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WORKING PAPER

OPPORTUNITIES TO ENHANCE NON-CARBON DIOXIDE GREENHOUSE GAS MITIGATION IN CHINA

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EXECUTIVE SUMMARY

In recent years, China has developed and implemented a range of policies to address climate change, reduce greenhouse gas (GHG) emissions, and transition toward a low-carbon and climate-resilient society. These policies respond both to global efforts to limit climate change, and to China's own need to promote sustainable development and cleaner production methods, address air pollution and other environmental impacts, and improve energy security.

While carbon dioxide (CO_2) emissions mitigation is the subject of increasing attention in China—as evident through recently announced domestic policies and the country's Intended Nationally Determined Contribution (INDC)—less attention has been paid to the remaining greenhouse gases (GHGs) covered by the Kyoto Protocol: methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3), collectively referred to as "non-CO_2 GHG emissions." These emissions are not insignificant. In 2012, China's non-CO_2 GHG emissions were estimated at 1.66 gigatonnes of CO_2 equivalent ($GtCO_2e$) (CAIT 2016)—higher than the total GHG emissions of countries like Japan, Germany, Canada, and Mexico in that same year (CAIT 2016). Moreover, research in this paper suggests that China's non-CO_2 GHG emissions could nearly double by 2030 (relative to 2005 levels) under the existing policy framework, as depicted in Figure E1.

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues. Most working papers are eventually published in another form and their content may be revised.

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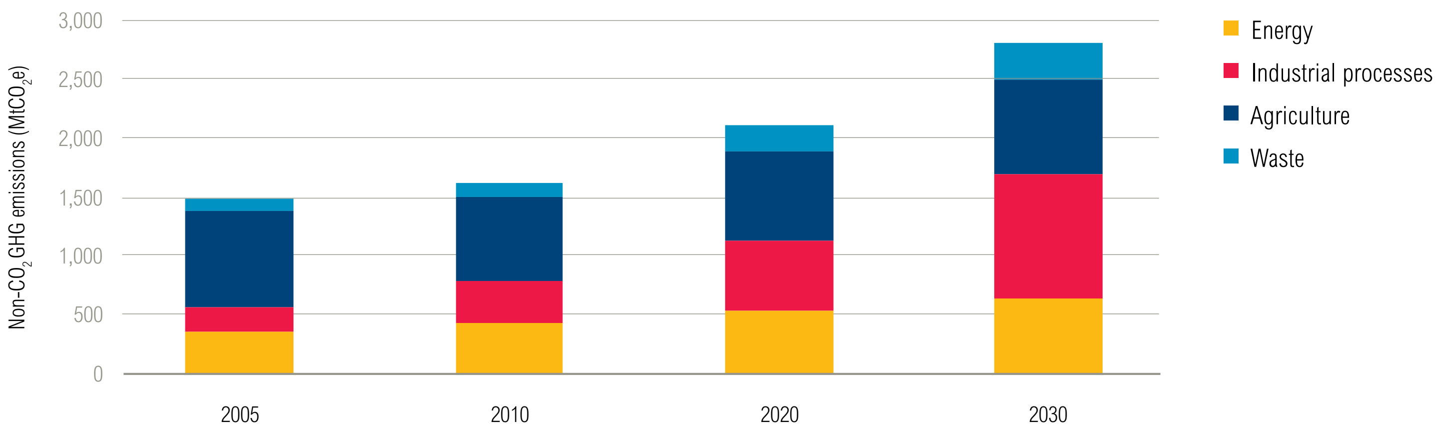
Figure E1 | **China's Historical and Projected Non-CO_2 GHG Emissions, Classified by Sector**



Source: Author calculations.

Despite the magnitude of these non-CO_2 GHG emissions, China has yet to announce a specific national policy or a mitigation target that is inclusive of all GHGs. However, much of the foundation for such a policy or target is already in place. Our analysis shows that:

China's current national development priorities already support non-CO_2 GHG mitigation efforts, provided there is an adequate allocation of financial resources. The 2008 Circular Economy Promotion Law, the 2012 Cleaner Production Promotion Law, and the 2013 Atmospheric Pollution Prevention Action Plan all promote initiatives that eradicate waste, improve resource utilization, and stimulate cleaner production processes—activities that are relevant to the mitigation of non-CO_2 GHGs. In addition, China's 13th Five Year Plan focuses on areas of green development, emphasizing resource efficiency and waste minimization, and mentioning the need to "control non-CO_2 GHG emissions."

China's Intended Nationally Determined Contribution (INDC) alludes to policies and measures that will reduce non-CO_2 GHG emissions. Although the four headline targets in China's INDC relate predominantly to CO_2 emissions mitigation, China also uses its INDC to outline the broad policies that the country will implement to achieve "enhanced action on climate change." These policies cover a range of themes, from improving climate strategies and promoting a low-carbon way of life, to enhancing financial and development support. The INDC describes the key measures that China will undertake in major sectors of the economy to reduce emissions—notably energy, industry, agriculture, and waste. These measures, though generally described only qualitatively, will have an impact on all of China's GHG emissions, not just CO_2.

China has tested a suite of technologies that will reduce non-CO_2 GHG emissions. China has developed, piloted, and implemented a number of technologies to reduce non-CO_2 GHG emissions in all sectors of the economy (albeit in a limited way). These technologies often come with co-benefits, such as improved production safety, enhanced resource utilization, and the use of alternative energy streams. In addition, in some instances, China has actively promoted these technologies by offering financial subsidies and more favorable tax policies.

China has significant non-CO_2 GHG mitigation potential. Our analysis shows that, just by scaling up existing technologies in all sectors of the economy, China can reduce its non-CO_2 GHG emissions by around 800 $MtCO_2e$ per annum by 2030, based on technical feasibility (neglecting any policy, legislative, and financial barriers). This is equivalent to almost a third of China's estimated non-CO_2 GHG emissions in 2030.

However, there is still more work to be done. Our research shows that in order to enhance non-CO_2 GHG mitigation efforts in China—while at the same time addressing the barriers facing these types of efforts—the government will need to:

1. **Develop timely and comprehensive national GHG inventories.**[1] The old adage proves true—you cannot manage what you do not measure. China developed its last official national GHG inventory for the 2005 calendar year. Though some institutions have published estimates of China's GHG emissions in interim years, these studies vary with regard to their assumptions and scope. Timely, robust, and credible GHG emissions data—presented at gas and source level—will form the crucial backbone for identifying key non-CO_2 GHG emissions sources, assessing GHG emissions changes over time, and prioritizing mitigation actions, not to mention serving as a key indicator for tracking policy implementation and effectiveness.

2. **Further develop source-specific non-CO_2 GHG reduction targets, then set an economy-wide GHG emissions reduction target.** Although the Chinese government has committed to peaking CO_2 emissions by 2030 and making best efforts to peak earlier (NDRC 2015b), it has not announced an economy-wide target that covers all GHGs. An economy-wide GHG reduction target will be an effective tool to drive down non-CO_2 GHG emissions; not only in achievement of the target itself, but also because it can act as a catalyst for:

   - Enhancing policy implementation and effectiveness
   - Driving and facilitating the right mix—and consistent implementation—of measures
   - Delegating responsibility and accountability for achieving targets
   - Promoting transparency in tracking and reporting progress toward target achievement
   - Building political will and improving cooperation between government departments

   While an economy-wide GHG emissions reduction target may take time to develop, this should not prevent the Chinese government from taking immediate and enhanced action on tackling non-CO_2 GHGs. Our research shows that there are five key non-CO_2 GHG emission sources that readily lend themselves to further mitigation efforts, based on an assessment of projected emissions growth, abatement potential, available technologies, and goals contained in China's INDC:

   - Methane emissions from coal mining activities
   - Nitrous oxide emissions from fertilizer application
   - Hydrofluorocarbon emissions from substitutes for ozone depleting substances
   - Hydrofluorocarbon emissions from HCFC-22 production
   - Methane emissions from rice fields

   As a first step, China can set mitigation targets for these specific emission sources. Over time, these targets can be scaled up to sector-level emissions reduction goals and, ultimately, economy-wide GHG targets.

3. **Strengthen non-CO_2 GHG mitigation policies and actions, allocate adequate financial resources, and coordinate non-CO_2 GHG emissions reduction efforts with efforts to address CO_2 emissions and air pollutants.** In order to achieve deep cuts in non-CO_2 GHG emissions—and support the achievement of an economy-wide GHG emissions reduction target—it will be important to strengthen non-CO_2 GHG mitigation policies and actions, and allocate adequate financial resources to these activities. As a first step, the Chinese government can undertake an assessment of the effectiveness of existing policies that are targeted toward the five key non-CO_2 GHG emissions sources (through monitoring and evaluation), and subsequently identify gaps and opportunities to improve them. For example, our research shows that few to no policies specifically address nitrous oxide emissions from fertilizer application and methane emissions from rice fields, despite these sources having significant abatement potential. On the other hand, while a number of policies exist to address HFC emissions, efforts to reduce these emissions have been limited due to high costs and other barriers. Finally, it will be important to coordinate non-CO_2 GHG emissions reduction efforts with

efforts to mitigate CO_2 emissions so that the Chinese government can develop a comprehensive climate change policy framework that addresses all GHGs. This will also provide an incentive to include non-CO_2 GHG mitigation projects in China's Certified Emission Reduction (CCER) program and proposed national emissions trading system—something that will be crucial to enhance non-CO_2 GHG emissions reduction efforts. There is also potential to identify synergies between future climate change policy and policies aimed at reducing local air pollutants, a point already alluded to in China's revised "Law of the Prevention and Control of Atmospheric Pollution." Though climate change and air quality policies may never fully overlap, it is important to recognize that any initiatives aimed at improving energy efficiency, enhancing resource utilization, or using cleaner fuels will have mutual benefits for both local air quality and the climate.

INTRODUCTION

In December 2015, 195 countries adopted the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). This Agreement sets landmark goals for taking action on climate change, aiming to hold the increase in global average temperature to well below 2 degrees Celsius (°C) above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C (UNFCCC 2015a). To achieve this, countries will aim to peak global greenhouse gas (GHG) emissions as soon as possible, and undertake rapid reductions thereafter to reach net-zero GHG emissions in the second half of this century (UNFCCC 2015a).[2]

As the world's largest GHG emitter, China will have a major role to play in the achievement of goals laid out in the Paris Agreement. In 2012, China is estimated to have emitted 10.7 gigatonnes[3] of carbon dioxide equivalent ($GtCO_2e$) if emissions from land-use change and forestry are included, accounting for 22 percent of global GHG emissions (CAIT 2016).

In recent years, China has developed and implemented a range of policies to address climate change, reduce GHG emissions, and transition toward a low-carbon and climate-resilient society. However, the majority of the country's climate policies, plans, and targets are geared toward reducing carbon dioxide (CO_2) emissions, often neglecting the remaining six GHGs covered by the Kyoto Protocol:[4] methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3), collectively referred to here as "non-CO_2 GHG emissions" (see Box 1 for more information). China's non-CO_2 GHG emissions are not insignificant. In 2012, these emissions comprised an estimated 18 percent of China's national GHG inventory including land-use change and forestry, and exceeded the total GHG emissions of countries like Japan, Germany, Canada, and Mexico in that same year (CAIT 2016).

This working paper aims to help policymakers and experts better understand China's non-CO_2 GHG emissions, as well as the opportunities available for mitigation. The paper is organized into five major sections. The first section presents China's historical non-CO_2 GHG emissions, and provides estimates of these emissions through 2030. The second section assesses China's current policy landscape and identifies specific non-CO_2 GHG mitigation policies, along with other national development policies that may support deep cuts in these emissions. The third section unpacks the specific actions and measures described in China's Intended Nationally Determined Contribution (INDC)[5] that relate to non-CO_2 GHG emissions, drawing from case studies to define the areas for mitigation in key sectors of the economy. The fourth section discusses the barriers facing non-CO_2 GHG mitigation in China, while the fifth (and final) section discusses major findings and proposes recommendations to address existing barriers and enhance non-CO_2 GHG mitigation efforts, highlighting successful examples from other major economies.

While policies to mitigate non-CO_2 GHG emissions are often coupled with initiatives to reduce air pollutants (like lead, particulate matter, ground-level ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide) and short-lived climate pollutants (like black carbon and tropospheric ozone), this paper focuses only on the six non-CO_2 GHGs that are covered by the Kyoto Protocol.

Box 1 | An Introduction to Non-CO_2 Greenhouse Gases

The targets for the first commitment period of the Kyoto Protocol under the UNFCCC (2008–2012) covered six greenhouse gases, namely, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). At the start of the second commitment period of the Kyoto Protocol in 2013, a seventh gas was included, nitrogen trifluoride (NF_3). The gases that contain fluorine atoms (HFCs, PFCs, SF_6, and NF_3) are often collectively termed "F-gases."

While CO_2 accounts for the majority of anthropogenic GHG emissions, non-CO_2 GHG emissions also contribute significantly to climate change. These GHGs have a greater ability to trap heat (expressed as a measure of the Global Warming Potential or GWP), and many have greater short-term impacts than CO_2. This working paper covers all six non-CO_2 greenhouse gases recognized by the Kyoto Protocol.

Table A1 presents an overview of the six non-CO_2 GHGs, provided in terms of each gas's chemical formula, GWP over a 100-year time horizon (sourced from the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report), and the associated emitting sector.

TABLE A1 | OVERVIEW OF NON-CO_2 GHG EMISSIONS

GREENHOUSE GAS	MOLECULAR FORMULA	GWP_{100}[a] (IPCC 2013)	EMITTING SECTOR			
			INDUSTRY	AGRICULTURE	ENERGY	WASTE
Methane	CH_4	28	×	✓	✓	✓
Nitrous oxide	N_2O	265	✓	✓	✓	✓
Hydrofluorocarbons[b]	HFC-23 (CHF_3)	12,400	✓	×	×	×
	HFC-32 (CH_2F_2)	677	✓	×	×	×
	HFC-125 (CHF_2CF_3)	3,170	✓	×	×	×
	HFC-134a (CHF_2CHF_2)	1,300	✓	×	×	×
	HFC-143a (CF_3CH_3)	4,800	✓	×	×	×
	HFC-152a (CH_3CHF_2)	138	✓	×	×	×
Perfluorocarbons[b]	PFC-14 (CF_4)	6,630	✓	×	×	×
	PFC-116 (C_2F_6)	11,100	✓	×	×	×
Sulfur hexafluoride	SF_6	23,500	✓	×	×	×
Nitrogen trifluoride	NF_3	16,100	✓	×	×	×

Notes:

[a] Global Warming Potential (GWP) is an index to measure the ability of a GHG to trap heat in the present-day atmosphere over a chosen time horizon, relative to the same mass of carbon dioxide. The term "carbon dioxide equivalent," or CO_2e, is used as a means to standardize the measure of global warming impact of each greenhouse gas, calculated based on each gas's respective GWP. GWPs can be assessed over different time horizons: 20-year, 100-year, and 500-year. For example, nitrous oxide has a GWP of 265 over a 100-year time horizon. This means that 1 tN_2O has an equivalent effect to 265 tCO_2e over a 100-year time horizon. Table A1 presents GWPs over a 100-year time horizon, because this is the metric that has been adopted by the United Nations Framework Convention on Climate Change (UNFCCC) to standardize the measure of global warming impact of each GHG, and made operational in the Kyoto Protocol (IPCC 2013). The IPCC updates the GWP values of GHGs at each release of its scientific assessment reports. The GWP values presented in Table A1 are sourced from the latest IPCC report, the Fifth Assessment Report (AR5), published in 2013.

[b] This is not an exhaustive list. Only some HFC and PFC compounds are presented here. Refer to "Chapter 8: Anthropogenic and Natural Radiative Forcing" of the IPCC's Fifth Assessment Report (IPCC 2013) for full details of the GWPs of all HFC and PFC compounds.

1. CHINA'S NON-CO_2 GHG EMISSIONS AND PROJECTIONS

1.1 Historical Non-CO_2 GHG Emissions

China officially reports its national GHG inventory—by gas and by source—through its National Communications submitted to the UNFCCC. To date, China has submitted two National Communications:

- The Initial National Communication (1NC), submitted in December 2004, presenting China's 1994 GHG inventory (NDRC 2004)
- The Second National Communication (2NC), submitted in November 2012, presenting China's 2005 GHG inventory (NDRC 2012)

China has yet to release an official inventory for any year after 2005.[6]

According to the 2NC, non-CO_2 GHG emissions in 2005 comprised 21 percent of China's national GHG inventory including land-use change and forestry (NDRC 2012), accounting for 1.49 $GtCO_2e$. Methane was the largest contributor to China's non-CO_2 GHG emissions in 2005, accounting for 13 percent of the country's total GHG inventory, followed by nitrous oxide (6 percent) and F-gases (2 percent). From a sector perspective, agriculture was the largest contributor to non-CO_2 GHG emissions in 2005 (accounting for 820 $MtCO_2e$), followed by energy (366 $MtCO_2e$), industrial processes (198 $MtCO_2e$), and waste (109 $MtCO_2e$). A detailed breakdown of China's non-CO_2 GHG emissions in 2005 is presented in Table 1, categorized by sector, gas, and emissions source.

Table 1 | **China's Non-CO_2 GHG Emissions in 2005**

EMISSIONS SOURCE	NON-CO_2 GHG EMISSIONS IN 2005 ($MtCO_2e$)
Energy	**365.5**
Methane	*324.0*
Fossil fuel combustion	2.6
Biomass combustion	45.4
Fugitive emissions from coal mining	271.4
Fugitive emissions from oil and gas systems	4.6
Nitrous oxide	*41.5*
Fossil fuel combustion	21.7
Biomass combustion	19.8
Industrial processes	**198.0**
Nitrous oxide	*33.0*
Nitric and adipic acid production	33.0
Hydrofluorocarbons	*148.8*
Production and use of alternatives for ozone depleting substances	42.5
HCFC-22 production	106.3
Perfluorocarbons	*5.7*

Aluminum production	5.5
Semi-conductor manufacturing	0.2
Flat panel display manufacturing	[not estimated]
Photovoltaic manufacturing	[not estimated]
Sulfur hexafluoride	*10.5*
Magnesium production	0.5
Power equipment manufacturing and operation	9.9
Flat panel display manufacturing	[not estimated]
Nitrogen trifluoride	*[not estimated]*
Semi-conductor manufacturing	[not estimated]
Flat panel display manufacturing	[not estimated]
Photovoltaic manufacturing	[not estimated]
Agriculture	**820.0**
Methane	*529.2*
Rice cultivation	166.4
Enteric fermentation	302.0
Animal manure management	60.1
Field burning of agricultural residues	0.7
Nitrous oxide	*290.8*
Animal manure management	82.5
Agriculture soils	208.3
Field burning of agricultural residues	0.1
Waste	**109.1**
Methane	*80.3*
Landfilling of solid waste	46.3
Domestic and industrial wastewater treatment	34.0
Nitrous oxide	*28.8*
Domestic wastewater treatment	28.8
Total	**1,492.7**

Note: China's 2005 GHG emissions were estimated using GWPs from the IPCC's Second Assessment Report, over a 100-year time horizon (NDRC 2012).
Source: NDRC (2012).

Unofficial sources, like WRI's Climate Data Explorer, CAIT, also provide more recent estimates for China's GHG emissions. In 2012, China's non-CO_2 GHGs emissions were estimated at 1.66 $GtCO_2e$ (CAIT 2016), an 11 percent increase relative to 2005 levels.[7]

1.2 Projected Non-CO_2 GHG Emissions

Some institutions have developed estimates of China's non-CO_2 GHG emissions through 2030, taking into account the country's existing set of policies. These studies vary with regard to their assumptions and scope. As such, it can be advantageous to review a suite of emissions projections, and develop an emissions dataset that is tailored to research needs and priorities.

This working paper assesses China's non-CO_2 GHG emissions projections using three research studies. These three studies were selected because they are relatively timely (the earliest study was published in 2012) and provide country-level non-CO_2 GHG emissions projections (as opposed to datasets from the IPCC[8] and others,[9] for example, which present regional emissions projections). These studies are:

- The Chinese research report, unofficially translated as "Technologies and Policy Recommendations for the Emissions Reduction of Non-CO_2 Greenhouse Gases from Typical Industries in China," published in 2014 and endorsed by China's Ministry of Environmental Protection (MEP) (Yang et al. 2014)—henceforth referred to as the "MEP study."
- The report "Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990–2030" published in 2012 by the United States Environmental Protection Agency (EPA 2012)—henceforth referred to as the "EPA study."
- A synthesis of the research conducted between 2013 and 2015 by Peking University in Beijing—henceforth referred to as the "PKU studies." These include:
  - "China's Historical and Projected HFC-23 Emissions, Including Policy Options up to 2050" (Fang et al. 2014);
  - "HFC-134a Emissions from Automobile Air Conditioners in China from 1995 to 2030" (Su et al. 2015); and
  - "Study on the Effect of the Control and Management of HFCs—Opportunities and Challenges" (CESE/PKU 2013).

The technical appendix of this working paper presents the full details of each study's non-CO_2 GHG emissions projections, while Table 2 below summarizes the scope of each study.[10]

Table 2 | **Scope of the MEP Study, the EPA Study, and the PKU Studies**

	MEP STUDY	EPA STUDY	PKU STUDIES
Overview	This report provides an estimate of China's non-CO_2 GHG emissions in the energy, industrial, and waste sectors	This report provides an estimate of non-CO_2 GHG emissions for 92 individual countries (including China) and eight regions in all sectors of the economy	These reports provide estimates of China's HFC emissions projections in the industrial processes sector
Publication date	2014	2012	2013–2015
Coverage	Five non-CO_2 GHGs (CH_4, N_2O, HFCs, PFCs, and SF_6) in certain sub-sectors of the economy	Six non-CO_2 GHGs (CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3) in the energy, industrial processes, agriculture, and waste sectors	HFCs in the industrial processes sector

Time period for projections	Up to 2020	Up to 2030	Up to 2030 and 2050
GWP values applied	GWP values over a 100-year time horizon sourced from the IPCC's Second Assessment Report	GWP values over a 100-year time horizon sourced from the IPCC's Second Assessment Report	GWP values over a 100-year time horizon sourced from the IPCC's Fourth Assessment Report
Emission projection method	Emissions projections are based on the current development of each sector and existing mitigation policies (where existing policies refer to policies that were in place in 2014). In the energy sector, emissions are estimated based on the anticipated achievement of sector-specific goals. In the industrial processes sector, emissions are estimated based on anticipated future demand for certain products. In the waste sector, emissions are estimated based on anticipated GDP growth. Refer to the technical appendix of this paper for full details of the emissions projection methods for the MEP study	Emissions projections are based on achieved emissions reductions in 2012. Future mitigation actions are included only if either a well-established program or an international sector agreement was in place as of 2012. According to the EPA, emissions projection estimates "are presented at the source-category level; therefore, only policies and programs that affect source-level emissions directly are reflected in the [emission] projections." Refer to the technical appendix of this paper for full details of the emissions projection methods for the EPA study	Emissions projections are based on the current development of the industrial sector. With regard to HFCs specifically, emissions are estimated based on the continuing growth of the Chinese automobile market and the phase-out of HCFC-22 under the schedule provided by the Montreal Protocol. Refer to the technical appendix of this paper for full details of the emissions projection methods for the PKU studies
Limitations	The two major limitations of the MEP study are: (1) emissions from the agriculture sector are not estimated; and (2) emissions are projected only to 2020	According to the EPA, the three major limitations of its study are: (1) some data were not incorporated into the estimates due to methodological and time limitations; (2) the projection methods applied entail significant uncertainty; and (3) actual policies and economic development in countries are likely to diverge from the assumptions that were used to construct the EPA's projections. The EPA's study is also relatively out of date in the context of China's rapidly changing policy environment, although it is the only study to comprehensively assess all of China's non-CO_2 GHG emission sources	The major limitation of the PKU studies are that they are constrained to mainly F-gas analysis in China's industrial sector

Of the studies assessed, the MEP study provides the most timely and comprehensive analysis of China's non-CO_2 GHG emissions. Additionally, its emissions projections are aligned with China's more recent policy developments. However, the MEP study covers only certain sub-sectors of the economy and the emissions projections extend only to 2020. The EPA study, while more out of date and perhaps less accurate due to its limitations (see Table 2 for more information), covers all sectors of the economy and projects China's non-CO_2 GHG emissions through 2030. The PKU studies, though timely and extremely detailed, provide estimates only for China's HFC emissions. Refer to the technical appendix of this working paper for the quantitative differences in emissions projections among the various studies.

While some emissions source projections align fairly well (for example, the EPA's and MEP's projections of fugitive emissions from coal mining activities in China are within 10 percent of each other) many do not—this is particularly true for non-CO_2 GHG emissions projections in China's industrial processes sector, where emissions estimates across studies can differ by more than 100 percent. This emphasizes the importance of thoroughly interrogating each study's underlying data, assumptions, and projection methods, and using timely, country-specific analysis where possible.

Accordingly, we have developed a new emissions dataset, based on the respective strengths of each study. The MEP study is used as the primary source, and any gaps in this study are filled with EPA data, apart from HFC emissions projections, which are sourced from the PKU studies. Additionally, the MEP data are projected through 2030, based on emissions growth rates forecast by the MEP in sub-sectors of the Chinese economy between 2010 and 2020. The new emissions dataset is presented in Table 3.

Table 3 | **New Dataset Collating China's Non-CO_2 GHG Emissions Projections from Various Studies**

EMISSIONS SOURCE	NON-CO_2 GHG EMISSIONS ($MtCO_2e$)			DATA SOURCE
	2010	2020	2030	
Energy	**~ 436**	**~ 538**	**~ 638**	
Methane	*~ 388*	*~ 475*	*~ 552*	
Fossil fuel combustion	35	39	44	EPA
Biomass combustion	49	46	43	EPA
Fugitive emissions from coal mining	300	387	461	MEP
Fugitive emissions from oil and gas systems	4	4	5	EPA
Nitrous oxide	*~ 48*	*~ 63*	*~ 86*	
Fossil fuel combustion	38	54	77	EPA
Biomass combustion	10	9	9	EPA
Industrial processes	**~ 361**	**~ 599**	**~ 1054**	
Nitrous oxide	*~ 49*	*~ 167*	*~ 249*	
Nitric and adipic acid production	49	167	249	MEP
Hydrofluorocarbons	*~ 238*	*~ 305*	*~ 578*	
Production and use of alternatives for ozone depleting substances	110	178	358	PKU
HCFC-22 production	128	127	220	PKU

Perfluorocarbons	*~ 20*	*~ 35*	*~ 80*	
Aluminum production	16	23	23	MEP
Semi-conductor manufacturing	3	3	3	EPA
Flat panel display manufacturing	0	1	5	EPA
Photovoltaic manufacturing	2	8	49	EPA
Sulfur hexafluoride	*~ 52*	*~ 85*	*~ 116*	
Magnesium production	9	19	29	MEP
Power equipment manufacturing and operation	31	36	40	MEP
Flat panel display manufacturing	12	30	47	MEP
Nitrogen trifluoride	*~ 2*	*~ 8*	*~ 31*	
Semi-conductor manufacturing	1	1	1	EPA
Flat panel display manufacturing	1	5	22	EPA
Photovoltaic manufacturing	0	2	7	EPA
Agriculture	**~ 702**	**~ 756**	**~ 805**	
Methane	*~ 358*	*~ 370*	*~ 380*	
Rice cultivation	125	114	107	EPA
Enteric fermentation	213	235	250	EPA
Animal manure management	20	21	21	EPA
Field burning of agricultural residues	1	1	1	EPA
Nitrous oxide	*~ 344*	*~ 387*	*~ 425*	
Animal manure management	14	16	17	EPA
Agriculture soils	329	370	406	EPA
Field burning of agricultural residues	1	1	1	EPA
Waste	**~ 128**	**~ 212**	**~ 308**	
Methane	*~ 111*	*~ 195*	*~ 291*	
Landfilling of solid waste	64	117	173	MEP
Domestic and industrial wastewater treatment	47	78	118	MEP
Nitrous oxide	*~ 17*	*~ 17*	*~ 17*	
Domestic wastewater treatment	17	17	17	EPA
Total	**~ 1,626**	**~ 2,106**	**~ 2,804**	

1.3 Limitations

Despite our best efforts to develop a robust and credible dataset for estimates of China's non-CO_2 GHG emissions to 2030, there are some limitations to this approach—which explain the approximate values of some emissions in Table 3 (indicated by ~):

- The MEP and EPA studies present emissions estimates based on GWP values from the IPCC's Second Assessment Report (SAR), whereas the PKU studies present emissions estimates based on GWP values from the IPCC's Fourth Assessment Report (AR4). The emissions estimates across these studies were not standardized against a common set of GWP values because this would create additional uncertainty. For example, the emissions source "production and use of alternatives for ozone depleting substances" includes several types of HFC compounds, each with a different GWP. If emissions from this source were adjusted to reflect another set of GWP values, it would involve making assumptions about the percentage share of the various HFC compounds in this emissions source (due to lack of granularity in the underlying data). These assumptions would have an impact on the overall emissions estimate because the GWP values for HFC compounds vary significantly, from 138 to 12,400 (over a 100-year time horizon) (IPCC 2013). The approximate magnitude of this assumption is estimated to be between 13 and 17 percent.[11]

- The emissions dataset presented in Table 3 is based on GWPs over a 100-year time horizon, which is in line with the metric adopted by the Kyoto Protocol. For the same reasons outlined above, it is not possible to adjust this emissions dataset to reflect GWPs over different time horizons because of the lack of granularity in the underlying data. However, it must be recognized that the choice of time horizon has a strong effect on the GWP values—and thus also on the calculated contributions of CO_2 equivalent emissions by source and by sector (IPCC 2013). This means that different conclusions might be drawn regarding China's top non-CO_2 GHG emissions sources, depending on the time horizon applied. For example, methane has a GWP of 84 over a 20-year time horizon, and 28 over a 100-year time horizon (IPCC 2013).

- The EPA, MEP, and PKU studies were published in different years, between 2012 and 2015. While all studies base their estimates on "existing policies" and "current growth projections," what is "existing" and current" will differ over the years, and no study takes into consideration policies enacted in 2015. Throughout this report, we define the new emissions dataset broadly as based on "existing policies," though it is important to note the distinctions in the underlying data. Please refer to the technical appendix of this working paper for full details on the policies and measures included in the estimates for each emissions source.

- The emissions dataset presented in Table 3 may not be fully comprehensive because it includes only the non-CO_2 GHG emissions sources identified in China's 2NC. Emissions sources that have not been quantified include: methane emissions from industry (for example, petrochemical production, ferroalloy production, silicon carbide production and consumption, and iron and steel production), and methane and nitrous oxide emissions from forest fires.

- The non-CO_2 GHG emissions data presented in Table 3 are totalized at a gas level and a sector level, and then at a national level. Although summing up the emissions source data is not strictly correct—due to the different assumptions, GWPs, and policies used in each of the studies—we did so to give a sense of future non-CO_2 GHG emissions trends in China. While caution should be exercised when using these totalized values, they are useful in identifying rapidly growing emissions sources, and key sectors and sub-sectors of the economy, which will likely require additional policy interventions to drive down non-CO_2 GHG emissions.

1.4 Non-CO_2 GHG Emissions Trends

In 2005, China's non-CO_2 GHG emissions accounted for 1.49 $GtCO_2e$ (NDRC 2012). Based on existing policies, we anticipate that these emissions will increase to approximately 2.10 $GtCO_2e$ in 2020 (a 41 percent increase above 2005 levels), and approximately 2.80 $GtCO_2e$ in 2030 (an 88 percent increase above 2005 levels). This is based on the dataset presented in Table 3. Tables 4 and 5 present China's historical and projected non-CO_2 GHG emissions, by sector and by gas, respectively, under existing policies (synthesized from Table 3).

Table 4 | **China's Historical and Projected Non-CO_2 GHG Emissions, by Sector**

SECTOR	CHINA'S NON-CO_2 GHG EMISSIONS ($MtCO_2e$)			
	HISTORICAL	ESTIMATED/PROJECTED		
	2005	2010	2020	2030
Energy	366	~ 436	~ 538	~ 638
Industrial processes	198	~ 361	~ 599	~ 1,054
Agriculture	820	~ 702	~ 756	~ 805
Waste	109	~ 128	~ 212	~ 308
Total emissions	**1,493**	**~ 1,626**	**~ 2,106**	**~ 2,804**

Table 5 | **China's Historical and Projected Non-CO_2 GHG Emissions, by Gas**

SECTOR	CHINA'S NON-CO_2 GHG EMISSIONS ($MtCO_2e$)			
	HISTORICAL	ESTIMATED/PROJECTED		
	2005	2010	2020	2030
Methane	934	~ 857	~ 1,040	~ 1,223
Nitrous oxide	394	~ 458	~ 633	~ 777
Hydrofluorocarbons	149	~ 238	~ 305	~ 578
Perfluorocarbons	6	~ 20	~ 35	~ 80
Sulfur hexafluoride	10	~ 52	~ 85	~ 116
Nitrogen trifluoride	[not estimated]	~ 2	~ 8	~ 31
Total emissions	**1,493**	**~ 1,626**	**~ 2,106**	**~ 2,804**

From a sector perspective, the industrial processes sector is set to become the largest contributor to China's non-CO_2 GHG emissions in 2030, mainly because of increasing demand for refrigeration services. Under existing policies, HFC emissions are likely to more than triple between 2005 and 2030 as HFCs are increasingly used as refrigerants in place of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which are being phased out under the Montreal Protocol.[12] We are also expecting to see significant growth in nitrous oxide emissions from the industrial processes sector between 2005 and 2030 (nearly doubling over 25 years), due to increased demand for nitric and adipic acid, both of which are used as feedstocks for fertilizers and synthetic products.

From a gas perspective, methane will likely remain the largest contributor to China's non-CO_2 GHG emissions (despite increasing by only an estimated 31 percent between 2005 and 2030). This is predominantly due to fugitive methane emissions from coal mining activities (which we anticipate will contribute to as much as 38 percent of China's total methane emissions in 2030).

F-gas emissions will likely see the greatest rate of increase between 2005 and 2030 (we anticipate an increase of nearly 400 percent over 25 years), predominantly due to rapid anticipated increases in HFC emissions.

China's non-CO_2 GHG emissions trends will be highlighted in Section 3 of this working paper, and will be indicated by a yellow shaded box. These emissions trends are based on the dataset presented in Table 3.

2. POLICY LANDSCAPE FOR MITIGATING NON-CO_2 GHG EMISSIONS IN CHINA

In recent years, China has developed and implemented a range of policies to address climate change, reduce GHG emissions, and transition toward a low-carbon and climate-resilient society. These policies respond both to global efforts to limit climate change, and to China's own need to promote sustainable development and cleaner production methods, address air pollution and other environmental impacts, and improve energy security. While the majority of China's climate policies are geared toward CO_2 mitigation, China has developed some select policies focused on non-CO_2 GHG reduction. Moreover, many of China's national development policies support non-CO_2 GHG mitigation efforts.

2.1 Policies that Directly Target Non-CO_2 GHG Emissions Mitigation

In August 2015, the Chinese government revised the Law of the Prevention and Control of Atmospheric Pollution—a law that will have an impact on all GHGs. Article 2 of the law states that (unofficially translated), "joint effort should be made across regions and coordinated control should be taken of air pollutants and greenhouse gases..." (Standing Committee of the National People's Congress 2015). Apart from this law, the majority of China's existing policies that support non-CO_2 GHG emissions mitigation focus specifically on two GHGs: methane from coal mining activities and hydrofluorocarbons from the industrial processes sector. Sections 2.1.1 and 2.1.2 discuss these policies in more detail.

2.1.1 Policies to Reduce Methane Emissions from Coal Mining Activities

Effective capture of coalbed methane (CBM) presents an opportunity for increased energy productivity and safety in China's coal industry (Aden et al. 2009), not to mention the added co-benefit of reducing fugitive methane, a significant contributor to China's non-CO_2 GHG emissions. Mining companies in China have been capturing and utilizing CBM since the 1990s and, in 2006, the Chinese government began enacting policies related to CBM, some of which are detailed in Table 6. Section 3.1 of this working paper delves into more detail about the actions that China has taken with regard to addressing CBM emissions.

Table 6 | **Policies to Reduce Methane Emissions from Coal Mining Activities**

June 2006	To address coal-mine safety, China's State Council issues "Opinions on Speeding up Coalbed Methane/Coal Mine Methane (CMM) Extraction and Utilization," which clarifies the guiding principles of gas extraction prior to coal mining, integrated with gas control and utilization. The policy requires that local land and planning authorities ensure that coal mines implement a safety-first approach, focusing on prevention, safety standards, and oversight by the government (IEA 2009).
April 2007	China's National Development and Reform Commission (NDRC) issues "Notice on Executing Opinions on Generating Electricity with CBM/CMM," which encourages the deployment of power generation projects using CBM/CMM. The notice requires that electricity generated by CBM/CMM power plants be given priority by grid operators who purchase surplus electricity at subsidized prices (IEA 2009).
December 2011	China's State Council releases its 12th Five-Year Plan (2011–2015) for CBM/CMM Development and Utilization. This Plan sets targets for reaching 16 billion cubic meters (m^3) of CBM production by 2015 (Guizhou CMM Recovery and Utilization Initiative 2012). This target was achieved in 2014 (Yong and Jianping 2015).

September 2013	China's State Council releases guidelines to encourage the development of the domestic CBM industry. These guidelines outline the measures that the government plans to introduce to support CBM extraction and utilization, including financial subsidies, more favorable tax policies, and the management of mining rights (China Law Insight 2013).
September 2013	China's State Council releases the "Atmospheric Pollution Prevention Action Plan (2013–2017)" with the ultimate objective of significantly improving China's air quality over five years. The Plan sets goals, among others, for reducing coal in the country's energy mix to less than 65 percent by 2017 (State Council 2013). The achievement of these goals could lead to reductions in the demand for and production of coal, which may, in turn, reduce methane emissions from coal-mining activities.
February 2015	China's National Energy Administration releases an action plan to increase the development and utilization of CBM, targeting the following achievements by 2020: add 1 trillion m^3 of CBM reserves while realizing a production capacity of 40 billion m^3 (20 billion m^3 of which will be from surface developments) (NEA 2015).

2.1.2 Policies to Reduce Hydrofluorocarbon Emissions from the Industrial Processes Sector

China has also made strides to control hydrofluorocarbon (HFC) emissions in recent years, as detailed in Table 7.

Section 3.2 of this working paper also delves into more detail about the actions that China has taken with regard to tackling HFC emissions from the industrial processes sector.

Table 7 | **Policies to Reduce HFC Emissions from the Industrial Processes Sector**

June 2013	China and the United States agree to work together on the phase-down of HFCs. Under this agreement China and the United States will work together and with other countries to use the expertise and institutions of the Montreal Protocol to phase down the production and consumption of HFCs, while continuing to include HFCs within the scope of UNFCCC and its Kyoto Protocol provisions for accounting and reporting of emissions (The White House 2013).
March 2014	China and the European Union agree to cooperate on taking domestic action to avoid or reduce the consumption of HFCs and work together to promote a global phase-down of these substances (European Commission 2014).
May 2014	China's State Council releases the 2014–2015 Energy Conservation, Emission Reduction, and Low-Carbon Development Action Plan. This Plan includes provisions to strengthen the management of HFCs and to speed up the phase-out and replacement of HFCs, targeting a cumulative HFC reduction of 280 $MtCO_2e$ during the 12th Five Year Plan (State Council 2015). This becomes China's first national non-CO_2 GHG mitigation target.
May 2015	China's National Development and Reform Commission (NDRC) issues a notification requesting companies to submit an HFC-23 mitigation plan by the end of 2015,[13] and providing subsidies for HFC-23 emissions mitigation, starting at 4 Yuan per tCO_2e in 2014 and transitioning to 1 Yuan per tCO_2e by 2019 (NDRC 2015c).
November 2015	To combat the rise in HFCs, China is one of the 197 parties to the Montreal Protocol that agree to work together toward an HFC amendment in 2016 "by first resolving challenges and generating solutions in the contact group on the feasibility and ways of managing HFCs at Montreal Protocol meetings" (UNEP 2015).

2.2 Policies that Indirectly Support Non-CO_2 GHG Emissions Mitigation

In addition to the specific policies and announcements related to non-CO_2 GHG emissions mitigation, a suite of national-level policies and laws exists that will also likely impact these emissions (the extent of the impact will depend on the provision of adequate financial resources and other factors). These policies and laws include:

- **The 13th Five-Year Plan.** In March 2016, the Chinese government released the country's 13th Five-Year Plan (FYP), outlining the strategic vision for the country in the period of 2016–2020. In the area of green development, the government emphasized the need to use resources efficiently and further develop the circular economy (discussed in more detail below)—both of which will affect non-CO_2 GHG emissions. In a chapter addressing climate change specifically, the government mentions that China will "control non-CO_2 greenhouse gas emissions" (the details of how this will be done are, however, not specified in the Plan) (China's National People's Congress 2016).

- **The Circular Economy Promotion Law.** The ultimate objective of a circular economy is to eradicate waste—through better product design, improved resource utilization, and increased recycling. China first introduced the concept of a circular economy in the late 1990s and, in 2008, published the Circular Economy Promotion Law. This law captures the essence of its name, and aims to promote more efficient use of resources, protect and improve the environment, and realize sustainable development (Standing Committee of the National People's Congress 2008). The law is supported in both China's 12th and 13th FYPs, which set goals for improving resource efficiency and further enhancing the circular economy (China's National People's Congress 2011, 2016). In April 2015, the NDRC issued China's Circular Economy Promotion Plan for 2015 (NDRC 2015a). This Plan details actions and targets to use resources (water, metals, land, and coal) more efficiently and to better manage resources and waste in industry, agriculture, and cities (China Water Risk 2015). The goals of the Circular Economy Promotion Plan that impact China's non-CO_2 GHG emissions include:
  - scaling up waste recycling and reuse by both municipal and industrial entities, focusing on Beijing, Tianjin, and Hebei (impacting CH_4 emissions);
  - generating power from low-concentration methane and coal gangue,[14] and increasing the use of coalbed methane (impacting CH_4 emissions);
  - increasing fertilizer use efficiency by 1 percent by the end of 2015 (impacting N_2O emissions);[15] and
  - carrying out 25 Circular Industrial Parks pilots between 2015 and 2020 (impacting N_2O, PFC, HFC, SF_6, or NF_3 emissions, depending on the type of industrial park targeted).

- **The Cleaner Production Promotion Law.** Cleaner production and the mitigation of GHG emissions go hand-in-hand. Any efforts to improve production methods—whether by raising the efficiency of resource utilization or avoiding the generation of pollutants—will lead to GHG emissions reductions. In February 2012, China's Standing Committee of the National People's Congress amended the Cleaner Production Promotion Law (which was originally adopted in June 2002). The law was introduced to stimulate cleaner production, with additional objectives similar to that of the circular economy—to protect the environment and human health and to promote the sustainable development of the economy and society as a whole. Under this law, the Chinese government is to formulate financial and taxation policies, among others, that facilitate the implementation of cleaner production, prepare a national plan, and allocate more funds to these initiatives (Standing Committee of the National People's Congress 2012). Between 2003 and 2009, in addition to water savings and reduced air pollutants, the application of cleaner production methods in China had avoided the combustion of more than 49 million tonnes of coal (Yin 2013). This is equivalent to approximate savings of 114 $MtCO_2$, 1.2 $ktCH_4$, and 1.8 ktN_2O.[16]

Looking ahead, China's non-CO_2 GHG emissions mitigation efforts are likely to be driven by policies focused on pollution control, production safety, and energy efficiency. This will be in addition to the goals contained in the country's Intended Nationally Determined Contribution (INDC).

3. NON-CO_2 GHG MITIGATION OPPORTUNITIES TO SUPPORT CHINA'S INDC

In June 2015, China announced its INDC, detailing the country's plan for post-2020 climate action. This plan includes four headline targets to be achieved by 2030 (NDRC 2015b):

- Peak CO_2 emissions around 2030 and make best efforts to peak early
- Lower CO_2 emissions per unit of GDP by 60 percent to 65 percent from 2005 levels
- Increase the share of non-fossil fuels in primary energy consumption to around 20 percent
- Increase the forest stock volume by around 4.5 billion cubic meters above 2005 levels

While these headline targets predominantly relate to CO_2 emissions mitigation, China devotes significant space in its INDC to outlining the measures that it will implement to "achieve enhanced action on climate change" in major sectors of the economy—notably energy, industry, agriculture, and waste.[17] These measures, though typically described only qualitatively, are likely to have an impact on all of China's GHG emissions, not just CO_2.

The aim of this section is to unpack the measures described in China's INDC that relate to non-CO_2 GHG emissions, many of which build on the policies outlined in Section 2 of this working paper. These measures are discussed in terms of China's existing policy framework, drawing from case studies to define the areas for non-CO_2 GHG mitigation in the major sectors of the economy.

3.1 Non-CO_2 GHG Mitigation Opportunities in the Energy Sector

In 2005, China's non-CO_2 GHG emissions in the energy sector comprised 24 percent of the country's total non-CO_2 GHG inventory, accounting for 366 $MtCO_2e$. Under the existing policy framework, these emissions are anticipated to grow to approximately 538 $MtCO_2e$ in 2020, and approximately 638 $MtCO_2e$ in 2030. The major contributor to China's non-CO_2 GHG emissions in the energy sector will remain fugitive methane emissions from coal-mining activities (set to account for 72 percent of the sector's non-CO_2 GHG emissions in 2030).

China's INDC outlines the country's plans for building a low-carbon energy system, which include: improving the efficiency of coal-fired plants, expanding the use of natural gas, and ramping up clean energy supply (nuclear, hydro, solar, wind, geothermal, tidal, and bioenergy) (NDRC 2015b).

While the INDC headline energy sector target (reaching a 20 percent share of non-fossil fuels in the energy mix by 2030) will predominantly impact CO_2 emissions, which are released during fossil fuel combustion, China also sets quantitative energy sector goals that will impact CH_4 emissions. According to the INDC, China plans to "reach a target of 30 billion cubic meters of coalbed methane production by 2020" (NDRC 2015b). China's 2014 coalbed methane production was estimated at 3.7 billion cubic meters (Andrews-Speed 2016).

3.1.1 Opportunities to Mitigate Coalbed Methane Emissions

Coalbed methane (CBM) is a naturally occurring methane-rich gas that develops in coal seams and is released during coal-mining activities—in direct proportion to the amount of mining activity. As the world's largest producer (and consumer) of coal, China emits significant quantities of CBM. In 2010, the fugitive emissions from coal-mining activities were estimated at 300 $MtCO_2e$ (Yang et al. 2014), accounting for more than 18 percent of China's total non-CO_2 GHG emissions.[18]

Mining companies in China have been capturing and utilizing CBM as an alternative energy source since the 1990s. When the Clean Development Mechanism (CDM)[19] was introduced in the early 2000s, it became economically feasible to undertake even more CBM utilization projects. In 2006, CBM projects in China attracted 63 percent of the total Certified Emission Reductions (CERs) issued under the CDM and, in 2008, the Shanxi Electric Power Corporation officially commenced operation of the world's largest CBM power plant (Aden et al. 2009). By the end of the first commitment period of the Kyoto Protocol in December 2012, the country had registered 124 CBM utilization projects under the CDM (Yang et al. 2014). However, the collapse of the CER market[20] in 2012 brought many of these projects to an abrupt halt.

In September 2013, in an effort to re-stimulate CBM utilization—with an associated co-benefit of reducing fugitive methane emissions—the Chinese State Council released guidelines to encourage the development of the domestic CBM industry. These guidelines outlined the measures that the government planned to introduce to support CBM extraction and utilization, including financial subsidies, more favorable tax policies, and the management of mining rights (China Law Insight 2013). Further announcements followed in February 2015, when the National Energy Administration released an Action Plan to promote the development and utilization of CBM (NEA 2015). This Action Plan specifically targets CBM utilization at surface developments, and power generation at low methane concentrations (Yang et al. 2014)—two areas that have not yet been extensively explored in China. The Plan aims to add 1 trillion cubic meters of CBM reserves by 2020, while realizing an extraction capacity of 40 billion cubic meters (20 billion of which will be from surface developments) (NEA 2015).[21] The Action Plan sets targets that all CBM emissions with methane concentrations in the coalbed gas above 9 percent will be utilized by 2020, along with 32 percent of emissions with methane concentrations in the coalbed gas below 9 percent. If these goals are achieved, China's coal-mining methane emissions could drop to 173 $MtCO_2e$ by 2020, implying a mitigation potential of 214 $MtCO_2e$ (Yang et al. 2014).

In the energy sector, the Chinese government **should accelerate mitigation efforts to reduce fugitive methane emissions from coal-mining activities** for the following reasons:

- Fugitive methane emissions from coal-mining activities are set to remain a large contributor to China's total non-CO_2 GHG emissions. These emissions are expected to grow to around 461 $MtCO_2e$ per annum by 2030 (under the existing policy framework), and will comprise approximately 16 percent of China's total non-CO_2 GHG emissions.[22]

- Significant abatement potential exists. If the goals laid out by China's Action Plan are reached, China's coal-mining methane emissions could fall to 173 $MtCO_2e$ by 2020, implying a mitigation potential of 214 $MtCO_2e$ per annum (Yang et al. 2014).

- Technologies are tried and tested. Mining companies have been effectively capturing and utilizing CBM as an alternative energy source since the 1990s (with a co-benefit of reducing the fugitive methane emitted to the atmosphere).

- Supportive policies are already in place, including financial subsidies and more favorable tax policies (for example, the State Council's guidelines to encourage the development of the domestic CBM industry).

- China's INDC includes plans to increase CBM utilization. These plans, if achieved, will have an associated benefit of reducing fugitive emissions from coal-mining activities.

3.2 Non-CO_2 GHG Mitigation Opportunities in the Industrial Processes Sector

In 2005, China's non-CO_2 GHG emissions in the industrial processes sector comprised 13 percent of the country's total non-CO_2 GHG inventory, accounting for 198 $MtCO_2e$. Under the existing policy framework, these emissions are anticipated to grow rapidly to approximately 599 $MtCO_2e$ in 2020, and approximately 1,054 $MtCO_2e$ in 2030. The major contributor to China's non-CO_2 GHG emissions in the industrial processes sector will be HFC emissions (set to account for 55 percent of the sector's non-CO_2 GHG emissions in 2030).

China aims to embark on a new path of industrialization, one that includes the circular economy and controls the expansion of industries with extensive energy consumption and emissions (NDRC 2015b). China's INDC describes the measures it will undertake to embark on this path, which include accelerating the elimination of outdated production capacity, optimizing the structure of the industry sector, and promoting the development of service and emerging industries (NDRC 2015b). While these measures will likely impact a range of GHGs,[23] China sets only one quantitative industrial sector goal that will impact non-CO_2 GHG emissions. According to the INDC, China plans to "reduce HCFC-22 production by 35 percent below 2010 levels by 2020, and by 67.5 percent by 2025" (NDRC 2015b).[24]

3.2.1 Opportunities to Mitigate HFC-23 Emissions

HCFC-22 is a popular refrigerant and is classified as an Ozone Depleting Substance (ODS) under the Montreal Protocol. Whilst HCFC-22 is not a GHG itself, the production of HCFC-22 releases a potent GHG: HFC-23. HFC-23 has the highest GWP among all HFC gases[25] and, with the rapid increase in the demand for HCFC-22, HFC-23 emissions in China have grown from less than 1 $MtCO_2e$ in 1980 to around 127 $MtCO_2e$ in 2010 (Fang et al. 2014), accounting for 8 percent of China's total non-CO_2 GHG emissions.[26] China's HFC-23 emissions are currently higher than those of every developed country and, under unmitigated emissions scenarios, are estimated to exceed the cumulative impact of HFC-23 emissions from developed countries by 2027 (Fang et al. 2014).

In the early 2000s, HFC-23 mitigation in China was predominantly driven by projects registered under the CDM. By 2009, China had registered 11 HFC-23-reducing projects under the CDM, achieving cumulative CERs of 299 $MtCO_2e$ (Cui et al. 2013). As a result of the implementation of these projects, China's HFC-23 emissions peaked at 155 $MtCO_2e$ in 2006 and decreased to a low of 108 $MtCO_2e$ in 2008 (Fang et al. 2014). In 2010, the CDM Executive Board revised the rules governing HFC-23 destruction on the basis that the existing methodology could lead to over-issuance of carbon credits. These more stringent rules meant that many of China's HFC-23 reducing projects could no longer be registered under the CDM. Further restrictions followed in 2011 when the European Commission banned any projects that destroy HFC-23 from participation in the EU Emissions Trading System (EU ETS) (European Commission 2011). As a result of these rules and restrictions, China's HFC-23 mitigation projects drew to a halt (as they were no longer financially viable without the CER revenue), and emissions began increasing again in 2010 (Fang et al. 2014).

In response to the increase in HFC-23 emissions, in November 2014 China's National Development and Reform Commission (NDRC) issued a notification about an "investment plan from the central government to establish an HFC phase-down demonstration project in 2014." This was soon followed by another notification in May 2015, which requested companies to submit an HFC-23 mitigation plan by the end of 2015.[27] The latter notification also provides subsidies for HFC-23 emissions mitigation, starting at 4 Yuan per tCO_2e in 2014 and transitioning to 1 Yuan per tCO_2e by 2019 (NDRC 2015c). These subsidies, when fully utilized, are estimated to have a mitigation potential of around 200 $MtCO_2e$ per annum by 2020 (Fang et al. 2014).

In the industrial sector, the Chinese government **should accelerate mitigation efforts to reduce HFC-23 emissions** for the following reasons:

- HFC-23 emissions are set to remain a large contributor to China's total non-CO_2 GHG emissions. These emissions are expected to grow to around 220 $MtCO_2e$ per annum by 2030 (under the existing policy framework), and will comprise approximately 8 percent of China's total non-CO_2 GHG emissions.[28]
- Abatement potential exists. If the subsidies proposed by the government are fully utilized, HFC-23 emissions could fall by an estimated 200 $MtCO_2e$ per annum by 2020.
- Technologies are tried and tested. Companies producing HCFC-22 in China have already mitigated a total of 299 $MtCO_2e$ since 2006, using decomposition techniques[29] (Cui et al. 2013).
- Supportive policies are already in place, including financial subsidies.

While China's INDC makes explicit reference only to HFC-23 reduction plans, the country will likely implement a mitigation response that includes all HFC gases. China has been working to phase down all HFC emissions since its joint announcement with the United States in 2013 (The White House 2013). China also includes phase-out and replacements targets for all HFCs in the 2014–2015 "Energy Conservation, Emission Reduction, and Low Carbon Development Action Plan" (State Council 2015). Box 2 provides some examples of the technologies that China has been pilot testing to reduce two other major HFC emission sources: HFC-134a and HFC-410a.

Box 2 | Additional HFC Mitigation Opportunities in China

In addition to HFC-22, the other two major sources of HFC emissions in China are HFC-134a and HFC-410a, both of which are used as refrigerants in air conditioning systems. Their use is on the rise as a result of the phase-out of their ozone-depleting predecessors: chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) under the Montreal Protocol.

HFC-134a and HFC-410a emissions occur when these chemicals leak from the equipment they are servicing. However, alternatives with low and even zero global warming potential are increasingly available (Bianco et al. 2014). They include "natural refrigerants" such as CO_2 and hydrocarbons (HCs) as well as hydrofluoroolefins (HFOs), which contain hydrogen, fluorine, and carbon, like HFCs, but have much lower GWPs (European Fluorocarbons Technical Committee 2015). Some of these alternatives are also more efficient, lowering the amount of electricity required to run the appliances or equipment. Despite these benefits, HFOs can still have high upfront costs and so standards are needed at either the national or international level to help spur a transition away from high-GWP HFC use.

HFC-134a mitigation opportunities in China

Prior to 1994, CFC-12 was the major refrigerant used in vehicle air conditioning systems. However, in response to the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer, CFC-12 was phased out and replaced with HFC-134a, a GHG with a GWP 1,300 times that of CO_2 over a 100-year time horizon (IPCC 2013). Due to the rapid rise in demand for HFC-134a in China, these emissions are estimated to have increased by more than 100 percent per annum between 1995 and 2000, and by approximately 34 percent per annum between 2001 and 2010 (Su et al. 2015). In 2010, China's HFC-134a emissions reached almost 22 $MtCO_2e$, accounting for nearly 10 percent of global HFC-134a emissions and 29 percent of developing countries' HFC-134a emissions (Su et al. 2015).

Though efforts to reduce HFC-134a emissions in China have yet to reach commercial scale (due to high costs and lack of technology[30]), several companies are actively exploring the replacement of HFC-134a with alternative, lower-GWP gases. In the Jiangsu Province, two companies are piloting the production of HFO-1234yf, a compound with zero Ozone Depleting Potential (ODP) and a GWP of less than 1 (Su et al. 2015). The drawback of using HFO-1234yf is that research and development is expensive, as is the refrigerant itself—the price of HFO-1234yf is approximately three to five times higher than that of HFC-134a (Su et al. 2015). Another company in China is pursuing the use of CO_2 as a replacement gas for HFC-134a and has already developed a prototype air conditioning unit. This technology, however, is not yet available on the Chinese market (Su et al. 2015).

HFC-410a mitigation opportunities in China

HFC-410a is a compound that is created when HFC-32 and HFC-125 are mixed in a 1 to 1 ratio. It is often used as an alternative to HCFC-22 in room air conditioning systems. HFC-410a has zero ODP and is non-flammable, and has a low toxicity and chemical stability—properties that have led to a rapid increase in its use over the last 15 years. Similar to HFC-134a mitigation efforts, several companies in China are investigating the replacement of HFC-410a with alternative, lower-GWP gases. Two Chinese enterprises are currently piloting the use of R-290 to replace HFC-410a/HCFC-22 in room air conditioner compressors. These pilot projects were approved by the Executive Committee of the Multilateral Fund of the Montreal Protocol in 2010. In the same year, the world's first pilot production line to use R-290 for split air conditioners was completed in Zhuhai, Guangdong Province. Additionally, in order to adapt these flammable coolants for application in room air conditioners, the Chinese Government revised its standard on "Special Requirements for Safe Heat Pump, Air Conditioner and De-Humidifiers in Home and Similar-Use Electronic Appliances." This removed some of the barriers associated with using R-290 as a coolant for room air conditioners (CESE/PKU, 2013).

Although China's INDC sets only one quantitative goal to reduce non-CO_2 GHG emissions from the industrial sector, it also states that the country will "actively control greenhouse gas emissions originating from industrial production processes" and will "strictly control the total expansion of industries with extensive energy consumption and emissions" (NDRC 2015b). These goals are likely to impact a range of industrial activities. For example, Box 3 discusses some of the options available to reduce N_2O emissions from nitric and adipic acid production in China. Box 4 presents solutions for reducing PFC emissions from electrolytic aluminum production, while Box 5 details options for reducing SF_6 emissions in China's industrial sector. These options/solutions are presented in the form of case studies because China's INDC does not address these emissions sources specifically.

Box 3 | Reducing N_2O Emissions from Nitric and Adipic Acid Production in China

Over the last five years, China has experienced the fastest growth in production of nitric and adipic acid in the world (GVR 2015). This growth was brought about by increased demand for fertilizers and synthetic products, for which both acids are feedstocks. The production of nitric and adipic acid results in significant N_2O emissions. In 2010, China's emissions from nitric and adipic acid production were estimated at 49 $MtCO_2e$, accounting for 3 percent of China's total non-CO_2 GHG emissions.[31] These emissions are anticipated to grow rapidly, to 167 $MtCO_2e$ by 2020 and 249 $MtCO_2e$ by 2030, under existing policy scenarios. China has already implemented effective techniques to reduce emissions from nitric and adipic acid production, some which are discussed in more detail below.

Catalytic decomposition to reduce N_2O emissions from adipic acid production

China's Shenma and Liaoyang chemical plants, which produce adipic acid, have employed a catalytic decomposition process [32] to remove N_2O from their production processes. This process, while expensive—it accounts for one-third of the plant's total production costs—has led to emissions reductions of approximately 17 $MtCO_2e$ per annum since 2010. Both plants' projects have been registered under the CDM to offset the high costs of the process. As an indication of scale, if catalytic decomposition were to be employed at all of China's adipic acid production plants, more than 98 percent of N_2O emissions from adipic acid production could be removed, equivalent to a mitigation potential of 183 $MtCO_2e$ by 2030 (based on projected growth under existing policy scenarios).

Catalytic decomposition to reduce N_2O emissions from nitric acid production

Many nitric acid-producing plants in China have opted to introduce catalytic decomposition at a secondary or tertiary stage of the production process to reduce N_2O emissions. By the end of 2011, China had registered 28 projects (by 19 companies) under the CDM, with an estimated total reduction potential of 5 $MtCO_2e$ per annum. Out of the 28 projects registered, the Kaifeng Jinkai chemical plant in Henan and the Liuzhou chemical plant in Guangxi are the only plants to employ a catalytic decomposition method in the tertiary stage of the production process. As an indication of scale, if catalytic decomposition were to be employed at all of China's nitric acid production plants, 71 percent of N_2O emissions from nitric acid production could be removed, equivalent to a mitigation potential of 45 $MtCO_2e$ per annum by 2030 (based on projected growth under existing policy scenarios).

However, the current opportunities for reducing N_2O emissions from nitric and adipic acid production in China are limited. The high costs of the catalyst, coupled with the expense of reforming the production process, pose significant barriers to these types of mitigation efforts. The Marginal Abatement Cost (MAC) results from the EPA's work on assessing the mitigation potential of non-CO_2 GHGs (EPA 2013) shows that no abatement potential exists for adipic acid and nitric acid production in China at a breakeven price of USD 0/tCO_2e. This means that China does not currently have any technologies to reduce N_2O emissions in nitric or adipic acid production that can be implemented at a zero net cost when considering all costs and associated benefits.

Source: Yang, L., T. Zhu, and Q.X. Gao. 2014. Technologies and Policy Recommendations for Emissions Reduction of Non-CO_2 Greenhouse Gases from Typical Industries in China. Beijing, China: China Environmental Sciences Press. (In Chinese.)

Box 4 | Technologies to Reduce PFC Emissions from Aluminum Smelting in China

The majority of China's PFC emissions are generated from aluminum smelting (Yang et al. 2014).[33] While PFC emissions from aluminum smelting did not contribute significantly to China's total non-CO_2 GHG emissions in 2010 (less than 1 percent), these emissions are anticipated to nearly double by 2030.[34]

Researchers and companies in China are piloting three different technologies to reduce PFC emissions from the aluminum smelting process:

- Automatic extinguishing anode effect technology: this technology was tested in an aluminum smelting factory in Henan, at a cost of 4.05 million Yuan per production line (equivalent to approximately US$620,000)[35], which reduced PFC emissions by around 30 percent.
- Inert anode technology: this technology was developed by the National Engineering Research Center for Aluminum Smelting in 2005 and applied at the Aluminum Corporation of China Limited in 2007. The cost is 1.35 million Yuan per production line (equivalent to approximately US$205,000), and emissions were reduced by about 30 percent.
- Aluminum oxide precision blanking technology: this technology costs 1.35 million Yuan per production line (equivalent to approximately US$205,000) and reduces PFC emissions by around 50 percent due to the non-anode effect.

The production of electrolytic aluminum in China is set to remain at about 24 million tonnes per annum over the next 15 years, implying that the PFC emissions from aluminum smelting are likely to remain constant at 23 $MtCO_2e$ per annum through 2030. However, if both the "inert anode technology" and the "automatic extinguishing anode effect technology" were to be applied to 50 percent of China's aluminum production lines, and aluminum oxide precision blanking technology were used in all production lines, the PFC emissions could decrease to 10 $MtCO_2e$ per annum by 2030, implying a mitigation potential of 13 $MtCO_2e$ per annum by 2030.

Source: Yang, L., T. Zhu, and Q.X. Gao. 2014. Technologies and Policy Recommendations for Emissions Reduction of Non-CO_2 Greenhouse Gases from Typical Industries in China. Beijing, China: China Environmental Sciences Press. (In Chinese.)

Box 5 | Technologies to Reduce SF_6 Emissions from the Industrial Sector in China

SF_6 emissions are a small but rapidly growing component of China's non-CO_2 GHG emissions. In 2010, these emissions were estimated at 52 $MtCO_2e$ and, under existing policy scenarios, are anticipated to grow to 116 $MtCO_2e$ per annum by 2030. SF_6 is released predominately during electric power transmission, flat panel display manufacturing, and magnesium smelting. In the electric power industry, SF_6 is used in transmission and distribution equipment for insulation and arc quenching. In the electronics industry, SF_6 is used for semiconductor and flat panel display production. In the magnesium smelting industry, SF_6 is used as a protective gas to prevent the magnesium from oxidizing at high temperatures. Technologies exist for mitigating these emissions and many of them are currently being pilot tested.

Technologies to reduce SF_6 emissions from electric power transmission

Based on the long-term development goals for China's electric power industry, the demand for SF_6 for power equipment maintenance may increase to 4,470 tonnes in 2020 and 5,007 tonnes in 2030. As a result, the associated SF_6 emissions could reach 40 $MtCO_2e$ per annum by 2030 under existing policy scenarios. Three major mitigation options are currently available to mitigate SF_6 emissions in electric power transmission:

- improving the design of equipment to reduce SF_6 consumption and leakage;
- utilizing alternative gases, such as a mixture of SF_6 and N_2, or N_2 alone; and
- recycling, which involves transferring SF_6 from electrical equipment into storage containers during equipment servicing or decommissioning so that the SF_6 can be reused.

The North China Grid Company has applied a mix of these measures to reduce SF_6 emissions across its distribution network. The company has reduced the leakage rate of SF_6 from its transmission and distribution equipment to 0.4 percent and is recovering 100 percent of the SF_6 that is emitted during maintenance. If these measures could be applied to China's entire electricity sector, and if SF_6 could be replaced with a mixture of N_2/SF_6 in an 8:2 ratio in all new equipment, the SF_6 emissions from electric power could decline to almost zero by 2030, implying a mitigation potential of 40 $MtCO_2e$ in 2030.[36]

Technologies to reduce SF_6 emissions from flat panel display manufacturing

To reduce SF_6 emissions from flat panel display manufacturing, it is possible to use alternative gases such as NF_3 or Carbonyl Fluoride (COF_2). However, because NF_3 is regulated by the Kyoto Protocol (due to its high GWP) the lower-GWP option of COF_2 is recommended. According to the growth trend of China's tablet PC and optical fiber manufacturing sectors, the demand for SF_6 may increase to 1,290 tonnes in 2020 and to 2,073 tonnes in 2030, resulting in SF_6 emissions of 29 $MtCO_2e$ in 2020 and 47 $MtCO_2e$ in 2030 (under existing policy scenarios). However, if COF_2 is used as an alternative gas to SF_6 in flat panel display manufacturing—and SF_6 is phased out completely by 2030—the SF_6 emissions from flat panel display manufacturing could reach zero by 2030, implying a mitigation potential of 47 $MtCO_2e$ in 2030.

Source: Yang, L., T. Zhu, and Q.X. Gao. 2014. Technologies and Policy Recommendations for Emissions Reduction of Non-CO_2 Greenhouse Gases from Typical Industries in China. Beijing, China: China Environmental Sciences Press. (In Chinese.)

3.3 Non-CO_2 GHG Mitigation Opportunities in the Agriculture Sector

In 2010, China's non-CO_2 GHG emissions in the agriculture sector comprised 43 percent of the country's total non-CO_2 GHG inventory, accounting for 702 $MtCO_2e$. Under the existing policy framework, these emissions are anticipated to increase to approximately 756 $MtCO_2e$ in 2020 and approximately 805 $MtCO_2e$ in 2030, due primarily to expected rises in nitrous oxide emissions from fertilizer application. As such, the major contributor to China's non-CO_2 GHG emissions in the agriculture sector will be agricultural soils (set to account for 51 percent of the sector's non-CO_2 GHG emissions in 2030).

China's INDC outlines the activities that the country will undertake to enhance climate action in the agricultural sector, including the following goals:

- promoting low-carbon development in agriculture, making efforts to achieve zero growth in fertilizer and pesticide utilization by 2020;
- controlling methane emissions from rice fields and nitrous oxide emissions from farmlands; and
- constructing a recyclable agriculture system that promotes a comprehensive utilization of straw, agriculture and forestry wastes, and animal waste.

These goals build upon the country's ongoing "Program of Introducing Advanced Forestry Technologies from other Countries," and termed the "948 plan" because it originally set out 948 projects to advance the use of agricultural techniques from other countries. This plan was released in 1994 and is regularly updated (calling for new projects as recently as 2015). In 2009, in line with the "948 plan," China's Ministry of Agriculture introduced three goals to reduce the GHG emissions from the agriculture sector. The goals are to: (1) implement small-scale biogas projects in rural areas, thereby reducing methane emissions; (2) carry out soil testing to optimize fertilizer application, thereby reducing nitrous oxide emissions; and (3) promote straw mulch tillage to increase the organic carbon content of soils, thereby reducing methane emissions (China Economic Net 2009).

3.3.1 Opportunities to Mitigate Nitrous Oxide Emissions from Fertilizer Application

Both China's INDC and the "948 plan" set goals for reducing nitrous oxide emissions from fertilizer application. These emissions are a major contributor to China's non-CO_2 GHG emissions. In 2010, China is estimated to have emitted approximately 330 $MtCO_2e$ from these applications, the highest of any country and accounting for 30 percent of the world's total (Dong et al. 2008). Farmers in China are currently experimenting with new fertilization techniques to reduce these emissions, which include the following:

- Conducting soil testing and formulated fertilization, which can improve the utilization ratio of nitrogen fertilizer, and avoid unnecessary N_2O emissions from farmlands caused by over-fertilization. In 2007, this technique was applied to 427,000 km^2 of China's farmland, raising the fertilization ratio by more than 3 percent and subsequently decreasing N_2O emissions by 3 percent (Huang 2006).

- Using controlled release of fertilizer,[37] which can reduce N_2O emissions by 80 percent (Huang 2006).

- Adding bio-inhibitors such as urease inhibitor hydroquinone and dicyandiamide to nitrogen fertilizers, which can reduce N_2O emissions by 30–62 percent (Shi et al. 2010).

- Employing precision agriculture, which includes precision fertilizing, precision sowing, and precision irrigation. Compared with traditional fertilization methods, precision agricultural techniques can increase crop yields and decrease fertilization use (Li 2009).

In the agriculture sector, the Chinese government **should accelerate mitigation efforts to reduce nitrous oxide emissions from fertilizer application** for the following reasons:

- Nitrous oxide emissions from fertilizer application are set to remain a large contributor to China's total non-CO_2 GHG emissions. These emissions are expected to grow to around 406 $MtCO_2e$ per annum by 2030 (under the existing policy framework), and will comprise approximately 14 percent of China's total non-CO_2 GHG emissions.[38]

- Abatement potential exists. If the goals laid out by the INDC are reached, and China can achieve zero growth in fertilizer use by 2020, the country will see a mitigation potential of 37 $MtCO_2e$ per annum by 2030.[39]

- Technologies are already being piloted. Several farmers are experimenting with new techniques that can significantly abate nitrous oxide emissions from fertilizer application.

- China's INDC includes plans to control nitrous oxide emissions from farmlands.

3.3.2 Opportunities to Mitigate Methane Emissions from Rice Fields

China's INDC also mentions plans for controlling methane emissions from rice fields. In 2010, methane emissions from rice fields in China were estimated at 125 $MtCO_2e$ (or 8 percent of total non-CO_2 GHG emissions).[40] Several rice field farmers in China have tested various techniques that will reduce methane emissions, with the ultimate objective of improving yields and reducing costs. These techniques often involve reducing rice seedlings' water exposure, thereby limiting the rate of methane generation.[41] The techniques include the following (Huang et al. 2011):

- Choosing rice varieties known to produce fewer GHG emissions—some varieties emit 50 percent less than their conventional counterparts. If these species were to be planted across the whole country, the CH_4 reduction potential could reach 28–30 $MtCO_2e$ per annum.

- Applying biomass residues as a low-CH_4-emitting fertilizer. Biomass residues are particularly low-emitting fertilizers, and are used in only 7 percent of rice paddies in China (the majority of rice paddies use organic fertilizer). If 60 percent of China's rice paddy fields were to use biomass residues by 2030, the CH_4 reduction potential could be as much as 28 $MtCO_2e$ per annum.

- Using an intermittent drying technique (as opposed to conventional irrigation). Currently, 28 percent of China's rice paddies use this technique. If the technique could be extended to 50 percent of China's rice paddies, the CH_4 reduction potential could reach 9–11 $MtCO_2e$ per annum.

- Using a semi-dry cultivation method, where rice seedlings are planted on a ridge and receive water from an adjacent ditch. If the technique could be extended to 50 percent of China's rice paddies, the CH_4 reduction potential could reach 43–75 $MtCO_2e$ per annum.

- Applying a novel technique known as "dry nursery and thin planting," which uses dry raised seedlings and lower-density cultivation methods. If this technique were to be applied across all of China's rice paddies, the CH_4 reduction potential could reach 2–6 $MtCO_2e$ per annum.

- Applying pesticide- and fertilizer-based CH_4 inhibitors, which can reduce methane emissions from rice paddies. If these inhibitors could be applied across all of China's rice paddy fields, the CH_4 reduction potential could reach 19–32 $MtCO_2e$ per annum.

(Note that most of the abovementioned techniques have some degree of overlap, and therefore the mitigation potentials cannot be summed.)

In the agriculture sector, the Chinese government **should also accelerate mitigation efforts to reduce methane emissions from rice fields** for the following reasons:

- Methane emissions from rice fields are set to remain a large contributor to China's total non-CO_2 GHG emissions. These emissions are expected to grow to around 107 $MtCO_2e$ per annum by 2030 (under the existing policy framework), and will comprise approximately 4 percent of China's total non-CO_2 GHG emissions.
- Significant abatement potential exists. The technique showing the greatest mitigation potential is the semi-dry cultivation method, which, if applied to 50 percent of China's rice fields, could reduce emissions by up to 75 $MtCO_2e$ per annum (Huang et al. 2011).
- Several technologies are already being tested. Many Chinese farmers are experimenting with new techniques that can significantly abate methane emissions from rice fields.
- China's INDC includes plans to control methane emissions from rice fields.

3.4 Non-CO_2 GHG Mitigation Opportunities in the Waste Sector

In 2005, China's non-CO_2 GHG emissions in the waste sector comprised 7 percent of the country's total non-CO_2 GHG inventory, accounting for 109 $MtCO_2e$. Under the existing policy framework, these emissions are anticipated to increase to approximately 212 $MtCO_2e$ in 2020, and approximately 318 $MtCO_2e$ in 2030. The major contributor to China's non-CO_2 GHG emissions in the waste sector will be landfilling of solid waste (set to account for 56 percent of the sector's non-CO_2 GHG emissions in 2030).

The re-use and minimization of waste is a common theme running though China's INDC. Embedded in this effort is China's drive toward a sustainable and circular economy. China devotes a full section in its INDC to the promotion of a low-carbon way of life, encouraging its people to support moderate consumption and curb extravagance and waste. The country specifically highlights its plans to improve waste separation and recycling, and intensify the recovery and utilization of methane from landfills.

In 2008, the Chinese government promulgated the "Standard for Pollution Control on Municipal Landfill Sites," (GB16889-2008), which requires municipal solid waste landfills with design capacities of greater than 2.5 million tonnes and depths of more than 20 meters, to construct a landfill gas utilization facility or flare(s) to handle the methane-rich landfill gas (EPA 2009). While this standard requires only large-scale landfills to capture and utilize/destroy methane-rich landfill gas, the country has also implemented similar projects at smaller landfills, typically with the support of the CDM. By 2010, China had received more than 608 million CERs from landfill gas projects (Yang et al. 2014). These projects include the collection of landfill gas for direct use in thermal applications, onsite flaring, electricity generation, or combined heat and power systems.

While methane emissions from the landfilling of solid waste will remain a contributor to China's non-CO_2 GHG emissions (these emissions are set to account for 6 percent of China's total non-CO_2 GHG emissions in 2030),[42] prioritizing mitigation efforts in this sector will be challenging in the absence of broader policies, specific landfill gas utilization targets, and/or financial incentives.

4. BARRIERS FACING NON-CO_2 GHG MITIGATION IN CHINA

In order to enhance non-CO_2 GHG mitigation in China, and build on the foundation of existing policies and the INDC, the Chinese government will also need to address the existing barriers facing these types of mitigation efforts. These barriers include the following:

- **Lack of data and knowledge.** To date, the majority of China's climate policies and targets have focused on CO_2 mitigation, and considerably less attention has been paid to understanding and quantifying non-CO_2 GHG emissions and mitigation potential. Moreover, if national GHG inventories are released only at 10-year intervals—as has been the case to date in China—it becomes challenging to track the impact of policies and mitigation measures. This is particularly relevant in the case of rapidly-growing emissions sources. For example, China's HFC-23 emissions are estimated to have grown by 14 times between 2005 and 2010, due to the phase-out of ozone depleting substances, and nitrous oxide emissions from adipic and nitric acid production are estimated to have increased by 60 percent over the same period (based on the emissions dataset presented in Table 3). China is, however, expected to publish a more up-to-date national GHG inventory as part of its Third National Communication and First Biennial Update Report submissions to the UNFCCC, which would address some of these concerns.

- **The absence of a non-CO_2 GHG mitigation target.** Overarching GHG reduction targets play a critical role in China because these targets drive action at both the provincial and company levels (because targets in China are generally apportioned to more granular levels). This approach results in greater accountability and responsibility for achieving the country's stated goals. Overarching targets also promote coordination among government departments, a factor particularly important to non-CO_2 GHG mitigation efforts because these GHGs are emitted by all sectors of the economy. While the same is true for CO_2 mitigation—where the government needs to coordinate across sectors like energy, transport, industry, and forests to achieve emissions reductions—these departments are brought together under a common goal: to work together to ensure that CO_2 emissions peak by 2030 (while making best efforts to do so earlier), and to reduce CO_2 emissions per unit of GDP by 60 to 65 percent below 2005 levels (NDRC 2015b). These departments also have experience in collaborating on other initiatives that impact CO_2 emissions, such as the Top 1,000/10,000 Program.[43] Without a non-CO_2 GHG mitigation target it may be difficult to delegate responsibility and accountability for reducing non-CO_2 GHG emissions, and to promote collaboration among government departments to drive down these emissions.

- **Cost.** Some non-CO_2 GHG mitigation initiatives are currently too costly to implement without the support of financial incentives or a carbon market. Our analysis shows that this is particularly true for N_2O and HFC reduction in the industrial sector (see Boxes 2 and 3 for more information). On the other hand, research suggests that China can advance non-CO_2 GHG mitigation in other sectors of the economy fairly efficiently. For example, according to the United States Environmental Protection Agency's report, *Global Mitigation of Non-CO_2 Greenhouse Gases*, China has a "cost-effective," non-CO_2 GHG mitigation potential of 200 $MtCO_2e$ in 2030. In the context of EPA's work, "cost-effective" refers to technologies that can be implemented at net-zero cost and may be potentially profitable—sometimes referred to as "no-regret" options.

- **Non-CO_2 GHG emissions mitigation projects are not yet well established under China's Certified Emission Reductions (CCER) program, nor are they included in the proposed national emissions trading scheme.** In December 2014, China's National Development and Reform Commission (NDRC) issued the "Interim Administrative Measures on Carbon Emissions Trading." These measures provide the institutional framework for the development of a unified national carbon market in China, which is expected to be implemented in three phases between 2015 and 2020 (PMR 2015). The piloting process ran from June 2013 to April 2015, with the majority of the credits traded during this time accruing from CO_2-mitigating projects: wind, hydro, solar PV, biomass, fuel switching, and energy conservation/energy saving. While 11.5 percent of the issuing projects were related to methane recovery and utilization, there were no projects related to N_2O or F-gas mitigation (PMR 2015). Moreover, in September 2015, during an official state visit to the United States, President Xi confirmed that China plans to launch a national emissions trading system in 2017, covering power generation, steel, cement, and other key industrial sectors, as well as implement a "green dispatch" system to favor low-carbon sources in the electric grid (The White House 2015). This national emissions trading scheme, while large in size—covering 31 provinces, six industrial sectors, and 15 sub-industries—is set to regulate only CO_2 emissions (Jiang 2015).

The next section discusses the major findings of this paper, and proposes three key recommendations to address the barriers outlined above. These recommendations are intended as a guide to help the Chinese government enhance non-CO_2 GHG mitigation efforts.

5. DISCUSSION AND RECOMMENDATIONS

While China has established an all-inclusive approach for tackling CO_2 emissions—notably setting an economy-wide quantitative goal for peaking CO_2 emissions by 2030—efforts and policies geared toward reducing non-CO_2 GHG emissions in the country have, to date, been developed incrementally, and typically focused on specific gases and sectors. Although fugitive methane emissions from coal-mining activities and HFC emissions from industrial activities have gained increasing prominence over the years, with the government going as far as providing financial incentives for the mitigation of these gases, China has yet to develop a comprehensive policy or mitigation target that covers all GHG emissions. However, much of the foundation for such a policy or mitigation target is already in place. Our research shows that:

China's current national development priorities already support non-CO_2 GHG mitigation efforts, provided there is adequate allocation of financial resources. The 2008 Circular Economy Promotion Law, the 2012 Cleaner Production Promotion Law, and the 2013 Atmospheric Pollution Prevention Action Plan promote initiatives that eradicate waste, improve resource utilization, and stimulate cleaner production processes—activities that are relevant to the mitigation of GHGs. In addition, China's 13th FYP focuses on areas of green development, emphasizing resource efficiency and waste minimization, and mentioning the need to "control non-CO_2 GHG emissions" (China's National People's Congress 2016).

China's INDC alludes to policies and measures that will reduce non-CO_2 GHG emissions. Although the four headline targets in China's INDC relate predominantly to CO_2 emissions mitigation, China also uses its INDC to outline the specific policies the country will implement to achieve "enhanced action on climate change." These policies cover a range of themes, from improving climate strategies and promoting a low-carbon way of life, to enhancing financial and development support. The INDC describes the key measures that China will undertake in major sectors of the economy to reduce emissions—notably energy, industry, agriculture, and waste. These measures, though generally described only qualitatively, will impact all of China's GHG emissions, not just CO_2.

China has already tested a suite of technologies that will reduce non-CO_2 GHG emissions. China has already developed and implemented a number of technologies to reduce non-CO_2 GHG emissions in all sectors of the economy. These technologies often come with co-benefits, such as improved production safety, enhanced resource utilization, and the use of alternative energy streams (such as the use of fugitive methane as an energy source in the mining and waste sectors). In addition, in some instances, China has actively promoted these technologies by offering financial subsidies and more favorable tax policies. By scaling up these existing technologies in all sectors of the economy, China can reduce its non-CO_2 GHG emissions by around 800 $MtCO_2e$ per annum by 2030, as detailed in Table 8—equivalent to almost a third of China's estimated non-CO_2 GHG emissions in that year. The mitigation potential presented in Table 8 draws on the analysis described in Section 3 of this working paper, and is based only on the scale-up of China's existing efforts to mitigate non-CO_2 GHG emissions. Therefore, this mitigation potential is based purely on technical feasibility (i.e. proven technologies), neglecting any policy, legislative, and financial barriers.

Table 8 | **China's Non-CO_2 GHG Mitigation Potential, Based on the Scale-up of Existing Technologies**

SECTOR	EMISSIONS SOURCE	MITIGATION POTENTIAL BY 2030 ($MtCO_2e$/annum)
Energy	CH_4 emissions from coal mining	214
Industry	HFC emissions from HCFC-22 production	200
	N_2O emissions from nitric and adipic acid production	228
	PFC emissions from aluminum smelting	13
	SF_6 emissions from electric power transmission	40
	SF_6 emissions from electronics production	47
Agriculture	CH_4 emissions from rice fields	75
Total		**817**

Source: Authors' calculations

There are five key emissions sources that readily lend themselves to further emissions reduction efforts. Table 9 provides a summary of the research presented in Sections 1, 2, and 3 of this working paper, with a focus on China's anticipated top ten non-CO_2 GHG emissions sources in 2030.[44] Based on the information contained in Table 9, we find that there are five key emissions sources that readily lend themselves to further emissions reduction efforts: methane emissions from coal-mining activities; nitrous oxide emissions from fertilizer application; hydrofluorocarbon emissions from substitutes for ozone depleting substances; hydrofluorocarbon emissions from HCFC-22 production; and methane emissions from rice fields. We have identified these five key sources for the following reasons:

- these emission sources are set to become/remain large contributors to China's total non-CO_2 GHG emissions;
- significant/some abatement potential exists;
- technologies to reduce emissions from these sources are either well-established or have been tested/piloted;
- some degree of supportive policy is already in place; and
- the goals of the INDC specifically address these emissions sources.

With a foundation in place to strengthen non-CO_2 GHG mitigation, China will still need to overcome the existing barriers that face these types of mitigation efforts. These barriers include lack of data and knowledge, the absence of non-CO_2 GHG reduction targets, high costs for certain mitigation technologies, and the exclusion of non-CO_2 GHG reduction projects from the proposed national emissions trading scheme.

Three recommendations can help to overcome these barriers:

1. Develop timely and comprehensive national GHG inventories[45]

The old adage proves true—you cannot manage what you do not measure. China developed its last official national GHG inventory for the 2005 calendar year. Though some institutions[46] have published estimates for China's GHG emissions in interim years, these studies vary with regard to their assumptions and scope. This makes it challenging to compare estimates and develop a reliable set of emissions data. The Paris Agreement—adopted by 195 countries (including China) under the UNFCCC in December 2015—states that "each Party shall regularly provide…a national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases…." This should spur the Chinese government to develop and release national GHG inventories at more frequent intervals (at least biennially). Timely, robust, and credible GHG emissions data—presented at a gas and source level—will form the crucial backbone for identifying key non-CO_2 GHG emissions sources, assessing GHG emissions changes over time, and prioritizing mitigation actions, not to mention serving as a key indicator for tracking policy

Table 9 | **China's Top Ten Estimated Non-CO_2 GHG Emissions Sources, and their Potential for Further Emissions Reduction Efforts**

EMISSIONS SOURCE	ESTIMATED EMISSIONS IN 2030 ($MtCO_2e$)	IDENTIFIED ABATEMENT POTENTIAL[a]	DO THE GOALS OF THE INDC SPECIFICALLY ADDRESS THIS EMISSIONS SOURCE?	ARE POLICIES ALREADY IN PLACE TO ADDRESS THIS EMISSIONS SOURCE?	ARE THERE TECHNOLOGIES AVAILABLE TO MITIGATE THESE EMISSIONS?
1. Methane emissions from coal-mining activities	461	High	Yes	Yes	Yes, technologies are well established
2. Nitrous oxide emissions from fertilizer application	406	Medium	Yes	No	Yes, technologies have been pilot tested on a small scale
3. Hydrofluorocarbon emissions from substitutes for ODS	358	Medium	No	Yes	Yes, technologies have been pilot tested on a small scale
4. Methane emissions from enteric fermentation	250	Not assessed[b]	No	Not assessed[b]	Not assessed[b]
5. Nitrous oxide emissions from adipic and nitric acid production	249	High	No	No	Yes, technologies have been pilot tested on a small scale
6. Hydrofluorocarbon emissions from HCFC-22 production	220	High	Yes	Yes	Yes, technologies are well established
7. Methane emissions from landfilling of solid waste	173	Not assessed[b]	No	Yes	Yes, technologies are well established
8. Methane emissions from wastewater	118	Not assessed[b]	No	Not assessed[b]	Not assessed[b]
9. Methane emissions from rice fields	107	High	Yes	No	Yes, technologies have been pilot tested on a small scale
10. Nitrous oxide emissions from stationary and mobile combustion	77	Not assessed[b]	No	Not assessed[b]	Not assessed[b]

Source: Authors' calculations

Notes:
[a] Abatement potential is classified as "high" if the mitigation potential is more than 40 percent of projected emissions under the existing policy framework. Mitigation potential is classified as "medium" if the mitigation potential is between 10 and 40 percent of projected emissions under the existing policy framework.
[b] Abatement potential, related policies, and technologies were identified only if China's INDC specifically addresses the emissions source.

implementation and effectiveness. Under the provisions of the Paris Agreement, China's national GHG inventories will be subject to technical expert reviews. This means that any domestic efforts to improve GHG emissions reporting should also be undertaken with the overall view of enhancing transparency and data quality.

2. Further develop source-specific non-CO_2 GHG reduction targets, then set an economy-wide GHG emissions reduction target

The Chinese government has more than a decade of experience in setting different types of GHG emissions reduction targets. In 2006, the NDRC announced the country's first energy intensity reduction target and forest coverage target as part of the 11th FYP (NDRC 2006). Then, in 2010, China pledged to reduce its CO_2 emissions per unit of GDP by 40 to 45 percent by 2020 relative to 2005 levels, along with other targets to increase forest coverage and increase the share of non-fossil fuels in the primary energy mix (NDRC 2010). Later in 2010, the Chinese government released the 12th FYP, which set binding targets to increase forest coverage, reduce energy intensity, reduce carbon dioxide emissions intensity, and increase the proportion of non-fossil fuels in the primary energy mix, all to be achieved by 2015 (China's National People's Congress 2011). More recently, in 2015, China committed to lower CO_2 emissions per unit of GDP by 60 to 65 percent by 2030 relative to 2005 levels, and to peak CO_2 emissions by 2030 (while making best efforts to peak earlier) (NDRC 2015b).

These national-level targets have proven to be effective in the following ways:

- Delegating responsibility and accountability for achieving targets, both at the sub-national and company levels. For example, the national-level energy intensity reduction target contained in China's 12th FYP (achieving a 16 percent reduction over five years) was apportioned to 31 provinces, each with targets ranging from 10 percent to 18 percent intensity reduction over five years (State Council 2010). This target was further apportioned to the company level, in the form of the Top 10,000 Energy-Consuming Enterprises Program. This was a mandatory program under the 12th FYP, where more than 15,000 of the largest enterprises in China were charged with the combined goal of reducing total energy consumption by 250 million tonnes of coal equivalent by 2015 (equating to about a 37 percent share of the total energy intensity reduction target) (IEPD 2016).
- Promoting transparency in tracking and reporting progress toward target achievement. For example, with regard to the abovementioned energy intensity target, China's NDRC provided quarterly updates on the energy intensity reduction achieved in each province, represented visually through a color-coded barometer (Song et al. 2015).
- Enhancing policy implementation and effectiveness. For example, the targets contained in China's 12th FYP were among the drivers for a new "Work Scheme on Controlling Greenhouse Gas Emissions for the 12th FYP" and a new "FYP for Energy Saving and Emission Reduction" (Song et al. 2015).
- Driving and facilitating the right mix—and consistent implementation—of measures.
- Building political will and improving cooperation among government departments that are united by a common goal.

These points demonstrate the value of setting national-level targets in China. These targets are really drivers for additional domestic action, highlighting the need for an economy-wide GHG reduction target that can act as a catalyst for enhanced action on non-CO_2 GHGs. Such an economy-wide target would also allow China to better align with the goals of the Paris Agreement; Article 4 of the Agreement encourages developing country Parties to "move over time toward economy-wide emissions reduction or limitation targets in the light of different national circumstances."

An economy-wide GHG emissions reduction target takes time to develop, particularly in the absence of current GHG emissions data. However, this should not prevent China from taking immediate and enhanced action on non-CO_2 GHGs. Our research shows that there are five key non-CO_2 GHG emissions sources that readily lend themselves to further mitigation efforts, based on an assessment of projected emissions growth, abatement potential, available technologies, supportive policies, and goals contained in China's INDC:

- Methane emissions from coal-mining activities
- Nitrous oxide emissions from fertilizer application
- Hydrofluorocarbon emissions from substitutes for ozone depleting substance

- Hydrofluorocarbon emissions from HCFC-22 production
- Methane emissions from rice fields

As a first step, China can set mitigation targets for these specific sources. Over time, these targets can be scaled up to sector-level emissions reduction goals, and ultimately, economy-wide GHG targets. The next revision of China's Nationally Determined Contribution (NDC) in 2020 may prove to be a good opportunity to set such an economy-wide GHG target, if earlier action has not been taken.[47]

Countries/regions like the United States and the European Union have developed their own economy-wide GHG policies and targets, which not only set a foundation for countries to move forward with addressing multiple sources of GHG emissions, but also provide the international community with examples of how similar types of programs can work in their own countries (see Boxes 6 and 7 for more information). These types of efforts are not limited to developed countries. Many developing nations have set economy-wide GHG reduction targets. Brazil, for example, has set an economy-wide

Box 6 | Learning from the U.S. Approach to Developing Policies and Targets to Reduce Methane Emissions

In 2013, President Obama made addressing methane emissions a key pillar of his Climate Action Plan (Executive Office of the President 2013). At the time the Plan was announced, EPA had a number of standards in place, and more rulemakings underway, that would reduce methane emissions as a co-benefit of addressing conventional air pollutants like volatile organic compounds (VOCs). For example, EPA regulates VOC emissions from landfills under section 111 of the Clean Air Act, which also indirectly reduces methane emissions (EPA 1996). And a 2012 EPA rule aimed at reducing VOC and other harmful pollutants from natural gas production is estimated to reduce methane emissions from natural gas systems by roughly 15–20 percent (EPA 2012).

In accordance with the president's Climate Action Plan, the federal government is now taking steps to address methane emissions directly. For example, in August 2015, the EPA issued two proposals to further reduce emissions of methane-rich gas from municipal solid waste landfills. The proposals would require new, modified, and existing landfills to begin capturing and controlling landfill gas at emissions levels nearly a third lower than current requirements (EPA 2015b).

In September 2015, the EPA proposed methane emissions standards for new and modified equipment used in the development of natural gas and petroleum.[48] Natural gas systems are the largest industrial source of methane emissions; by working to reduce those emissions without curtailing natural gas production, the Obama administration is demonstrating that emissions reductions and continued growth can be mutually supportive.

Box 7 | Learning from the European Union's Approach to Developing Policies and Targets to Reduce F-Gas Emissions

HFC Emissions

The European Union (EU)—along with a number of other countries, environmental organizations, chemical manufacturers, and equipment manufacturers—is advocating for a global phase-down of high-GWP HFCs through amendments to the Montreal Protocol. Momentum for these amendments appears to be building. While most of these amendments propose somewhat similar phase-down schedules for Non-Article 5 (i.e., developed) countries (10–15 percent reduction in HFC and HCFC production and consumption below 2009–2016 levels by 2030–2036), one of the key differences between these proposals is the phase-down schedule for Article 5 (i.e., developing) countries (NRDC 2015). In November 2015, the 197 parties to the Montreal Protocol agreed to work together toward an HFC amendment in 2016 "by first resolving challenges and generating solutions in the contact group on the feasibility and ways of managing HFCs at Montreal Protocol meetings" (UNEP 2015). However, in the absence of international rulings, several countries, and the EU, are moving ahead with their own efforts to curb high-GWP HFC use.

Other F-Gas Emissions

In 2006, the EU adopted the European Directive 2006/40/EC on mobile air conditioning systems. Starting in 2011, car manufacturers could no longer use gases that have a GWP of 150 or greater in new types of cars and vans, and in all new cars and vans produced starting in 2017 (European Commission 2015). The most recent EU F-Gas Regulation was adopted in April 2014 (replacing the original F-Gas Regulation adopted in 2006) and limits the amount of F-gases sold within the EU, beginning in 2015, with the ultimate goal of phasing down the sale of F-gases to one-fifth the level of 2014 sales by 2030 (European Commission 2015). The F-gas regulation also bans the use of these gases in many types of new equipment where alternatives are available, in addition to prohibiting leakage of F-gases in existing equipment.

target to reduce its GHG emissions by 37 percent by 2025 relative to 2005 levels (Federative Republic of Brazil 2015). Similarly, Mexico unconditionally commited to reducing its GHG emissions (including black carbon) by 25 percent below business-as-usual levels by 2030 (Government of Mexico 2015).

3. Strengthen non-CO_2 GHG mitigation policies and actions, allocate adequate financial resources, and coordinate non-CO_2 GHG emissions reduction efforts with efforts to address CO_2 emissions and air pollutants

Strengthen Policy and Financial Resources
In order to achieve deep cuts in non-CO_2 GHG emissions—and support the achievement of an economy-wide GHG emissions reduction target—it will be important to strengthen non-CO_2 GHG mitigation policies and actions, and allocate adequate financial resources to these activities. As a first step, the Chinese government can undertake an assessment of the effectiveness of existing policies that are targeted toward the five key non-CO_2 GHG emissions sources (identified in Table 9). For example, our analysis shows that nitrous oxide emissions from fertilizer application and methane emissions from rice fields are subject to no policy controls, clearly demonstrating the policy gap and the need for new policies to support/drive GHG emissions reduction efforts in these sectors. Additionally, although China has put in place several policies to address HFC emissions and coalbed methane emissions, it will be important to monitor and evaluate the success of these existing policies and identify opportunities to improve them, especially considering the significant abatement potential that still exists in these sectors. For example, our research shows that many HFC mitigation initiatives are currently too costly to implement without the support of financial incentives or a carbon market (see Box 2 for more information), demonstrating the need to improve upon existing policies.

Coordinate Efforts
It will be important to coordinate non-CO_2 GHG emissions reduction efforts with efforts to mitigate CO_2 emissions so that the Chinese government can develop a comprehensive climate change policy framework that addresses all GHGs. This will also incentivize the government to identify synergies between CO_2 and non-CO_2 GHG mitigation. For example, reduced electricity production that might result from restrictions on fossil fuels (in an effort to drive down CO_2 emissions) would also reduce SF_6 emissions because of the chemical's use in electrical switchgear (Hyman et al. 2002). Finally, coordinated efforts should spur the Chinese government to include non-CO_2 GHG mitigation projects in the CCER program and proposed national emissions trading system—something that will be crucial to enhance non-CO_2 GHG emissions reduction efforts. To date, the majority of non-CO_2 GHG mitigation initiatives in China have been implemented with the support of the CDM, though the 2012 CER market collapse[49] brought many of these projects to an abrupt halt.[50] Potential also exists to identify synergies between future climate change policy and policies aimed at reducing local air pollutants, a point already alluded to in China's revised Law of the Prevention and Control of Atmospheric Pollution. Article 2 of the law states that (unofficially translated), "...joint effort should be made across regions and coordinated control should be taken of air pollutants and greenhouse gases…." Though climate change and air quality policies may never fully overlap, it is important to recognize that any initiatives aimed at improving energy efficiency, enhancing resource utilization, or using cleaner fuels will have mutual benefits for both local air quality and the climate.

It is clear that China's response to addressing non-CO_2 GHG emissions will have a notable impact on the global GHG emissions trajectory. Ultimately, however, if the goals of the Paris Agreement are to be reached, including achieving net-zero GHG emissions in the second half of this century, China will need to take enhanced action on mitigating all of its GHGs, not just CO_2.

TECHNICAL APPENDIX: SOURCE DATA FOR CHINA'S NON-CO_2 GHG EMISSIONS PROJECTIONS

This appendix presents the original source data that were used to develop a new dataset for China's non-CO_2 GHG emissions. Table 10 presents the original data from the EPA study, MEP study, and PKU studies. Table 11 presents the collated dataset (as presented in Section 1 of this working paper), together with detailed descriptions of the methods used to project non-CO_2 GHG emissions.

Table 10 | **China's Non-CO_2 GHG Emissions Projections from Studies by the EPA, MEP, and PKU**

EMISSIONS SOURCE	NON-CO_2 GHG EMISSIONS ($MtCO_2e$)								
	2010			2020			2030		
	EPA[a]	MEP[b]	PKU[c]	EPA[a]	MEP[b]	PKU[c]	EPA[a]	MEP[b]	PKU[c]
Energy									
Methane									
Fossil fuel combustion	35	[n.e.]	[n.e.]	38	[n.e.]	[n.e.]	44	[n.e.]	[n.e.]
Biomass combustion	48	[n.e.]	[n.e.]	46	[n.e.]	[n.e.]	43	[n.e.]	[n.e.]
Fugitive emissions from coal mining	296	300	[n.e.]	354	387	[n.e.]	436	[n.e.]	[n.e.]
Fugitive emissions from oil and gas systems	4	[n.e.]	[n.e.]	4	[n.e.]	[n.e.]	5	[n.e.]	[n.e.]
Nitrous oxide									
Fossil fuel combustion	38	[n.e.]	[n.e.]	54	[n.e.]	[n.e.]	77	[n.e.]	[n.e.]
Biomass combustion	10	[n.e.]	[n.e.]	9	[n.e.]	[n.e.]	8	[n.e.]	[n.e.]
Industrial processes									
Nitrous oxide									
Nitric and adipic acid production	7	49	[n.e.]	9	166	[n.e.]	10	[n.e.]	[n.e.]
Hydrofluorocarbons									
Production and use of alternatives for ozone depleting substances	58	26	110	188	86	178	599	[n.e]	358
HCFC-22 production	62	91	128	132	230	127	147	[n.e]	220
Perfluorocarbons									
Aluminum production	11	16	[n.e.]	14	23	[n.e.]	18	[n.e.]	[n.e.]
Semi-conductor manufacturing	3	[n.e.]	[n.e.]	3	[n.e.]	[n.e.]	3	[n.e.]	[n.e.]

Flat panel display manufacturing	0	[n.e.]	[n.e.]	1	[n.e.]	[n.e.]	5	[n.e.]	[n.e.]
Photovoltaic manufacturing	2	[n.e.]	[n.e.]	8	[n.e.]	[n.e.]	49	[n.e.]	[n.e.]
Sulfur hexafluoride									
Magnesium production	1	9	[n.e.]	2	18	[n.e.]	2	[n.e.]	[n.e.]
Power equipment manufacturing and operation	13	30	[n.e.]	19	6	[n.e.]	26	[n.e.]	[n.e.]
Flat panel display manufacturing	0	12	[n.e.]	26	30	[n.e.]	132	[n.e.]	[n.e.]
Nitrogen trifluoride									
Semi-conductor manufacturing	1	[n.e.]	[n.e.]	1	[n.e.]	[n.e.]	1	[n.e.]	[n.e.]
Flat panel display manufacturing	1	[n.e.]	[n.e.]	5	[n.e.]	[n.e.]	22	[n.e.]	[n.e.]
Photovoltaic manufacturing	0	[n.e.]	[n.e.]	2	[n.e.]	[n.e.]	7	[n.e.]	[n.e.]
Agriculture									
Methane									
Rice cultivation	125	[n.e.]	[n.e.]	114	[n.e.]	[n.e.]	107	[n.e.]	[n.e.]
Enteric fermentation	213	[n.e.]	[n.e.]	234	[n.e.]	[n.e.]	250	[n.e.]	[n.e.]
Animal manure management	20	[n.e.]	[n.e.]	21	[n.e.]	[n.e.]	21	[n.e.]	[n.e.]
Field burning of agricultural residues	1	[n.e.]	[n.e.]	1	[n.e.]	[n.e.]	1	[n.e.]	[n.e.]
Nitrous oxide									
Animal manure management	14	[n.e.]	[n.e.]	16	[n.e.]	[n.e.]	17	[n.e.]	[n.e.]
Agriculture soils	329	[n.e.]	[n.e.]	370	[n.e.]	[n.e.]	406	[n.e.]	[n.e.]
Field burning of agricultural residues	1	[n.e.]	[n.e.]	1	[n.e.]	[n.e.]	1	[n.e.]	[n.e.]
Waste									
Methane									
Landfilling of solid waste	47	64	[n.e.]	49	117	[n.e.]	49	[n.e.]	[n.e.]
Domestic and industrial wastewater treatment	132	47	[n.e.]	137	78	[n.e.]	138	[n.e.]	[n.e.]
Nitrous oxide									
Domestic wastewater treatment	17	[n.e.]	[n.e.]	17	[n.e.]	[n.e.]	17	[n.e.]	[n.e.]

Notes:
[a] EPA's non-CO_2 GHG emission projections are based on GWP values from the IPCC Second Assessment Report over a 100-year time horizon.
[b] MEP's non-CO_2 GHG emission projections are based on GWP values from the IPCC Second Assessment Report over a 100-year time horizon.
[c] PKU's non-CO_2 GHG emission projections are based on GWP values from the IPCC Fourth Assessment Report over a 100-year time horizon.
[n.e] means not estimated

Table 11 | **New Dataset Collating China's Non-CO_2 GHG Emissions Projections from Various Studies, along with Respective Emissions Projection Methods**

EMISSIONS SOURCE	NON-CO_2 GHG EMISSIONS ($MtCO_2e$)			DATA SOURCE	PROJECTION METHOD
	2010	2020	2030		
Energy					
Methane					
Fossil fuel combustion	35	39	44	EPA	Based on the International Energy Agency (IEA)'s 2009 forecasts of coal, oil, and natural gas consumption in China through 2030
Biomass combustion	49	46	43	EPA	Based on the IEA's 2009 forecasts of biomass fuel consumption in China through 2030
Fugitive emissions from coal mining	300	387	461	MEP	Based on the assumption that 100 percent of the fugitive emissions from coal-mining activities with methane concentrations above 9 percent will be captured and utilized by 2020, along with 32 percent of the fugitive emissions from coal mining activities with methane concentrations of less than 9 percent
Fugitive emissions from oil and gas systems	4	4	5	EPA	Based on the United States Energy Information Administration (EIA)'s projections of natural gas and oil production in China through 2030
Nitrous oxide					
Fossil fuel combustion	38	54	77	EPA	Based on the IEA's 2009 forecasts of coal, oil, and natural gas consumption in China through 2030
Biomass combustion	10	9	9	EPA	Based on the IEA's 2009 forecasts of biomass fuel consumption in China through 2030
Industrial processes					
Nitrous oxide					
Nitric and adipic acid production	49	167	249	MEP	Based on the assumption that the production of adipic acid will reach 1.4 Mt in 2020 (with an associated GHG emissions rate of 0.296 tN_2O/t adipic acid) and that the production of nitric acid will reach 17 Mt in 2020 (with an associated GHG emissions rate of 0.0095 tN_2O/t nitric acid). Additionally, it is assumed that there are no future mitigation efforts (due to current prohibitively high costs)
Hydrofluorocarbons					
Production and use of alternatives for ozone depleting substances	110	178	358	PKU	With regard to HFC-134a, it was assumed that the growth of the Chinese automobile market continues in direct proportion with GDP growth, and that HFC-134a continues to be used in automotive air conditioners. Additionally, it was assumed that there is a linear increase in HCF-134a recovery, from 0 percent in 2010 to 10 percent in 2030. With regard to HFC-410a, it is assumed that this compound is introduced at a rate that equals the phase-out of HCFC-22 under the schedule of the Montreal Protocol
HCFC-22 production	128	127	220	PKU	Based on the assumption that the average of the annual mean co-production ratio of HFC-23/HCFC-22 between 2008 and 2012 stays fixed at 2.82 percent through 2020, and that China's existing CDM projects are approved for three consecutive crediting periods (with these crediting periods ending between 2027 and 2030)

Energy					
Perfluorocarbons					
Aluminum production	16	23	23	MEP	Based on the assumption that the production of electrolytic aluminum in China will reach 24 Mt in 2015 and remain stable between 2015 and 2030
Semi-conductor manufacturing	3	3	3	EPA	Based on the assumption that, for years prior to 2020, China's semi-conductor manufacturing GHG emissions grow at a rate equivalent to the five-year compound annual growth rate of China's GDP. Additionally, it is assumed that China will commit to reducing these emissions by 10 percent by 2020, relative to 2012 levels. Due to limited information, it is assumed that, in 2025 and 2030, China will maintain emissions at their assumed reduction goal level
Flat panel display manufacturing	0	1	5	EPA	Based on projected world maximum design capacities for flat panel displays (estimated using five-year, global compound annual growth rates), and China's projected share of world capacity
Photovoltaic manufacturing	2	8	49	EPA	Based on projected world maximum design capacities for photovoltaics (from the DisplaySearch database (https://technology.ihs.com/), and China's projected share of world capacity
Sulfur hexafluoride					
Magnesium production	9	19	29	MEP	Based on the assumption that magnesium production will reach 810 tonnes in 2020, and no further mitigation efforts are undertaken
Power equipment manufacturing and operation	31	36	40	MEP	Based on the assumption that SF_6 emissions from power equipment manufacturing and operation will grow by 2 percent between 2010 and 2020
Flat panel display manufacturing	12	30	47	MEP	Based on the assumption that flat panel display manufacturing will reach 1290 tonnes in 2020, and no further mitigation efforts are undertaken
Nitrogen trifluoride					
Semi-conductor manufacturing	1	1	1	EPA	Based on the assumption that, for years prior to 2020, China's semi-conductor manufacturing GHG emissions grow at a rate equivalent to the five-year compound annual growth rate of their GDP. Additionally, it is assumed that China will commit to reducing these emissions by 10 percent by 2020, relative to 2012 levels. Due to limited information, it is assumed that, in 2025 and 2030, China will maintain emissions at their assumed reduction goal level
Flat panel display manufacturing	1	5	22	EPA	Based on projected world maximum design capacities for flat panel displays (estimated using five-year, global compound annual growth rates), and China's projected share of world capacity
Photovoltaic manufacturing	0	2	7	EPA	Based on projected world maximum design capacities for photovoltaics (from the DisplaySearch database (https://technology.ihs.com/), and China's projected share of world capacity

Agriculture					
Methane					
Rice cultivation	125	114	107	EPA	Based on projected harvested rice area data in China through 2018/2019, sourced from the Food and Agriculture Policy Research Institute (FAPRI 2010)
Enteric fermentation	213	235	250	EPA	Based on the projected demand for beef, pork, lamb, and milk in China, sourced from the International Food Policy Research Institute (IFPRI 2009)
Animal manure management	20	21	21	EPA	Based on livestock product growth rates, sourced from IFPRI (2009)
Field burning of agricultural residues	1	1	1	EPA	Emissions are assumed to remain at their 2005 levels
Nitrous oxide					
Animal manure management	14	16	17	EPA	Based on livestock product growth rates, sourced from IFPRI (2009)
Agriculture soils	329	370	406	EPA	Based on predicted regional growth in fertilizer consumption, sourced from Tenkorang and Lowenberg-DeBoer (2008)
Field burning of agricultural residues	1	1	1	EPA	Based on the assumption that emissions remain constant between 2005 and 2030
Waste					
Methane					
Landfilling of solid waste	64	117	173	MEP	Based on China's forecast GDP growth rate made in 2014, and no further mitigation efforts
Domestic and industrial wastewater treatment	47	78	118	MEP	Based on China's forecast GDP growth rate made in 2014, and no further mitigation efforts
Nitrous oxide					
Domestic wastewater treatment	17	17	17	EPA	Based on projected population growth rates for China made in 2014, and projected protein consumption data, sourced from the 2009 Food and Agriculture Organization (FAO)'s Statistical Yearbook

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ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
1NC	Initial National Communication
2NC	Second National Communication
AR4	IPCC's Fourth Assessment Report
BAU	Business As Usual
C_2F_6	Hexafluoroethane
CBM	Coalbed Methane
CCER	China Certified Emission Reduction
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
CF_4	Tetrafluoromethane
CFCs	Chlorofluorocarbons
CH_4	Methane
CMM	Coal Mine Methane
CO_2	Carbon Dioxide
COF_2	Carbonyl Fluoride
EPA	United States Environmental Protection Agency
FYP	Five-Year Plan
GHG	Greenhouse Gas
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HFOs	Hydrofluoroolefins
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
MAC	Marginal Abatement Cost
MEP	China's Ministry of Environmental Protection
N_2O	Nitrous Oxide
NDC	Nationally Determined Contribution
NDRC	China's National Development and Reform Commission
NF_3	Nitrogen Trifluoride
ODS	Ozone Depleting Substance
PFCs	Perfluorocarbons
PKU	Peking University
SF_6	Sulfur Hexafluoride
SAR	IPCC's Second Assessment Report
tCO_2e	Tonnes of Carbon Dioxide Equivalent
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar

ENDNOTES

1. China is expected to publish a more up-to-date national GHG inventory as part of its Third National Communication and First Biennial Update Report submissions to the UNFCCC, which may address some of these concerns.
2. It's important to understand that the Paris Agreement's long-term goal includes GHGs other than carbon dioxide. The text refers to balancing anthropogenic GHG emissions and removals in the second half of the century. Coupling this aim with the temperature goal to limit warming to well below 2°C and trying to limit it to 1.5°C, scientists have established when during the second half of the century this needs to occur (WRI 2015a):
   - To have a likely chance of keeping warming to below 2°C, CO_2 emissions must drop to net zero between 2060 and 2075 and total GHG emissions need to decline to net zero between 2080 and 2090.
   - To have a likely chance of keeping warming to below 1.5°C, CO_2 emissions must drop to net zero between 2045 and 2050 and total GHG emissions need to decline to net zero between 2060 and 2080.
3. 1 gigatonne is equivalent to 1 billion metric tons. 1 metric ton is equivalent to 1000 kilograms.
4. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change (UNFCCC), which commits its Parties by setting internationally binding emissions reduction targets. The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005 (UNFCCC 2015b).
5. For more information, see http://www.wri.org/indc-definition.
6. Along with other non-Annex I Parties, China was expected to present a more up-to-date national GHG inventory in its Biennial Update Report (BUR), which was due to be submitted to the UNFCCC before the end of 2014 (UNFCCC 2012). According to Decision 2 of the 17th Conference of Parties (COP17), "the first BUR submitted by non-Annex I Parties shall cover, at a minimum, the inventory for the calendar year no more than four years prior to the date of the submission, or more recent years if information is available" (UNFCCC 2012). However, China's first BUR remains to be released.
7. There is a small variance between CAIT's estimates for China's non-CO_2 GHG emissions in 2005 and the 2NC. CAIT estimates China's non-CO_2 GHG emissions in 2005 to be 1,410 $MtCO_2e$, whereas the 2NC puts these emissions at 1,493 $MtCO_2e$ (a 6 percent difference).
8. The Data Distribution Centre (DDC) of the IPCC (IPCC 2014) presents two sets of emissions scenario data: "IS92" presents the six alternative IPCC emissions scenarios that were published in the 1992 Supplementary Report to the IPCC Scientific Assessment. "SRES" presents the four IPCC scenarios that were published in the IPCC's Third Assessment Report, which were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. While these studies present emissions projection data for specific GHGs, the data are only presented at a regional level, meaning that China's emissions projections are merged with those of other countries in Asia. These emissions projections are also relatively out of date, with the latest dataset developed in 2000.
9. Research conducted by groups such as Stanford University's Energy Modeling Forum (EMF 2009) and the United States Climate Change Science Program (CCSP 2008) have developed emissions projections up to 2100, but these projections are presented only at the global level (the exceptions being specific country/regional analysis for the United States and European Union).
10. Note that these studies quantify only the non-CO_2 GHG emissions occurring within China's borders, and do not take into consideration the non-CO_2 GHG emissions from China's overseas investments and imports.
11. The approximate magnitude of this assumption is calculated as follows: assume the emissions source "production and use of alternatives for ozone depleting substances" is made up of HFC-134a (ranging from 25 to 75 percent), with the remainder being made up of HFC-410a (where HFC-410a is a compound that is created when HFC-32 and HFC-125 are mixed in a 1 to 1 ratio). The GWP of HFC-134a over a 100-year time horizon in the SAR is 1,300 while in AR4 it is 1,430. The GWP of HFC-32 and HFC-125 in the SAR is 650 and 2,800, respectively, while in AR4 the GWP of these compounds is 675 and 3,500, respectively. Applying this assumption shows that the calculated emissions from this source can vary by between 13 and 17 percent, depending on whether GWP values are sourced from the SAR or AR4.
12. The Montreal Protocol was established in 1987 to facilitate a global approach to combat depletion of the stratospheric ozone layer. Every country in the world is a party to the Protocol, and it has successfully phased out or is in the process of phasing out several key classes of chemicals, including CFCs, HCFCs, and halons. The transitions out of CFCs and HCFCs provide major ozone layer protection benefits, but the unintended consequence is the rapid current and projected future growth of climate-damaging HFCs (The White House 2013).
13. By June 2015, nine companies in China had submitted an HFC-23 mitigation plan.
14. Coal gangue is a byproduct of coal mining. The average production of coal gangue is approximately 10 to 15 percent of raw coal production in China, depending on mining and geological conditions (Zhou et al. 2013).
15. By the end of 2015, fertilizer use efficiency had increased by 2.2 percent, surpassing the original target.
16. About three-quarters of the coal that China produces is bituminous coal, with the remaining quarter made up of lignite and anthracite (Fridley 2012). Assuming the lignite and anthracite comprise equal portions of the remaining quarter, the coal use avoided due to cleaner production methods is assumed to be 37 million tonnes bituminous coal, 6 million tonnes lignite and 6 million tonnes anthracite. Applying the respective emission factors from the IPCC's *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, the emissions savings are calculated as 114 $MtCO_2$, 1.2 $ktCH_4$, and 1.8 ktN_2O.
17. Although China's INDC also includes a section on "Controlling Emissions from Building and Transportation Sectors," this paper does not assess opportunities for non-CO_2 GHG mitigation in the building and transport sectors. This is because the non-CO_2 GHG emissions from these sectors are relatively small contributors to China's total non-CO_2 GHG emissions. For example, in 2005, non-CO_2 GHG emissions from the transport sector contributed less than 0.01 percent of China's total non-CO_2 GHG emissions (NDRC 2012).
18. Based on the emissions dataset presented in Table 3.
19. The CDM allows emissions reduction projects in developing countries to earn certified emissions reduction (CER) credits, each equivalent to one tonne of CO_2. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emissions reduction targets under the Kyoto Protocol. The mechanism stimulates sustainable development and emissions reductions, while giving industrialized countries some flexibility in how they meet their emissions reduction limitation targets (UNFCCC 2015c).

20. In 2012, CER prices dropped by more than 70 percent over the course of one year (CDM Policy Dialogue 2012), which was largely due to the modest emissions reduction targets that were adopted by countries for the period up to 2020 (Point Carbon 2014).
21. This Action Plan is notably more ambitious than the INDC's target of reaching 30 billion cubic meters of CBM production by 2020.
22. Based on the emissions dataset presented in Table 3.
23. The industrial processes sector is the only sector in China to emit six GHGs covered by the Kyoto Protocol. See Box 1 for more information.
24. This target implies a reduction in HFC-23 emissions of 44 $MtCO_2e$ per annum by 2025. This calculated abatement is based on the emissions dataset presented in Table 3 of this working paper, and under the assumption that the reduction in HCFC-22 production is in direct proportion to HFC-23 emissions (which are produced as a by-product of HCFC-22).
25. The GWP of HFC-23 over a 100-year time horizon is 12,400 (IPCC 2013).
26. Based on the emissions dataset presented in Table 3.
27. By June 2015, nine companies in China had submitted an HFC-23 mitigation plan.
28. Based on the emission dataset presented in Table 3.
29. HFC-23 decomposition is a process where HFC-23 and a supplemental fuel (such as coal gas and diesel oil) are fed into an incinerator, and are oxidized with sufficient air. In the incinerator, the organic matter is decomposed completely, and HFC-23 is converted into CO_2, hydrogen fluoride (HF), and other gases that are neither greenhouse gases nor ozone depleting substances (text adapted from the registered CDM project titled "Shandong Dongyue HFC-23 Decomposition Project." Accessible at: https://cdm.unfccc.int/filestorage/7/T/Z/7TZGJPKFU27EIL1UGEF1U3KHH16LJS/DongyueHFC23PDD.pdf?t=bVN8bzJha216fDAu2ZXN8kON52jzjs_bQ--W).
30. The patents for replacing HFC-134a with HFO-1234yf are predominantly held in the United States and Europe by Honeywell and DuPont (Trager 2014).
31. Based on the emissions dataset presented in Table 3.
32. Catalytic decomposition is a process which is conducted at 500 degrees Celsius, where N_2O is passed over a catalyst (for example, CuAl2O4) and converted to nitrogen and oxygen, typically at a decomposition rate of 99 percent or higher (Smith 2010).
33. During the aluminum smelting process, two types of PFCs (tetrafluoromethane (CF_4) and hexafluoroethane (C_2F_6)) are produced when the carbon from the anode and fluorine for the dissociated molten cryolite bath combine.
34. Based on the emissions dataset presented in Table 3.
35. Based on a conversion rate of US$1 = ¥6.53 (January 2016, see http://www.xe.com/currencycharts/?from=USD&to=CNY&view=1Y)
36. Based on the emissions dataset presented in Table 3.
37. A controlled release fertilizer is a fertilizer that gradually releases nutrients into the soil. The speed at which the fertilizer is released is based on the solubility of the fertilizer compound.
38. Based on the emissions dataset presented in Table 3.
39. Based on the emissions dataset presented in Table 3.
40. Based on the emissions dataset presented in Table 3.
41. Most of the world's rice grows in inundated conditions, and one of the most promising techniques for reducing rice-related emissions is to reduce or interrupt the periods of flooding. The production of rice in flooded paddies produces methane because the water blocks oxygen from penetrating the soil, creating conditions conducive to growth of methane-producing bacteria. Shorter flooding intervals and more frequent interruptions of flooding lower bacterial methane production and thus methane emissions (Adhya et al. 2014).
42. Based on the emissions dataset presented in Table 3.
43. The Top 1,000 Energy-Consuming Enterprises Program focused on the largest 1,000 enterprises in China and successfully achieved and surpassed its energy-saving target of 100 million tonnes of coal equivalent (Mtce) during the 11th Five-Year Plan, with reported savings of just over 150 Mtce. This built the foundation for expanding the Top 1,000 Program to the Top 10,000 Program under the 12th Five-Year Plan. The Top 10,000 Program aims to cover two-thirds of China's total energy consumption, or 15,000 industrial enterprises that use more than 10,000 tce per year, and around 160 large transportation enterprises (such as large shipping companies), and public buildings that use more than 5,000 tce per year. The target of the Top 10,000 Program is an absolute energy saving target of 250 Mtce by 2015 (IEPD 2016).
44. Based on the emissions dataset presented in Table 3.
45. China is expected to publish a more up-to-date national GHG inventory as part of its Third National Communication and First Biennial Update Report submissions to the UNFCCC, which may address some of these concerns.
46. These institutions include World Resources Institute (through CAIT, the Climate Data Explorer), the International Energy Agency (IEA), and the United States Energy Information Administration (EIA), among others.
47. One of the core ingredients of the Paris Agreement is its ambition mechanism, which lays out a process to continue strengthening countries' climate action in a regular and timely way. Under this ambition mechanism, countries will submit an updated NDC every five years, with the expectation of progression and highest possible ambition in each successive contribution (WRI 2015b).
48. Creating an environmental regulation in the United States works as follows: Step 1: The EPA proposes a regulation, also known as a Notice of Proposed Rulemaking. The proposal is listed in the Federal Register so that members of the public can consider it and provide comments. Step 2: The EPA considers the comments received when the proposed regulation was issued, and revises the regulation accordingly. The EPA then issues a final rule. Step 3: Once a regulation is completed, it is codified when it is added to the Code of Federal Regulations (CFR). The CFR is the official record of all regulations created by the federal government (EPA 2016).
49. In 2012, CER prices dropped by more than 70 percent over the course of one year (CDM Policy Dialogue 2012) which was largely due to the modest emissions reduction targets that were adopted by countries for the period up to 2020 (Point Carbon 2014).
50. In the past, China's HFC projects that were registered under the CDM were criticized for not providing adequate proof of "additionality," a concept which demonstrates that a certain emissions reduction project could not have occurred in the absence of the revenue stream created by the sale of CERs under the CDM. This will be an important concern to address if HFC mitigation projects are included in the CCER program or national emissions trading scheme.

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We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

ABOUT THE OPEN CLIMATE NETWORK

The Open Climate Network (OCN) brings together independent research institutes and stakeholder groups to monitor countries' progress on climate change. We seek to accelerate the transition to a low-emission, climate-resilient future by providing consistent, credible information that enhances accountability both among and within countries. www.openclimatenetwork.org.

This working paper is part of an OCN initiative to inform the post-2020 GHG mitigation goals in Nationally Determined Contributions under the United Nations Framework Convention on Climate Change. The OCN Secretariat, based at the World Resources Institute, is managing this multi-country effort. For more information regarding this initiative, contact openclimate@wri.org.