an additional US\$2.4bn for China's GDP and 87,000 new jobs in cooling-related supply chains.

Within China's cooling sector, some areas stand out as benefiting from the greatest scope for emissions reduction. Air conditioning has greater potential for energy efficiency improvements than refrigeration. In the scenario that models the most aggressive policy response (*Windfall*), air conditioning has the potential to deliver a 31% reduction in emissions relative to the *Current Trends* scenario—nearly 6 times than refrigeration's potential reduction in emissions—representing US\$152bn in savings over ten years.

Refrigerants' large contribution to emissions suggests that a transition to low-Global Warming Potential (GWP) refrigerants would provide a significant boost to China's fight against climate change. Phasing in low- or zero-GWP refrigerants could reduce annual emissions from China's domestic cooling sector by up to 266 Mt in CO₂ equivalent by 2030, relative to the *Current Trends* scenario. There is evidence from both producers and consumers of cooling that the market is eager to comply with the principles of the Kigali Amendment to the Montreal Protocol.

The fast-growing mobile cooling sector provides an opportunity for green development of transport refrigeration and mobile air conditioning. Stocks have grown sevenfold since 2009, and the mobile cooling sector will account for 181 Mt of annual emissions by 2030 without new actions to green the sector. As customers grow more environmentally conscious and the government continues to promote electric cars, industry-driven efficiency standards in mobile air conditioning represent an opportunity for automakers to gain market share through innovation.

Greening China's cooling sector will not be easy. Decades of rapid development means that consumer awareness of environmental objectives remains low. Cheap, subsidised, electricity will not help in the development of a conservation-minded society. Vague standards for energy efficiency make enforcement difficult for regulators and companies are not clear on how to comply. And safety concerns over use of the most environmentally-friendly refrigerants are preventing their widespread adoption.

China is already a global leader in the cooling sector, from production to technology and standards. By combining the best practices of other countries with current initiatives, the government can facilitate a green policy environment that grows Chinese companies' market share, supports the fight against global warming and enhances China's image in the international community.

Introduction

Demand for cooling has grown rapidly in China, where the sector is now responsible for as much as half of the country's electricity consumption during peak times. The commercial spaces requiring air conditioning that were once limited to China's top-tier cities can now be found all over the country, and supply chains are evolving to better handle growing requirements for temperature-controlled logistics. This growth is a major contributor to global warming. There is some good news, however: thanks to more efficient equipment, emissions growth is slower than growth in cooling demand.

China has increasingly prioritised environmental sustainability in recent years, with positive results. Air quality continues to improve, reflecting years of legislation aimed at reducing emissions and transitioning to cleaner energy, with rigorous (if uneven) implementation. Phase-outs are also planned for the most problematic greenhouse gases (GHGs). Despite this progress, there is evidence that even greater sustainability efforts will be required in the next decade. Using a scenario-based forecast, The EIU has analysed China's potential emissions profile in the period to 2030, as well as the policy environment that will shape this profile.

This report is based on expert interviews, an extensive literature review and a bespoke model for cooling emissions and economic consequences. Five policy scenarios based on cooling utilisation, energy efficiency and refrigerant standards represent possible paths forward for China's cooling sector.

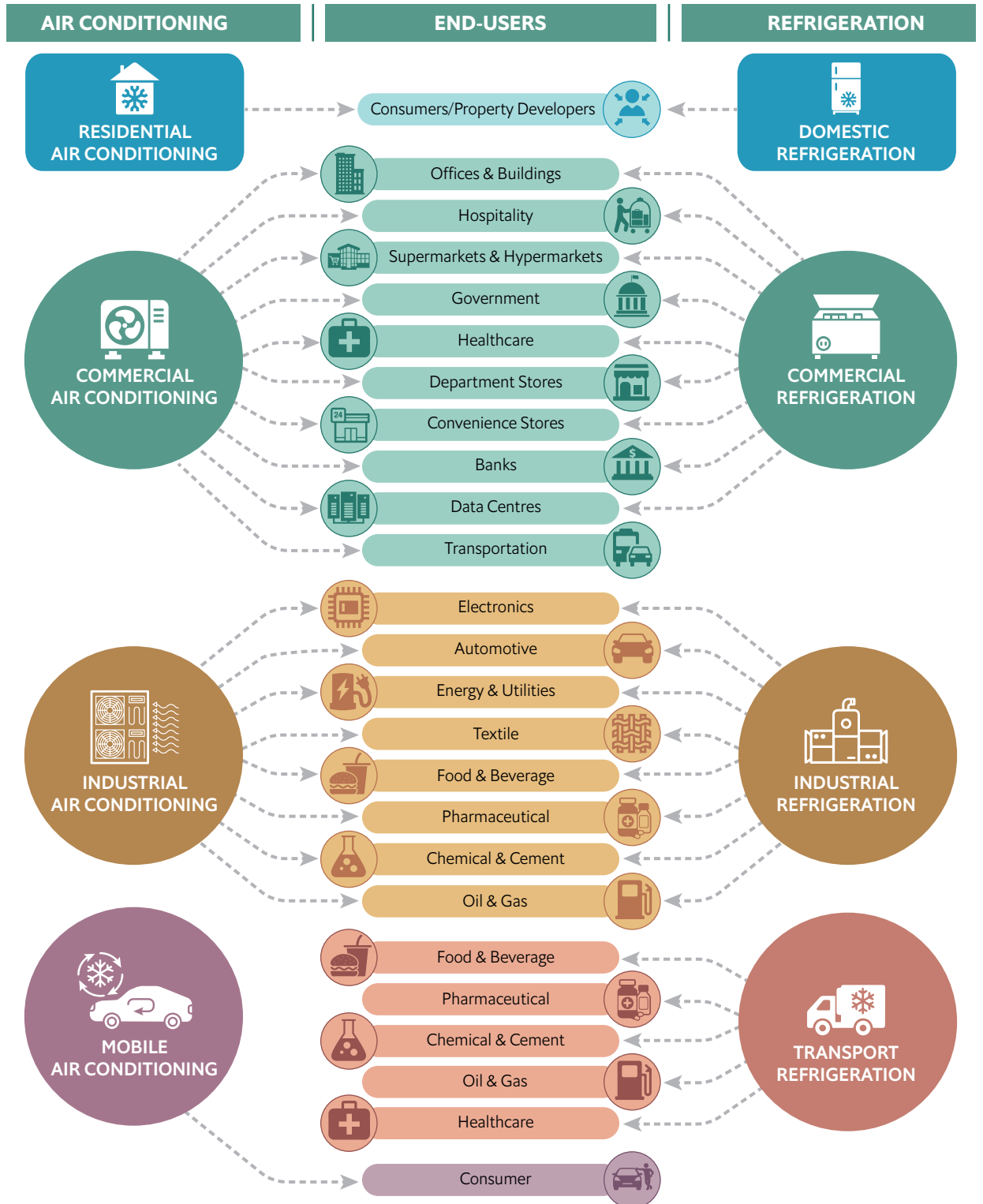
- Section One of this report presents the policy scenarios, our model and the results of the scenario-based forecasts.
- Section Two introduces the economic context for China's cooling sector, explores the policy implications of the model's findings and presents considerations for cooling stakeholders in China.

What is cooling and who uses it?

Refrigeration and air conditioning (AC) are the primary forms of cooling in use today.¹ Refrigeration refers to 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 that require careful temperature control, such as imaging and scanning. Air conditioning refers to the systems that control ambient temperature (the temperature of the surrounding air) for the benefit of people in the home, in the workplace and on the move. In buildings, air conditioning may be provided by small fixed units or by large centralised "chillers" that generate and transport chilled water to remove heat. Room air conditioners (RACs), which are typically mounted in windows, account for approximately 70% of air conditioners in use today.

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 different types of cooling device, including small RACs to cool individual rooms; all-in-one heating and cooling systems in homes, known as packaged units; and chillers that cool whole buildings and industrial processes. In this report, we analyse and forecast four types of air conditioning use and four similar segments for refrigeration.

Figure 1: Cooling segments and end users

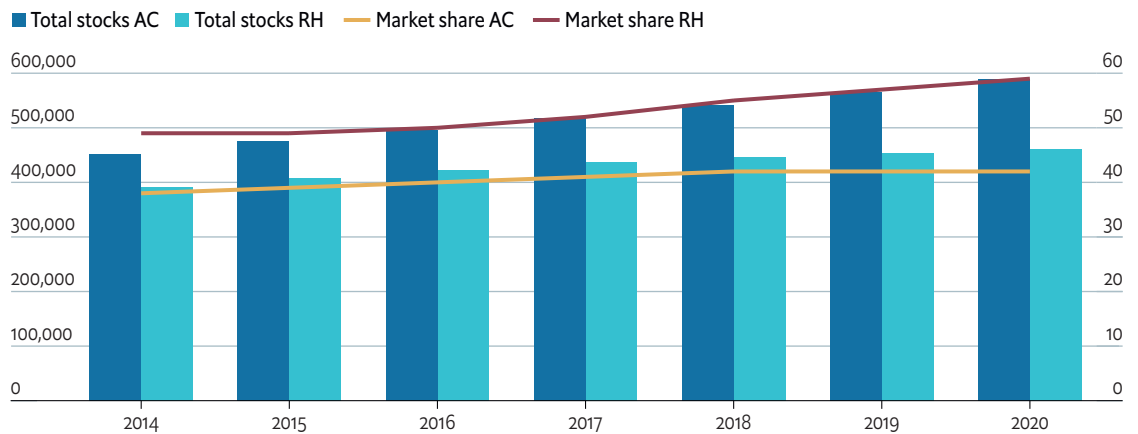


Sources: PS Intelligence, EIU Analysis.

Overview of China's cooling sector

Domestic demand for cooling equipment has been buoyant in China. Like many modern aspects of the country's economy, the cooling sector has outpaced rapid GDP growth. Since 2009 mobile air conditioning equipment stocks have grown 6.5 times, and transport refrigeration equipment stocks are now 7.5 times larger than in 2009. The rate of growth is now slowing but is still strongly positive. Although household ownership of cooling equipment exceeded 95% in 2019, there is still significant new demand from rural households, as well as urban demand for newer, more sophisticated equipment. China's role in the international market has also grown significantly: Chinese products now account for 42% of global air conditioning equipment, and China's refrigeration market share has reached 58%.

Figure 2: Domestic stocks and China's International market share²

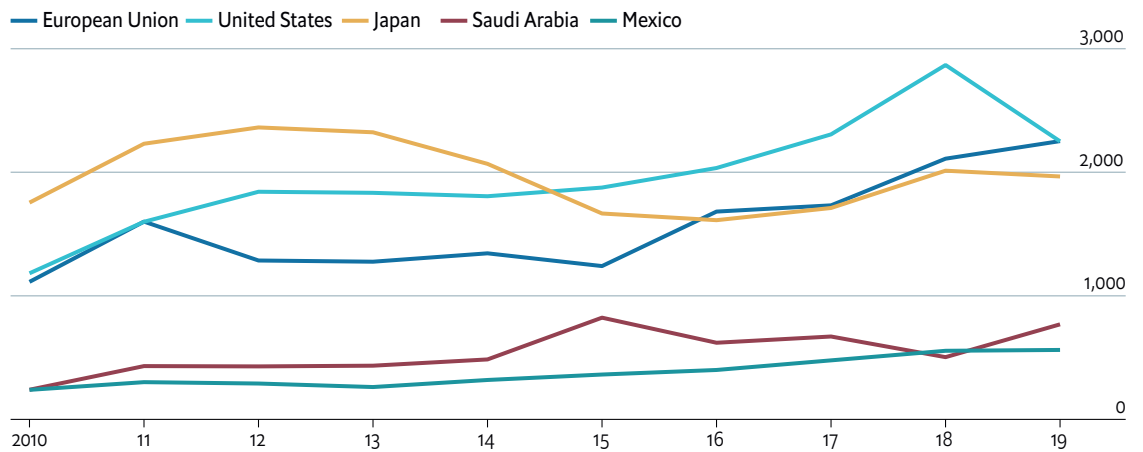


Note: International market share refers to Chinese producers' share of the international cooling market excluding China.
Source: PS Intelligence and EIU analysis.

China's dominance of the international cooling market is evident in trade statistics, which document that China exported US\$26.6bn worth of cooling equipment in 2019, accounting for an estimated 61% of foreign demand. Export destinations are diverse: the United States and Japan are the two largest destinations, importing 13.9% and 12.1%, respectively, of China's exported cooling equipment; six of the next eight leading export destinations are developing economies.

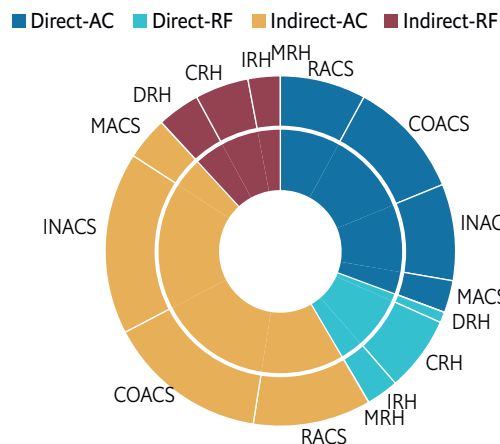
Direct cooling emissions are the greenhouse gases that stem from the use of refrigerants, which can leak into the atmosphere at any point during the cooling equipment life cycle: manufacturing, installation, operation and disposal. Often represented in terms of CO₂ equivalent, these compounds typically have a far more potent Global Warming Potential (GWP).⁴ There are some compounds that pose little to no risk. Propane, for example, is a common refrigerant that yields little GWP, and ammonia yields no GWP. However, both propane and ammonia are inflammable, impeding the wider adoption of low-GWP refrigerants.

Figure 3: Top destinations of China's cooling exports, 2010-19³
(US\$m)



Source: International Trade Centre.

Figure 4: Total emissions by sector
(%)



Source: The Economist Intelligence Unit.

Key:

Air conditioning (AC)		Refrigeration (RH)	
RACS - residential air conditioning	COACS - commercial air conditioning	DRH - domestic refrigeration	CRH - commercial refrigeration
INACS - industrial air conditioning	MACS - mobile air conditioning	IRH - industrial refrigeration	MRH - transport refrigeration.

Source: PS Intelligence and EIU analysis

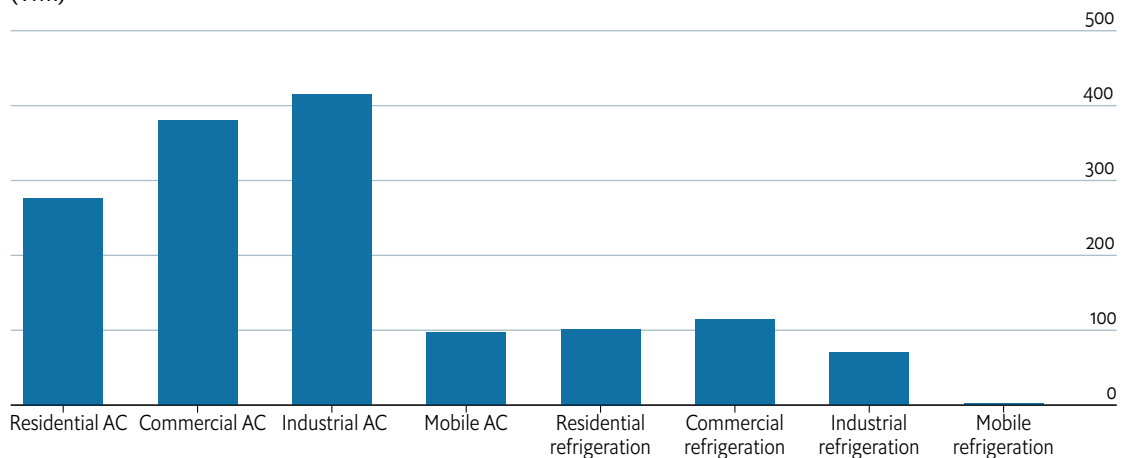
Total direct cooling emissions reached 568 Mt of CO₂ equivalent (MTCO₂e) in 2019, accounting for 42% of total emissions. The industrial and commercial sectors are major contributors to direct emissions, as the cooling equipment used in these sectors is larger than household or mobile equipment. These sectors are also susceptible to fire hazards from low-GWP refrigerants, posing a policy obstacle to wider adoption. Transportation and installation safety is a critical component of the soft infrastructure behind these refrigerants, and specialised training for technicians who work with these refrigerants is a necessary prerequisite for their wider adoption.

These trade-offs dominate discussions of how governments can facilitate the transition to a lower-emission cooling sector. The business case is relatively straightforward, as there is strong demand for more efficient and environmentally friendly cooling equipment. In Ghana, for example, where R22 air conditioners are being phased out, consumers are ready to purchase lower-GWP equipment at a premium price, according to Philipp Munzinger, project manager at GIZ Proklima. The same trend is

apparent in China, where the private sector is ready to make the transition. “Not only are refrigerants like ammonia (R717) better for the environment, but they are up to 30% more energy efficient,” says Henry Ha, CEO of MetCold, a cold-chain service company in China. “That makes a big difference, particularly in large-scale industrial cold storage facilities” (one of cooling’s biggest contributors to global warming). While it is encouraging that the technology for a cleaner cooling sector exists, and that the market is eager to implement such technology, complex policy dynamics prevent more rapid adoption of these options (discussed in more detail in Section Two of this report).

Indirect emissions—that is, CO₂ resulting from electricity generation—account for the majority of cooling’s contribution to climate change. Energy intensity is improving in China but fossil fuels continue to dominate the country’s energy mix, particularly coal, which accounts for 53% of installed capacity. Promisingly, renewables represent a significant and growing share of installed capacity: hydroelectric power generation is responsible for 19%, while solar and wind contribute 11% and 8%, respectively. However, installed capacity is not the same as energy use; for example, one estimate puts wind’s contribution to actual electricity use at just 4%.⁵ Nuclear power generation continues to grow. With 45 reactors in operation, 12 under construction, 22 planned and dozens more at the proposal stage, China is home to the fastest growing nuclear power network in the world.⁶

Figure 5: Annual electricity use 2019
(Twh)



Source: The Economist Intelligence Unit.

The cooling sector consumed roughly 1.4trn kWh of electricity in 2019—20% of the total amount of electricity consumed in China. Indirect emissions added up to 787 MtCO₂. Commercial and industrial cooling is more energy-intensive than residential or mobile cooling, as it tends to consume more electricity and run for longer periods.

In the next decade, there are multiple possible paths forward for China’s cooling sector, each of which will have a different impact on climate and the environment. These paths are summarised in the following section, which presents our approach to forecasting and our policy-based scenarios for the adoption of cleaner cooling in China.

Section one: Scenarios exploring the impact of cleaner cooling in China

China is a signatory to the Kigali Amendment to the Montreal Protocol, which “aims for the phase-down of hydrofluorocarbons (HFCs) by cutting their production and consumption”.⁷ HFCs have been the predominant refrigerants used in the global cooling sector since the Montreal Protocol began phasing out chlorofluorocarbons (CFCs), which were a primary contributor to the depletion of the Earth’s ozone layer. While HFCs are far less destructive to the ozone layer than CFCs, they carry a high GWP and are now a major contributor to climate change. The Kigali Amendment aims to facilitate a transition away from these chemicals, and to shift global cooling towards refrigerants that are safe for both the ozone layer and the global climate.

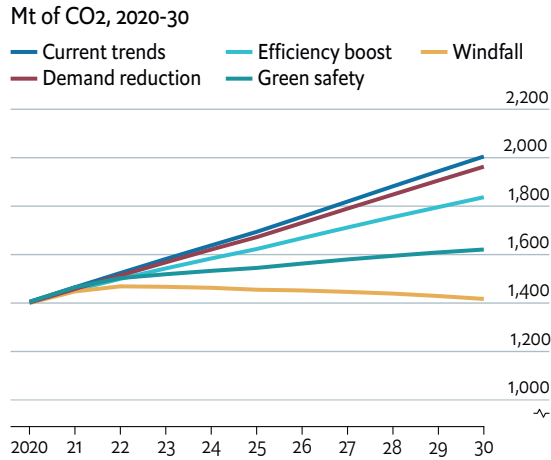
The Chinese government has already committed to enacting policy that facilitates a transition away from using fluorinated gases as refrigerants. The National Cooling Plan lays out the pathway for a greener cooling sector in the next decade, identifying more stringent energy efficiency standards, the production of green and high-efficiency cooling products and retrofits of existing cooling infrastructure as key priorities.⁸ Given China’s dominance in the international cooling market, these policies will have a significant global impact. The policy is indicative of China’s climate priorities, going beyond compliance with international climate norms and demonstrating political and industrial leadership, particularly as it relates to energy efficiency. (Section Two of this report describes the policy environment on cleaner cooling in detail.)

While China’s priorities are ambitious, there is scope for further action to reduce the climate impact of the country’s cooling sector. The government can use three main policy levers to reduce the cooling sector’s contribution to climate change: (1) consumer-focused campaigns to reduce the use of cooling equipment, cutting carbon emissions at scale; (2) higher energy efficiency standards, providing a supply-side remedy to the same problem; and (3) requirements to use cleaner refrigerants, eliminating the climate impact of leaks during manufacturing, use or disposal.

The EIU has developed a scenario-based forecast to explore the impact of each of these policy levers. In the period to 2030, the model shows great potential for further reductions in greenhouse gas emissions for the cooling sector, accompanied by a positive economic impact in each scenario. In the scenario that models the most aggressive policy response, China can bring annual emissions growth to zero by 2030 - an astounding achievement given the rapid growth of China’s emissions profile in the past few decades.

Scenario title	Policy lever
Demand Reduction	Consumer awareness campaigns help to reduce the use of cooling equipment across residential, commercial, industrial and mobile sectors in the period to 2030.
Efficiency Boost	Energy efficiency standards meet the targets of the national cooling plan, resulting in the proliferation of ultra-efficient equipment.
Green Safety	The safety issues associated with low-GWP refrigerants are resolved through technical training and oversight, facilitating a faster transition away from fluorinated gases.
Windfall	The combined impacts of the steps taken in the <i>Demand Reduction</i> , <i>Efficiency Boost</i> and <i>Green Safety</i> scenarios demonstrate the vast potential of pulling all of these policy levers together.

Figure 6: Scenario results, emissions from China's domestic cooling consumption



Current Trends is the reference scenario in our forecast, extrapolating pre-2020 trends in the cooling sector through to 2030. Four alternative scenarios are summarised in the box below.

Concerns about the economic impact of regulation tend to focus on increases in cost for cooling consumers and/or equipment manufacturers. However, there are significant economic benefits associated with the policy levers explored in this report. In each scenario, consumers benefit significantly in the period to 2030 through energy cost savings. In the Efficiency Boost scenario, higher energy efficiency standards also lead to a greater international market share for Chinese producers

of cooling equipment.

At the most basic level, the main factors driving cooling emissions over time are the stocks of equipment, the GWP of refrigerants and the emissions intensity of electricity generation.

Our scenarios rely on a foundational forecast of emissions under our Current Trends scenario, which is a product of the following indicators:

- Energy efficiency (i.e. consumption per cooling unit)
- Cooling utilisation, affected by climate and weather
- Market share for Chinese producers of cooling equipment
- Refrigerants used in cooling equipment

The model varies these factors across scenarios, allowing for segmentation between the Chinese domestic cooling market and the global market (excluding China).

Refrigeration	Air conditioning
Industrial	Industrial
Commercial	Commercial
Residential	Residential
Mobile	Transport

The model produces estimates for:

- Demand for cooling equipment
- Direct emissions (i.e. emissions from refrigerants used in cooling equipment)
- Indirect emissions (i.e. CO₂ emissions from cooling's energy consumption)

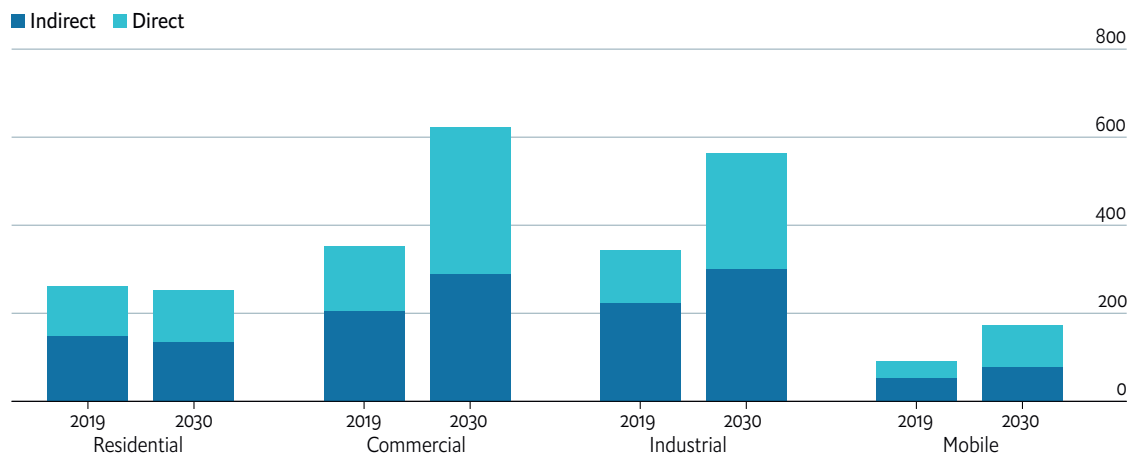
The outputs are disaggregated by the following cooling sectors:

In addition, the model produces estimates of the economic contribution of the cooling sector to China's exports, GDP and employment levels. We also model the level of energy consumption (and expenditure of energy consumption) by the cooling sector.

Scenario overview: *Current Trends*

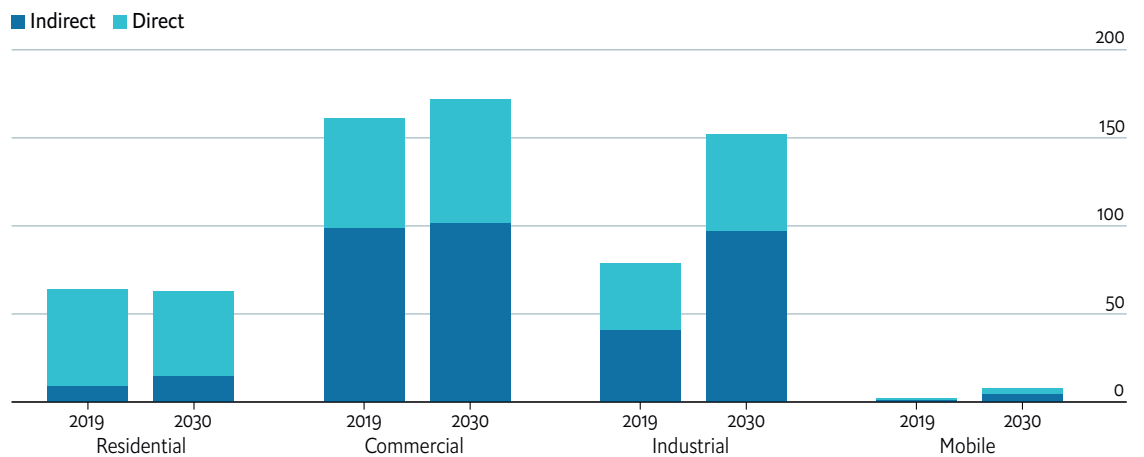
Our foundational forecast extrapolates current trends in China's energy efficiency and cooling utilisation out to 2030. We forecast China's emissions over the 2020-30 period based on a continuation of improvements in emissions intensity of electricity production evident between 2010 and 2020. This trend shows the emissions intensity of electricity production in China falling 18% between 2014 and 2018. This fall has been brought about by a trend of decreasing dependence on fossil fuel in the total

Figure 7: Current trends scenario results, air conditioning emissions
(Mt CO₂)



Source: The Economist Intelligence Unit.

Figure 8: Current trends scenario results, refrigeration emissions
(Mt CO₂)



Source: The Economist Intelligence Unit.

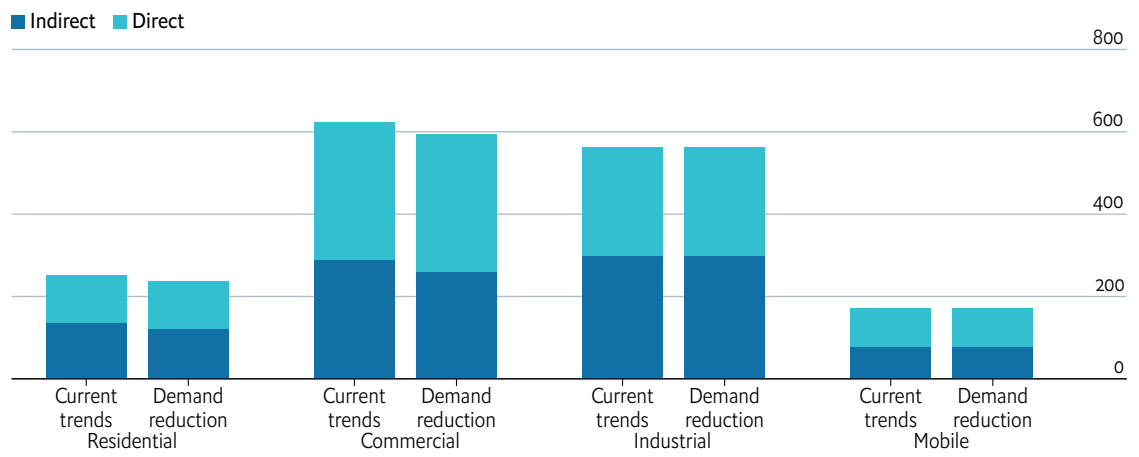
energy mix of the economy. It is important to note that, as of December 2019, the Climate Action Tracker rated “business as usual” in China as “highly insufficient” for holding global warming below twodegrees.⁹

Figures 7 and 8 represent the expected outcome of a continuation of pre-2020 industrial, regulatory and consumer trends throughout the next decade. The Current Trends scenario provides the basis for comparison for our four alternative scenarios.

Scenario overview: Demand Reduction

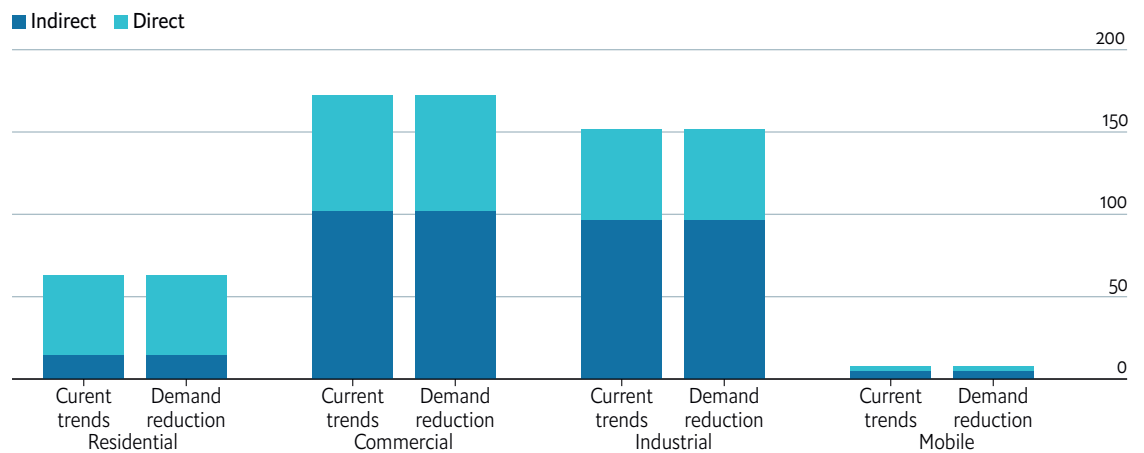
A shift in non-efficiency measures—such as consumer behaviour, building design and urban planning initiatives—could have an immense impact on China’s emissions profile. Possible levers for facilitating this scenario include policies that reduce energy consumption, such as revisions to the energy tax and

Figure 9: Demand reduction scenario results, air conditioning emissions
(Mt of CO₂, 2030)



Source: The Economist Intelligence Unit.

Figure 10: Demand reduction scenario results, refrigeration emissions
(Mt of CO₂, 2030)



Source: The Economist Intelligence Unit.

subsidy scheme, green building codes and consumer awareness campaigns. Some of these policies are already in place in China, while others have been implemented in other countries and now constitute best practice. (Section Two of this report discusses these policies in greater detail.) The Demand Reduction scenario forecasts the impact of a 10% decline in cooling use in China in the period to 2030, relative to the *Current Trends* scenario.

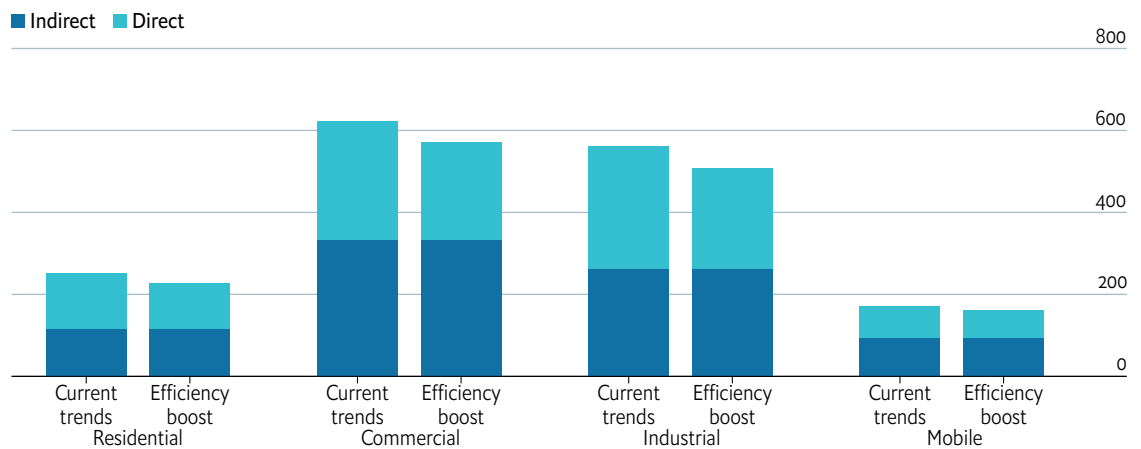
There is a precedent for such a demand reduction. Following the March 11, 2011 tsunami and ensuing nuclear disaster, Japan shut down its nuclear reactors and embarked on a nationwide campaign to conserve energy. The crisis and its aftermath demanded that society immediately and dramatically reduce energy consumption. Japanese households, businesses and government offices settled into a new normal. One such example is the Cool Biz campaign, which predated the crisis but has become a summer fixture. Cool Biz encourages workers to dress casually, get out of the office during peak hours (either through flexible work, reduced overtime or holidays), and switch off electronics when not in use. Tokyo offices and shops rarely set air conditioning at temperatures below 28°C. Households are encouraged to use blinds to keep out direct sunlight. Japanese society has adopted these practices as the new norm. In 2019, Japan's domestic energy consumption was 7,733 kWh per person—the lowest figure since 1996, roughly 11.5% lower than in 2010. Despite the tragic circumstances, Japan's experience demonstrates the 10% decline modelled in Demand Reduction, is an ambitious but plausible goal for China.

Scenario overview: *Efficiency Boost*

The National Development and Reform Commission (NDRC) published its National Cooling Plan on June 13, 2019, developed in consultation with the Ministry of Industry and Information Technology and the Ministry of Finance. The plan establishes energy efficiency guidelines for the cooling industry in the period to 2030.

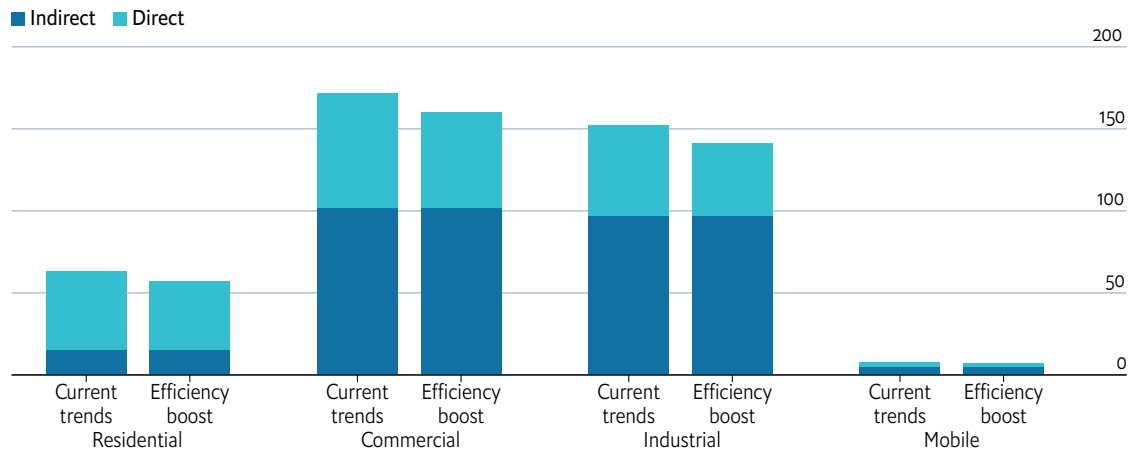
The mechanisms for achieving the plan's targets focus on introducing more stringent energy efficiency standards, eliminating the production of obsolete equipment and using refrigerants with a lower GWP in cooling equipment. The plan also calls for increased research and development (R&D)

Figure 11: Efficiency boost scenario results, air conditioning emissions
(Mt of CO₂, 2030)



Source: The Economist Intelligence Unit.

Figure 12: Efficiency boost scenario results, refrigeration emissions
(Mt of CO₂, 2030)



Source: The Economist Intelligence Unit.

in cooling technology, accelerated elimination of hydrochloro-fluorocarbons (HCFCs) and limited use of HFCs. Preferential fiscal policy will act as an incentive, and punitive actions may be taken against producers that do not meet standards, including possible suspension of production.

In the Efficiency Boost scenario, we consider the possibility that the energy efficiency thresholds outlined in the National Cooling Plan are fully realised ahead of schedule, and that new targets are implemented for greater improvements in the period to 2030. The model allows for variation in efficiency targets across residential, commercial, industrial and mobile sectors for both air conditioning and cooling. The model forecasts sector-specific improvements in energy efficiency in 2030, which is expected to be 47%–60% higher than in 2019.

Scenario overview: *Green Safety*

The technical frontier for the cooling sector (i.e. the best technology currently available) has promising implications for the fight against global warming. Low-GWP cooling alternatives are already commercially available, many of which have GWPs that are roughly comparable to CO₂, rather than fluorinated gasses (which are thousands of times more potent; Figure 13). There is a trade-off, however. These alternatives

Figure 13: Common refrigerants and global warming potential (GWP)

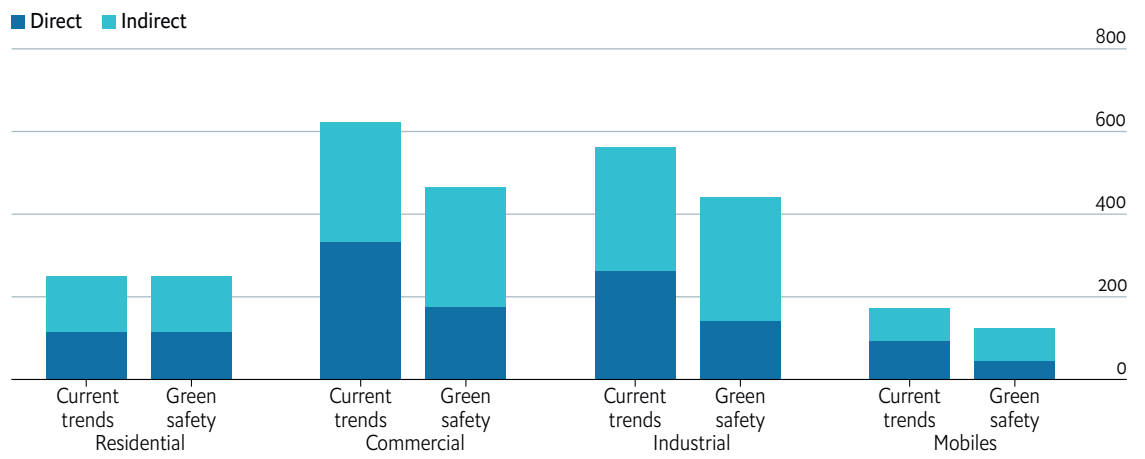
Type	Current Refrigerant	GWP	Substitute 1	GWP	Substitute 2	GWP	Substitute 3	GWP
Residential AC	R407C, R410A, R32	1764	R290	3				
Commercial AC	R410A, R32R, R407C	1910	R32	675	R1234yf	4	R290 (Propane)	3
Industrial AC	"R407C, R134a,	1537	R449A	1397	R450A	605	R290 (Propane)	3
Mobile AC	R22"	1300	R513A	631	R450A	605	R1234yf	4
Residential refrigeration	R134a	1958	R513A	631	R450A	605	R600a(isobutane)	3
Commercial refrigeration	R134a, R600a, R404a	2866	R290	3				
Industrial refrigeration	R-404A, R22, R744, R717, R134a	2866	R449A	1397	R450A	605	R290 (Propane)	3
Transport refrigeration	R404A, R22, R744, R718, R134a	2088	R449A	1397	R513A	631	R744	1

Source: European Commission, 10 GIZ11, Energy Foundation China12

(such as propane or ammonia) are more dangerous to manufacture, operate and service, increasing the risk of industrial accidents. Fortunately, there are ways to mitigate this risk, enabling a transition to a greener cooling sector without compromising safety (see section two of the report for further details).

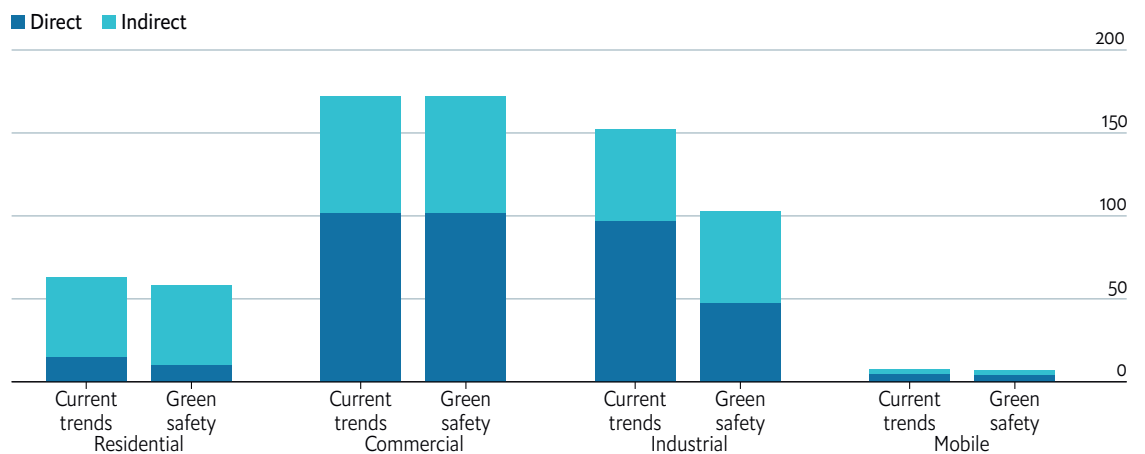
The *Green Safety* scenario demonstrates the potential improvement in emissions output delivered by a complete transition to low-GWP refrigerants, assuming that safety issues are resolved through standards and training. The emissions and economic impact outputs for the Green Safety scenario are the product of a much faster reduction in cooling's blended GWP—the average GWP for the refrigerants used in the sector—in the period to 2030, which is roughly 47% below 2019 levels at the end of the forecast period. The rate at which the blended GWP declines in the Green Safety scenario is 2.7 times faster than in the *Current Trends* scenario.

Figure 14: Green Safety Scenario results, air conditioning emissions
(Mt of CO₂, 2030)



Source: The Economist Intelligence Unit.

Figure 15: Green safety scenario results, refrigeration emissions
(Mt of CO₂, 2030)



Source: The Economist Intelligence Unit.

Scenario overview: *Windfall*

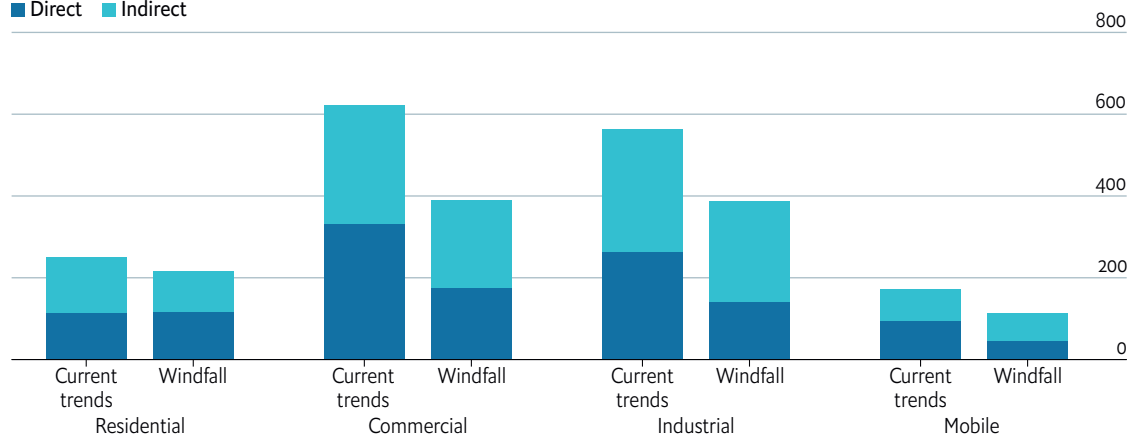
The most optimistic scenario considers the combined impact of the demand-side utilisation shifts modelled in the *Demand Reduction* scenario, the efficiency gains modelled in the *Efficiency Boost* scenario and the green refrigerant transition modelled in the *Green Safety* scenario. In the *Windfall* scenario, China's energy efficiency improves across all cooling segments (with a range of 47% to 60%), utilisation rates for cooling equipment fall 10% below the *Current Trends* forecast for 2030, and blended GWP declines to 47% of 2019 levels. The benefits to China's emissions profile are significant.

Each of these scenarios has an associated economic cost and varying impacts on household, business and government budgets. There are also implications for supply chains, which must adapt to an evolving policy environment. However, the model predicts economic benefits in all scenarios,

Figure 16: Windfall scenario results, air conditioning emissions

(Mt of CO₂, 2030)

■ Direct ■ Indirect

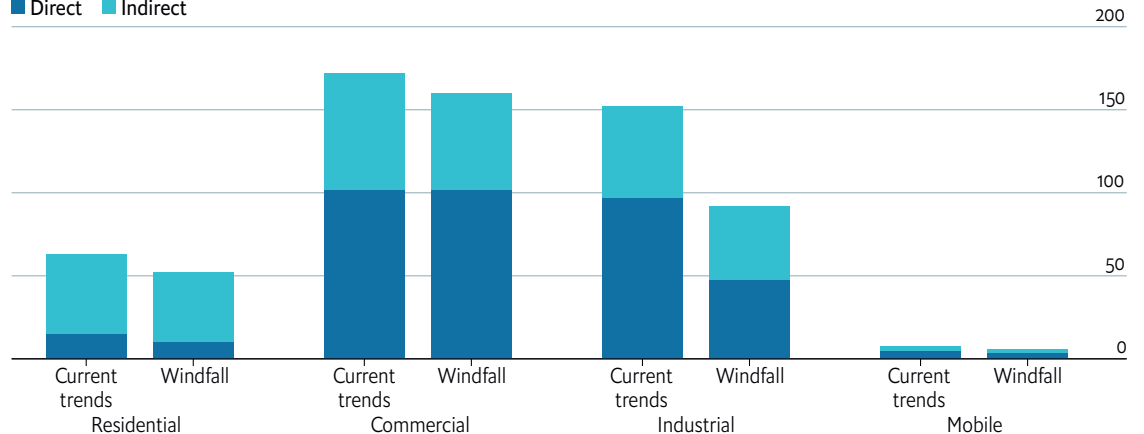


Source: The Economist Intelligence Unit.

Figure 17: Windfall scenario results, refrigeration emissions

(Mt of CO₂, 2030)

■ Direct ■ Indirect



Source: The Economist Intelligence Unit.

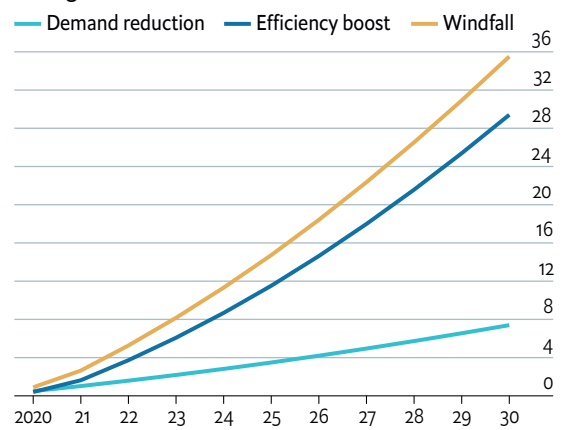
including electricity cost savings and growth in international market share for Chinese producers of cooling equipment.

Economic benefits of policy scenarios

Regulation is not without cost. From awareness campaigns to higher standards for the cooling sector, each of the policy levers implemented in our scenarios has an associated investment or divertive effect on economic activity. This model does not consider the costs associated with upgrading technology—for example, through R&D, retrofits of equipment or the reorientation of supply chains for greener production. However, the model predicts benefits for both consumers and producers of cooling equipment, with expert interviewees identifying energy savings and market share as the primary benefits to the Chinese economy. Domestic consumers benefit from energy cost savings between 2020 and 2030 in both the Demand Reduction scenario (2.5% cost savings) and the Efficiency Boost scenario (8.7%). The combined impact of policy levers implemented in the Windfall scenario translates into 10.9% cost savings over the next ten years, relative to the Current Trends scenario, constituting a significant economic benefit. Windfall would also create 87,000 new jobs in the cooling supplychain.

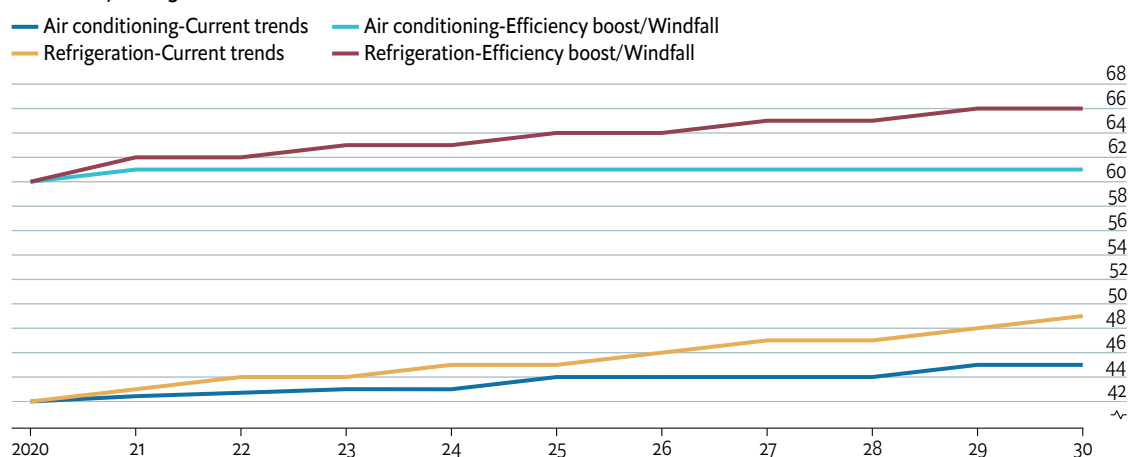
There are supply-side benefits, too: Chinese producers take greater international market share (primarily in Europe) in the Efficiency Boost scenario, as more Chinese-made equipment meets higher energy efficiency standards. These market share gains are also present in the Windfall scenario.

Figure 18: Chinese consumers' annual energy savings, 2020-30
Savings in US\$ bn



Source: The Economist Intelligence Unit.

Figure 19: Chinese producer's international market share
Mt of CO₂, 2020-30



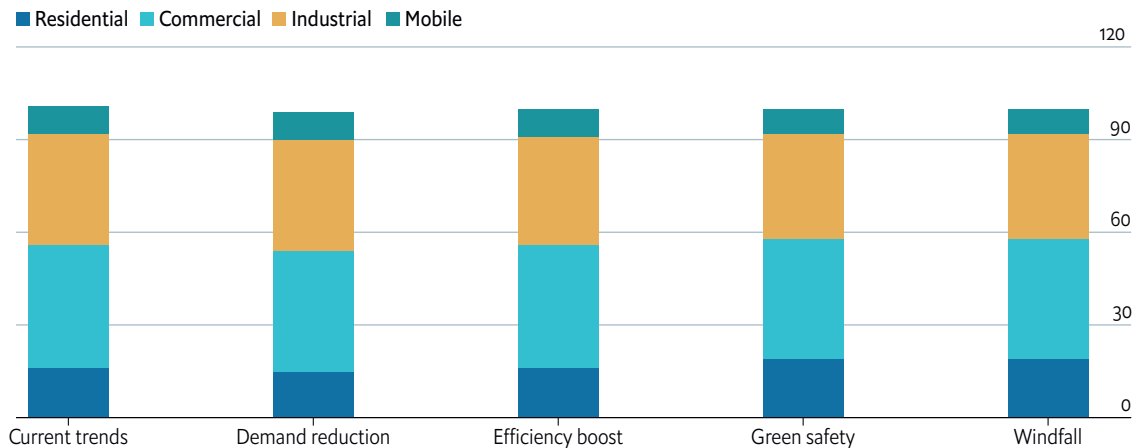
Source: The Economist Intelligence Unit.

Five narratives for the future of cooling in China

The primary narrative that emerges from these scenarios is that significant emissions reductions are possible without compromising economic growth. In addition to this primary narrative, five key narratives emerge regarding specific cooling segments, reflecting important differences between air conditioning and refrigeration; residential, commercial, industrial and mobile cooling; and direct and indirect emissions.

1. The commercial sector is the largest contributor to cooling emissions, but is willing and able to change quickly. Total emissions from commercial refrigeration and air conditioning reached 513 Mt in 2019, accounting for 38% of total emissions from cooling. In each scenario, commercial cooling remains the greatest contributor to global warming in 2030, representing around 40% of total emissions. (The industrial sector is a close runner-up, at 36%.) While there are fewer commercial units than residential, they are often much larger and can have substantially higher direct and indirect emissions per unit. Although industrial air conditioning and refrigeration units are even larger than those used in commercial settings, there are far fewer of these units, and they make a smaller contribution to overall emissions. Commercial air conditioning and refrigeration represent the greatest challenge and the greatest opportunity for improvement.

Figure 20: Emissions breakdown, 2030
(%)



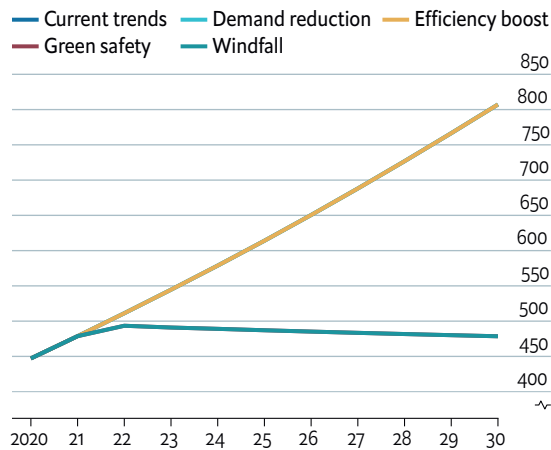
Source: The Economist Intelligence Unit.

Compared to the residential sector, the commercial sector may be more willing and able to adopt cleaner cooling technology, as more efficient equipment saves energy costs and contributes to a competitive advantage over peers. If the largest emissions contributor reacts quickly, we would expect a rapid reduction in total emissions. Chinese corporates are increasingly cognisant of their social and environmental impact. In December 2017 Alibaba launched its Poverty Relief Fund, a US\$1.5bn programme that includes initiatives for environmental protection.¹³ The Demand Reduction scenario highlights the potential emissions reduction brought about by an acceleration of this trend.

However, higher efficiency standards may become a burden for some businesses as efficient technologies tend to be more expensive, particularly if corporations are required to invest in new product development without government support. Depending on the market, these added business costs may percolate down to consumers.

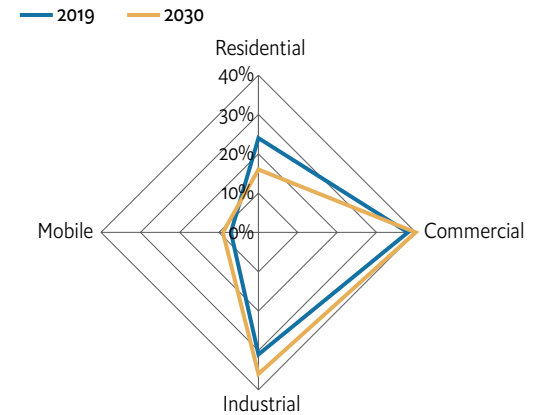
2. There is clear scope for greater reductions in direct emissions. The greatest potential comes from the refrigerant transitions in the Green Safety and Windfall scenarios, where direct emissions from domestic use grow at less than 0.6% per year in the period to 2030, compared with 5.4% in the otherscenarios.

Figure 22: Direct emissions, air-conditioning
Mt of CO₂, 2020-2030



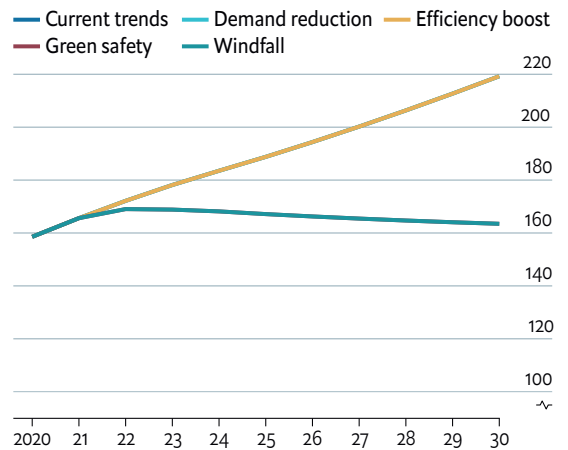
Source: The Economist Intelligence Unit.

Figure 21: Sector emissions breakdown for current trends
(%)



Source: The Economist Intelligence Unit.

Figure 23: Direct emissions, refrigeration
Mt of CO₂, 2020-30



Source: The Economist Intelligence Unit.

Refrigerants make a large contribution to emissions, which suggests that a transition to low-GWP refrigerants would provide a significant boost to China's fight against climate change. Phasing in low- or zero-GWP refrigerants could reduce annual emissions in China's domestic cooling sector by up to 266 Mt in CO₂ equivalent by 2030, relative to the Current Trends scenario. A top-down approach would require prudent management to avoid major disruption. For example, a rapid phase-down of existing refrigerants could jolt manufacturers that have not sufficiently diversified production to include cutting-edge refrigerants, with negative implications for employment. Many producers have just completed the transition from HCFCs to HFCs and will need time to manage existing inventories and prepare for a new transition to different products. However, there is evidence that the market is eager to comply with the principles of the Kigali Amendment (discussed in more detail in Section Two of this report).

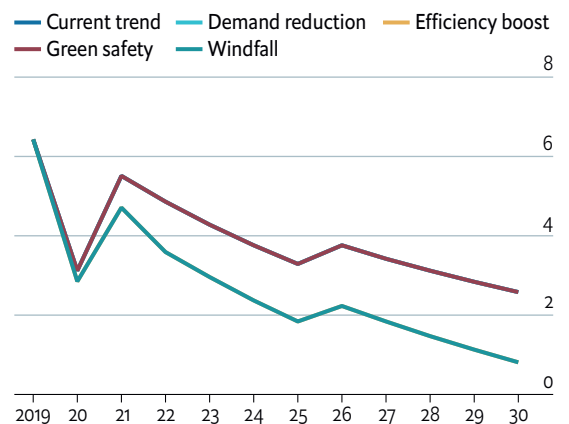
3. Neither energy efficiency improvements nor reduced demand are sufficient on their own to keep cooling emissions from electricity production stable in the period to 2030. The cooling sector's indirect emissions equate to roughly driven by large stocks of cooling equipment and high cooling utilisation rates in China. Among households, the ownership rate of air conditioners and refrigerators has already exceeded 95%. Although ownership rates are lower for the commercial and industrial sectors, the equipment is more energy-intensive and operates for longer (on average, eight hours per day for commercial air conditioning and 20 hours per day for industrial refrigeration). Economic and social factors are pushing greater use of cooling, greater demand for electricity and increased emissions from energy production. Only the combined impacts of better efficiency and reduced demand—as in the *Windfall* scenario—result in a contraction for indirect emissions in the period to 2030. In that scenario a 0.2% average annual decline translates to total indirect emissions that are 21% below those in the *Current Trends* scenario.

Although the cooling sector's consumption of electricity is sizable, it may not be significant enough to be prioritised over other more energy-intensive applications. Electricity generation is a priority distinct from the cooling sector, and emissions-intensive industries such as cement production and agriculture have long received more attention from the government. Nonetheless, there is great potential for electricity savings in the cooling industry. If cooling efficiency improves and demand grows slower than in the *Current Trends* scenario, Chinese consumers and businesses can collectively save at least US\$177bn in electricity costs over the next ten years.

4. The fast-growing mobile cooling sector provides an opportunity for green development of transport refrigeration and mobile air conditioning. Transport refrigeration and mobile air conditioning are powered, at least in part, by vehicle diesel/petrol and do not benefit from increased efficiency in electricity production in China to the same extent as other segments. Although electric vehicles are gaining market share in China, they only account for a small portion of existing stocks and their effect on emissions is yet to manifest in a significant way. Mobile air conditioning will still be "dirtier" than other sectors until electric vehicles take a majority market share. As customers grow more environmentally conscious and the government continues to promote electric cars, industry-driven efficiency standards in mobile air conditioning represent an opportunity for automakers to gain market share through innovation.

5. Air conditioning has greater potential for energy efficiency improvements than refrigeration. The *Windfall* scenario lays out potential emissions improvements relative to the *Current Trends* scenario for both sectors: 31% for air conditioning and 22% for refrigeration. The model's estimates for improvement in energy efficiency consider the gap between current efficiency standards prevalent in the market and potential optimum levels.

Figure 24: Emissions growth rates for mobile air conditioning, 2020-30
(%)



Source: The Economist Intelligence Unit.

Indirect emissions from air conditioners increase by 2.2% per year in the Current Trends scenario. In the Windfall scenario, increased energy efficiency coupled with lower utilisation curb indirect emissions growth to a negative -0.3%, resulting in a carbon footprint that is 174 Mt lower in 2030 than in the Current Trends scenario.

The GDP elasticity of energy—that is, the growth rate of energy consumption divided by GDP growth—is a good measure for understanding energy efficiency patterns in an economy. Studies show that when the GDP elasticity of energy (electricity) consumption is less than one, the economy is improving its energy (electricity) efficiency gradually and sustainably over time. By this metric, our forecast shows sustainable energy growth in all years of our forecast period.

The model presents multiple possible futures for China, all of which are dependent on the government's choices in the near term. In the following section of this report, international best practices in cooling policy translate the policy levers implemented in our scenarios from theoretical abstracts into practical tools.

Section two: Cooling sector policy environment

Cooling policy: Global trends, best practices and progress in China

Clean cooling requires policy interventions, from commitments to international agreements (such as the Montreal Protocol and the United Nations Framework Convention on Climate Change [UNFCCC] Paris climate accord) through to national measures such as energy efficiency standards, building codes, and financial support to increase uptake of greener practices, such as carbon taxes and fiscal benefits for the adoption of good practices. Informal mechanisms, such as awareness-raising and voluntary codes and standards, can also play a productive role.

China has shown strong engagement in the green cooling agenda overall, introducing a raft of policies and plans to improve energy efficiency and phase out environmentally damaging practices and appliances. This includes a national cooling plan published in 2019 (described in the box below), energy performance standards schemes, financial incentives to encourage the lowering of energy intensity, and commitments to phase out environmentally harmful gases used in cooling systems.¹⁴

China's Green and High-Efficiency Cooling Action Plan (2019)

China's national cooling plan commits to improving cooling efficiency and environmental friendliness, expanding the supply of green cooling products and enabling the cooling industry to sustainably meet demand for higher quality of life. It outlines a 2022 target to improve the energy efficiency of residential air conditioners and variable-refrigerant-flow air conditioners by 30%, and to increase the market share of green and high-efficiency cooling products by 20%, generating annual electricity savings of 100 terawatt-hours (TWh). By 2030 it commits to improving the cooling efficiency of large-scale public buildings by 30%, the overall energy efficiency of cooling by over 25% and the market share of green and high-efficiency cooling products by over 40%, producing annual electricity savings of 400 TWh.

The plan states that these targets will be achieved through a suite of interventions, including substantially upgraded energy efficiency standards to phase out inefficient products, energy-saving retrofits for air conditioning systems and efficiency upgrades for old data centres. Such interventions are intended to ensure that minimum energy performance standards reach or exceed the entry-level import requirements of developed countries, and to promulgate national and industry standards for issues like green design and manufacturing. The plan also pledges to promulgate product and safety standards for low-GWP refrigerants, and it commits stakeholders to increase R&D for environmentally friendly refrigerants and promote the reuse and safe disposal of refrigerants. The plan pledges support, where conditions allow, for "cooling as a service" innovations such as outsourced cooling, metered cooling and guaranteed contracting for cooling demand.

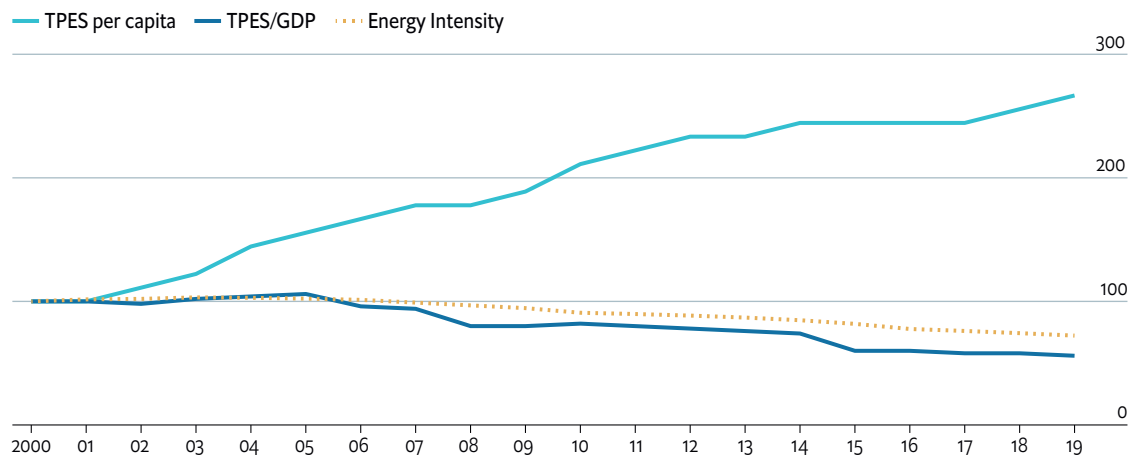
This section of the report surveys China's policy actions to date and draws best practices and insights from other contexts and expert interviewees. It focuses on two core domains: **energy efficiency** in the cooling sector (including product labels and performance standards, building codes and incentives to encourage responsible behaviours) and **phase-outs of greenhouse gases** that are used in cooling systems.

Energy efficiency

Our model estimates that electricity demand and refrigerants have roughly equal shares of cooling emissions. China's energy system still draws heavily on fossil fuels, which means that CO₂ emissions from cooling increased fivefold between 2000 and 2017, driven by increased demand.¹⁵ Reducing the energy used by cooling and accelerating China's broader decarbonisation represents a critical policy domain.

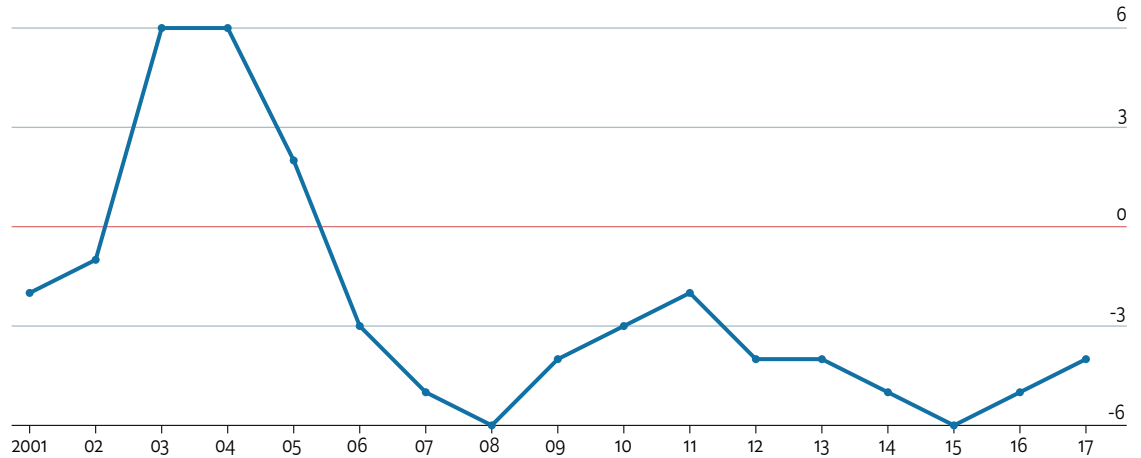
According to the International Energy Agency's (IEA) Efficiency Policy Progress Index,¹⁶ China accounted for more than half of the world's policy progress between 2000 and 2016, with rapid improvement achieved between 2011 and 2015. China is also rated as a "good performer" by the Regulatory Indicators for Sustainable Development (RISE) initiative, which assesses policy support across three pillars of sustainable energy: access to modern energy, energy efficiency and renewable energy. In 2017 China's score for energy efficiency was 68%—higher than the scores of Japan, Spain, Sweden and Switzerland. Energy usage trends reflect this progress. China has exerted great downward pressure on its energy intensity, quantified across multiple measures. The country improved its energy intensity at an average rate of 2.2% per year between 2003 and 2013, rising to 5.1% between 2014 and 2017.¹⁷

Figure 25: Total primary energy supply (TPES) and macro-economic indicators, 2000-17
Index (2000=100)



Source: China Energy Statistical Yearbook 2017, National Bureau of Statistics, December 2017.

Figure 26: China energy consumption growth per unit of GDP, 2001-17
(%)



Source: Annual Report on China's Energy Development 2017, China Electric Power Planning and Engineering Institute, April 2018.¹⁸

China's energy efficiency performance is a product of multiple laws, strategies and programmes. These include the 1998 energy conservation law, which established a legal framework outlining responsibilities for governments, energy-consuming entities and manufacturers; and created mechanisms to prohibit products falling short of mandatory efficiency requirements.¹⁹ There are also forward-looking plans such as the Energy Supply and Consumption Revolution Strategy (2016-2030), which commits to aligning China's energy consumption per unit of GDP with current global averages, as well as ensuring that the energy efficiency performance levels of China's main industrial products are among the most advanced in the world.²⁰ China has pursued energy efficiency measures in the refrigeration sector specifically. These include technical collaborations with the United Nations Development Programme (UNDP) as early as 1999, which imposed mandatory measures to restrict inefficient cooling technologies, according to Hu Xiaohong, formerly of the China Household Electrical Appliances Association.

China: Energy efficiency strategies, plans and laws

- 14th Five Year Plan (2021-2025)
- Strategic Action Plan for Energy Development (2014-2020)²¹
- 13th Five Year Plan for Energy Development (2016-2020)
- Four Revolutions and One Co-operation Strategic Vision (2014)
- Energy Supply and Consumption Revolution Strategy (2016-2030)
- Energy Conservation Law (1998)

China has also steered the commercial sector through the **Top-1000 programme**, launched in 2006, which required the 1,000 largest industrial enterprises in China (accounting for 33% of national energy usage) to conduct energy-saving assessments and actions. By 2010 companies had exceeded the energy-savings target of 100m tonnes of coal equivalent (tce). China expanded the initiative to become

the **Top 10,000 programme** during the 12th Five Year Plan (2011-2015), covering the 15,000 enterprises that use more than 10,000 tonnes of coal equivalent each year and account for two-thirds of China's total energy consumption.²² The programme sought to lower the energy intensity of key products and establish long-term efficiency mechanisms. Industrial enterprises were required to conduct energy assessments, including consumption analysis; identify energy-saving opportunities and develop proposals for energy-saving measures; implement technical retrofits and energy utilisation reporting; and improve energy management skills.²³ The Top 10,000 programme offered financial incentives for these efforts, including a \$30 payment for every tonne of coal equivalent saved per year. Top 10,000 is complemented by the **Top Runner programme** (based on a programme in Japan), which identifies high-efficiency product models and benchmarks.²⁴ "The Top Runner programme sets the energy standard according to the best available technology in the market and over time upgrades the energy efficiency as the technology improves," says Stephen Andersen, director at the Institute for Governance and Sustainable Development. "This is an alternative to a periodic review of minimum energy performance standards. It was spectacularly successful in Japan."

Minimum energy performance standards in China

Minimum energy performance standards (MEPS) are regulatory restrictions designed to phase out or eliminate inefficient products. Countries with standards that prohibit the sale of substandard cooling equipment include Chile²⁵ and Australia.²⁶ There are also regulations that restrict the rental of properties that do not meet minimum energy efficiency standards (for example, in the UK), including heating, ventilation and air conditioning (HVAC) efficiency.²⁷

China introduced energy efficiency standards in 1988 and issued its first specific MEPS and categories the following year,²⁸ including MEPS for fixed-speed RACs.²⁹ Today China's MEPS cover refrigerators, RACs, water coolers, industrial equipment and vehicles, to name a few, and the government aims to eliminate the bottom 20% of products from the market. In 2005 China also introduced a mandatory energy information label for four products: air conditioners, household refrigerators, clothes washers and unitary air conditioners.³⁰

Since the 12th Five Year Plan, China has released and amended MEPS for 54 end-use, energy-consuming products and 73 products on a per-unit-of-product basis in energy-intensive industries, including steel and petrochemicals.³¹ The national cooling plan includes commitments to crack down on fraudulent labelling and strengthen product spot checks, and to include the results in national enterprise credit information and public disclosures; to ensure that MEPS reach or exceed entry-level import standards for developed countries; and to accelerate the promulgation of standards to data centres, mobile air conditioners and cold storage warehouses, with a view to phasing out 20%–30% of low-efficiency cooling products.³²

China's MEPS have had an important impact on reducing energy consumption by appliances, according to one review by the Lawrence Berkeley National Laboratory, a US agency. One scenario analysis predicts that improvements in MEPS could lead to a 50% increase in air conditioner efficiency by 2030 (compared with a 2017 baseline), cutting cooling energy demand by more than 200 TWh.³³ Expert interviewees and third-party research point to ways to improve the efficacy of MEPS.

The policy environment has room to evolve. Our analysis revealed three priorities for policymakers and businesses in the next decade.

- **Elevate performance standards.** There are differences between an appliance's rated performance and its real operating efficiency.³⁴ Nihar Shah, director of the Lawrence Berkeley National Laboratory's Cooling Efficiency Research Program, points out that there is a lack of adequate test laboratories to determine the real efficiency of appliances. "There's no way to verify whether [a product] is efficient as stated," he observes. "You have to take the air conditioner, put [it] into your test chamber, wait for [a] few hours to stabilise the chamber and another few hours to test it, so there is a whole involved process." Shared conformity assessments and regional testing laboratories could help to address this problem. Efficiency measures also need to take a life-cycle approach, recognising that equipment degrades due to dirt accumulation and the corrosion of heat exchangers. "When you install an air conditioner or refrigeration equipment, it usually has the highest efficiency when it's new," says Mr Andersen. "But if it's badly maintained, it loses a lot of energy efficiency. You cannot be just concerned about the name plate energy efficiency. You have to be concerned about what happens over the lifetime." Other challenges include ensuring market compliance with mandatory standards and labelling programmes.³⁵
- **Make the business case.** Efforts to phase out inefficient cooling equipment need to respond to economic concerns from industry stakeholders. Fortunately, there is a clear business case for efficiency upgrades. Jiang Lin, chair of China Energy Policy at the Lawrence Berkeley National Laboratory, notes that as manufacturing increases the scale of production, the costs of higher-efficiency equipment typically come down. In the US, the amount of energy used by new domestic refrigerators has fallen dramatically, and equipment costs have also come down in real terms. Over time, energy efficiency improvements are often absorbed into prices, which means that consumers do not face significantly higher upfront costs and save considerably on electricity costs.³⁶ Furthermore, as global trends move towards cleaner and more efficient products in international markets, decisions to invest in inefficient technology production risk losses in a green economy.³⁷ The business case can also be made to government: less energy-intensive cooling systems could reduce China's peak load problem, especially in the summer, which has been sufficiently severe to prompt the development of new coal plants, according to DrLin.
- **Design the right price incentives.** Pricing carbon in a way that reflects its true environmental cost is essential to drive efficiency decisions. Globally, there have been an estimated 58 carbon pricing initiatives—either emission trading schemes (ETS) or carbon taxes—implemented or scheduled across 46 national jurisdictions. China has been experimenting with an ETS, the expansion of which is expected in the months ahead. One survey indicates that an increase in the national carbon price is anticipated, with the ETS increasingly affecting investment decisions through to 2025.³⁸ China has also sought to encourage retailers to transition to green cooling products, initiating rebate programmes such as the Energy Saving Subsidy and Green for Old.³⁹

Building codes

Greening China's enormous building stock—estimated at 60.6bn m² in 2016⁴⁰—is critical to achieving a clean cooling transition. Buildings accounted for 18% of China's total final energy consumption in 2017,⁴¹ and heating and cooling jointly represent the single largest source of energy demand, accounting for 40% of final energy use in buildings.⁴²

The long-term trends are concerning. Energy demand for space cooling has increased by 13% per year since 2000—the fastest growth globally—culminating in nearly 400 TWh of consumption by 2017.⁴³ Many building types associated with economic growth are heavy energy users, such as offices and commercial premises, data centres, shopping malls and modern residential developments.

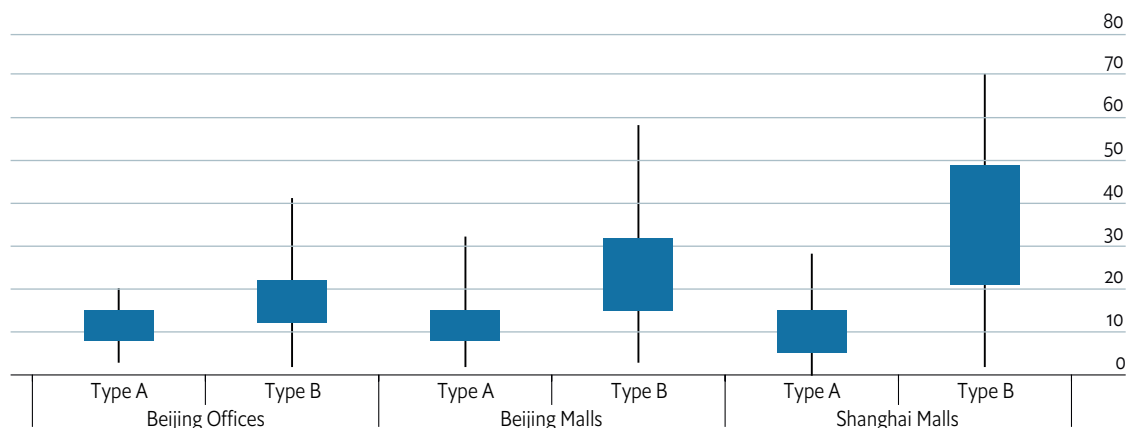
Growing numbers of promoted and installed heating and cooling systems are “full time” and “full space”, with energy-hungry HVAC and inoperable windows too often viewed as symbols of modern, high-quality buildings. One study found that over three-quarters of pre-furnished buildings in 2017 had a multi-split or central HVAC,⁴⁴ and the number of households in Beijing and Shanghai using multi-split or central HVAC grew fivefold between 2000 and 2018, compared to a doubling of those using lower-energy-demand mini-splits.⁴⁵ This is not because such systems are necessarily better for consumers; surveys show minimal difference in satisfaction between mini-split, multi-split and central HVAC. The energy waste is a result of systems operating without adapting to occupancy.

The rise in “Type B” buildings

China's energy standards system splits non-residential buildings into two categories: those with operable windows which cool using natural ventilation, fans, or mini- or multi-split HVAC (Type A); and those with inoperable windows and

centralised HVAC systems (Type B), including commercial offices and shopping centres. Energy usage differs significantly between the two (see Figure 26). The number of Type B buildings is growing rapidly. In Beijing, for example, the percentage of buildings classified as Type B increased from 7% in 2008 to 17% in 2013, the latest year for which the IEA has data on the topic.⁴⁶

Figure 27: Range of cooling intensity of non-residential buildings in Beijing and Shanghai, 2015
KWh/m²



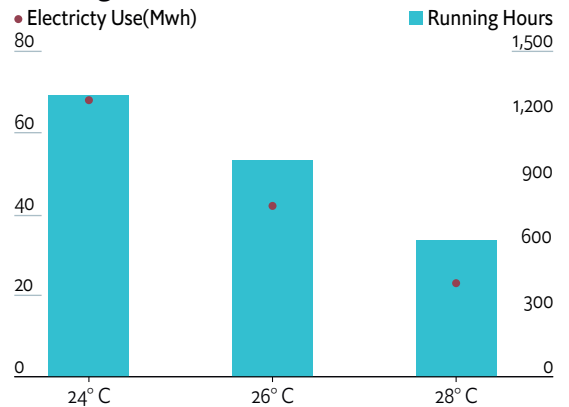
Source: BERG and International Energy Agency¹⁷

While policies are important, experts highlight the power of even small behavioural interventions and nudges. Default building temperature settings of 26 degrees rather than 24 degrees, for instance, can reduce annual cooling electricity usage by over 20 MWh (see Figure 28). “I don’t know that we can expect behaviour to change all that much, particularly when it’s not constrained by other variables,” says Nihar Shah. “Changing set points and controls are the low hanging fruit in reducing utilisation.”

China’s policy response

China has published building codes since 1986, including 44 new or revised standards related to energy efficiency. In 2007 a policy defined efficiency and safety as equally important prerequisites for the approval of construction projects.⁴⁸ Other measures include a **Green Building Action Plan** (2013) and the **13th Five Year Plan for Building Energy Conservation and Green Building Development**. The latter of these two plans includes a range of targets and binding commitments, such as increasing the proportion of new buildings that are urban green buildings to 50% by 2020, and building more than 10m m2 of ultra-low-energy building (ULEB) or nearly zero-energy building (NZEB) demonstration projects by 2020.^{49,50} China has also introduced its own green building evaluation standard (2014), which uses a seven-indicator index to award subsidies to compliant projects. The global rating scale—Leadership for Energy and Environmental Design (LEED)—is also used in some commercial projects.⁵¹

Figure 28: Annual cooling hours and electricity use at different temperature settings in office buildings, 2007



Source: Qin et al. (2007), “Influence of raising set teperature of air conditioning systems in summer on energy consumption of office buildings”.

Figure 29: Main Indicators in the 13th five year plan for building energy conservation and green building development

Main indicators	Cumulative growth rate (%)	Attribute
Energy efficiency improvement of new urban buildings (%)	20	Binding
Share of green urban buildings in new buildings (%)	30	Binding
Share of green building materials used in new urban buildings (%)	40	Binding
Implementation of energy-saving renovation in existing residential buildings (108 m2)	5	Binding
Implementation of energy-saving renovation in public buildings (108 m2)	1	Binding
Decrease in the average heating energy intensity in residential buildings in northern cities per unit area (%)	-15	Expected
Decrease in the energy intensity in existing public urban buildings (%)	-5	Expected
Increase in the use of renewable energy in urban buildings (%)	2	Expected
Share of energy-efficient buildings in existing urban residential buildings (%)	20	Expected
Share of the implementation of energy-saving measures for developed areas and rural residential buildings in key areas (%)	10	Expected

Source: China Energy Efficiency Report, International Energy Charter

These measures have made a difference. While total energy consumption by Chinese buildings has grown, the annual growth rate has moderated over time, declining from 11.9% during the 10th Five Year Plan to 6% during the 11th/12th Five Year Plan.⁵² However, there is much more progress to be made. According to the 2017 Regulatory Indicators for Sustainable Energy (RISE) index, building codes were China's lowest scoring sub-indicator.⁵³ Recommendations for improvement included updating codes, creating an effective compliance system and increasing building performance information disclosure during sale or lease. Interviewees also call for efforts to improve the efficiency of buying decisions. Ben Hartley, who leads the cooling programme at SEforAll (an advocacy group), notes that new developments in China tend to be constructed as "shells" which tenants fit out with their own appliances and facilities. "That limits the ability for new buildings to be fully controllable. The tenant makes the decision, so you lose that ability to, for instance, do bulk purchases of green cooling technologies." China can also look to global progress and evidence from greener building practices for energy-efficient solutions (see the box below).

Cool roofs, urban design and nature-based solutions

Cities and urban developments are increasingly exploring architectural and design innovations to lower temperatures, which can lessen demand on cooling systems. Measures include installing windows that reflect solar heat gain without affecting the entry of light (low-emissivity windows), reducing cooling loads by around 20% or more compared with ordinary glass.⁵⁴ These windows are not currently required as part of window energy performance standards in China.⁵⁵ Natural ventilation is a second option. Field tests of 58 office buildings in China found that using natural ventilation in building design could reduce hours of air conditioning by as much as 40% without compromising comfort levels.⁵⁶ One study forecasts a 100 TWh saving using improved "building envelope" measures such as low-emissivity windows and cool roofs, along with smart cooling devices that ensure energy is used when and where cooling services are needed.⁵⁷

Roofing innovation is key. **Cool roofs** reflect more sunlight and absorb less heat (using reflective paints, tiles, shingles or sheet coverings) and can

be retrofitted to existing buildings.⁵⁸ **Green roofs** draw on the cooling properties of vegetation. One Chicago-based study found that green roofing reduced roof temperatures by one to three degrees.⁵⁹ The use of reflective surfaces and green space is still rare in Chinese buildings, partly because of perceived costs and a lack of promotion among developers.⁶⁰

Urban design and zoning can also tackle urban heat island (UHI) effects, where building materials and infrastructure retain heat, and urban activity generates heated emissions (like fuel exhaust). Demand for cooling in buildings is sensitive to broader urban temperatures, which are often significantly higher due to UHI effects. UHI effects also impinge on the efficiency of cooling technologies, as higher temperatures around the equipment increase the amount of energy needed to cool effectively.⁶¹ A city with more than 1m people can be one to three degrees warmer than its surrounding areas.⁶²

Some cities are showing policy leadership in addressing UHI effects. Stuttgart, in Germany, has actively pursued urban climate planning and heat island management. While not a tropical climate, the city's location in a valley, combined with economic activity centred on manufacturing,

makes heat clearance an imperative. Its interventions to reduce overheating and improve air quality include exploiting natural wind patterns in urban design, using dense vegetation and green corridors, and banning construction in strategic locations.⁶³ Greater use of vegetation can increase ventilation and reduce UHI effects.⁶⁴ Medellin, in Colombia, has used nature-based solutions (defined as those that simultaneously provide human well-being and biodiversity benefits), including greening the verges of roads and

waterways to reduce UHI effects.⁶⁵

Other cities are investing in collecting granular heat data from sensors to inform UHI-related policy and planning strategies. Portland, in the US, is working with academics at Portland State University to produce detailed urban heat maps. A housing zoning update recently proposed planning amendments that will limit surface parking areas in residential zones and require landscaped gaps between buildings and streets to allow for planting of trees.⁶⁶

Environmentally friendly refrigerants

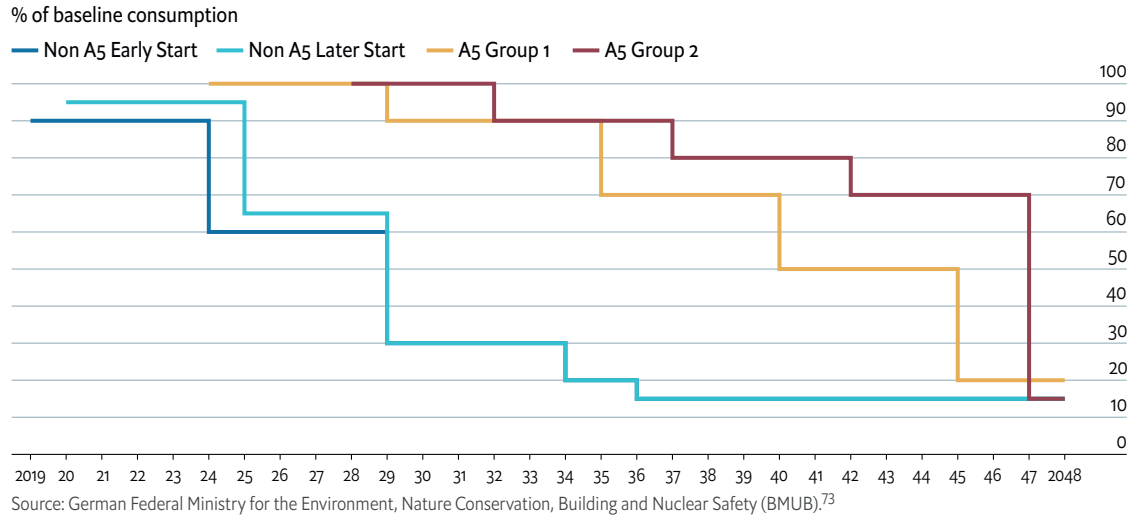
Cooling technologies create direct emissions through the release of gases used in air conditioning and refrigeration, spanning their production, usage and disposal. HFCs (man-made fluorinated gases) first emerged as replacements for ozone-depleting substances but have had damaging environmental effects, trapping heat in the atmosphere at a rate thousands of times faster than carbon dioxide.^{67,68} They are also the fastest growing greenhouse gas, growing at 10%–15% per year.⁶⁹ Annual consumption of fluorinated gases (F-gases)—the chemical group to which HFCs belong—could quadruple in the cooling sector by 2030.⁷⁰

In October 2016 a phase-down of HFCs was agreed as an amendment to the Montreal Protocol, the treaty that committed countries to phase out chemicals that contribute to global warming and ozone layer damage. The Kigali Amendment committed signatories to cut production and consumption of HFCs by 80% over 30 years. Developing countries should peak in terms of production and consumption of HFCs by 2024, with reductions reaching 80% by 2045.⁷¹

If successful, the Kigali Amendment—to which China is a signatory—could avoid up to 0.4 degrees of global warming by the end of the century, and 0.5 degrees under an accelerated phase-down.⁷² “The [Kigali] timeline that was laid out was very carefully planned to give us a level of predictability, that they could meet those commitments based upon technology and the training of the workforce and everything else that goes into bringing products to consumers and into buildings,” says Stephen Yurek, CEO of the Air Conditioning, Heating and Refrigeration Institute (AHRI). “China was engaged continuously in this, both the government and the manufacturers. The timelines are very doable.”

Experts believe the coming decade is essential for action. “The 2020s are decisive in terms of cooling,” says Mr Munzinger, highlighting the need for “a transition now to avoid this massive lock-in of high and mid-GWPs, which will create a massive lock-in with serious consequences for the next two to three decades”.

Figure 30: Phase-out schedules for HFC



While alternatives already exist at commercial scale, all options involve trade-offs.⁷⁴ HCFCs were an improvement over CFCs, but they have high GWPs and deplete the ozone layer. HFCs have less of an effect on the ozone layer but have problematic GWPs. Hydrocarbons (natural refrigerants) are superior on both counts but present unpalatable safety challenges, particularly given the politics of industrial accidents in China. However, these safety challenges can be mitigated through technical training.

Policy responses

The European Union has been a policy leader in phasing out harmful cooling gases, introducing a 2006 directive limiting high-GWP refrigerants in vehicles⁷⁵ and an action plan to cut fluorinated gas emissions by two-thirds by 2030.⁷⁶ It also ratified the Kigali Amendment, and in 2017 HFC consumption was 12% below its first step-down specified under the agreement.^{77,78}

The US, which has not signed the Kigali Amendment, has seen progress at the state level. California has committed to reducing HFC emissions to 40% below 2013 levels by 2030⁷⁹ and banned a range of cooling refrigerants (with staggered introduction of the bans) from January 2019. Phase-outs are also in play in Delaware,⁸⁰ New York, Maryland and Connecticut,⁸¹ and further state-level engagement is expected. Australia, which accepted the Kigali Amendment in October 2017,⁸² commenced an HFC phase-down on 1 January, 2018.

China was a signatory to the 1987 Montreal Protocol and had eliminated 280,000 tonnes of annual ozone-depleting substance (ODS) production capacity by 2018, according to government statements.⁸³ It participated in the phasing-out of HCFCs, converting air conditioning production lines to HFCs amounting to over 10m units of output per year between 2013 and 2015⁸⁴ and demonstrating sustained policy commitment to the Montreal agenda.

China produces over 60% of the world's HFCs and remains an essential partner in achieving a global phase-out of harmful gases. The task is sizeable, given that the country manufactures the chemicals, and the appliances using them, in such significant quantities.⁸⁵ The government has shown commitment to addressing the problem, however. HFCs were discussed at the first summit between Xi

Jinping and Barack Obama in 2013⁸⁶ and a raft of policies and measures have since been developed (see the table below).

China's HFC policy timeline

- 2014 The National Plan for Climate Change (2014-2020) calls on industry to significantly reduce HFC emissions and invest in HFC alternatives.
- 2015 The NDRC organises local commissions to report HFC-23 disposals by enterprises and arranges random third-party verification.
- 2017 The NDRC reports HFC-23 inspection results and announces the provision of quota-based subsidies for enterprises involved in responsible destruction.
- 2019 China releases the Green and High-Efficiency Cooling Action Plan (绿色高效制冷行动方案), which sets out overall targets for green cooling by 2020 and 2030. It also includes commitments to add refrigerant GWP to energy efficiency labels and promulgate product and safety standards to promote low-GWP refrigerants.
- 2020 The Ministry of Ecology and Environment released a draft amendment to the existing Regulation on Administration of Ozone Depleting Substances, adding HFCs to the controlled substances.

Chinese companies are among the global firms developing greener cooling solutions. For example, Gree, Midea and Haier have committed to increasing production of more environmentally friendly split-type propane (R290) RAC units.⁸⁸ (China and India are the dominant manufacturers of propane RACs.)⁸⁹ China increased its political engagement with the Kigali discussions after its domestic industry came forward with viable product offerings:

“As soon as they were able to develop their own equipment for HFCs, the Chinese government changed its mind [over Kigali] and began to persuade other countries to adopt something similar to the Kigali agreement,” says Didier Coloumb, director general of the International Institute of Refrigeration (IIR). For China’s cooling industry to be globally competitive, all exporting producers will need to align with the trend towards alternative, climate-friendly components.⁹⁰

To achieve optimal phase-outs of harmful refrigerants, there are several important considerations. These include managing the safety risks of alternative refrigerants; adapting building codes to accommodate safety profiles, including the informal and shadow sector; and exploring incentive mechanisms.

Alternative refrigerants pose safety challenges, requiring strong training protocols and adaptations to building codes. Environmentally friendly alternative refrigerants have downsides that require improvements in linked areas such as installation and maintenance. Ammonia (R717), for instance, has a low GWP and high energy efficiency but has caused industrial accidents from leaks and fires.^{91,92,93} Some alternative refrigerants create a combustion by-product—hydrogen fluoride—which is toxic and can maim or kill through inhalation, contact or ingestion.⁹⁴ Precautionary hazard labels are essential (such as no-smoking instructions, advice on wearing protective gloves and eye protection, and guidance on actions in the event of a leak).⁹⁵ Regular maintenance and checking protocols are

also required, as is high-quality training.⁹⁶ In China, “manufacturers [currently] do their own training; they’ll take a group of technicians, provide the instruction, and then deliver them to the job site to do the work,” says Mr Yurek. “The biggest issue comes once the products are installed and it’s turned over to a homeowner or a building, be it a hotel, office building and so on. Then they have their onsite technicians. In there, I think there’s more need for training in China.” Building codes also need to adapt to accommodate the safety risks of newer refrigerants. “Most low-GWP refrigerants are either mildly flammable or explosive, so you need to update building codes to make sure the equipment installation and maintenance is done safely. China has the ability to change that because of their centralised government, and they seem to have been working toward that.”

Include the informal sector. There is a gap between regulations and commercial realities, especially in the small or medium-sized enterprise (SME) sector or informal industry, says Nihar Shah. Larger companies tend to comply with rules due to both brand and reputational risks; smaller players, competing on price, may be less likely to comply, both with energy efficiency standards and bans on refrigerants. Greater use of intelligent risk management tools at customs could help to address this problem. Increasing the use of QR codes could also assist buyers to check products and strengthen market surveillance, says Patrick Blake, programme officer at the UN Environment United for Efficiency programme. One review assessed China and India’s efforts to reduce the refrigerant HFC-23 and found a substantial discrepancy with actual emissions data, which showed higher atmospheric levels in 2018 than at any point in history. This indicated that reported reductions had not materialised, or that there may be significant unreported production of HCFC₂₂, causing HFC-23 as a by-product.⁹⁷

Explore incentive mechanisms. The green transition requires well-designed incentive schemes, both for energy efficiency and refrigerant phase-outs. For instance, refrigerant leakage does not tend to come from manufacturing, installation and operation, but from building errors (like piercing a refrigerant line) and during the disposal phase. Finding price incentives to improve the governance of refrigerants and reduce leakage is key. “It requires the development of a system that makes it financially worthwhile for a technician to reclaim, collect and turn that refrigerant in,” says Mr Yurek. He cites Refrigerants Australia and Refrigerants Canada as two good case studies in creating financial incentives. China has outlined mechanisms in its national cooling plan that lay the basis for market interventions, including introducing corporate income tax credit or waivers for enterprises purchasing green and high-efficiency cooling products; guiding banks and financial institutions to provide funding support for green and high-efficiency cooling product manufacturers and renovation; and boosting green loans and green bonds.⁹⁸

Other mechanisms including technical assistance and financial support from international organisations such as the United Nations Industrial Development Organisation and the World Bank Group, which has channelled over \$1bn in grants to phase out the consumption and production of ozone-depleting substances.^{99,100} Mr Andersen highlights measures like capital depreciation schedules for the most efficient equipment to increase their attractiveness. The commercial benefits of engaging with clean cooling are also critical. Government bodies are proving more active in advancing standards and “future-oriented cooling, but somehow, industry is not corresponding to that political will” says Mr Munzinger.

Conclusion

Cooling and refrigeration technologies are essential to every aspect of our lives, from food and medicine supply chains, to data centres that power knowledge industries, to homes and workplaces. As a by-product of economic development, demand for these technologies—both from citizens and industry—is on a rapid upward curve.

In 2019 The Economist Intelligence Unit's report, *The Cooling Imperative*, examined technological and policy progress towards meeting this growing demand for cooling—especially in the context of a warming climate and continued growth in demand in emerging markets—while simultaneously shifting to more efficient and environmentally friendly technologies. This follow-up report focuses on China specifically. As the world's second largest economy and a dominant manufacturer of cooling equipment, China is essential to increasing access to cooling and transitioning the industry towards more sustainable technologies.

International benchmarks and rankings have attested to China's overall progress in reducing its energy intensity, supported by empirical trends showing a moderation of energy intensity to GDP over time. China is among the jurisdictions experimenting with carbon price mechanisms and is a world leader in other green energy industries, including solar technology. Chinese cooling manufacturers are also among those developing lower-impact cooling appliances and technologies. These manufacturers stand to benefit from further investment and R&D in this area, aligning them with global policy shifts towards greener cooling (as laid out in the UNFCCC Paris agreement and the Kigali Amendment) and supporting efforts to maintain or grow export markets.

To continue and deepen China's policy progress, third-party research and experts interviewed for this report identified the following areas of focus.

- **Improving the sophistication of energy performance standards.** Energy performance standards can help to phase out inefficient products, incentivise innovation and encourage greener purchasing decisions, but systems are hard to calibrate effectively. Flaws and challenges include divergences between rated performance and real operating efficiency, especially as equipment degrades over time. These divergences indicate a need for a life-cycle approach, along with investments to ensure compliance and monitoring. This includes stamping out fraudulent labelling schemes and spotting non-compliance by SMEs and the informal sector.
- **Focusing on implementing green building codes and greening urban planning to tackle UHI effects.** Evidence from other contexts shows that choices around building design and urban planning substantially affect temperatures and thus shape demand for cooling technologies. For example, a large number of buildings are rendered temperature-inefficient through their use of inoperable windows and heat-absorptive materials, as well as their reliance on “full-space and full-time” cooling systems or use of unnecessarily high default temperature settings. Innovations and associated incentives are needed to increase the use of natural ventilation and other mechanisms (such as cool and green roofing) to reduce building temperatures. This involves working with

developers and home users to increase awareness of alternative options. Chinese cities can also adopt practices that are emerging elsewhere to lower overall urban temperatures, such as increased vegetation, construction zone restrictions and greater use of reflective materials in urban infrastructure.

- **Upgrading skills to manage safety risks with effective, efficient and environmentally friendly alternative refrigerants.** Low-GWP options like ammonia and propane can help to support the green cooling transition. Chinese manufacturers are already engaged in the production of low-GWP equipment, as well as transition planning. However, these alternative options have downsides, such as flammability and toxicity, and have been linked with industrial accidents. Ensuring appropriate training for installation and maintenance, along with relevant labels and hazard warnings, can reduce the risks associated with otherwise promising refrigerants. Building codes also need to be revised to accommodate new risk factors.
- **Supporting the business community with appropriate incentives, and monitoring compliance and adherence among smaller companies and the informal sector.** Despite the long-term business benefits, the green cooling transition can incur short-term costs for the business community, which may mean that some smaller companies evade regulations and best practices. There are already gaps between formal regulations and realities on the ground in terms of both energy efficiency observance and the use of banned refrigerants. One possible response to this problem is to introduce incentive schemes to ensure relevant parties correctly dispose of harmful refrigerants. Measures that offset the costs of upgrades can also help, such as corporate income tax credits, waivers, green loan instruments and capital depreciation schedules. China has already explored or promised such instruments, the scope and scale of which should be continually monitored for new opportunities.

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Annex: Methodology

This study uses a model based on best practices established in literature with some unique elements that reflect the specific scope of this study. Variable inputs include:

1. The technology used in the sector, both in terms of refrigerants and energy efficiency of cooling equipment. These inputs determine the level of emissions from cooling equipment for a given utilization rate.
2. Consumer behaviour, including how much equipment is used, energy consumption patterns, and how quickly consumers switch best available technology.
3. Demand for cooling equipment from domestic and export markets.

There are significant differences in cooling equipment—as well as the associated emissions—in different economic sectors. To capture this nuance, the model estimates eight separate sectors: four each for air conditioning and refrigeration (each split into residential, commercial, industrial and mobile sectors).

Modelling cooling equipment in service

Based on the Perpetual Inventory Method, new sales and disposal of old equipment drive changes in equipment stocks.¹ Forecasts of new sales are based on The EIU's previous work in *The Cooling Imperative*, which uses an econometric model of cooling demand based on number of households, population, income levels, urbanisation, electricity access and various measures of industrial activity.²

Modelling emissions

Estimates are based on the forecasted equipment stock, segmented into direct emissions (from i.e. leakage of refrigerants) and indirect emissions (i.e. those associated with electricity consumption), based in part on a model presented in Liu and Cai's 2018 study on carbon emissions in China.³ Direct emissions vary based on the global warming potential (GWP) of different refrigerants, as well as the amount of each refrigerant that leaks into the atmosphere during cooling equipment's lifespan.

¹ See Grilliches in Berleemann, M., Wesselhöft, J. E. (2014). *Estimating aggregate capital stocks using the perpetual inventory method. Review of Economics*, 65(1), 1-34.

² *The Cooling Imperative*, The Economist Intelligence Unit (2019), [<http://www.eiu.com/graphics/marketing/pdf/TheCoolingImperative2019.pdf>].

³ Liu, Z., & Cai, B. (2018), *High-resolution Carbon Emissions Data for Chinese Cities*. [<https://www.belfercenter.org/sites/default/files/files/publication/Emissions%202018.pdf>].



Assumed refrigerants in air conditioning

Residential	Commercial	Industrial	Mobile
R407C	R410A	R407C	R134A
R410A	R32R	R134A	
R32	R407C	R22	

Assumed refrigerants in air conditioning

Residential	Commercial	Industrial	Mobile
R134A	R404A	R404A	R407C
R600A	R22	R22	R410A
R404A	R744	R744	R404A
	R717	R718	R134A
	R134A	R134A	

Refrigerant stock is a product of unit stock (adjusted for depreciation) with average unit capacity per sector, and the model estimates leakage at installation, service and disposal for each sector.

Sector	Initial average charge (kg)	Emissions on installation (% of initial charge)	Emissions on operation (% of initial charge per year)	Refrigerant remaining at disposal (% of initial charge)	Recovery efficiency (% of remaining refrigerant)
Air conditioning					
Residential	1.38	1	6	80	80
Commercial	11.26	1	10	80	80
Industrial	70	1	15	70	80
Mobile	0.75	0.5	20	50	50
Refrigeration					
Residential	0.32	1	0.5	80	70
Commercial	110	3	25	70	70
Industrial	253	3	25	100	90
Mobile	6.5	1	50	50	70

Indirect emissions depend on the electricity consumption of cooling equipment. Electricity usage is the product of the number of units in service, the utilisation rate, and the electricity consumed per hour in operating the equipment. Emissions intensity of electricity takes into account fossil fuels' declining share in power generation in China. Unlike the other sectors, mobile air conditioning and refrigeration are typically powered with petrol.

Modelling economic impact

Economic outcomes vary across scenarios as changes in the equipment manufactured in China affect the country's market share in certain high-standard markets, with a particular focus on the European Union. Economic estimates are grounded in assumptions about how China's market share is likely to change in response to a shift to more energy-efficient equipment (in the *Efficiency Boost and Windfall* scenarios). Data on market size and economic ties round out scenario impacts on China's exports, GDP and employment.

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