COMMENTARY:

China's hydrofluorocarbon challenge

Junjie Zhang and Can Wang

China should take more active participation in a prospective agreement on the global phase-down of hydrofluorocarbons.

China has recently agreed to work towards limiting the production and consumption of the climate-damaging hydrofluorocarbons (HFCs). In the scenario of HFC regulation proposed by the North American countries, China has to reduce its annual growth rate of HFC emissions from 40% in 2005–2009 to 13% in 2010–2018. Although Chinese leaders face obstruction from the domestic industrial lobbies, we argue that a phase-down of HFCs is aligned with China's self-interest while contributing to global climate mitigation.

HFCs are used as replacements for ozone-depleting substances; however, many of them are potent greenhouse gases[1]. Owing to the rapid growth of demand for air conditioning and refrigeration, the use and release of HFCs, and hence their contribution to climate forcing, are projected to increase significantly under the business-as-usual scenario[2]. The situation has been exacerbated by the accelerated phase-out of hydrochlorofluorocarbons (HCFCs) in accordance with the 2007 Montreal Protocol[3].

China is a major HFC producer and consumer. From 2005 to 2010, its HFC production tripled to about 180 thousand metric tons. On a global-warming potential (GWP)-weighted basis, China's HFC production in 2010 that would eventually be emitted into the atmosphere was 230 million metric tons (MMT) of carbon dioxide equivalent (MMT CO_2e), of which 150 MMT CO_2e was for domestic HFC consumption. In comparison, China's fossil-fuel CO_2 emissions have grown 38% since 2005, hitting 7.03 billion metric tons in 2010 (ref. 4). Although HFC emissions are still small compared with those from energy use, they are increasing much more rapidly.

China only recently shifted its stance by joining the United States and other countries in finding ways to limit HFCs. In the 2013 US–China Sunnylands Summit, presidents Obama and Xi signed a landmark agreement on working together to cut HFC consumption and production. This commitment was confirmed again later in the St Petersburg's G20 meeting. These moves have been widely applauded as a positive step towards implementing a meaningful HFC agreement to combat global climate change.

Although the Chinese top leadership has agreed to limit HFCs, it is not yet clear how the proposal will be implemented or what its impact on the nation's HFC industry is likely to be. To project China's degree of participation, it is therefore necessary to understand the dynamics of the HFC industry.

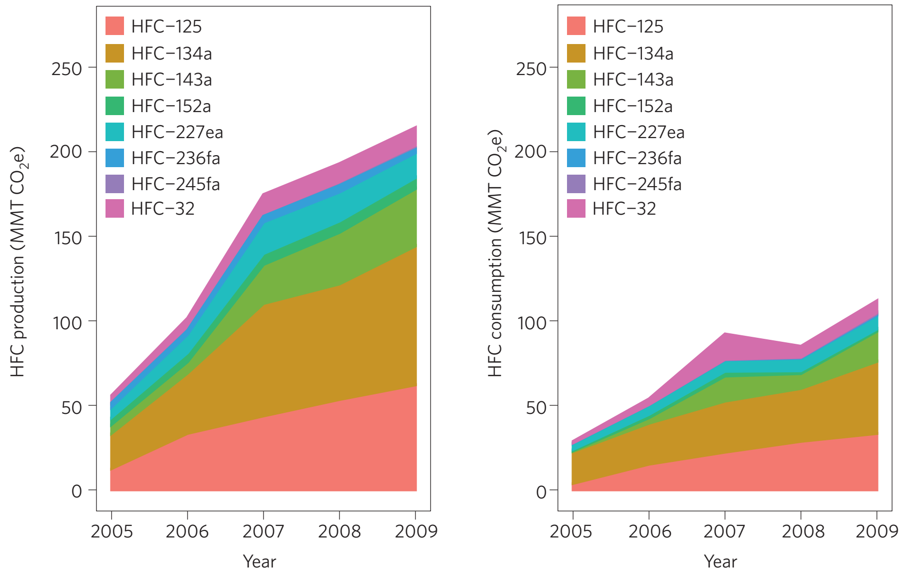

Figure 1 | Carbon dioxide equivalent (CO_2e) emissions of HFC production and consumption in China (2005–2009). The calculations are based on the data in Supplementary Tables 1 and 2. As HFC data reporting is not required by either the United Nations Framework Convention on Climate Change or the Montreal Protocol, data were collected mainly from industrial surveys and supplemented with data from international organizations, government reports, trade associations and firm disclosures. The 100-yr global warming potential was used to convert HFC emissions to CO_2e.

HFC production and consumption

After a decade of rapid growth, China has become one of the most important players in the production and use of HFCs. Among the 11 categories of HFCs produced in China, data are available for the eight most commonly used substances: HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa and HFC-245fa. The omitted three substances, HFC-23 (as substitute for ozone-depleting substances), HFC-161, and HFC-365mfc, account for only a small share of HFC production. In addition, HFC-23 by-product emissions are discussed separately because of the different generation and abatement processes. China's HFC production and consumption on a GWP-weighted basis in 2005–2009 is shown in Fig. 1.

Most HFCs produced in China are potent climate pollutants. In 2009, CO_2e emissions

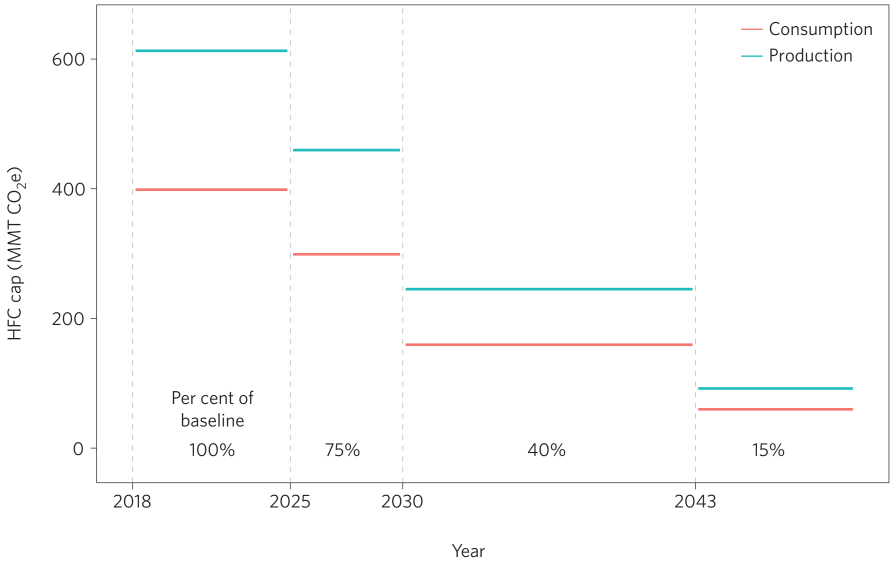

Figure 2 | China's HFC reduction steps under the 2013 North American HFC amendment proposal. The calculation is based on Supplementary Tables 3–5. The proposed baseline and reduction steps were determined on the basis of global warming potential instead of ozone-depleting potential. The percentage of reduction is applicable to the Article 5 countries.

of HFC-134a (100 yr GWP 1,430) alone accounted for 38% of total emissions of HFC production, followed by HFC-125 (100 yr GWP 3,500) at 29%. Both substances have been growing with average annual growth rates above 40% yr^{-1} in the period 2005–2009. The high-GWP HFCs are growing faster than the low-GWP HFCs.

HFC consumption is driven by the ever-increasing demand for residential, commercial and vehicle air conditioners and refrigeration equipment. The combined CO_2e of HFC-134a and HFC-125 accounted for 68% of HFC consumption emissions in 2009. Consumption growth is mainly from high-GWP HFCs. For example, HFC-143a (100 yr GWP 4,470) experienced the fastest growth at 149% yr^{-1} in the period 2005–2009, reaching 16% of China's total HFC consumption emissions in 2009.

HFC production and consumption slowed down during the 2008 global financial crisis. However, growth in HFC manufacture and use is returning to its historic trajectory as the global economy recovers. The projected HFC growth hinges on the demand for refrigerators and air conditioners, cost-effectiveness of low-GWP alternatives, progress of HCFC phase-out and international regulations. Unless controlled, HFCs will continue to grow rapidly until the low-GWP alternatives are technically mature and economically attractive.

North American HFC amendment

To preserve the climate benefits of the ozone treaty, the United States, Canada and Mexico have proposed since 2009 to use the Montreal Protocol to control climate-damaging HFCs[5]. As of 2013, the so-called North American Proposal (NAP) has gained support from 112 countries, including major emerging economies such as China and India[6]. As the proposal is likely to form the foundation of the future HFC agreement, we analyse its implication for China's HFC emissions.

Considering data constraints, NAP suggests to use HCFC activities to calculate HFC production and consumption baselines for those parties that are regarded as developing countries in the Montreal Protocol (referred to as Article 5 parties). In the base years (2008–2010), China's average annual HCFC production was 681 MMT CO_2e and consumption was 443 MMT CO_2e. HCFC-22 accounts for about 80% in both production and consumption. The 2013 NAP suggests that the HFC baseline is 90% of the average HCFC production and consumption in the base years. Therefore, China's HFC production baseline is 613 MMT CO_2e and the consumption baseline is 398 MMT CO_2e. China's HFC cap under NAP is illustrated in Fig. 2.

The cap for Article 5 countries does not take effect until 2018, which allows China to continue to increase its use of HFCs. Given that China's HFC production and consumption were 230 and 150 MMT CO_2e in 2010, the average annual growth rate for both consumption and production needs to be lower than 13% during 2010–2018. The regulated growth rate is about one-third of the historic rate in the period 2005–2009. After 2025, China is required to cut back the use of HFCs step by step. The ultimate goal is to limit HFC production and consumption to 92 and 60 MMT CO_2e by 2043. To achieve this target, China needs to limit the growth of high-GWP HFC production capacity well before the cap becomes binding.

HFC-23 by-product emissions

HFC-23 is one of the most potent greenhouse gases with a 100 yr GWP of 14,800. It is of very limited direct use and its emissions mainly come from HCFC-22 production lines. As the world's largest producer of HCFC-22, China generated about 182 MMT CO_2e HFC-23 as a by-product in 2010[7]. Destruction of HFC-23 has been subsidized by the Kyoto Protocol's Clean Development Mechanism (CDM). China has dominated the CDM activities with 11 registered HFC-23 projects, eliminating 66 MMT CO_2e per year.

HFC-23 has been a controversial issue since the start of the CDM[8]. One argument is that HFC-23 incineration projects are being overcompensated. This is a natural outcome of a competitive carbon market: every unit of emissions reduction has the same price regardless of its source of abatement. Although HFC-23 incineration is much cheaper than switching to renewable energy, their carbon credits are equally valuable.

The deeper concern is that the lucrative business opportunities could create a perverse incentive for chemical companies to expand HFC-23 production and increase overall emissions. This is a common problem for a baseline-and-credit programme like the CDM that does not have emissions caps in developing countries[9].

HFC-23 mitigation is unlikely to continue under the CDM regime. Under NAP, the HFC-23 by-product emissions controls that are not registered as CDM projects will be eligible for funding under the Montreal Protocol's Multilateral Fund. The rate of subsidy has not been determined. If HFC-23 abatement is only compensated by its cost, this would imply a huge discount compared with the price of carbon credit.

Opportunities and obstacles

The recent diplomatic breakthroughs on HFCs have important implications for climate talks. On the one hand, given the sluggish progress of international climate negotiations, a global phase-down of HFCs reduces climate risks, buying time for the formation of a comprehensive climate treaty on CO_2 emissions[10]. On the other hand, top emitters have achieved some success in exploring alternative platforms for climate change diplomacy outside the United Nations Framework Convention on Climate Change[11]. The more focused dialogues, such as the US–China bilateral talk and the G20 forum, have the potential to complement the unwieldy United Nations-led process.

However, China's participation in a new HFC agreement still faces many obstacles. For the fluorine chemical industry, although NAP allows China to increase production up to 2018, the HFC production lines have to retire gradually after 2025. As they lack indigenous technologies, domestic chemical companies are reluctant to make early moves. For the air conditioning and refrigeration industry, low-GWP alternatives are generally more expensive, which raises concern that the manufacturing sector may become less competitive. For the HFC-23 by-product emissions controls, the rate of subsidy of the Multilateral Fund is likely to be much lower than that of the CDM carbon market. The HCFC-22 production facilities have less incentive to capture and destroy HFC-23 under the Montreal Protocol.

We address the above concerns with the following points. First, the Multilateral Fund can assist in financing the conversion of the existing manufacturing processes, technology transfer and capacity building. Second, most HFC production capacity is flexible enough to produce non-HFC chemicals, which lowers the cost of switching. Third, whether or not China joins in an HFC agreement, developed countries' embargo of HFCs will eventually eliminate the international demand for China's HFC exports. Fourth, the sooner the domestic firms start to develop low-GWP substitutes, the better the chance they will avoid being locked into a high-GWP HFC production and consumption economy. Last, but not least, the remarkably generous subsidy for HFC-23 incineration by carbon emissions reduction credits is not sustainable, which has already been addressed by the CDM executive board.

Reducing HFC emissions is a cost-effective option for China to contribute to the global climate target that limits temperature increase to 2 °C above pre-industrial levels. A study shows that China is unlikely to achieve the Copenhagen commitment to slash its carbon intensity by 40–45% by 2020 relative to the 2005 level without further mitigation effort[4]. A phase-down of HFCs is an economically viable way of compliance as it affects a small number of sectors with moderate costs. In addition, switching to some cooling and insulation technologies without refrigerants ('not-in-kind' alternatives) can reduce not only HFCs, but also CO_2 emissions from energy consumption.

Eliminating HFCs is also associated with political benefits. As the world's top greenhouse gas emitter, China has been under mounting pressure in international climate negotiations. Although China has taken domestic actions to slow down emissions growth, it is questioned frequently for its incongruous international commitment. An active participation in the phase-down of HFCs will alleviate China's diplomatic pressure on climate change. Furthermore, while China and the United States are competing on many fronts, HFC phase-down can be a promising area of collaboration for both countries to build mutual political trust and improve diplomatic relations. ❐

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Additional information

Supplementary information is available in the online version of the paper.

COMMENTARY:

The global groundwater crisis

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Groundwater depletion the world over poses a far greater threat to global water security than is currently acknowledged.

Groundwater — the water stored beneath Earth's surface in soil and porous rock aquifers — accounts for as much as 33% of total water withdrawals worldwide[1]. Over two billion people rely on groundwater as their primary water source[2], while half or more of the irrigation water used to grow the world's food is supplied from underground sources[1].

Groundwater also acts as the key strategic reserve in times of drought[3], in particular during prolonged events such as those in progress across the western United States (Fig. 1), northeastern Brazil and Australia. Like money in the bank, groundwater sustains societies through the lean times of little incoming rain and snow. Hence, without a sustainable groundwater

nature climate change

SUPPLEMENTARY INFORMATION
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China’s hydrofluorocarbon challenge

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Table 1: Main HFCs produced in China [1]

Substance	100-year GWP	ODSs Replaced
HFC-32 [2]	675	HCFC-22
HFC-125 [2]	3,500	HCFC-22
HFC-134a [3]	1,430	CFC-12, HCFC-22
HFC-143a [4]	4,470	R502
HFC-152a [5]	124	CFC-12
HFC-227ea [6]	3,220	CFC-12, Halon 1301
HFC-236fa [6]	9,810	Halon 1211
HFC-245fa [6]	1,030	HCFC-141b

[1] Sources: GWP is adapted from the 2013 North American HFC amendment proposal.

[2] HFC-32 and HFC-125 are components for mixed refrigerant such as R407, R410, R504, and R404. Mixed refrigerant are widely used in domestic refrigeration, central air conditioning, industrial refrigeration, transport refrigeration, and cold storage. Compared with HFC-125, the production and consumption of HFC-32 varied widely, partly attributed to the demand shock caused by the 2008 global financial crisis.

[3] HFC-134a is primarily used for automobile air conditioners, which accounts for about 80% of all consumption. Other main usage includes domestic, industrial and commercial refrigeration (15%), plastic insulation foams, and medical aerosols. HFC-134a has the largest share in all HFCs and it has been increasing steadily.

[4] HFC-143a is used to make blend refrigerant R404a, which is used in commercial refrigeration (eg. freezers in supermarket and cold storage), transport refrigeration, and vessel refrigeration.

[5] HFC-152a is the second largest HFC widely used as refrigerant, aerosol propellant, foam expansion agent. It can also be used as a feedstock for manufacturing HFC-143a. Because HFC-152a has both low ODP and low GWP, its use is expected to increase dramatically.

[6] HFC-227ea is commonly used as a gaseous fire suppression agent, medical aerosol propellant, and refrigerant. HFC-236fa is mainly used as a fire extinguishing agent and HFC-245fa is used as a foam blowing agent.

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Table 2: China's HFC production and consumption (2005-2009) [1]

	2005	2006	2007	2008	2009
Panel A: HFC Production (metric tons)					
HFC-32	6,197	10,515	19,083	18,733	18,378
HFC-125	3,588	9,540	12,488	15,264	17,734
HFC-134a	14,604	24,922	46,505	47,777	57,423
HFC-143a	1,181	1,503	5,167	6,827	7,592
HFC-152a	33,030	43,201	51,877	53,896	52,527
HFC-227ea	1,928	3,363	5,800	5,321	4,564
HFC-236fa	245	233	349	401	187
HFC-245fa	253	293	0	323	714
Total	61,026	93,570	141,269	148,542	159,119
Panel B: HFC Consumption (metric tons)					
HFC-32	1,357	4,988	22,197	9,573	10,395
HFC-125	1,088	4,335	6,363	8,194	9,520
HFC-134a	13,210	16,946	21,116	21,870	29,799
HFC-143a	104	721	3,317	1,968	3,993
HFC-152a	6,189	15,908	22,607	13,480	10,229
HFC-227ea	1,125	1,786	2,090	2,289	2,527
HFC-236fa	26	5	16	41	86
HFC-245fa	0	90	264	300	795
Total	23,099	44,779	77,970	57,715	67,343

[1] Sources: Survey of China's HFC industry.

Table 3: 100-year GWP for HCFCs [1]

Substance	100-year GWP
HCFC-21	151
HCFC-22	1,810
HCFC-123	77
HCFC-124	609
HCFC-141b	725
HCFC-142b	2,310
HCFC-225ca	122
HCFC-225cb	595

[1] Sources: The 2013 North American HFC amendment proposal.

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Table 4: China's HCFC production and consumption in the base years (2008-2010) [1,2]

	2008		2009		2010	
	Metric tons	CO_2eq tons	Metric tons	CO_2eq tons	Metric tons	CO_2eq tons
Panel A: HCFC Production						
HCFC-22	287,159	519,757,790	312,045	564,801,450	310,000	561,100,000
HCFC-123	2,558	196,966	2,238	172,326	2,819	217,063
HCFC-124	365	222,285	474	288,666	401	244,209
HCFC-141b	81,298	58,941,050	91,880	66,613,000	98,711	71,565,475
HCFC-142b	22,724	52,492,440	29,125	67,278,750	33,957	78,440,670
HCFC-225	0	0	0	0	0	0
Total	394,104	631,610,531	435,762	699,154,192	445,888	711,567,417
Panel B: HCFC Consumption						
HCFC-22	173,811	314,597,910	200,559	363,011,790	220,985	399,982,669
HCFC-123	367	28,259	298	22,946	748	57,596
HCFC-124	0	0	279	169,911	-14	-8,648
HCFC-141b	40,139	29,100,775	50,323	36,484,175	56,688	41,098,583
HCFC-142b	16,862	38,951,220	21,811	50,383,410	23,531	54,355,455
HCFC-225ca	0	0	42	5,124	56	6,808
Total	231,179	382,678,164	273,312	450,077,356	301,993	495,492,462

[1] Sources: The 2008-2009 data are from the Sector Plan for HCFC Phase-out in the Industrial and Commercial Refrigeration and Air Conditioning (ICR) Sector in China `http://www.undp.org/content/dam/undp/documents/projects/CHN/00063099/PRODOC.pdf`; The 2010 production data are from `http://www.multilateralfund.org/Our\%20Work/webhelp/index.html#!hcfcProdPhasOutManaPlanForChin`; The 2010 consumption data are from UNEP/OzL.Pro/ExCom/71/30 `http://www.multilateralfund.org/71/English/1/7130.pdf`. The GWP data are from Table 3.

[2] The data set only includes the part that will be eventually emitted into the atmosphere, so it does not include the production for feedstock use.

Table 5: China's HFC baseline (metric tons CO_2eq) [1]

	2008-2010 HCFC Average [2]	HFC Baseline
Production	680,777,380	612,699,642
Consumption	442,749,327	398,474,395

[1] The 2013 North American HFC amendment proposal suggests the HFC baseline for Article 5 parties is 90% of the average HCFC production and consumption over 2008-2010. Article 5 parties are defined in the Montreal Protocol as those with per capita consumption and production of ODSs less than 0.3 kg/year.

[2] The HCFC production and consumption data are from Table 4.

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ID	Province	1st period $ktCO_2eq/yr$	Credit start	Total issuance (kCERs)
CDM00473	Jiangsu	8,411.43	12/1/2006	51,463.55
CDM00294	Zhejiang	5,789.68	8/1/2006	37,955.13
CDM00356	Shandong	10,110.12	1/1/2007	59,508.85
CDM00472	Jiangsu	10,437.25	12/22/2006	63,011.17
CDM00672	Zhejiang	3,656.60	11/1/2006	26,231.66
CDM00673	Zhejiang	4,783.75	1/1/2007	33,509.81
CDM00741	Sichuan	2,065.53	5/1/2007	13,193.01
CDM01000	Zhejiang	4,809.63	4/6/2007	28,231.66
CDM01578	Jiangsu	3,473.39	5/1/2008	12,927.61
CDM01678	Shandong	4,248.09	9/14/2007	21,780.17
CDM01848	Zhejiang	7,865.28	4/20/2009	29,450.57

[1] Sources: UNEP Risoe CDM/JI Pipeline Analysis and Database: `http://www.cdmpipeline.org`. The approved GWP for HFC-23 CDM projects is 11,700 for the first commitment period under the Kyoto Protocol. CER: certified emission reduction, 1 CER = 1 ton carbon dioxide equivalent. All registered projects receive carbon credits for 7 years.