



The Climate and Environmental Benefits of Controlling SLCPs in P.R. China

A UNEP/PRCEE Synthesis Report



UNEP



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Glossary

This glossary has been compiled from definitions in other UNEP reports including the UNEP/WMO Assessment (UNEP/WMO, 2011); the UNEP near-term climate protection and clean air benefit report (UNEP, 2011a); the UNEP report on hydrofluorocarbons (UNEP, 2011b); and the UNEP report on nitrous oxide (UNEP, 2013).

Aerosols: are collections of airborne solid or liquid particles (excluding pure water), with a typical size of between 0.01 and 10 micrometers and residing in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. They may influence the climate directly by scattering and absorbing radiation, and indirectly by acting as cloud condensation nuclei or modifying the optical properties and lifetime of clouds.

Albedo: a measure of the reflectivity of the earth's surface. It is the fraction of solar energy (shortwave radiation) reflected from the Earth back into space. Snow covered surfaces have a high albedo. The Earth's albedo varies mainly through varying cloudiness, snow, ice, leaf area and land cover changes.

Anaerobic digestion: a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste and/or to release energy.

Anthropogenic: resulting from human activities.

Atmospheric brown clouds (ABCs): are regional scale plumes of air pollution that consist of copious amounts of tiny particles of soot, sulphates, nitrates, fly ash, and many other pollutants. The brownish colour of ABCs is due to the absorption and scattering of solar radiation by anthropogenic black carbon, fly ash, soil dust particles, and nitrogen dioxide gas.

Atmospheric lifetime: the time it takes for 67% of a molecule to be removed from the atmosphere in the absence of new emissions of the same molecule.

Baseline or reference scenario: is the state against which change is measured. It might be a 'current baseline', in which case it represents observable, present-day conditions. It might also be a 'future baseline', which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines. The scenario used in UNEP/WMO (2011) for comparison with the scenarios where black carbon and methane measures have been implemented is that of the International Energy Agency (IEA) World Energy Outlook 2009 with incorporation of all presently agreed policies affecting emissions.

Biogas: typically refers to a gas produced by the biological breakdown of organic matter in the absence of oxygen. Biogas originates from biogenic material and is a type of biofuel. Biogas is produced by anaerobic digestion or fermentation of

biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material and energy crops.

Biomass: in the context of energy, the term biomass is often used to refer to organic materials, such as wood, animal dung and other agricultural wastes that can be burned to produce energy or converted into a gas and used for fuel.

Black carbon (BC): is formed through the incomplete combustion of fossil fuels, biofuel and biomass and is emitted as part of anthropogenic and naturally occurring soot. It consists of pure carbon in several linked forms. Black carbon warms the Earth by absorbing sunlight and re-emitting heat to the atmosphere and by reducing albedo (the ability to reflect sunlight) when deposited on snow and ice.

Carbon dioxide equivalent (CO₂e): a simple way to place emissions of various climate change agents on a common footing to account for their effect on climate. A quantity that describes, for a given mixture and amount of greenhouse gas, the amount of carbon dioxide that would have the same global warming ability, when measured over a specified timescale.

Cardiovascular disease: the class of diseases that involve the heart or blood vessels.

Climate change: the long-term fluctuations in temperature, precipitation, wind, and all other aspects of the Earth's climate. It is also defined by the United Nations Convention on Climate Change as "change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition leads to natural climate variability observed over comparable time periods".

Coal bed methane (CBM): is a kind of hydrocarbon gases contained in coal bed with methane as the main component, adsorbed on the surface of coal matrix particle, and part of which is dissociated in the pores of the coal or dissolved in the coalbed water.

Coal mine methane: mine gas consisting of a mixture of methane, other hydrocarbons and water vapour. It is often diluted with air and associated oxidation products.

Crop residue: there are two types of agricultural crop residues. Field residues are materials left in an agricultural field or orchard after the crop has been harvested. These residues include stalks and stubble (stems), leaves, and seed

Pods. Process residues are those materials left after the processing of the crop into a usable resource. These residues include husks, seeds, bagasse, and roots.

Diesel particle filter: a device designed to remove diesel particulate matter or soot from the exhaust gas of a diesel engine.

Dimming: the observed widespread reduction in sunlight at the surface of the Earth. Dimming shows significant regional variations.

Drainage efficiency: usually expressed in percentage, it is the proportion of methane (by volume) captured in a methane drainage system relative to the total quantity of gas liberated.

End-of-pipe technologies: methods used to remove already formed contaminants from a stream of air, water, waste, product or similar. These techniques are called 'end-of-pipe' as they are normally implemented as a last stage of a process before the stream is disposed of.

Enteric fermentation: a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal. Methane is a byproduct of this process.

Global warming potential (GWP): the global warming potential of a gas or particle refers to an estimate of the total contribution to global warming over a particular time that results from the emission of one unit of that gas or particle relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1.

Global warming: an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, "global warming" often refers to the warming that occurs as a result of increased emissions of greenhouse gases from human activities.

Greenhouse gases: gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H₂O), carbon dioxide, nitrous oxide (N₂O), methane (CH₄), and ozone (O₃) are the primary greenhouse gases in the Earth's atmosphere. Moreover there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol.

Ground-level ozone: ozone at the bottom of the atmosphere and at the level which humans, crops and ecosystems are exposed to its impacts.

Near-term warming: in terms of this report and the Integrated Assessment of Black Carbon and Tropospheric Ozone (UNEP/WMO, 2011), this refers to global warming from the present up to about the next 20 to 40 years (i.e., global warming during the 2010-2050 period).

Ozone (O₃): the triatomic form of oxygen and a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photochemical reactions involving gases resulting from human activities. It is a primary component of photochemical smog. In high concentrations, tropospheric ozone can be harmful to a wide range of living organisms. Tropospheric ozone acts as a greenhouse gas. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O₂). Stratospheric ozone plays an important role in the stratospheric radiative balance. Depletion of stratospheric ozone results in an increased ground-level flux of ultraviolet (UV-) B radiation.

Ozone precursors: chemical compounds, such as carbon monoxide (CO), methane, non-methane volatile organic compounds (NMVOCs), and nitrogen oxide (NO_x), which in the presence of solar radiation react with other chemical compounds to form ozone, mainly in the troposphere.

Particulate matter (PM): very small particles of solid or liquid matter such as soot, dust, fumes, mists or aerosols. The physical characteristics of PM, and how they combine with other particles, are part of the feedback mechanisms of the atmosphere. Particulate matter that is less than 2.5 µm in aerodynamic diameter is referred to as PM_{2.5} and those less than 10 µm including PM_{2.5} are referred to as PM₁₀.

Premature deaths: the number of deaths occurring earlier due to a risk factor than would occur in the absence of that risk factor.

Short-lived climate pollutants (SLCPs): are agents that have relatively short lifetime in the atmosphere - a few days to a few decades - and a warming influence on climate. The main short lived climate pollutants are black carbon, methane and tropospheric ozone. These SLCPs are also dangerous air pollutants, with various detrimental impacts on human health, agriculture and ecosystems. Some hydrofluorocarbons (HFCs) are also short-lived and have substantial climate impacts but are not air pollutant and therefore do not have direct harmful effects on human health, agriculture and ecosystems.

Tropospheric ozone: ozone in the portion of the atmosphere from the Earth's surface to the lowest 10-20 km of the atmosphere.

Ventilation air methane (VAM): methane emitted from coal seams that enters the ventilation air and is exhausted from the ventilation shaft at a low concentration, typically in the range of 0.1% to 0.75% by volume.

Volatile organic compounds (VOCs): organic chemical compounds that under normal conditions are gaseous or can vaporize and enter the atmosphere. VOCs include compounds such as methane, benzene, xylene, propane and butane. Methane is primarily emitted from agriculture (from ruminant animals and cultivation), whereas non-methane VOCs (or NMVOCs) are mainly emitted from transportation, industrial processes and use of organic solvents.

Yellow-label vehicles: passenger cars whose emissions do not meet the China I standard and heavy-duty vehicles whose emissions do not meet the China III standard.

Foreword



Recent work by the World Health Organisation has shown that air pollution—graphically illustrated by recent smogs in China and elsewhere in Asia—is resulting in far more serious impacts than previously estimated. Indoor and outdoor air pollution contributes to over 7 million premature deaths globally each year. Meanwhile, time is becoming perilously short to avoid dangerous “tipping points” that could irreversibly alter the course of development in China and many other climate change-vulnerable countries and regions.

As the severity of air pollution and climate change challenges becomes more evident, so too do opportunities for tackling them. In particular, it has become readily apparent that because air pollution and global warming have many common sources and pathways, policies that deliberately address the two in an integrated manner can secure policy objectives more quickly and economically. Simply stated, an integrated approach to air pollution and climate change can save money and lives.

One of the keys to unlocking this potential lies in short-lived climate pollutants (SLCPs). These damage health and food security and contribute substantially to near-term regional and global climate changes.

Through the collaboration of United Nations Environment Programme and Policy Research Center for Environment and Economy of the Ministry of Environmental Protection of the People’s Republic of China, this report has been developed to provide information on the benefits that could accrue to

China if efforts are geared towards mitigating SLCP emissions and to outline detailed concrete steps for seizing these benefits.

The report shows that mitigating the emissions of two SLCPs—black carbon and methane—will lead to a significant improvement in human health globally including in China. Also, their mitigation will significantly reduce crop yield losses in China and globally. In addition, an approximate 0.5° Celsius global temperature increase (projected for 2050) would be avoided.

In laying out these options, the report clarifies that targeting SLCPs alone will not solve the world’s air pollution or climate change problems. Rather, it maintains that tackling SLCPs alongside traditional pollutants such as sulphur dioxide and nitrogen oxides is an essential element of an integrated approach to tackling the problem. This approach, when complemented with deep cuts in carbon dioxide emissions, can dramatically improve public health, food security and the well-being of current and future generations.

We have only one atmosphere. Its protection requires international stewardship. But it also needs urgent and aggressive action at the national level. China’s success in implementing clean cookstoves, efficient brick kilns, and many other SLCP control measures suggests it may be able to replicate and scale up many workable solutions. Its broader advocacy of co-control strategies, and the recent toughening of air pollution and energy efficiency policies, suggest it could make the commitment needed to catalyse wider and long-lasting change in China and globally.

It is fitting, therefore, that this report is among the first to address ways of mitigating SLCPs at the national level. We hope that other countries will benefit from the experience it communicates and that China and the world will breathe easier from the changes that follow. .

A handwritten signature in black ink that reads "Achim Steiner". The signature is fluid and cursive.

Achim Steiner
UN Under-Secretary-General,
UNEP Executive Director

Preface

Short-lived Climate Pollutants (SLCPs) have not been as well recognized as other air pollutants in the policy arena or in research programmes until recently. Today, their impacts on human health, food security, climate and sustainable development in general are broadly understood.

One of the major steps towards the increased understanding of the impacts of SLCPs was the 2011 assessment coordinated by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). This assessed the current scientific understanding of SLCPs – black carbon, methane and tropospheric ozone – especially relating to their impacts on human health, food security and near-term climate change at the global scale. The assessment provided a sound foundation for scientific consensus and also showed that technically-feasible and cost-effective measures are available, which if implemented, could potentially have a transformative effect on human health, food security and near-term climate change.

Whilst the assessment was carried out with a global focus, achieving the benefits highlighted would require actions on a national scale, including the development of pathways taking into consideration the culture, distinctive economic, planning and regulatory character, and wider socio-economic priorities of countries.

For China, the impacts of SLCPs are very pertinent and the need to create national structures for reducing SLCP emissions cannot be overemphasized. SLCPs have contributed to the various air pollution episodes in China

in recent years and have significantly affected human well-being and socio-economic development.

This report, by Chinese scientists and experts, takes up the task of identifying how China can achieve the potential benefits from mitigating SLCPs by synthesising current China-relevant knowledge on air pollution and SLCPs and by reviewing existing efforts as well as presenting options for further action. It provides information on the benefits that could accrue to China, if actions are taken at the national level and if cooperation is strengthened internationally.

The development of the report would not have been possible without the significant commitment of the various contributors. UNEP and PRCEE are therefore very grateful to the Chinese scientists and experts, as well as their international collaborators who rose to the challenge of producing this report. We are also very grateful to the many reviewers whose comments and suggestions helped improve the text.

We believe that their efforts have resulted in a report that could prove to be a significant milestone for a number of reasons: in the better integration of science and policy; in scientific and policy cooperation across national boundaries; and most of all in developing urgently-needed efforts to reap the tremendous benefits of health improvement, food security and near-term climate change that the mitigation of SLCPs could deliver for the world and for the populace of the Peoples Republic of China.

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Executive Summary

In recent years, the People's Republic of China has shown significant commitment to environmental-friendly socio-economic development. One reflection of this is in its 11th (2006-2010) and 12th (2011-2015) National Economic and Social Development Five-Year Plans (FYP), which both contained several important environmental-related targets and encourage significant investment in achieving these targets. Among the targets are those that could contribute to improved local air quality including the goal of decreasing energy consumption per GDP by 20%, and reducing total SO₂ emissions by 10% as contained in the 11th FYP and the goal of increasing non-fossil fuel proportion in primary energy consumption to 11.4%, decreasing energy consumption per GDP by 16%, reducing CO₂ emissions per GDP by 17%, decreasing total nitrogen oxides (NO_x) emissions by 10%, and total SO₂ emissions by 8%, as contained in the 12th FYP. National records show that the air quality-related targets in the 11th FYP were achieved and exceeded. Success is also being achieved towards the 12th FYP including in the installation of a significant proportion of desulfurization and denitrification facilities and reduction of CO₂ emissions per GDP.

However, there remains more work to be done in order for China to move toward sustainable development. For example, many parts of China still experience episodes of poor air quality and the associated challenges are having significant socio-economic and environmental impacts on China and its populace. Researches undertaken within and outside China show that, controlling Short-lived Climate Pollutants (SLCPs) could contribute towards improving local air quality while also contributing to combating climate change. This report therefore reviews the sources of SLCPs emissions, in particular black carbon and methane, in China and presents information on their impacts. It also highlights the benefits of mitigating SLCP emissions, as well as technical measures for controlling emissions and policy options for achieving emission reduction.

1. What are the challenges and what is the role of SLCPs?

Although air pollution has been recognized as a serious problem for decades in China, recent haze and smog

episodes have heightened government and public concerns on the importance and urgency of improving air quality.

Between 2012 and 2014, different parts of China experienced varied level of air pollution. While Beijing experienced 138 days of pollution in 2013, Guangzhou and Shenzhen experienced about 15 and zero days respectively in the same year. Since January 2013, smog episodes have occurred in 25 provinces and 100 large and medium-sized cities in China, with a national average number of days of smog of about 30, the highest in the past 52 years. In January 2014, Beijing suffered three consecutive days of heavy air pollution, with an Air Quality Index value of 500—the maximum pollution level possible—in most parts of the city.

SLCPs play an important role in air pollution as well as in climate in China.

SLCPs are substances such as black carbon, methane, tropospheric ozone and many hydrofluorocarbons (HFCs)¹, which have a significant impact on near-term climate change but have a relatively short lifespan in the atmosphere (from a few days to about a decade) compared to carbon dioxide (CO₂) and other long-lived gases. This means that action taken now to control their emission can have effects on global warming in a matter of months or years.

Beyond their near-term climate impacts, SLCPs particularly black carbon, methane², and tropospheric ozone³, also pollutes the air. They therefore have substantial impacts on human health and the environment and have contributed to air pollution in China.

Black carbon has a significant impact during periods of haze by scattering light and increasing the complexity of air pollution. It is an important component of PM_{2.5}, whose concentration has been shown to be high in Chinese cities, contributing to regional hotspots of pollution (Figure ES1).

- 1 Although many hydrofluorocarbons (HFCs) are also short-lived and are very potent greenhouse gases, they are not air pollutants and are therefore not within the scope of this report.
- 2 Methane on its own is not an air pollutant but it is an important precursor for the formation of tropospheric ozone, which is both an air pollutant and an SLCP.
- 3 Unlike many other air pollutants, tropospheric ozone is not directly emitted from any one source. It is formed by the interaction of sunlight with carbon monoxide (CO), methane, non-methane volatile organic compounds (NMVOCs) and nitrogen oxides (NO_x).

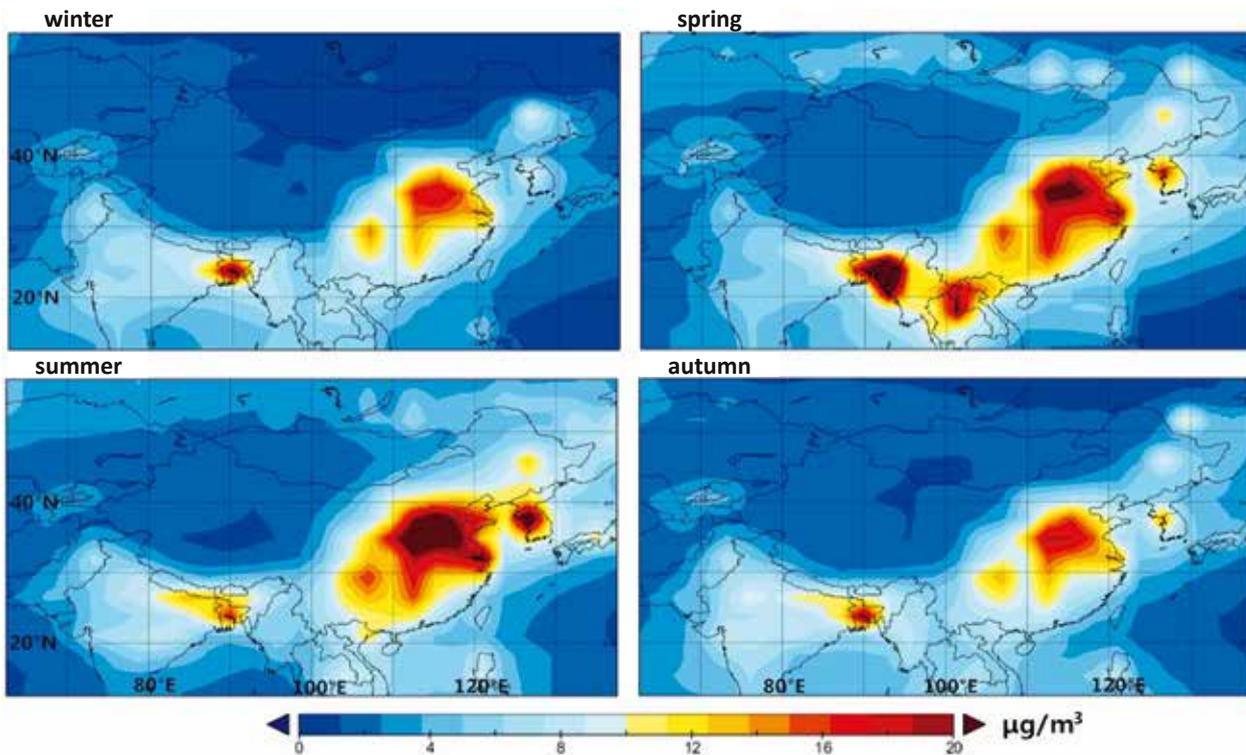


Figure ES1. Distribution of simulated PM_{2.5} concentration (only including anthropogenic aerosols)

Source: Zhang, et al. (2014)

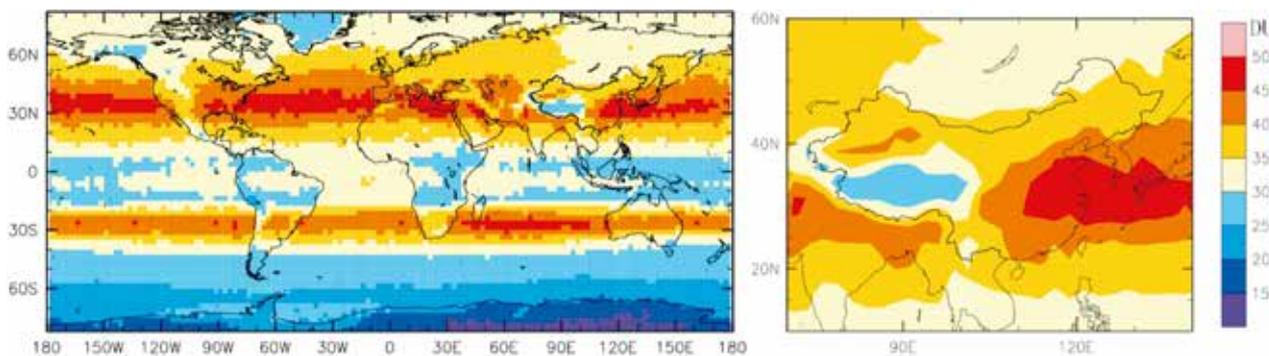


Figure ES2. Distribution of tropospheric ozone column concentration observed by satellite in 2010-2013

Source: Zhang, et al. (2014)

Tropospheric ozone, as a primary component of smog, also plays an important role in air pollution; its average concentration over China often exceeds the global average (Figure ES2).

2. What is the estimate of China's anthropogenic emissions of black carbon and methane and what are the sources?

Although China's current per capita emissions of black carbon and methane are generally not as high as those of other high emitting countries, its total emissions compared to other countries is considerably high.

Emissions of black carbon in 2010 were estimated at about 1.83 Teragrams (Tg), while that of methane was estimated at approximately 920 million tons of CO₂equivalent (Mt CO₂e)⁴. China's contribution to global black carbon emissions

ranged from 20% to 24% between 1990 and 2007, while its contribution to methane emissions was about 13% of total global emissions in 2010. This means that mitigating black carbon and methane emissions in China can contribute both to solving the country's air pollution challenge and to mitigating regional and global warming.

Anthropogenic emissions of black carbon and methane come from various sources in China.

For black carbon, they come from five main sectors: residential (using coal, oil or wood biomass as cooking or heating fuels), industry (using biomass, coal or oil), transport (off-road and on-road vehicles using diesel fuel), power generation (using coal and oil as fuel) and open burning of biomass (burning of agricultural waste and residues as well as using fire for land clearing). For methane, anthropogenic sources can be broadly categorized into emissions from the energy sector (coal mining, oil and natural gas production and stationary and mobile fossil fuel combustion), from agriculture (enteric fermentation, rice cultivation and livestock manure/waste management), and from the waste

⁴ 2010 estimate of methane emissions presented in this report was by USEPA and was derived by projecting 2005 estimates from the China government submission to the UNFCCC. It must be noted that the USEPA estimates have not been validated by the Chinese Government; hence they are not necessarily recognized or endorsed by the government and have been included here only due to dearth in alternative data.

management sector (wastewater treatment and municipal solid waste landfills).

The residential sector is the highest emitter of black carbon in China, contributing up to 47% of emissions in 2010, followed by the industrial and transportation sectors, which emitted 32% and 15% of emissions, respectively. For methane emissions, coal mining (32%), enteric fermentation (23%), rice cultivation (14%) and wastewater treatment (14%) essentially comprised China's methane emission profile for 2010.

3. What are the impacts of air pollution and SLCPs emissions in China?

Air pollution in China comes with substantial environmental, social, and economic impacts on human health, food security and the climate, with associated economic costs.

- The Global Burden of Disease (GBD) study indicates that ambient and household air pollution, of which black carbon is a major contributor, has become a major risk factor for disability-adjusted life-years in China and is implicated in the poor health situation of many and consequently human mortality in China.
- Increased concentrations of tropospheric ozone, especially at ground level, leads to reduced crop productivity⁵. Studies have shown that exposure to tropospheric ozone led to between 1% and 9% reduction in the yield of wheat, rice and corn and 23% to 27% reduction in the yield of soybeans in China, Japan and South Korea in 1990 and a relative loss in the yield of rice, maize, soybean and wheat of approximately 4%, 5%, 11% and 19%, respectively in 2000.
- Black carbon can also contribute to regional changes in climate. Model results have shown that the presence of anthropogenic aerosols, including black carbon, have resulted in a change in night and diurnal temperatures during winter in the industrialized parts of China.
- Black carbon emissions have also been implicated in recent alterations in precipitation patterns and intensities in some parts of China.
- At the global scale, black carbon, methane, and tropospheric ozone, are potent warming agents and therefore major contributors to climate change.
- The economic costs associated with air pollution and SLCP emissions in China are significant. The World Bank and the Development Research Centre of the State Council of China's cabinet jointly put the overall health cost of air pollution in China at between USD 100 and USD 300 billion a year. Studies have also suggested that economic losses associated with crop losses induced by increased

⁵ It is important to note that while ozone concentrations are undoubtedly related to methane emissions, this report did not estimate the exact quantity of ozone concentration in China directly attributed to methane emissions compared to those attributed to other ozone precursors (that is, NO_x, NMVOCs, and CO). Hence, discussions on ozone, including its impact on crop yield, are broadly related to total concentration of tropospheric ozone irrespective of the compounds responsible for its formation.

exposure to tropospheric ozone were about USD 3.5 billion in 1990 and between USD 3.0 and USD 5.5 billion in 2000.

4. What are the benefits of mitigating SLCP emissions in China and globally?

The impacts highlighted above provide an indication of expected benefits from mitigating SLCPs in China and globally.

A UNEP/WMO assessment in 2011 focused on the global and regional benefits of the implementation of 16 black carbon and methane emission reduction measures, and another publication by Shindell and colleagues in 2012 provides information on benefits that could accrue to China through 14 similar measures.

Results from Shindell and colleagues indicate that implementing the 14 measures could:

- significantly improve human health and consequently reduce human mortality in China.
- prevent an average of 16 million tons of crop losses of four staple crops (maize, wheat, rice and soybean), per year in China by 2030 and beyond⁶. The global estimate for annual avoided crop yield losses of the four staple crops in 2030 and beyond was estimated at an average of about 52 and 53 million tons in the UNEP/WMO Assessment and by Shindell and colleagues respectively; hence, about 30% of the benefits from the avoided crop losses would accrue to China (Figure ES3).
- help avoid increased regional warming. Estimates by both Shindell and colleagues and the UNEP/WMO assessment indicate that East Asia, which includes China, could avoid an average temperature increase of about 0.6°C by 2050 (Figure ES3).
- help avoid increased future global warming by an average of about 0.5°C by 2050. Furthermore, if the black carbon and methane reduction measures are implemented alongside deep and persistent CO₂ emission reductions, it would increase the likelihood of keeping the global temperature increase within the 2°C warming target (Figure ES3 and ES4).

Several other studies have indicated that implementing black carbon and methane mitigation measures could provide other benefits in China, including:

- reducing emissions of a variety of co-emitted substances including carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO₂), total PM_{2.5}, and organic carbon, thus contributing to other air pollution control policies.
- reducing the global impact of climate change on China. Recent modelling results suggest that SLCP mitigation can decrease the rate of sea level rise by between 24% and 50%. This is particularly important to many Chinese coastal cities that have been experiencing sea level rise and associated extreme events in recent years.

⁶ These avoided crop yield losses may be greater if other crops are included in the analysis.

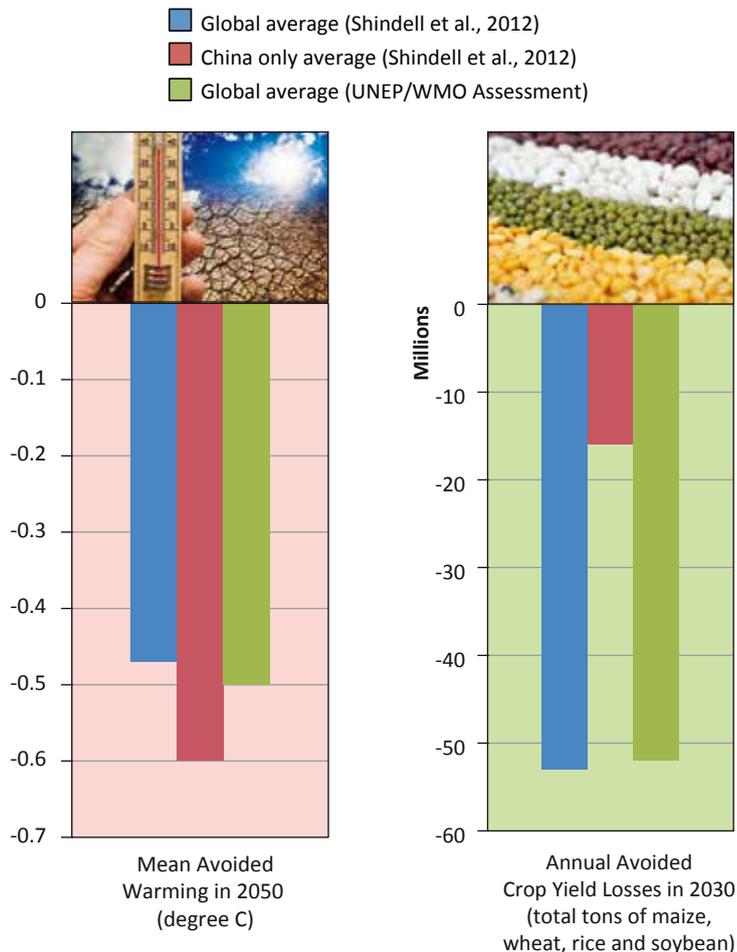


Figure ES3: Global and China specific benefits from full implementation of identified measures in 2030 compared to the reference scenario. The climate change benefit is estimated for a given year (2050) and crop benefits are for 2030 and beyond.

Source: UNEP/WMO (2011) and Shindell et al. (2012)

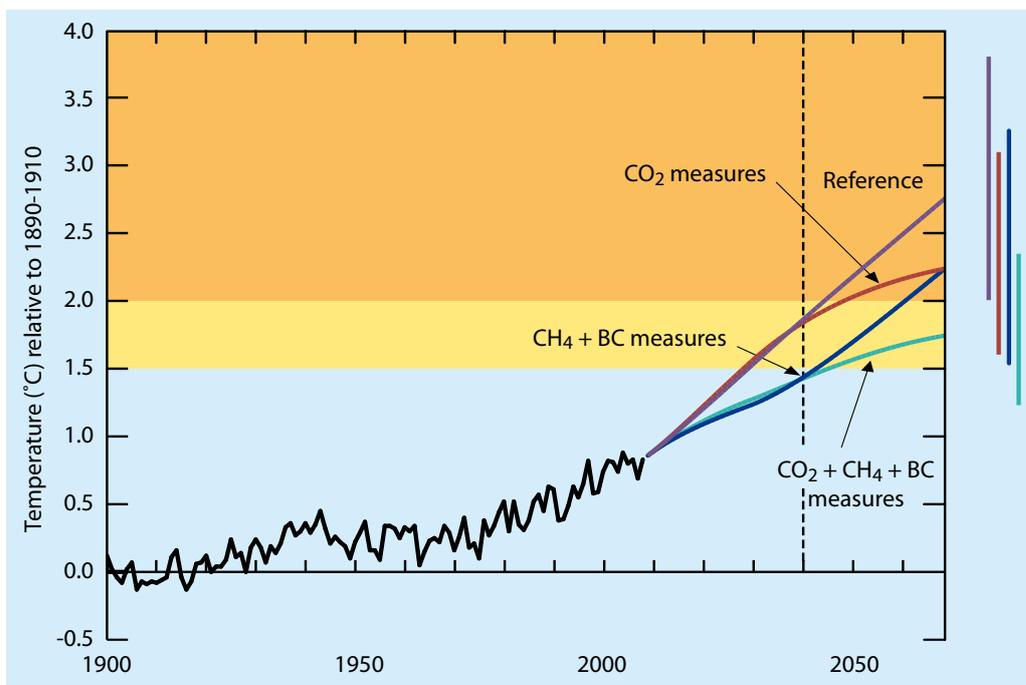


Figure ES4. Observed deviation of temperature to 2009 and projections under various scenarios

Source: UNEP/WMO, 2011

Note: Linear implementation of the identified BC and CH₄ measures between 2010 and 2030, together with measures to reduce CO₂ would greatly improve the chances of keeping Earth's temperature increase to less than 2°C relative to pre-industrial levels. The bulk of the benefits of CH₄ and BC measure are realized by 2040 (dashed line).

Explanatory notes: Actual mean temperature observations through 2009 and projected under various scenarios thereafter, are shown relative to the 1890–1910 mean temperature. Estimated ranges for 2070 are shown in the bars on the right. A portion of the uncertainty is common to all scenarios, so that overlapping ranges do not mean there is no difference, for example, if climate sensitivity is large, it is large regardless of the scenario, so temperatures in all scenarios would be towards the high-end of their ranges.

- reducing disruption of regional rainfall patterns and intensities that have been affecting some parts of China, especially in the north. This could contribute to improve water resource availability.
- providing energy security, creation of local employment, increased economic development and improved safety in the mining industry.

Importantly, the UNEP/WMO assessment indicates that many of the measures that would yield these gains could be implemented:

- **without significant technical innovation**, since the mitigation measures required are technically proven and are often already in use; and
- **at little or no net cost**—although initial capital investment may be needed for effective implementation of some of the measures, many will achieve cost savings over time.

The assessment also indicates that the most substantial benefits from implementing the measures will be felt immediately in or close to the regions where action is taken to reduce emissions.

Hence, actions taken in China to reduce SLCPs emissions will provide benefits to China. Striving to achieve these benefits, therefore, opens the prospect of more effective air pollution control and climate programmes, which would not only have a transformative effect on near-term climate change, health and food security, but also contribute to wider socio-economic development.

5. How has the Chinese Government been responding to air pollution and SLCP issues?

The Chinese Government has been responding to the country's air pollution concerns, and the focus of air pollution control has moved forward with some relative successes in recent years.

Air pollution prevention measures and policies have been widening from concentrating on traditional pollutants such as SO₂ and NO_x to embrace monitoring and policy development on particulate matter, ozone and other pollutants. China has also already introduced routine monitoring of PM_{2.5} and ozone in key areas. Furthermore, new strategies (for example, the Air Pollution Prevention Action Plans) have been put in place and new regulations are being enacted. Additionally, more resources have been allocated for tackling air pollution challenges.

Furthermore, China has made major contributions to the abatement of black carbon and methane emissions in a number of sectors.

For example, the emissions of black carbon from China's coal-burning power stations have been very low due to tightening of smoke and dust emission standards. China has also been successful in replacing inefficient and polluting traditional coke ovens with more efficient and less polluting ones; its programme to introduce improved heating and cooking stoves in rural communities has been judged as

the largest globally and it is a leader in the recovery and use of coal mine methane and in the reduction of methane emissions from rice paddies. In the transport sector, the move from China III to China IV reduced the standard emission of particles from diesel engines by 80%, resulting in an estimated emission reduction of 40-50 thousand tons of black carbon; the "Action Plan for Prevention and Control of Airborne Pollution" of the State Council of China required the elimination of all yellow label vehicles by 2017, and the action plan could reduce black carbon emissions by 78% from these fleets by then if it succeeds.

Whilst these achievements represent tangible progress in combating air pollution and reducing SLCP emissions, recent air pollution episodes (as described above) indicate that much still needs to be done to improve air quality and reduce black carbon and methane emissions.

6. What are the measures and opportunities for enhancing the reduction of black carbon and methane emissions in China?

Achieving the climate and health benefits potentially available from black carbon and methane mitigation would require scaling up current activities significantly and achieving substantial further advances.

Potential further measures and policy development can already be identified in a number of sectors (Table ES1), which, if adopted, could deliver increased emission reductions. These include:

- **for the residential sector**, government advice and support (for example through subsidy programmes) on use of improved stoves for heating and cooking; ensuring that stoves that are promoted do indeed reduce black carbon emissions; and possibly banning residential access to medium-volatile bituminous coals. A wider extension of district heating systems in suburbs and villages could further reduce black carbon emissions from households.
- **for the industrial sector**, developing stronger environmental regulations on emission reductions in the sector; increasing government supervision and stronger enforcement of regulations to ensure pollution control equipment is installed and operates effectively in industrial boilers, coal-fired boilers and small-scale furnaces. Furthermore, implementing coke dry quenching techniques, and promoting the rapid replacement of traditional brick kilns with cleaner tunnel technologies, could further reduce black carbon emissions from, respectively, coke ovens and brick kilns.
- **for the transportation sector**, radically improving emission controls on on-road and off-road mobile equipment through the elimination or upgrading of old and high-emission vehicles; bringing forward the planned introduction of tighter emission standards for new heavy- and light-duty diesel vehicles; installation of particulate filters to existing diesel vehicle fleets; ensuring availability and use of clean fuels including low-sulfur diesel and petrol; and promoting the use of hybrid or electric vehicles.

Table ES1. Examples of available measures which could further reduce black carbon and methane emissions in China.

Sector	Examples of Emissions Reduction Measures
Black Carbon	
 <p>Residential</p>	<ul style="list-style-type: none"> • Further advice and support on use of improved stoves for heating and cooking • Wider extension of district heating systems in suburbs and villages • Consider ban on residential access to Medium-Volatile-Bituminous coals.
 <p>Industrial</p>	<ul style="list-style-type: none"> • Stronger environmental regulation on emission reduction • Increased supervision and stronger enforcement of regulations • Implementing coke drying quenching technique • Promoting rapid replacement of traditional brick kilns with cleaner tunnel technologies
 <p>Transport</p>	<ul style="list-style-type: none"> • Eliminating or upgrading of old and high-emission vehicles • Earlier implementation of planned tighter emission standards for new heavy duty diesel and light duty diesel vehicles • Installation of particulate filters in existing diesel vehicle fleets • Ensuring availability and use of clean fuels including low-sulfur diesel and petrol • Promoting the use of hybrid or electric vehicles instead of traditional diesel engine vehicles
 <p>Agriculture</p>	<ul style="list-style-type: none"> • Implementing alternatives to agricultural residue burning such as deep ploughing of biomass and turning biomass to briquette, biogas or biodiesel
Methane	
 <p>Agriculture</p>	<ul style="list-style-type: none"> • Increase use of mid-season drainage management techniques in rice cultivation • Promoting the use of hybrid rice varieties that produce lower emissions • Improved rice cultivation fertilization management • Wider expansion of the use of biogas digesters for animal manure • Increase research into reducing emissions from enteric fermentation
 <p>Coal Mining</p>	<ul style="list-style-type: none"> • Move towards increased utilization of drained Coal Mine Methane • Enhance the utilization of low-concentration Coal Mine Methane • Promote the utilization of Ventilated Air Methane
 <p>Waste Management</p>	<ul style="list-style-type: none"> • Up-scaling existing programmes in landfills and wastewater management • Seeking beneficial after-use of wastes, such as generating electricity using landfill gas • Prioritize technologies that reduce multiple greenhouse gases

© Residential: Shutterstock 159351536, 13657796; Industrial: Shutterstock 105818573, 195877046, 205844872; Transport: Shutterstock 8092834, 90192967; Agriculture - Black Carbon: Shutterstock 58783444; Agriculture - Methane: Shutterstock 77769157, 120331270; Coal Mining: Shutterstock 114186547; Waste Management: Shutterstock 127192349, 150521066, 90868025

- **for the agricultural sector**, seeking alternatives to agricultural residue burning, such as deep ploughing of biomass and turning biomass into briquettes, biogas or biodiesel could help reduce the emissions of black carbon from biomass burning. For methane emissions, the success in reducing emissions from rice paddies can be further extended by using mid-season drainage management techniques, by promoting hybrid rice varieties that produces fewer emissions, and by fertilization management. For methane emissions from animal manure, wider expansion of the use of biogas digesters (which, by 2010, had been installed in 40 million rural households) is recommended. For methane emissions from the so far intractable enteric fermentation, more support for national and international research programmes is required.
- **for coal mine methane emissions**, building on China's experience as a leader in the use of coal mine methane as an industrial and domestic fuel to move towards its increased utilization; building on China's pioneering work on techniques to enhance the utilization of low-concentration coal mine methane (with a methane concentration of less than 30%); and promoting the utilization of ventilated air methane (from coal mine ventilation, with a methane concentration of less than 0.75%).
- **for the waste management sector**, the considerable scope for scaling up existing programmes in landfills and wastewater management could be enhanced by recognizing the beneficial after-uses of waste, such as generating electricity using landfill gas. Furthermore, in selecting treatment options, technologies beneficial for the reduction of multiple greenhouse gases, not just methane, would need to be given priority.

Implementing black carbon and methane mitigation measures could yield significant emission reductions.

One analysis indicates that methane emissions could be reduced in China by about 31 Mt per year by 2030, equivalent to approximate 650 MtCO₂e per year, with substantial emission reductions coming from coal mining, waste management and rice cultivation. Analysis of overall black carbon emission reduction potential is not available but one result shows that emissions from burning coal in the residential sector could be reduced by up to 80% relative to the level of year 2000. More research on SLCPs emissions reduction potential is, however, still needed in China.

7. How can SLCPs mitigation programmes be fitted into China's atmospheric and socio-economic development policies?

The availability of technical measures and recent developments, including reforms in air pollution control laws, provide critical entry points for the development of SLCP strategies.

Opportunities exist for China to scale up existing mitigation policies and develop new ones, through national strategies and processes in a way that can optimize health, food security and climate benefits, as well as secure the wider socio-economic benefits associated with them. Examples of these include recent enhanced political commitments to tackle air pollution, the associated allocation of more resources, and the Thirteenth Five-Year Plan.

Harnessing these opportunities would require ensuring that SLCP mitigation measures and policies complement other national atmospheric policies; that the actual emission reductions required can be delivered in a cost-effective manner; and that the general policy planning and implementation systems are in place for successful execution.

These factors point to a need for a more integrated and aggressive approach to air pollution and SLCP mitigation.

SLCP mitigation policies would need to be designed in a manner that enhances atmospheric, climate, and developmental benefits. Climate change and air pollution have often been regarded as distinct phenomena, but evidence now indicates that policies addressing the two together can optimize economic, social and environmental benefits. An integrated approach would also ensure that antagonistic policies or strategies that could favour air quality objectives at the expense of climate change or other sustainable development objectives, or vice versa, are avoided.

For example, while investing efforts into reducing methane as a precursor to tropospheric ozone is justified because of the proven mitigation potential, it is important that this does not detract from efforts to mitigate other ozone precursors (VOCs, NO_x and CO). Instead synergies need to be sought between existing policies in a way that maximizes benefits. Indeed, if well designed and effectively implemented, VOCs and NO_x controls would lead to reduction in ozone and could also reduce CO₂ by allowing more carbon uptake by ecosystem. Also, energy saving policies aimed at mitigating CO₂ could lead to reductions in VOC and NO_x. This could result in near-term air quality benefits as well as longer term climate benefits.

Many of the recent successes in abating SO₂ emissions in China have been removing sulfates that cool the atmosphere, thereby exposing previously hidden warming. Therefore, putting in place an integrated response that takes into consideration the health and climate benefits of sulphate and SLCPs emissions reduction is crucially important.

8. What are the necessary ingredients for integrating SLCPs into national policies?

Inevitably, implementation barriers could frustrate the deployment, integration and dissemination of SLCP mitigation measures. If the potential benefits are to be realized, effective research, planning and implementation processes that can deliver SLCP mitigation objectives in a coherent and effective way need to be in place.

- **A more targeted and integrated approach is required to enable decision-makers to set policy priorities, targets and timescales across the range of relevant sectors and mitigation options.** Some



individual SLCPs are already covered in current air quality and climate plans and programmes, but the coverage is fragmentary and scattered. The existing elements could now be brought together in an integrated planning and implementation process so that overall targets for mitigation can be set and progress measured, and in particular so that the comparative feasibility and cost-effectiveness of alternative SLCP mitigation measures can be assessed.

- **This integrated SLCP planning process needs to be effectively linked to the main programmes** (such as transport, industry and waste management) through which most mitigation initiatives could be implemented, as well as being linked with air quality, climate and developmental policies.
- **The information base on SLCPs could be strengthened to better support policy formulation.** A comprehensive emissions inventory of SLCPs needs to be developed to provide scientific data for the formulation and implementation of policies and to make the policymaking process more measurable, reportable and verifiable. The monitoring network could be reviewed to make

sure that it can objectively reflect the real situation in China's atmospheric environmental quality, and consideration could be given to putting other SLCPs into a unified environmental testing network.

- **Strengthen international communication and cooperation.** In developing its own strategy, China could learn from the experiences and lessons of other international SLCPs mitigation efforts, as well as policy and scientific initiatives at regional and hemispheric scales.
- **While SLCP mitigation policies are being developed, early progress could be made by reviewing relevant current policies to strengthen their contribution to SLCP mitigation.** This might include focusing more closely on black carbon emission sources in policies to address PM_{2.5} generally; or enhancing clean use of diesel vehicles in the transportation sector.

Developing coherent policies and targets for SLCP mitigation could then be the bridge to forming a comprehensive multipollutant strategy taking into account climate and air pollution as well as other developmental concerns.



Chapter 1

Introduction

1.1. Background

In recent years, more extreme weather events, including rising temperatures and disturbance to tropical rainfall and regional circulation patterns such as the Asian monsoon, have begun to affect the livelihoods of millions of people, not least in China (IPCC, 2014)⁷. Reports from the Intergovernmental Panel on Climate Change (IPCC) increasingly indicate that such changes reflect the long-term impact of human-induced climate change rather than short-term variability, and that they are expected to become more severe (IPCC, 2012).

At the same time, there is increasing international concern about air pollution, particularly in rapidly developing countries. A 2014 report from the World Health Organization (WHO) found that around 7 million people died prematurely in 2012 as a result of air pollution worldwide⁸. This conclusion is of growing relevance to China where, in the last two years, coastal and central regions have suffered unprecedented air pollution episodes (see Chapter 2 for more discussion on air pollution and its impact in China).

The recent air pollution episodes in China are a manifestation of wider and long-present air quality problems but they have now become a focus of political and public concern. Indeed it is arguable that the episodes now persistently afflicting many cities in China and cities in other rapidly developing countries represent a major challenge to air quality policy comparable to the Los Angeles and London smogs of the 1940s and 1950s respectively, and that the policy response to them could prove of equal international significance. Nor is the issue simply one of environmental quality: with the better understanding of the relationship between the environment and economy that has emerged in recent years has come a clearer recognition that if not tackled effectively such pollution, like climate change, could undermine the achievement of China's wider social and economic goals.

The two issues of air pollution and climate have usually been treated separately. This not only means that potential synergistic benefits are missed; it can also result in antagonistic policies between air pollution and climate. However, in recent

years it has become clear from research both in China and internationally that air pollution and climate are intimately connected, in their sources, pathways and the measures needed to address them. This is particularly true for the group of air pollutants known as Short-Lived Climate Pollutants (SLCPs), whose potential importance in tackling China's air pollution and medium term climate challenges is the subject of this report.

1.2. Short-lived Climate Pollutants

SLCPs are listed and briefly described in Box 1.1. Their distinct characteristic is that they not only have severe human health, food security and other socio-economic impacts – particularly in the case of black carbon, methane and tropospheric ozone – but they also contribute substantially to climate change. Hence, their mitigation can yield multiple benefits.

In climate terms, SLCPs contributes significantly to the total climate forcing attributed to non-CO₂ emission. However their particular importance is that their relatively short residence time in the atmosphere means that if emissions are reduced, atmospheric concentrations will decrease in a matter of weeks to years, with a noticeable effect on global temperature during the following decades. Hence, measures to control SLCPs can significantly slow climate change. While deep and persistent cuts in CO₂ and other long-lived greenhouse gases remain non-negotiable to stabilize global temperature rise through 2100 and beyond, reducing SLCPs could make the immediate and critical contribution of reducing the rate of near-term warming.

Two of the critical SLCPs in climate terms – black carbon and methane – are among the most important atmospheric substances in terms of human health, food security and ecosystems impacts. Black carbon is an air pollutant in its own right and methane is an important precursor for the formation of tropospheric ozone. Black carbon and tropospheric ozone are responsible for extensive damage to human health and crop yields losses in China and worldwide (Chapter 3 and 4). These SLCPs are therefore the primary focus of this report. It should be noted however that hydrofluorocarbons (HFCs) are also important SLCPs in climate terms (see Box 1.1) but do not have the characteristic of direct human health and food security impact like black carbon, methane and tropospheric ozone; hence they are not within the scope of this report.

7 See also for example: http://news.xinhuanet.com/english/china/2013-08/06/c_132607372.htm; <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=80235>; <http://www.bloomberg.com/news/2014-01-17/extreme-weather-wreaking-havoc-on-food-as-farmers-suffer.html>

8 See: <http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/>

Box 1.1. Short-Lived Climate Pollutants⁹

Short-lived climate pollutants (SLCPs) are agents that have relatively short lifetime in the atmosphere - a few days to a few decades - and a warming influence on climate. The main short lived climate pollutants are black carbon, methane and tropospheric ozone. They are currently the most important SLCPs contributing to human enhancement of the global greenhouse effect. These SLCPs, which are the focus of this report, are also dangerous air pollutants, with various detrimental impacts on human health, agriculture and ecosystems. Some hydrofluorocarbons (HFCs) are also short-lived and have substantial climate impacts (see below) but they do not have direct harmful effects on human health and crop productivity and are not within the scope of this report.

Black Carbon

Black carbon is a major component of soot and is produced by incomplete combustion of fossil fuel and biomass. It is emitted from various sources including diesel cars and trucks, residential stoves, forest fires, agricultural open burning and some industrial facilities. It has a warming impact on climate that is about 700 times stronger than CO₂ when its global warming potential is estimated over a 100 year timeframe (UNEP/WMO, 2011). Its lifetime varies from a few days to a few weeks. When deposited on ice and snow, black carbon causes both atmospheric warming and an increase of the melting rate. It also influences cloud formation and impacts regional circulation and rainfall patterns. In addition, black carbon impacts human health. It is a primary component of particulate matter in air pollution which is the major environmental cause of premature death globally.

Methane (CH₄)

Methane is a greenhouse gas that is over 20 times more potent than CO₂ when its global warming potential is estimated over a 100 year timeframe. It has an atmospheric lifetime of about 12 years. It is produced through natural processes (i.e. the decomposition of plant and animal waste), but is also emitted from many man-made sources, including coal mines, natural gas and oil systems, and landfills. Methane directly influences the climate system and also has indirect impacts on human health and ecosystems, in particular through its role as a precursor of tropospheric ozone.

Tropospheric Ozone

Tropospheric ozone (O₃) is the ozone present in the lowest portion of the atmosphere (up to 10-15km above the ground). It is responsible for a large part of the human enhancement of the global greenhouse effect and has a lifetime of a few days to a few weeks. It is not directly emitted but formed by sunlight-driven oxidation of other agents, called ozone precursors, in particular methane but also carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs) and nitrogen oxides (NO_x). Tropospheric ozone, especially at the ground-level, is a harmful pollutant that has detrimental impacts on human health and plants and is responsible for reductions in crop yields.

Hydrofluorocarbons

Hydrofluorocarbons (HFCs) are man-made greenhouse gases used in air conditioning, refrigeration, solvents, foam blowing agents, and aerosols. They have variable atmospheric lifetimes but many remain in the atmosphere for less than 15 years. Although, HFCs represent a small fraction of the current total greenhouse gases (less than one percent), their warming impact is particularly strong and, if left unchecked, they could account for nearly 20 percent of climate pollution by 2050 (UNEP, 2011a; Velders et al., 2012). Recent studies suggest that mitigating HFCs can help avoid as much as 0.5 degree Celsius warming by 2100 (Xu et al., 2012). Some efforts are already being undertaken to curb HFCs mitigation in China. For example, China announced an agreement with the United States in 2013 to work together to phasedown the production and consumption of HFCs through the Montreal Protocol¹⁰.

9 Descriptions adapted from <http://www.unep.org/ccac/Short-LivedClimatePollutants/Definitions/tabid/130285/Default.aspx>

10 See: <http://www.whitehouse.gov/the-press-office/2013/06/08/united-states-and-china-agree-work-together-phase-down-hfcs>

1.3. Benefits of Mitigating SLCPs

International research, consolidated in an assessment by the United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO) (UNEP/WMO, 2011), recently highlighted the potential magnitude of the benefits of action to mitigate black carbon and methane emissions – in scale, cost-effectiveness and speed of impact – and highlighted the case for early international and national action. In particular, it indicated that Asia, including China, would benefit significantly from mitigation actions.

The assessment concluded that fully implementing a package of 16 measures for which cost-effective¹¹ and tested technologies were available which could provide the benefits described below:

11 The assessment indicated that many of the measures will achieve cost savings over time; however, initial capital investment may be needed in some countries for effective implementation of some of the measures.

Health Benefits

The Assessment indicates that implementing the black carbon measures would yield reduced PM_{2.5} and consequently PM₁₀ levels, resulting in improved air quality and therefore, reduced global annual mortality by an estimated 2.4 million premature deaths by 2030, with more than 80% of this benefits accruing to Asia. Several research results including by the Chinese Academy for Environmental Planning (See Chen et al., 2013) and by Shindell et al. (2012) showed that China will significantly benefit in terms of improvement in human health and reduced human mortality if measures to reduce PM₁₀, of which black carbon is a major constituent, are implemented in China.

Crop Yield Benefits

Globally, implementing the measures also provides the benefit of reduced agricultural crop losses. The assessment estimates that significant reductions in black carbon

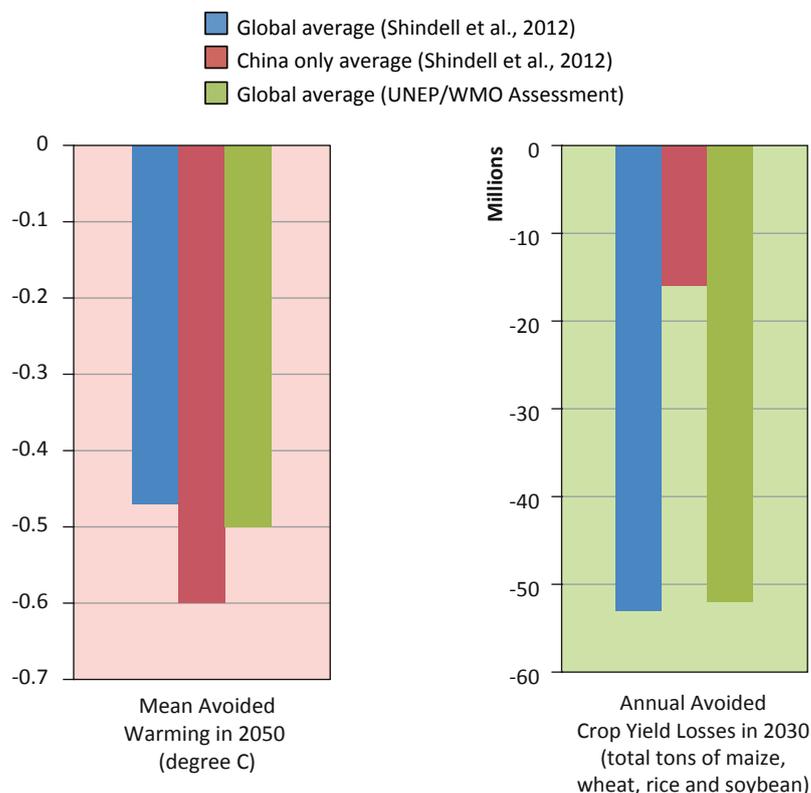


Figure 1.1. Global and China specific benefits from full implementation of identified measures in 2030 compared to the reference scenario. The climate change benefit is estimated for a given year (2050) and crop benefits are for 2030 and beyond.

Source: UNEP/WMO (2011) and Shindell et al. (2012)

and methane (and consequently tropospheric ozone) concentrations could yield an average of about 52 million tons of avoided crop yield loss of four staple crops – maize, wheat, rice and soybean (Figure 1.1). These gains are however expected to be greater if other crops are included in the calculations. Global modelling further shows that China benefits most from emission reduction measures, an average of 16 million tons of avoided crop yield loss of the four staple crops annually by 2030 and beyond, equivalent to about 30% of the average global total (Shindell et al. 2012).

Regional Climate Benefits

Reducing black carbon and methane emissions could reduce regional warming. Result obtained by Shindell et al. (2012) indicate that mitigating black carbon and methane emissions would result in avoided warming spread over the Earth. The UNEP/WMO assessment and Shindell et al. (2012) indicate that the East Asia region, which includes China, could avoid about 0.6 degree Celsius increased temperature through black carbon and methane emissions reduction in 2030 (Figure 1.1). Mitigating black carbon and methane emissions would also substantially decrease regional atmospheric heating by particles, thereby reducing disruption of regional climate, including shift in regional precipitation pattern and intensity, which China is already experiencing as a result of black carbon emissions (Menon et al., 2002; Meehl et al., 2008; Wang et al., 2009). A 2008 UNEP assessment shows that atmospheric brown clouds (ABCs)¹² – of which black carbon is a major component –

are causing severe threats to the water and food security of Asia because of its alteration of rainfall patterns, including in Eastern China (Ramanathan et al., 2008).

Mitigation of Sea-Level Rise

Recent modelling results (Hu et al., 2013) have shown that mitigating SLCPs could result in a decreased rate of sea-level rise by between 24 and 50% by 2100. Although this is more important for small island countries, it is also vital for China. This is because cities in China, including Guangzhou, Zhanjiang and Shenzhen, have been projected to experience increased flood losses in the future due to sea-level rise and subsidence (Hallegatte et al., 2013). According to the Chinese State Oceanic Administration, marine disasters associated with rising sea levels and storm waves resulted in 121 deaths and economic losses of 16.3 billion yuan (about USD 2.6 billion) in 2013¹³. SLCP emission reduction could yield an added benefit by the mitigation of this sea-level rise, with consequent reduction in associated socio-economic losses.

Global Climate Benefits

According to the assessment, if the full package of measures is implemented worldwide, the global mean warming rate over the next few decades could be greatly reduced. The black carbon and methane measures could help avoid about 0.5 degree Celsius global warming (Figure 1.1). When the measures are implemented alongside CO₂ emission reduction measures, temperature increase globally has an increased chance of being held below the 2 degree Celsius warming target (Figure 1.2).

¹² Atmospheric brown cloud refers to an air pollution layer containing aerosols, including soot (black carbon) or dust. This pollution layer has solar radiation absorption and scattering characteristics that leads to regional and global climatic effects as well as human health and food security risk.

¹³ See: http://www.soa.gov.cn/xw/hyyw_90/201403/t20140319_31029.html

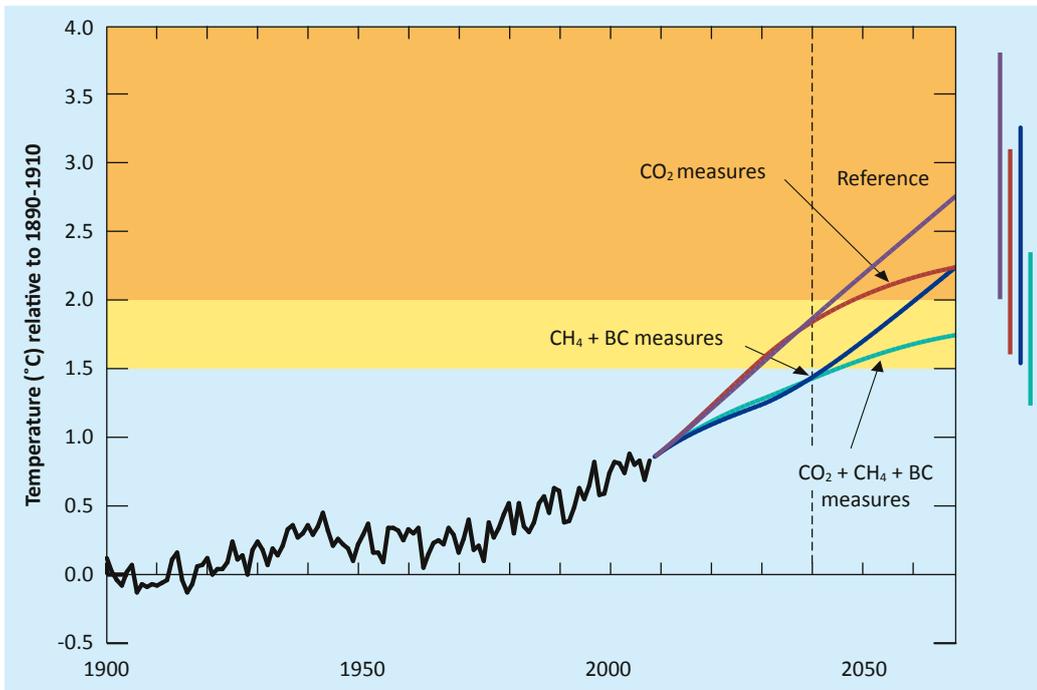


Figure 1.2. Observed deviation of temperature to 2009 and projections under various scenarios

Source: UNEP/WMO, 2011

Note: Linear implementation of the identified BC and CH₄ measures between 2010 and 2030, together with measures to reduce CO₂ would greatly improve the chances of keeping Earth's temperature increase to less than 2°C relative to pre-industrial levels. The bulk of the benefits of CH₄ and BC measure are realized by 2040 (dashed line).

Explanatory notes: Actual mean temperature observations through 2009 and projected under various scenarios thereafter, are shown relative to the 1890–1910 mean temperature. Estimated ranges for 2070 are shown in the bars on the right. A portion of the uncertainty is common to all scenarios, so that overlapping ranges do not mean there is no difference, for example, if climate sensitivity is large, it is large regardless of the scenario, so temperatures in all scenarios would be towards the high-end of their ranges.

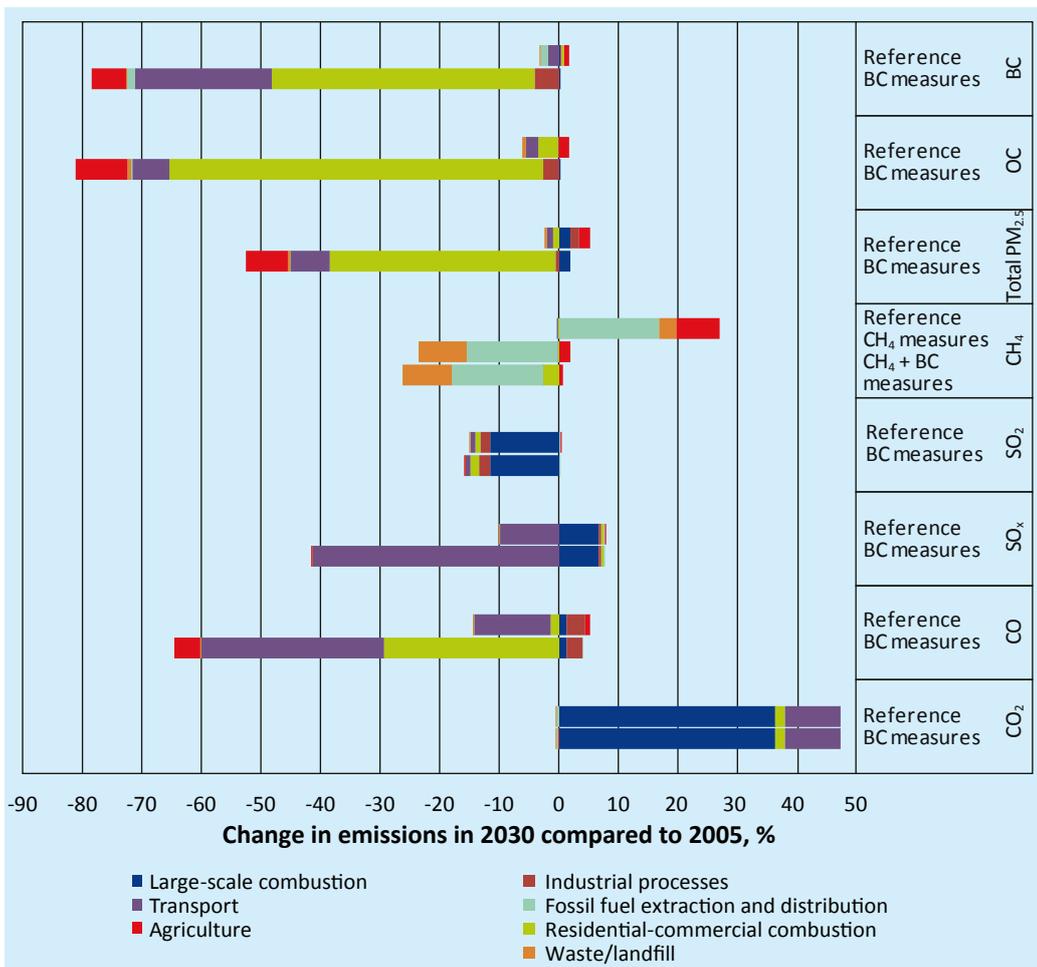


Figure 1.3 Effect of the implementation of 16 measures in different sectors on the emissions of black carbon, methane emissions and co-emitted substances (CO₂, CO, NO_x, SO₂, total PM_{2.5} and organic carbon) projected in 2030 relative to 2005.

Source: UNEP/WMO, 2011

Other Co-benefits

Apart from the benefits described above, mitigating black carbon and methane, and SLCPs in general, will provide further benefits across the sustainable development spectrum, including energy security; creation of local employment; increased revenue; increased economic development; and improved safety in the mining industry (see Chapter 5). Furthermore, measures to mitigate emissions of black carbon will also reduce co-emitted pollutants, for example nitrogen oxides (NO_x) and VOCs, and this can further reduce the overall impact of air pollution, particularly in the case of fine particulate matter (PM_{2.5}) (See Figure 1.3).

1.4. The Global Assessment and National Action

The benefits from mitigation of SLCPs will be experienced mainly at local level, in the form of health benefits and crop yield improvements, but achieving the full global benefits summarized earlier will require full mitigation of black carbon and methane emission sources throughout the world. This will require cooperative international action, but as emphasized in UNEP (2011b), action at the national scale will be critical. This is because the pattern of SLCPs emissions, appropriate technologies and the opportunities and barriers to effective mitigation will vary significantly between regions and countries. This is because many of the measures needed to reduce SLCPs are deeply embedded in existing sectoral programmes and national policies; and because national governments will need to mesh SLCPs mitigation measures into their wider social, economic and environmental priorities.

At the same time there are also important benefits for those countries taking action. Although, substances once emitted may be transported at regional and hemispheric scale, the benefits, in the case of black carbon emission reduction, will significantly accrue to the country taking the action. A further advantage is the wide range of potential 'entry points' for SLCP policy. This means that it can be developed flexibly and opportunistically, and sit comfortably within the framework of a government's current pattern of national priorities. If action in one particular field is difficult in policy or practical terms, there will be a variety of alternative options, in different areas, through which the necessary mitigation could be delivered.

A number of countries, for example Bangladesh, Colombia, Ghana, Mexico and Norway have already begun work on

national SLCPs mitigation strategies. In view of the scale of its SLCPs emissions, the environmental challenges it faces and the experience it has already accumulated, China could have much to gain from further action on SLCPs, and what it is able to achieve will certainly have wide international significance.

1.5. Objective and Structure of Report

The above discussion highlights the opportunity for achieving air quality, public health, food security, climate and other sustainable development benefits from mitigating SLCPs. Whilst these benefits have been shown to be substantial in China, work on SLCPs has not featured in an integrated manner on the policy agenda in China; yet such an approach could yield substantial sustainable development benefits at the national, regional, and global levels.

With this in mind, this synthesis report aims to inform Chinese policymakers and stakeholders about the:

- contribution of SLCPs to the public health threat posed by air pollution in China; as well as their threat to food security, and to regional and global climate change;
- measures that would achieve substantial reductions in the emission of SLCPs in China and therefore deliver substantial gains in health, food security and climate; and,
- options for achieving a coherent and action-oriented approach to SLCP mitigation.

Chapter 2 continues from the discussions in this chapter to highlight the relationship between SLCPs and air pollution especially in the Chinese context. Chapter 3 and 4 look more closely at black carbon and methane respectively, highlighting their emission sources, trends and projections in China, as well as their impacts. Chapter 5 discusses the various mitigation measures for black carbon and methane, reviewing current mitigation efforts in China and highlighting what more could be done. Chapter 6 takes stock of the potential implications of SLCP mitigation for environment and development policy in China, and in the light of experience in China, considers how effective national strategies could be developed – in China and elsewhere – to secure the benefits of SLCPs mitigation and thus help achieve national and international policy goals for climate and pollution more quickly and economically.

Chapter 2

Air Pollution and SLCPs in China

Chapter 1 of this report briefly discussed the air pollution challenge in China, the linkage between air pollution, SLCPs and climate change, and the potential benefits from black carbon and methane emissions reduction. This chapter presents in more detail the air pollution challenge in China highlighting the sources and causes of air pollution. It also discusses the contribution of black carbon and methane to poor air quality in China and then briefly reviews the recent evolution of policies in China targeted at tackling the air pollution challenge.

2.1. The Chinese Air Pollution Challenge

Air pollution has been recognized as a serious problem for decades in China, but recent haze¹⁴ and smog¹⁵ episodes have heightened government and public concerns over degraded air quality.

Reviewing recent air quality trends offers a clearer picture of the scope and magnitude of air pollution problems in China. An analysis of haze days in the winter half-year between 1961 and 2012 by Song et al (2014) indicated an increasing trend in the number of haze days in central-eastern China. Based on the new criteria for conditions that qualify as haze days as set out by the Chinese Ministry of Environmental Protection¹⁶, Guangzhou experienced 14 to 15 days of pollution in 2013, while Beijing had 138 days in the same year¹⁷. The new criteria also show that Shenzhen had zero haze days in 2013. According to Zhang et al. (2014b), the level of pollution in early 2014 peaked at a level that is 35 times higher than the World Health Organization recommended limit. Indeed, since January 2013, smog episodes have occurred in 25 provinces and 100 large and medium-sized cities in China, with a national average number of days of smog of about 30, the highest in the past 52 years¹⁸. In addition, the China Meteorological Administration

(CMA) and Chinese Academy of Social Sciences (CASS) joint report, the Green Paper on Climate Change, stated that the average numbers of hazy days in 14 provinces in 2013 were the highest annual figures recorded over a period spanning more than five decades for those provinces. For 2014, in the month of January, Beijing suffered three consecutive days of heavy pollution with monitoring data indicating an Air Quality Index (AQI)¹⁹ of 500 (the maximum pollution level possible) in most part of the city²⁰.

2.2. Causes and Sources of Air Pollution in China

Key air pollutants in China include sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), ammonia (NH₃), volatile organic compounds (VOCs), and ozone (O₃). Another important air pollutant is particulate matter (PM) which can be classified into two types based on their sizes: PM_{2.5} and PM₁₀. PM_{2.5} has diameter less than 2.5 micrometer and has high negative impact on human health due to its small size which makes it easy to penetrate human cells and blood. PM₁₀ has diameter less than 10 micrometer and includes PM_{2.5}. PM_{2.5} is formed from primary and secondary particles²¹ (Perrino, 2010; Hu and Jiang, 2013). Black carbon, as well as secondary sulfate and nitrate particles formed from SO_x or NO_x precursors are the dominant component of PM_{2.5} (WHO, 2003; Aneja et al., 2006; Li et al., 2009; Perrino, 2010; Xia and Gao, 2011; Son et al., 2012; Ebisu and Bell, 2012; Hu and Jiang, 2013). Carbonaceous aerosols (including black carbon) and major ions (sulfates, nitrates and ammonium) were shown to represent 69% of PM_{2.5} in Beijing (Zheng et al., 2005), with dust, secondary sulfate, nitrate, and ammonium, coal combustion, diesel and gasoline exhaust, and industry identified as their major sources (Dan et al., 2004; Song et al., 2005; 2007; Zheng et al., 2005). Indeed, Hu and Jiang (2013) identified the automobile industry, coal industry, industrial combustion processes, the construction and cement manufacturing industry as key contributing

14 Haze refers to the obscuration of the clarity of the lower atmosphere due to presence of suspended particles including dust, smoke and other dry particles.

15 Smog occurs when haze combines with smoke, fine particulate matter and other forms of emissions including VOCs, CO, NO_x, and SO₂ resulting in a mixture having ground-level ozone as its primary constituent.

16 The new criteria defines days that qualifies to have experienced haze pollution as those with an average concentration of PM_{2.5} above 75 micrograms per cubic meter and visibility is less than 5 km for more than six consecutive hours due to an increasing concentration of fine particulate matter in the air.

17 See: http://www.chinadaily.com.cn/china/2014-05/14/content_17505810.htm

18 See <http://www.globaltimes.cn/content/838575.shtml> and http://usa.chinadaily.com.cn/epaper/2013-12/31/content_17207629.htm

19 Air quality index (AQI) provides an indication to the public on the level of cleanliness or pollution of air and the potential health implications. In China, the AQI is ranked between I and VI depending on the level of pollution with I representing excellent air and VI representing severely polluted air.

20 See: http://www.chinadaily.com.cn/china/2013-01/14/content_16110693.htm

21 Primary particles are formed from combustion, industrial processes and natural process (for example dust or wind erosion), while secondary particles are formed indirectly through nucleation, condensation or processes that result in growth of primary gaseous

economic sectors to air pollution and the haze and smog issues in China.

It should be noted also that changing weather conditions also influence air pollution, and in particular the haze issue, in China. For instance, the frequent occurrence of cold air and changes in wind circulation, contribute to haze. This is because high humidity, low wind speed and other factors can inhibit the dispersion of pollution. Without cold air circulation, haze becomes stuck, hovering over or around urban clusters (Ma et al., 2013; Zhao et al., 2013; Feng et al., 2014).

2.3. Impacts of Air Pollution in China

The air pollution challenge in China comes with substantial environmental, social, and economic impacts. First and prominently, are the human health impacts and associated economic effects. The Global Burden of Disease (GBD) study 2010 showed that the ambient and household air pollution have become a major contributor to risk factor for age-standardized disability-adjusted life years (DALY) in China (Yang et al., 2013). Their results also show that ambient and household air pollutions are implicated in poor human health situation and consequently human mortality in China in year 2010. Other research results including Chen et al. (2010) and references cited therein also affirm the results of the GBD study. Second is the impact on food security due to loss in crop yield (see Chapter 3 and 4) and third, are the environmental impacts in the form of reduced visibility and the associated negative impact on daily social and economic activities.

The economic costs of air pollution have been shown to be significant in China. Studies carried out by Matus et al. (2012) suggested that air pollution due to PM₁₀ cost the Chinese economy a total of USD 112 billion in 2005 – a 400% increase in such damage when compared to 1975 values. Another estimate by Chen et al. (2010) put the economic losses associated with air pollution in 113 Chinese cities in 2006 at approximately 341 billion Yuan (range 188 to 469 billion Yuan). A joint report by the World Bank and the Development Research Centre of the State Council of the Chinese Cabinet put the health cost associated with air pollution in China at between USD100 and USD300 billion annually.²²

2.4. Chinese Government's Response to the Air Pollution Challenge

The Chinese Government has been responding to the country's air pollution concerns. Within the past two years alone, it has introduced revised air quality standards ("Ambient Air Quality Standards" (GB3095-2012)²³), added daily monitoring of PM_{2.5} to the list of monitored pollutants²⁴, and added eight-hour monitoring of ozone to the routine air quality monitoring system²⁵. Furthermore,

in 2013 it released an Airborne Pollution Prevention Action Plan for China that places a cap on air pollutants emissions in the critical Jing-Jin-Ji, Yangzi Delta, and Pearl Delta regions²⁶. The 2013 Action Plan also includes a 10% National Target by 2017 for PM₁₀; and 25% (Beijing, Hebei, Tianjin); 20% Yangtze River Delta; 15% Pearl River Delta reduction targets for PM_{2.5} by 2017 relative to 2012 levels (see Figure 2.1). Moreover, following the release of the 2013 action plan, subnational governments have passed complementary policies supporting the Airborne Pollution Prevention Action Plan. For example, new air pollution control laws have been passed in Beijing²⁷ as well as in Shanghai and Tianjin²⁸. Particulate matter and in particular PM_{2.5}, is now part of the focuses of China's new air pollution control policies.

China has achieved relative success in its efforts to regulate SO₂ from large stationary sources. Beginning during the 9th and 10th Five Year Plan (2001-2005 and 2006-2010), efforts were increased to bring down SO₂ emissions. Among other things, the efforts included the development of two control zones for areas generating large emissions of SO₂. These were also complemented by a set of reductions targets that have expanded in scope to include NO_x through the 10th, 11th and 12th Five Year Plans. Desulfurization devices had been installed in about 83% of thermal power plants as at 2010²⁹, and had increased to 90% in 2012³⁰. Also, denitrification facilities have been installed in 27.6% of coal-fired units as at 2012 (Zhang, 2014). While these regulations initially made modest progress, SO₂ emissions have begun to drop notably since the 11th Five Year Plan and now appear to be reflected in some improvement in air pollution (Table 2.1). This is also partly attributable to the introduction of energy efficiency targets in the 11th Five Year Plan and carbon intensity targets in the 12th Five Year Plan which have had collateral effects on SO₂ emissions.

It is important to note however, that whilst this represents a tangible progress, recent air pollution episodes as highlighted in Section 2.1 indicate that much still needs to be done. There are still opportunities for improvement in China's air quality, for example through increasing the ratio of plants equipped with denitrification and desulfurization devices in the industrial sector, tackling indoor air pollution, and developing strategies and policies targeted at air pollutants that are not yet well represented in existing strategies and policies.

2.5. The Place of Black Carbon and Methane

SLCPs, in particular black carbon and methane – as a precursor for tropospheric ozone formation – play an important role in air quality in China. Recent research by Zhang et al. (2014) has highlighted their increasing role in air pollution as well as in climate change in China generally. Their results show that anthropogenic aerosols present in PM_{2.5} (including black carbon) were in high concentration

22 See: <http://phys.org/news/2014-03-health-china-polluted-air-bn.html> and <http://uschinaha.org/wp-content/uploads/2014/01/China-Updates-Issue-85-2014-4-11.pdf>

23 See: [http://www.chinacsrmap.org/Uploads/file/%E3%80%8A%E7%8E%AF%E5%A2%83%E7%A9%BA%E6%B0%94%E8%B4%A8%E9%87%8F%E6%A0%87%E5%87%86%E3%80%8B%E7%BC%88GB3095-2012%E7%BC%89\(1\).pdf](http://www.chinacsrmap.org/Uploads/file/%E3%80%8A%E7%8E%AF%E5%A2%83%E7%A9%BA%E6%B0%94%E8%B4%A8%E9%87%8F%E6%A0%87%E5%87%86%E3%80%8B%E7%BC%88GB3095-2012%E7%BC%89(1).pdf)

24 See: <http://www.theguardian.com/environment/2011/oct/03/china-air-pollution-quality-standards>

25 See: http://www.acap.asia/event/ozone/ozone2_presen/2.pdf

26 See: http://english.mep.gov.cn/News_service/infocus/201309/t20130924_260707.htm and <http://cleanairinitiative.org/portal/node/12066>

27 See: http://www.huffingtonpost.com/2014/02/10/beijing-air-pollution-law_n_4762548.html

28 See http://policyintegrity.org/documents/PARKERPanel1_2014.pdf

29 See: http://www.gov.cn/zwgk/2011-12/20/content_2024895.htm

30 See: http://www.theicct.org/sites/default/files/2.20Situation%20and%20Mission%20of%20Air%20Pollution%20Prevention%20and%20Control%20in%20China_Shize.pdf

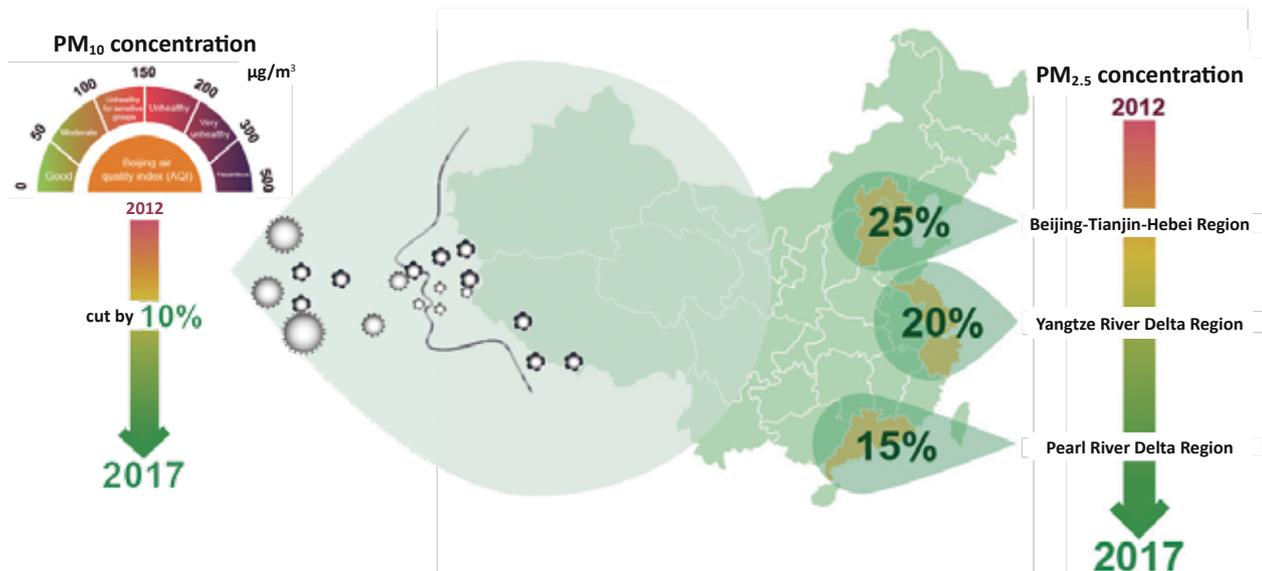


Figure 2.1. Schematic of the Chinese airborne pollution prevention and control action plan, 2013
 Source: Adapted from China's Daily (http://www.chinadaily.com.cn/china/fightairpollution/2013-09/11/content_16962092.htm)

Table 2.1. Key Environmental Protection Indicators of China's Air Quality during the 11th and the 12th Five Year Plan

Indicators	2005	2010	2015 (Expected)
Total emission of SO ₂ (10,000 tonne)	2549	2295	2086
Total emission of NH ₃ -N (10,000 tonne)	-	264	238
Total emission of NO _x (10,000 tonne)	-	2274	2046
Percentage of cities whose AQI is above II for more than 292 days in a year	69	75	>80

Source: 2005 and 2010 data are from Statistical Bureau of China; 2015 is projection from Investment Year Book of China 2013.

in some Chinese cities (Figure 2.2). Black carbon plays an important role during haze episodes because it has very strong light absorbing and scattering properties (UNEP/WMO, 2011). Hence, high concentration of black carbon aerosols could strengthen the seriousness of haze³¹ and increase the complexity of air pollution (Han et al., 2012 and references there in).

Also, findings by the same authors (Zhang et al., 2014) show that the average concentration of tropospheric ozone over China during the period between 2010 and 2013 exceeds the global average (Figure 2.3). Methane is a precursor for the formation of tropospheric ozone, a harmful air pollutant and major constituent of photochemical smog (Royal Society, 2008). Methane contributes to a complex series of reactions that leads to the formation of ozone (Golomb and Fay, 1989).

Intercontinental contributions to annual background concentrations of tropospheric ozone have been found to be most strongly influenced by changes in methane, followed by NO_x, NMVOCs, and CO, with methane contributing about 50% to the increase (UNEP/WMO, 2011). The concern about methane (as a precursor to tropospheric ozone formation) has been further strengthened by the fact that anthropogenic emissions are projected to increase globally (including in Asia), in contrast to emissions of other tropospheric ozone precursors (NO_x and CO), which are projected to decrease,

with those of NMVOCs already decreasing (Royal Society, 2008). It is therefore not surprising that research driving recent interest in SLCPs has focused on methane as an ozone precursor.

It is important to note however, that while ozone concentrations are undoubtedly related to methane emissions, this report has not estimated the amount of ozone concentration in China that is directly attributed to methane emissions versus other ozone precursors (NO_x, NMVOCs, and CO). Hence, unless otherwise stated, discussions on ozone in the report are based on total concentration irrespective of the compounds responsible for its formation. Furthermore, although this report focused on methane mitigation measure as a means of reducing tropospheric ozone concentrations (especially because of the proven mitigation potential), these efforts should not detract from policies aimed at mitigating other ozone precursors in China and indeed elsewhere. Instead, synergies need to be sought between policies so as to maximize benefits. Indeed, if well designed and effectively implemented, VOCs and NO_x controls could lead to reduction in particulate matter, ozone, and carbon dioxide³², (see for example Nguyen and Daddub, 2002 and references therein; Prinn et al., 2005), leading to air pollution and climate benefits. Furthermore, energy saving policies that mitigate CO₂ could lead to reductions in VOC and NO_x. This could result in near-term air quality

31 See: <http://climate-science.org/Guest/pdf/AirborneParticles.offset.GreenhouseEffect.pdf>; <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=49398>; and <http://www.earthmagazine.org/article/still-haze-what-we-dont-know-about-black-carbon>

32 By allowing more carbon uptake by ecosystem leading to less warming (Prinn et al., 2005).

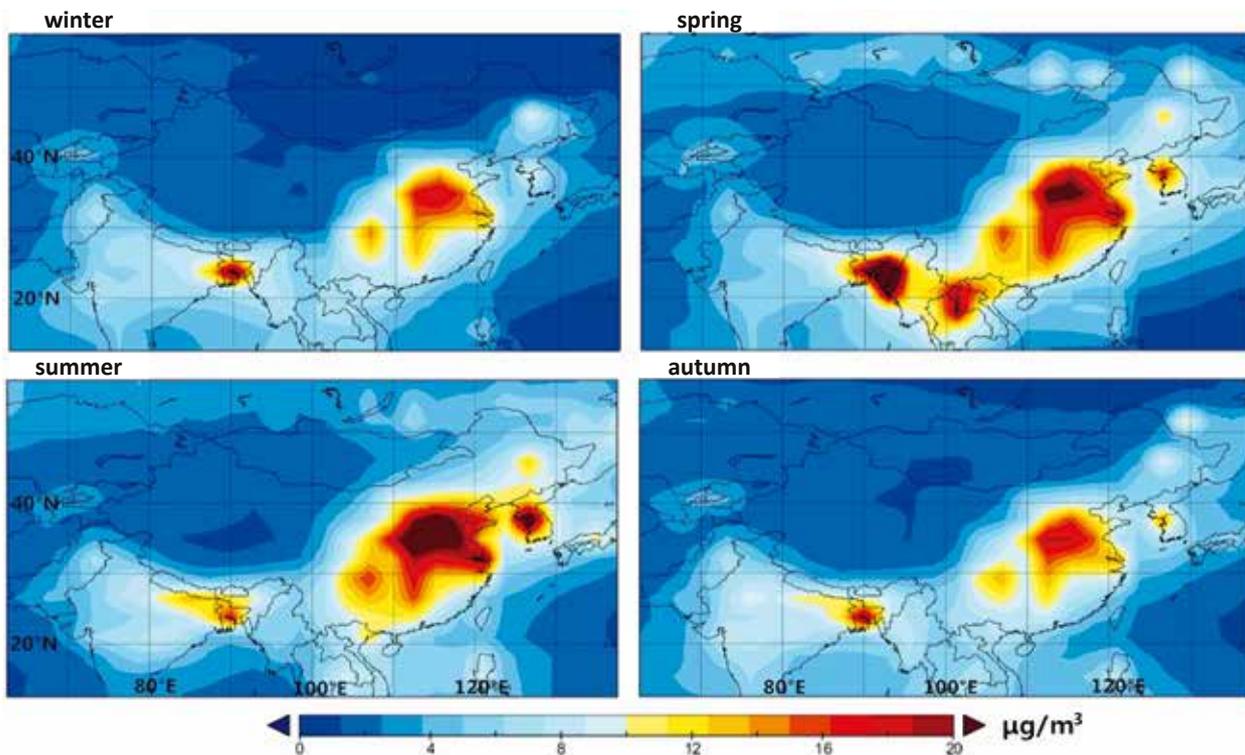


Figure 2.2. Distribution of simulated PM_{2.5} (only including anthropogenic aerosols)
 Source: Zhang, et al. (2014)

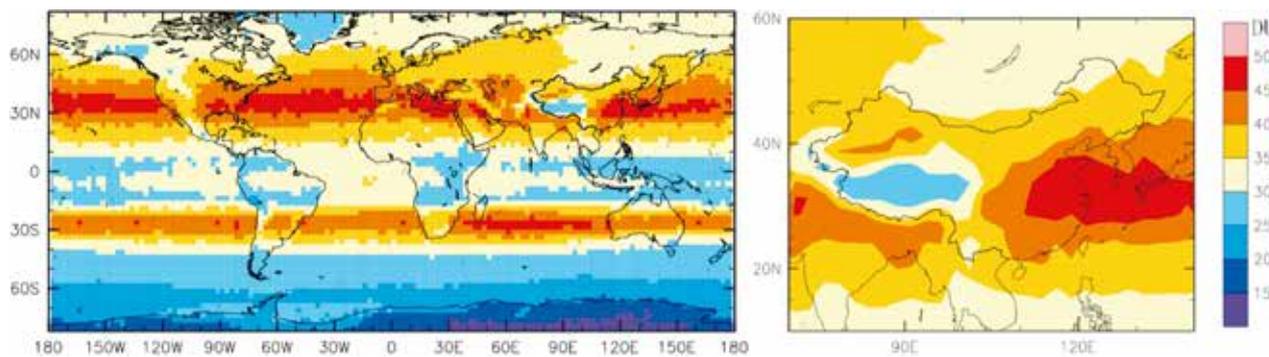


Figure 2.3. Distribution of tropospheric ozone column concentration observed by satellite in 2010-2013
 Source: Zhang, et al. (2014)

benefits as well as longer term climate benefits. This calls for an integrated approach to the development of air quality and climate policies that yield synergistic outcomes (see Chapter 6).

The preceding discussion highlights the importance of black carbon and methane for air pollution in China, and indeed globally. The body of science has underlined their negative impacts and has also shown that several benefits will accrue from their mitigation, especially in Asia and in China in particular (see Chapter 1, 3 and 4). China can reap

these benefits especially with the slate of recent policies and resources that have been targeted on PM_{2.5} (see Section 2.4). This set of policies could now provide a firm and supportive foundation for comprehensive measures to mitigate SLCP emissions. It remains important however, that any SLCPs mitigation strategy needs to take into consideration existing air pollution control policies as well as China's distinctive atmospheric conditions.

Chapter 3

Black Carbon and Its Impacts

Chapter 2 discussed the challenges of air pollution in China and how SLCPs contribute to these challenges. This chapter focuses specifically on black carbon as a major contributor to environmental and climate challenges in China. The chapter starts by describing the various sources of black carbon emissions and then discusses current emission trends and projections. It ends by describing the various impacts of black carbon in China, including impacts on human health, climate and crop yield.

3.1. Sources of Black Carbon in China

Generally, black carbon is either emitted from natural sources such as savanna and forest fires, volcanic eruptions and other geogenic releases, or from anthropogenic sources. Anthropogenic sources include diesel engines for transportation and industrial use, residential fuels such as biomass and coal for cooking and heating, human initiated open burning of forest and savanna (including burning of agricultural wastes), and industrial facilities such as small boilers and brick kilns. The major sources of anthropogenic black carbon emissions vary between developed and developing countries. Emissions in developed countries are dominated by the transportation³³ and industrial sectors, as well as wood burning from the residential sector (UNEP/WMO, 2011), while those in developing countries are dominated by the residential sector and the open burning of biomass (USEPA, 2012).

In China, black carbon is emitted from all known anthropogenic sources albeit in varying amounts. The sources can be broken down into five main sectors: residential (rural and urban residence using biomass, coal or oil as fuel for

cooking and heating), industry (using biomass, coal or oil for industrial processes and in industrial boilers), transport (including off-road vehicles and on-road vehicles using diesel fuel), power generation (using coal and oil as fuel) and open burning of biomass (including burning of agricultural waste and residues as well as using fire for land clearing). Table 3.1 presents a breakdown of 2010 black carbon emissions by sector (excluding open biomass burning) as retrieved from the MEIC – Multi-resolution Emission Inventory for China Model³⁴. The table also includes 2010 emissions for other pollutants which are usually co-emitted with black carbon. The total emission of black carbon from China in 2010 (excluding emissions from biomass burning) is estimated at 1.72Tg/yr. If the 2010 estimate for biomass burning by Lu et al. (2011) is added (0.11Tg), total emissions in 2010 will be approximately 1.83Tg/yr. The contribution of each sector to this estimate is discussed below.

Residential

According to the MEIC Model, this sector is the largest contributor to black carbon emissions in China, with total emissions of 0.85Tg in 2010 or approximately 47% of total emissions reported in the MEIC Model. This agrees with the findings of several authors including Street et al. (2001); Ohara et al. (2007); Lei et al. (2011); Lu et al. (2011); Qin and Xie (2011); Wang et al. (2014) and CAAC (2013). One major factor responsible for high emissions from this sector is the fact that fuels are burned in small domestic stoves, cookers and heaters under poor burning conditions and without adequate emission control (Street et al., 2001; Qin and Xie 2011).

33 Although emissions from the transportation sector are believed to be reducing due to implementation of vehicle emissions standards (UNEP/WMO, 2011)

34 The MEIC (Multi-resolution Emission Inventory for China) is a recently developed open-access model framework which aims to provide emission data on China to the user community at different spatial resolution and time scale. See <http://www.meicmodel.org/>.



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Table 3.1. Anthropogenic Emissions of BC and Major Co-emitted Pollutants in China, 2010 (Tg/yr)

Anthropogenic sources	BC	SO ₂	CO	NO _x	OC	VOCs	PM _{2.5}
Off-road vehicles	0.15	0.06	1.36	2.20	0.05	0.20	0.24
On-road vehicles	0.13	0.16	19.0	4.78	0.05	2.15	0.25
Industrial process	0.48	4.03	61.8	2.67	0.51	6.22	4.61
Industrial boilers	0.11	11.0	12.3	5.23	0.07	1.62	0.96
Rural resident	0.72	1.85	61.2	0.70	2.32	4.59	3.88
Urban resident	0.13	1.63	9.73	0.35	0.16	0.36	0.45
Electricity and heating	0.003	9.77	4.57	11.4	0.00	0.11	1.21
Total	1.72	28.5	170.0	27.3	3.16	15.3	11.6

Source: MEIC Model (Multi-resolution Emission Inventory for China)

Industrial

The MEIC Model put the industrial sector as the second largest contributor to black carbon emissions in China, with total emissions of 0.59Tg in 2010 or approximately 32% of total emissions. Findings by Cao et al. (2006; 2011); Lei et al. (2011); Lu et al. (2011); and Qin and Xie (2011) also affirm that industrial emissions are the second most dominant black carbon emission source in China. Cao et al. (2006) ascribes emissions from industries to uncontrolled or poorly controlled coal-fired boilers, brick kilns and furnaces in rural industry.

Transport

The transport sector (including off-road and on-road vehicles) is the third largest contributor to black carbon emissions in China, with total emissions of 0.28Tg in 2010 or approximately 15% of total emissions, according to the MEIC Model. Studies including Lu et al (2011); Wang et al. (2012) and Zhang et al. (2013) also agree that this sector is the third dominant contributor. According to Wang et al. (2012), emissions from this sector are primarily from diesel engines which were responsible for 85% of the total from the sector in 2007.

Power Generation

The MEIC model indicates that this sector contributes the least to black carbon emissions in China. Emissions in 2010 are estimated at 0.002 Tg equivalent to 0.1% of total emissions. This estimate differs from those by Lu et al. (2011) and Wang et al. (2012) which put emissions from power plants in China at 0.02 and 0.07 respectively (that is 1% and 4% respectively) in 2010. According to Street et al. (2001) and Cao et al. (2006), emissions from power plants are generally low because the high temperature combustion condition in power plants tends to burn out any black carbon that is formed. Furthermore, most power plants in China are equipped with electrostatic precipitators to collect particulate matter.

Open Burning of Biomass

Although not included in the MEIC Model, the burning of crop residues in the field or the use of fire for land clearing has been identified as a source of black carbon emissions in China (Street et al., 2001). Available studies put this activity as the fourth largest contributor to black carbon emission. Lu et al. (2011) and Zhang et al. (2013) respectively reported emissions of 0.07Tg and 0.11Tg in 2008 equivalent to 4.2%

and 6.1% of total emissions respectively for that year. Year 2010 emissions were estimated as 0.11Tg by Lu et al. (2011), equivalent to 5.8% of total emissions. Also worthy of note in terms of biomass burning is the emission of brown carbon³⁵ which is not discussed in detailed in this report.

3.2. Trend of Black Carbon Emissions in China

Although its per-capita emission of black carbon is generally not high compared to that of developed countries, China is the highest emitter of black carbon globally (Wang et al., 2012; Zhang et al., 2013). Some estimates put emissions from China at 20% of the global total (Bond et al., 2004). Estimates derived by using the supporting information in Wang et al. (2014) shows that China's contribution to global black carbon emissions ranged between 20% and 24% between 1990 and 2007. A recent study by Wang et al. (2014) however suggests that the black carbon emissions in China (and India) could be 2 or 3 times higher than current estimates.

With the rapid growth of China's economy in recent years, the combustion of coal, other fossil fuels, and biofuels has increased considerably, resulting in an increase in black carbon emissions. According to Ramanathan and Carmichael (2008), black carbon emissions from China doubled between 2000 and 2006. Figure 3.1a shows the trend in black carbon emissions in China between 1990 and 2010 based on the MEIC Model, while 3.1b shows the breakdown of emission by sector between 2000 and 2010. Figure 3.1a shows that total emissions from China ranged between 1.37 and 1.62Tg between 2000 and 2004 and 1.71 and 1.75Tg between 2005 and 2010 indicating an increasing trend in the former years and almost levelled emissions in the later years. This agrees with results from Klimont et al. (2009) and Wang et al. (2012) which suggest similar trends. Results by Qin and Xie (2011)

³⁵ Brown carbon is an atmospheric aerosol mainly emitted during biomass combustion (Chen and Bond, 2010; Lack et al., 2012), but also from coal combustion (Cai et al., 2014). According to recent finding (for example, Feng et al., 2013; Saleh et al. 2014), it plays a key role in the warming of the atmosphere through its light absorbing characteristics. It has been noted to be a particularly strong absorber of short wavelength solar radiation and is now thought to be a net warming agent (for example Bahadur et al., 2012; Feng et al., 2013; Saleh et al. 2014). Results by Yang et al. (2009) suggest that brown carbon is an important source of light absorption in China, although they determine that black carbon absorbs more light than brown carbon. Because knowledge on brown carbon aerosol is only emerging, little information exists on its emissions in China and globally. However a recent preliminary study by Cai et al. (2014) reported an estimate of about 270 Gg of brown carbon emission in China in year 2000, with 65% of this attributed to field agricultural biomass burning and the rest to residential coal combustion.

however indicated that emissions increased between 2005 and 2009.

The observed almost levelled emission trend in China can be attributed to several factors including enforcement of stricter emission laws in the industrial sector, improvement in technology in the transport and industrial sectors, rapid urbanization resulting in reduced rural population, change in fuel composition (for example, replacement of coal stoves with liquid petroleum or natural gas), and expansion of centralized heating systems (Wang et al., 2012; Wang et al., 2014).

3.3. Projections of Black Carbon Emissions in China

There is a lack of literature on black carbon emission projections for China underlining the need for more research

on the emissions, trends and projections needed as a baseline reference for decision making. A review of existing emission projection-related studies indicates that total black carbon emissions from China could either increase or decrease depending on the implementation of emission reduction strategies. A reduced use of coal and biomass in the residential sector would result in a decrease, while increased future emissions will be due to possible unsuccessful technology advance or failure of government policies.

Ohara et al. (2007) showed that emissions will decrease to between 0.66 and 0.91Tg in 2020 from the 1.09Tg values of year 2000. They however indicate that a failure of government policies could result in increased emissions to 1.42Tg in 2020. Studies by Klimont et al. (2009) projected total emissions in 2020 and 2030 to be 1.3 and 1.11Tg respectively as compared

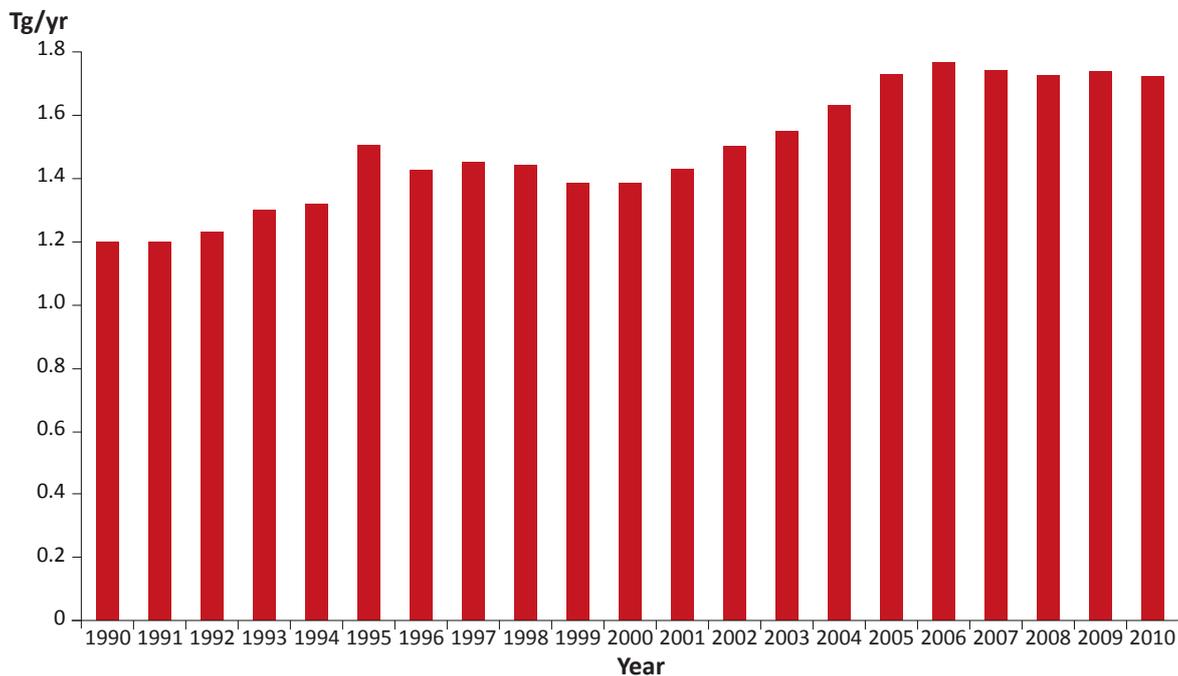


Figure 3.1A. Total black carbon emissions from anthropogenic sources, 1990-2010
 Source: MEIC Model (Multi-resolution Emission Inventory for China). <http://www.meicmodel.org/>

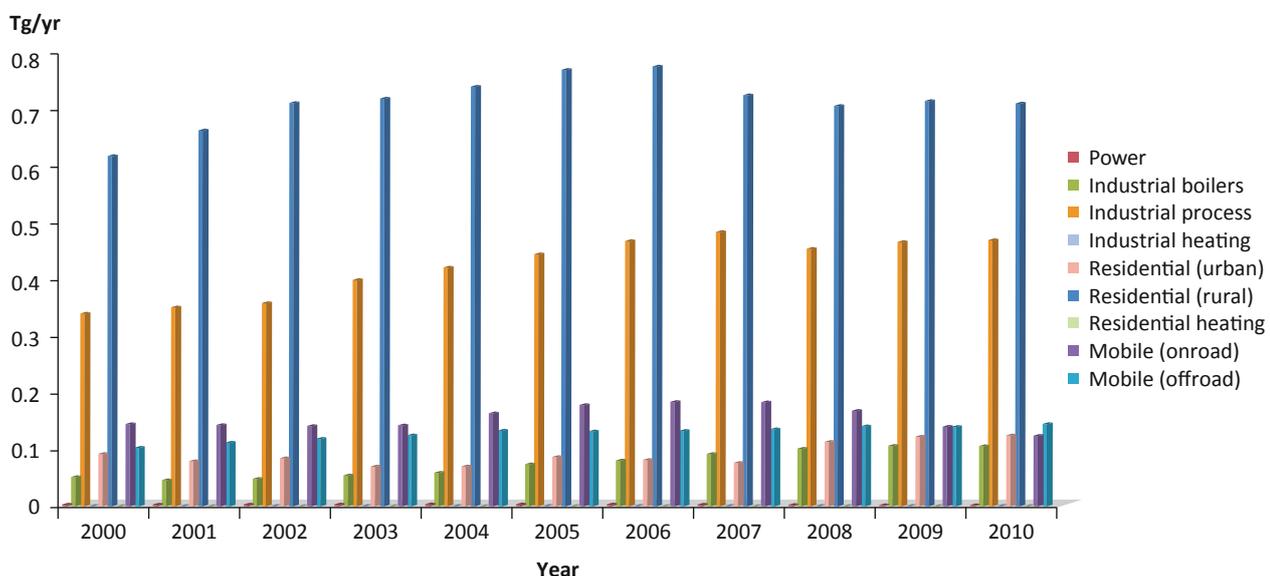


Figure 3.1b. Sectoral breakdown of black carbon emissions from anthropogenic sources, 2000-2010
 Source: MEIC Model (Multi-resolution Emission Inventory for China). <http://www.meicmodel.org/>

to emissions of 1.35 in year 2000. Finally, Wang et al. (2012) forecasted that the median values of 2020 emissions could increase to 1.98 and the decrease to 1.85 and 1.47Tg in 2030 and 2050 respectively as compared to year 2000 emission of 1.62Tg. However they indicate that 2050 emissions could increase to 2.18Tg if uncertainty in technology advances is taken into consideration. The projections from these studies suggest a general trend of decreased future emission, if policies are successful, even though the year 2000 baseline for each study differs.

Emissions from the transportation sector are expected to continue rising due to rapid increase in vehicle population (Street et al., 2001; Qin and Xie, 2012; Wang et al., 2012). Wang et al. (2014) stated that the number of motor vehicles in China increased from 13 million in 2000 to 78 million in 2010. Also, Qin and Xie (2012) stated that the number of vans, the major contributor to vehicular black carbon emissions, increased by about 10 times and the car-to-passenger population ratio has increased by more than 100 times between 1980 and 2009. With the development of the economy and society, vehicle emissions are expected to continue to grow. Qin and Xie (2011) stated that total vehicular emissions may be difficult to reduce unless total vehicle population is restricted. Already, studies by Chen et al. (2012) suggest that the use of diesel vehicles has already become the predominant black carbon emission source, exceeding the residential sector and open biomass burning, in the Yangtze River Delta. This suggests that a possible measure for reducing black carbon emission could be by discouraging the use of diesel vehicles.

3.4. Impacts of Black Carbon in China

Black carbon in the atmosphere has detrimental effects on health and agriculture. It also contributes to global climate change and disruption of regional climatic conditions. This section discusses these impacts in China in more details.

3.4.1 Human Health Impact of Black Carbon in China

Black carbon, a major component of soot, contributes to indoor and outdoor particulate matter pollution. Research has found that exposure to black carbon is harmful to human health and has provided sufficient evidence of the association of cardiopulmonary morbidity and mortality with black carbon exposure (WHO, 2012). As a constituent of PM_{2.5}, black carbon has been shown to penetrate and remain in the human body (especially when emitted from diesel engines) with negative consequences for human health (Rissler et al., 2012). Scientific evidence on the health effects of short-term black carbon exposure includes increased inflammatory response in the respiratory system (Lin et al., 2011) and lung function changes in children with bronchial hyperresponsiveness (Boezen et al, 1999). Wang et al. (2013) show in a recent study that exposure to black carbon emissions has been associated with increase in hospital visits in nine urban districts in Shanghai. Another study by Geng et al. (2012) showed a significant association between black carbon exposure and cardiovascular mortality in China. As highlighted in Chapter 2, black carbon is an important component of PM_{2.5} which has been implicated as a leading

risk factor for disability-adjusted life-years in China (Yang et al., 2013) as well as a leading cause of mortality.

The health impact of black carbon exposure is of particular concern for the vulnerable members of the Chinese community including women, children and the elderly. Brauer et al. (2008) suggested that exposure to increased concentration of traffic-related air pollution (including PM_{2.5} and black carbon) is associated with increased risk of having babies with low birth weights in China. Moreover, studies in Shanghai found positive associations between black carbon exposure and childhood asthma (Hua et al., 2014). Research in Shanghai also showed a significant association between pulmonary inflammation and black carbon exposure in 34 elderly people (Zhu et al., 2012). Another study by Baumgartner et al. (2014) indicates that exposure to black carbon significantly impacts women's blood pressure thereby increasing their risk of cardiovascular-related illnesses. The impact of black carbon was found to be twice that of particulate matter.

3.4.2 Climate Impact of Black Carbon in China

Black carbon aerosol affects the climate in a number of ways. Its ability to absorb light energy and to darken surfaces link it to a range of climate-related impacts, including temperature rise, ice and snow melt and alteration of precipitation patterns. These impacts, as they relate to China, are discussed below.

Contribution to global warming

Black carbon aerosols contribute to global warming in two ways. First, it captures energy by directly absorbing both incoming and outgoing radiation resulting in the heating up of the atmosphere. Secondly, black carbon, when deposited on snow and ice, darkens the bright surface, thereby weakening its reflective ability and increasing light absorbing ability. Furthermore, black carbon aerosols can modify the microphysical properties of droplets and hence increase the reflectivity and lifetime of clouds (IPCC, 2013). The properties of black carbon including its high global warming potential (estimated at about 700³⁶ – UNEP/WMO, 2011) make its emissions a major contributor to current global warming (Ramanathan and Carmichael, 2008; IPCC 2013). Bond et al. (2013) indicated that the total climate forcing of black carbon is 1.1 W/m², however, the latest IPCC Assessment Report (IPCC 2013) estimates that the radiative forcing of black carbon (direct and snow/ice albedo effect) to be 0.64 W/m².

Since black carbon is a major contributor to global warming, reducing its emissions could help slow down the rate of climate change in the short term. It must be noted however, that black carbon is usually co-emitted with other substances including sulfates, NO_x, and organic carbon, which in contrast to black carbon have cooling effects. Hence, estimates of overall warming of black carbon must take into consideration the ratio between emitted black carbon and the co-emitted substances. This ratio is dependent on the emission source and fuel type. Black carbon from

³⁶ In simple terms, this means that one kilogram of emitted black carbon aerosols can warm the atmosphere 700 times more than one kilogram of carbon dioxide when estimated over a 100 year timeframe.

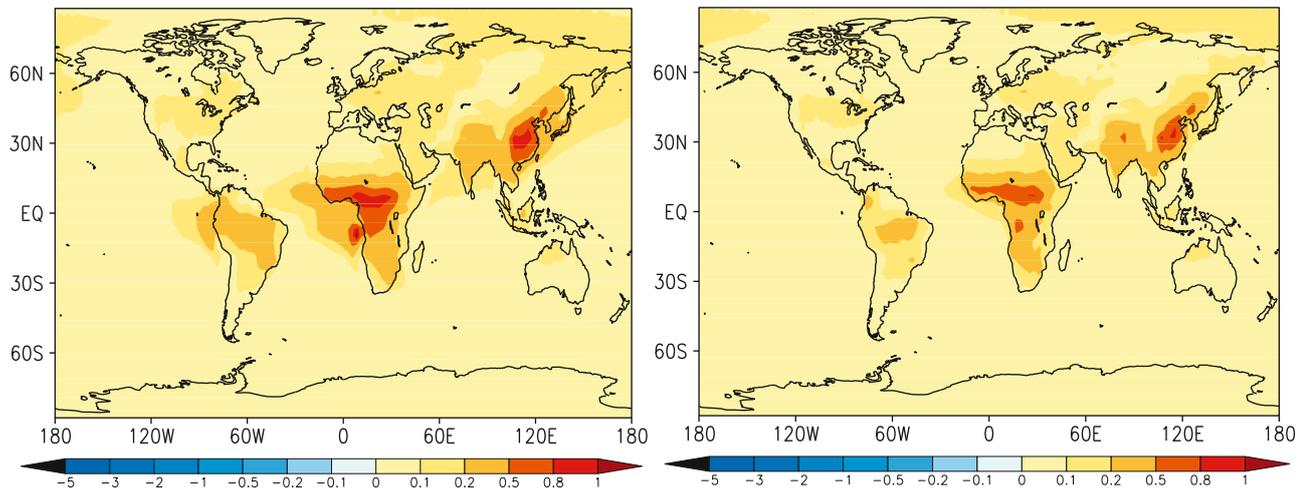


Figure 3.2. Annual mean distributions of the simulated direct radiative forcing (W/m^2) due to black carbon under all sky (left) and clear sky (right) conditions

Source: Zhang et al. 2012.

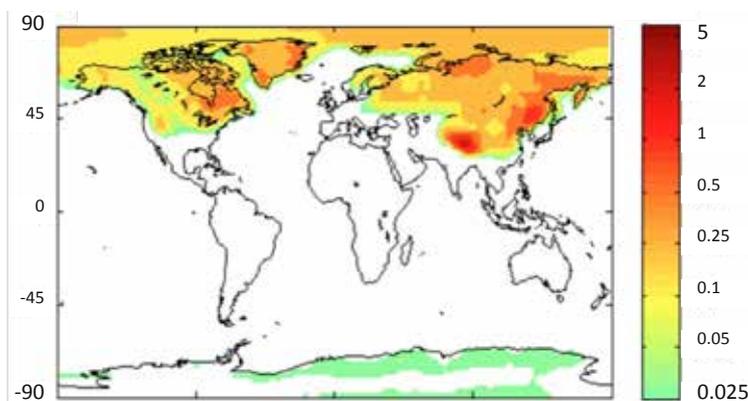


Figure 3.3 Regional variability in snow/ice albedo forcing for black carbon from all sources

Source: Bond et al. 2011

fossil fuel has a high ratio of black carbon to co-emitted species compared to black carbon from biomass, hence emissions from fossil fuel combustion engines will warm the atmosphere more than that from wildfires or open burning of biomass (USAID, 2012; UNEP, 2014). It therefore means that reducing black carbon emissions from sources with a high black carbon to co-emitted cooling substances provides the greatest likelihood of producing climate benefits.

Impacts on Regional Climate

Apart from global climate impacts, black carbon also has spatial, temporal, and regional climate characteristics (Sasser et al., 2012). China, being one of world hotspots of black carbon emissions, has the highest direct radiative forcing in East Asia³⁷, especially to the south, the southwest and the east of China, where the maximum value of radiative forcing reached approximately $+1.0 \text{ W m}^{-2}$ (Figure 3.2) (Zhang et al. 2012). A modelling study by Huang et al. (2006) shows that anthropogenic aerosol, including black carbon, resulted in 0.7°C increase in night time temperature and 0.7°C decrease

in day time temperature during winter in the industrialized parts of China.

The direct warming from black carbon is further reinforced by the snow/ice albedo effect³⁸ thereby amplifying the impacts of black carbon's radiative forcing. This warming has particularly high impacts on the Tibetan areas of China. It is estimated that warming caused by black carbon emissions may be a major contributor to forcing on the Tibetan side of the Himalayas (Ramanathan et al., 2007). For example, modelling results by Bond et al. (2011) show that snow/ice albedo radiative forcing from black carbon impacts the Himalayas of China, including on the Tibetan side (Figure 3.3). In a study by Xu et al. (2009), it was found that black soot aerosols deposited on the Tibetan glaciers is a factor in the observed rapid glacier retreat in that area³⁹. Results by Ming et al. (2009) also support these findings. Furthermore, Kopacz et al. (2011) indicated that emissions from India and China are a major contributor of black carbon to the Himalayas.

³⁸ In climate processes, the albedo effect produces a positive feedback that reinforces an initial change in the area of ice or snow. Hence, warming results in a decrease in ice cover and consequently the albedo, thereby leading to increased absorption of solar and energy and consequently more warming. The reverse is also true for cooling.

³⁹ There are some uncertainties associated with this finding.

³⁷ Although the radiative forcing could reduce when the cooling effect of sulfates is taking into consideration

Impacts on pattern and intensity of precipitation

Black carbon (and other particles) causes surface dimming⁴⁰ by absorbing and scattering incoming solar radiation. By absorbing sunlight in the atmosphere, black carbon particles act as condensation nuclei thereby affecting cloud formation (UNEP/WMO, 2011), with complex implications for rainfall as well as the monsoon. Model results by Menon et al. (2002) suggest that black carbon is a possible contributor to the observed tendency towards increased floods and droughts in some parts of China and the moderate cooling in China and India (while most of the world is warming), indicating the role of black carbon in shaping floods and droughts episodes. Wang et al. (2009) through model simulations attributed an increased summer precipitation in the north of China and decreased precipitation in the south of the Yangtze River to black carbon emissions. Furthermore, studies by Meehl et al. (2008) found a general decrease in summer precipitation throughout China due to black carbon effects except for the Tibetan Plateau where a small precipitation increase was suggested. These findings are further supported by those of Jiang et al. (2013) which through modelling found that the suppression of precipitation in North China and enhancement of precipitation in South China and adjacent ocean regions can be attributed to anthropogenic aerosols, including black carbon. The foregoing suggests that black carbon impacts China's precipitation pattern, although further research is needed to understand how these changes occur and the extent of impacts in China.

3.4.3. Impacts on crop yield

As discussed in Section 3.4.2, the dimming effect of black carbon (in combination with other aerosols) can lead to alteration in precipitation intensity and pattern. In particular, a cloud of black carbon aerosol can decrease or shift precipitation to a different location (Jacobson, 2006).

⁴⁰ Surface dimming refers to the gradual reduction in the amount of direct irradiance at the Earth's surface due to increased presence of aerosol particles in the atmosphere.

It can also lead to increased frequency of drought and flood (Menon et al., 2002), with negative effects on crop yield. Furthermore, crop yields are strongly dependent on the amount of solar radiation received by plants. The dimming effect of black carbon aerosol has been suggested to reduce the amount of sunlight reaching the Earth's surface with possible negative consequences for crop yields⁴¹ (Li et al., 2011). Studies by Chameides et al. (1999) indicate that the yield of rice and wheat in China was reduced by between 5% and 30% due to the dimming impact of aerosols and regional haze in the 1990s. It should be noted, however, that detailed and recent studies on the impact of black carbon or aerosols in general on crop yield in China are scarce; hence more studies are needed to determine the magnitude of black carbon's impact on crop yield in China and globally.

3.5. Potential Sectors for Black Carbon Emission Reduction

The inventory, trend, and projection discussed above, as well as the negative health impacts associated with indoor and outdoor emissions of black carbon and other particulate matter, suggest that black carbon emission reduction strategies in China should target all the main emitting sectors – residential, industrial and transportation. A recent study by Chen et al. (2013) suggests that fossil fuel combustion such as in household cooking and transportation is responsible for 80% of black carbon emissions in China, further strengthening the need for targeted emission reduction in these sectors. Furthermore, in order to maximize climate benefits, emission reduction needs to target sources with a high black carbon to co-emitted particles ratio; making fossil fuel combustion engines, especially diesel vehicles, a potential sector for targeted emissions reduction. Emission reduction measures for these sectors are discussed in Chapter 5 of this report.

⁴¹ Other findings (for example Steiner and Chameides, 2005; Mercado et al., 2009; and references cited in both) however indicate that increased scattering of light due to black carbon could lead to increased photosynthesis thereby leading to increase plant growth.

Chapter 4

Methane and Its Impacts

Chapter 3 focused on black carbon. This Chapter looks at methane. It provides a synthesis of how methane as a greenhouse gas and an important precursor for the formation of tropospheric ozone poses environmental and climate challenges to China. The chapter starts by describing the major sources of methane emission in China and then discusses current emission trends and projections. It ends by describing the various impacts of methane, including those on health, climate, and crop yield.

4.1. Sources of China's Methane Emission

Emissions of methane to the atmosphere come from natural and anthropogenic sources. Natural sources of methane include wetlands (the largest natural source), termites, oceans, sediments, volcanoes and wildfires. Anthropogenic sources of methane can be broadly categorized into emissions from the agricultural, energy and waste management sectors. Below, an inventory of methane emissions in China is presented mainly from two sources – the Chinese Second National Communication on Climate Change to the United Nations Convention on Climate Change (UNFCCC)⁴² which provides inventory for the year 2005 and the USEPA report on global anthropogenic non-CO₂ greenhouse gas emissions (USEPA, 2012), which provides inventory and projection for up to year 2030. It must be noted however that data in the USEPA report have not been validated by the Chinese Government; hence they are not necessarily recognized or endorsed by the government. They have been included here only due to dearth in alternative data.

The Chinese Second National Communication on Climate Change puts total methane emissions in 2005 at about 930

MtCO₂e. Year 2010 estimation is approximately 920 MtCO₂e (USEPA, 2012⁴³; Brink et al., 2013), equivalent to 13% of total global emission in that year (Figure 4.1a). China's emissions per-capita is however less than that of the next two largest emitters: USA and India (Zhang and Chen, 2014). Methane is emitted from the energy, agriculture, and waste management sectors. In addition, land use change (forest conversion) also emits a small amount of methane. Figures 4.1b and 4.1c show the sectoral breakdown of emissions in 2005 and 2010. The contribution of each sector is discussed below.

Energy

According to China's Second National Communication on Climate Change, emissions from the energy-related activities in 2005 was about 320 MtCO₂e. Year 2010 emissions from the sector according to USEPA (2012), based on projection of 2005 emissions, are estimated at 383.3 MtCO₂e. This is equivalent to 41.6% of total methane emissions in that year making the sector the largest contributor to China's methane emissions in 2010. Emissions from this sector come from coal mining (Coal Mine Methane – CMM)⁴⁴, oil and natural

42 See: <http://www.ccchina.gov.cn/archiver/ccchinaen/UpFile/Files/Default/20130218145208096785.pdf>

43 Estimates for years between 2010 and 2030 by USEPA was derived by projection using 2005 data based on country-prepared, publicly-available reports of emissions and calculations based on activity data and default emission factors. The projection calculations use IPCC default methodologies, international statistics for activity data and the IPCC Tier 1 default emission factors, with a range of assumptions about economic activity, technology development and implementation emissions reductions measures. Details of the methodology used in obtaining these estimates can be found in the appendices and annex to USEPA (2012) at <http://www.epa.gov/climatechange/EPAactivities/economics/nonco2projections.html>

44 Coal mine methane (CMM), is an unconventional natural gas which exists in coal seams and has methane as the main component. Coal mining activities can result in the release of CMM into the atmosphere. China's methane emissions from this source consist mainly of the venting of unused extracted gas and fugitive emissions – leakage of methane from the mine shafts or other unintended release of the gas.



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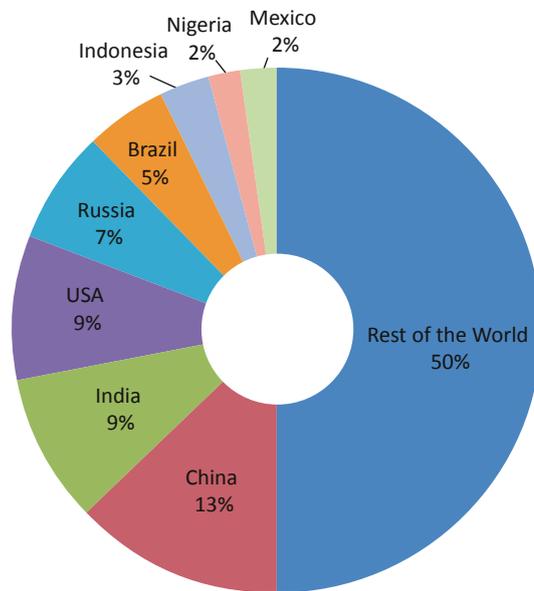


Figure 4.1a. Global methane emission in 2010
 Source: Brink et al. (2013)

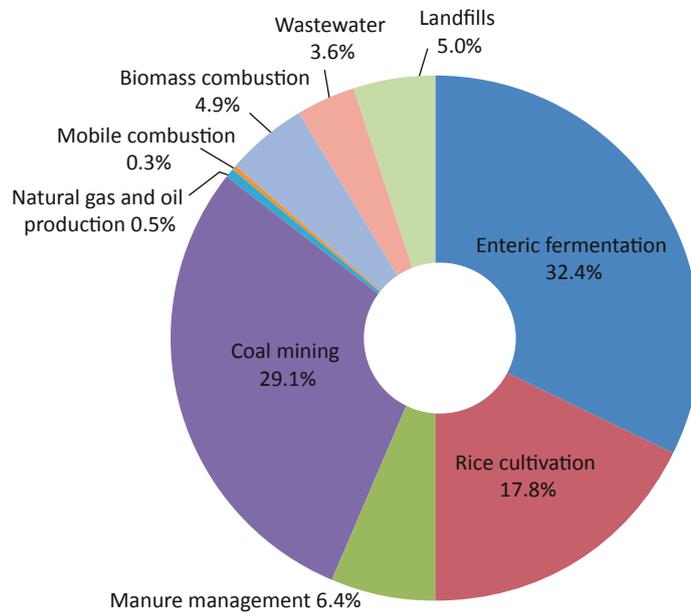


Figure 4.1b. China's methane emission by sector in 2005
 Source: Chinese Second National Communication on Climate Change

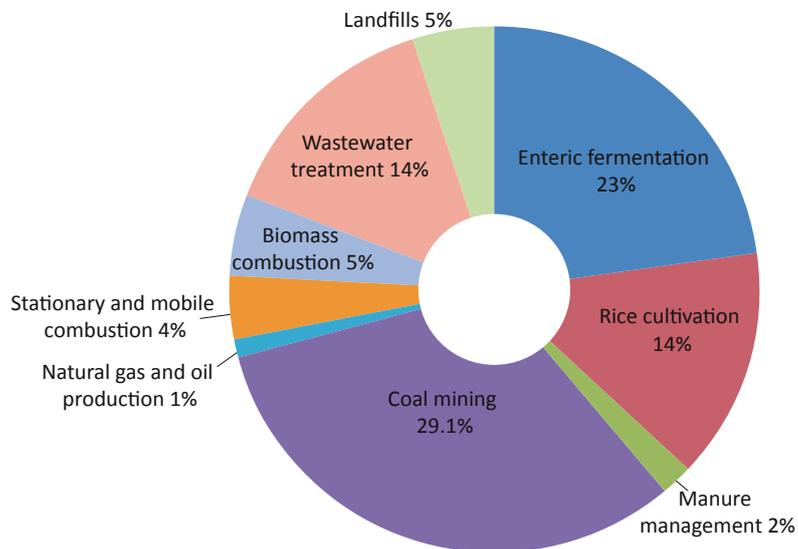


Figure 4.1c. China's methane emission by sector in 2010
 Source: Brink et al. (2013)

Table 4.1. The Emission Inventory of Agricultural Activities in China, 2005

Sectors	CO ₂ equivalent (eq. Million tons CO ₂)	Methane (10 ⁴ tons CH ₄)	Nitrous oxide (10 ⁴ tons N ₂ O)
Rice cultivation	166	792.6	
Agricultural soil	208		67.2
Enteric fermentation	302	1437.9	
Animal manure management	143	286.4	26.6
Total	819	2516.6	93.8

Source: The Chinese Second National Communication on Climate Change

gas production⁴⁵ and fossil fuel combustion (stationary and mobile combustion)⁴⁶. Emissions from the energy sector also include the combustion of biomass for energy purposes. China's methane emissions from the energy sector in 2010 are largely dominated by coal mining activities (295.5 MtCO₂e; 32%), followed by biomass combustion (48.5 MtCO₂e; 5.3%), then stationary and mobile combustion (35.1 MtCO₂e; 3.8%), with the least being oil and natural gas production (4.2 MtCO₂e; 0.5%). Year 2007 estimates by Zhang and Chen (2014) indicate that energy-related activities were responsible for 45.3% of emissions with coal mining accounting for 38.3%, and biomass combustion and oil and natural gas responsible for 5.3 and 1.6% in that year respectively.

Agriculture

The Chinese Second National Communication on Climate Change puts China's total emissions of methane from agricultural activities in 2005 at approximately 530 MtCO₂e. In that year, methane emissions from enteric fermentation⁴⁷, rice cultivation⁴⁸ and livestock manure/waste management⁴⁹ were 14.4 Tg, 7.9 Tg and 2.9 Tg respectively. The agricultural sector also contributed to emissions of other greenhouse gases including N₂O as shown in Table 4.1. In 2010, the agricultural sector was the second largest contributor to China's methane emissions accounting for 38.9% of total emissions (that is, 358.2 MtCO₂e) (USEPA, 2012). Just as in 2005, enteric fermentation was the dominant emission source in 2010. China's 2010 methane emissions from enteric fermentation, rice cultivation, manure management and biomass burning (field burning of crop residues)⁵⁰ were 212.5, 124.6, 20.1 and 1 MtCO₂e respectively, equivalent to 23.1, 13.5, 2.2 and 0.1% of total emissions respectively in that year. Zhang and Chen (2010) reported that emissions from agricultural activities in 2007 were 461 MtCO₂e, equivalent to 46.6% of total emissions in that year.

Waste

According to China's Second National Communication on Climate Change, methane emission in 2005 from the waste sector was approximately 80.2 MtCO₂e, with solid waste disposal on land⁵¹ responsible for 46.3 MtCO₂e of this and wastewater treatment⁵² responsible for the rest. Emissions from the sector in 2010 according to USEPA (2012) were estimated at 179.1 MtCO₂e, accounting for 19.5% of total methane emissions in that year. Wastewater treatment (domestic sewage and industrial wastewater treatment) was responsible for 14.3% (132 MtCO₂e) while Municipal Solid Waste (MSW) landfills were responsible for 5.1% (47.1 MtCO₂e) in 2010. As stated earlier, it must be noted that the 2010 USEPA estimates are based on projections starting with 2005 data from the Chinese government to the UNFCCC. Because they are projections, they may not be necessarily accurate as they are associated with uncertainties due to assumptions on activity data including population growth, economic growth, waste generation per capita, percentage of waste going to landfills, degradable organic carbon in the waste, oxidation factor, and consequently emission factors. The estimates may be further affected by the fact that waste disposal and management is likely influenced by multiple drivers apart from economic and population growth used in the estimates. A 2007 estimate by Zhang and Chen (2014) indicates that the waste management sector was responsible for approximately 14% of emissions in that year with MSW landfill, industrial wastewater and domestic sewage accounting for 8.2, 4.1 and 1.5% of China's total methane emission respectively⁵³.

Notably, based on the 2010 estimates, coal mining, enteric fermentation, rice cultivation and wastewater treatment essentially determine China's methane emission profile when all the specific emission sources within each emission sector are ranked. They together accounted for about 83%

45 During oil and gas production, methane can be emitted by venting of unwanted gases, unintended release during extraction and production activities, and due to leakages from transmission pipes.

46 Incomplete combustion of fossil fuels in stationary and mobile vehicles can lead to methane emission.

47 Enteric fermentation is a natural aspect of the digestive system of ruminant animals in which food is broken down by microorganisms into simple forms that can be absorbed into the blood stream of the animal. Methane is a byproduct of this process.

48 Methane is a natural product from flooded rice fields. The warm and waterlogged soil during rice cultivation provides a suitable condition for microbes to break down organic matter with methane as a resulting byproduct.

49 The decomposition of animal waste or manure in the absence of oxygen (anaerobic conditions) results in the production of methane

50 Methane is produced during burning of woodlands, savanna and agricultural waste/residues due to incomplete combustion.

51 The anaerobic decomposition of organic materials in MSW landfills leads to the production of methane, which is emitted into the atmosphere if there is no system for collecting and utilizing it.

52 The handling and treatment of domestic sewage and industrial wastewater could lead to production of methane when the organic materials in them decompose under anaerobic condition.

53 Zhang and Chen (2014) estimated 2007 methane emissions from waste management using the IPCC Tier 1 methodology based on waste disposal data obtained from the China Urban Construction Statistical Yearbook. They calculated methane emission as $E = MSWT \times MCF \times DOC \times DOCF \times F \times 16/12$, where E is methane emissions from landfill; MSWT is the total waste disposed to landfills; MCF is the methane correction factor based on the method of and depth available at landfills; DOC is the fraction of degradable organic carbon in the waste, DOCF is the fraction of total DOC that actually degrades; F is the fraction of methane in landfill gas (default value is 0.5); and 16/12 the conversion ratio (methane/carbon). Details of the data used to arrive at their final estimate are available in the paper.

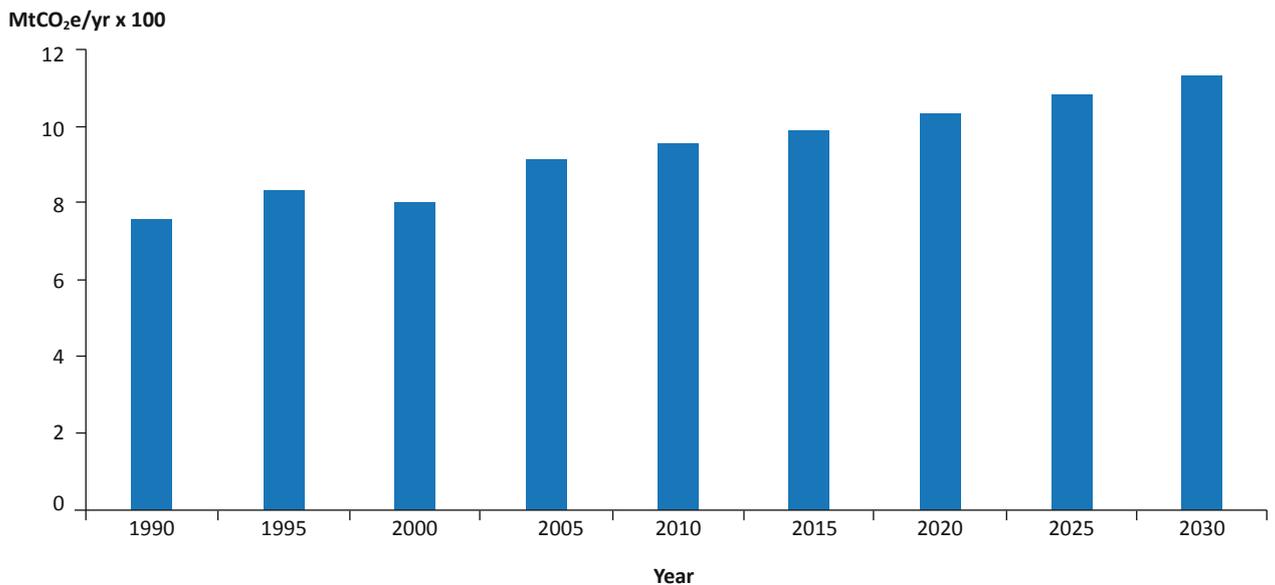


Figure 4.2. Trend and Projection in China's total methane emission, 1990 to 2030
Source: USEPA (2012)

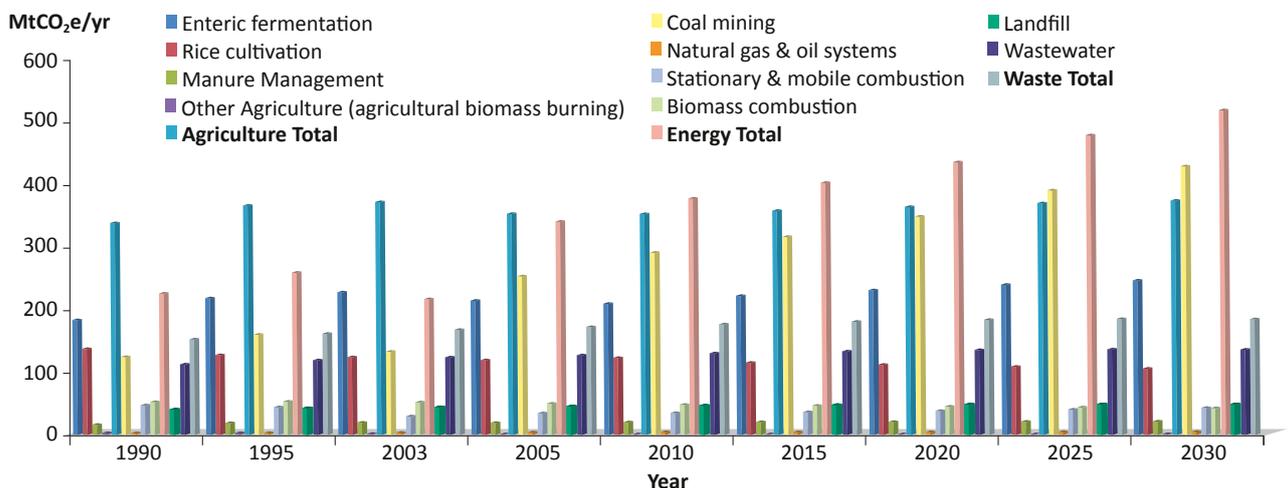


Figure 4.3. Sectoral breakdown of trend and projection of China's methane emission, 1990 to 2030
Source: USEPA (2012)

of emissions, with coal mining being the dominant emissions source.

4.2. Trend of Methane Emission in China

Figure 4.2 shows the trend in China's methane emissions derived from data obtained from USEPA (2012). Figure 4.3 shows the sectoral breakdown of emissions. The figures show that methane emissions have generally been on an increasing path in the last 20 years in China with a slow down around 2000. The increase can be attributed to China's large and growing population and associated economic activities for meeting the needs of the population including energy, food and waste management.

The trend is better understood by looking at the contribution from each emission sector. As can be seen in Figure 4.3, emissions from the agricultural sector appear almost to have levelled since 2005. But emissions from the waste management sector have been increasing since 1990 which could be due to increasing population and

improvement in living standards. Emissions from the energy sector have also been increasing since 2000. Zhang et al. (2014) found that total energy-related methane emissions in China tripled between 1980 and 2007 with an average annual increase rate of 4.7%. The authors attribute the increasing trend in the energy sector to growth in coal production in China which increased sharply since 2000 with coal output from China amounting to 2.7 billion tons in 2007, 1.7 billion tons higher than in 1990.

It must be noted, however, that China has been a leading example in implementing methane capture technologies in coal mines (Brink et al., 2013). Since the introduction of incentive policies for the recovery and utilization of CMM in China in 2005, the amount of extracted CMM has increased rapidly. National extraction of CMM was 2.2 billion m³ in 2005, and the figure was up to 12.6 billion m³ in 2013, close to 6 times more than the total amount in 2005. According to Brink et al. (2013), China has greatly increased its rate of CMM gas capture and its utilization rate is improving. China

hosted 40 of the world's 96 CMM capture projects at active coal mines globally in 2009 (Higashi, 2009), including the world's largest CMM project, the Shanxi Jincheng power project at the Sihe Coal Mine with 120 MW of electrical output (OECD/IEA, 2009). Hence, while methane emissions are still increasing in China, the rate of increase would have been higher but for efforts at mitigating emissions from coal mine activities.

4.3. Future Projections of China's Methane Emissions

Just as in the case of black carbon, literature on future projections of Chinese methane emissions is very scarce and more studies are needed on emissions inventory, trends and projections in order to provide information and data that can guide decision making. A summary of future projections based on data from USEPA (2012) is presented below.

Figure 4.3 shows that total methane emissions will increase by about 18% by 2030 compared to 2010 emissions from 930 MtCO₂e to about 1100 MtCO₂e. An estimate by Høglund-Isaksson et al. (2012) also projected similar values for total methane emissions in China in 2030. Total global methane emissions have been projected to increase by 25% by 2030 (UNEP/WMO 2011). The energy sector is the dominant source of China's projected growth with about 37% increase compared to 2010 values. Within the energy sector, emissions from coal mining activities are dominant with a projected increase of about 47% compared to 2010 values, followed by stationary and mobile combustion (24% increase) and oil and natural gas (11% increase). Emissions from biomass combustion for energy purposes are projected to decrease by 11% compared to 2010 values.

Emissions from the agricultural sector are projected to increase by only 6% between 2010 and 2030. This is dominated by enteric fermentation whose emissions are projected to increase by about 18% compared to 2010 values, followed by animal manure/waste management projected to increase by about 7%. Interestingly, emissions from the rice sector are projected to decrease by approximately 14% compared to 2010 values.

For the waste management sector, emissions are set to increase by approximately 5% with emissions from MSW landfills and wastewater treatment contributing equally to this increase.

4.4. Impact of Methane in China

Methane is a very potent greenhouse gas and a major contributor to anthropogenic climate change. Furthermore, although not an air pollutant, methane is an important precursor for the formation of tropospheric ozone, another important greenhouse gas, but also a major air pollutant with detrimental effects on health and agriculture. This section discusses in detail these impacts from a Chinese perspective.

4.4.1 Methane's Impacts on Human Health and Crop Yield in China

As stated above, methane is a significant precursor for the formation of tropospheric ozone which negatively affects human health, plants and ecosystems. Transported by wind,

tropospheric ozone pollution can spread as far as thousands of kilometers from where the precursors were emitted⁵⁴. However, as stated in Section 2.4, this report has not estimated the exact amount of ozone concentration in China that is directly attributed to methane emissions versus other ozone precursors including NO_x, NMVOCs, and CO; hence the human health and crop yield impacts described here are broadly related to total concentration of tropospheric ozone (especially at the ground-level) rather than those specific to ozone formed directly from methane emissions.

Studies have shown that tropospheric ozone can lead to decreased lung function, exacerbate bronchitis, emphysema and asthma, contribute to chronic lung disease, and can have adverse effect on respiratory mortality (Devlin et al., 1991; Touloumi et al., 1997; Bell et al., 2005; Royal Society, 2008; Jerrett et al., 2009; Dennekamp and Carey, 2010).

Whilst studies specific to China on the impact of tropospheric ozone on human health are scarce, the few available show that ozone is having a negative effect on human health in China. Zhang et al. (2006) reported that an increase in ozone concentrations in Shanghai resulted in a total daily mortality of 119, corresponding to a 0.45% increase between 2001 and 2004. Their results show that the daily mortality is almost equally distributed among male (53%) and female (47%) but also shows that approximately 84% of those affected are elderly, with negligible impact (0.3%) on children of up to 4 years. Another study by Yang et al. (2012) found that increase in tropospheric ozone concentrations was responsible for a 1.62 and 6.15% increase in cardiovascular-related mortality in Suzhou in the warm and cold season respectively. Given the limited number of China-related studies, more research needs to be undertaken to estimate the health and associated economic impact of increased tropospheric ozone in China.

The impact of tropospheric ozone on terrestrial vegetation is well established. Ozone can lead to reduced crop productivity, and negatively impact on tree growth and carbon sequestration (Royal Society, 2008 and references therein). Several publications have highlighted these impacts on China's crop yield. A study by Wang and Mauzerall (2004) suggested that increased ozone concentrations resulted in a 1-9% loss in the yield of wheat, rice, and corn and 23-27% loss in the yield of soybeans in China, Japan and South Korea in 1990. This resulted in an economic loss of USD 3.5 billion for China alone. The study further projected an increase in economic loss of 82% in 2020 compared to 1990 situation in a business as usual situation. A more recent study by Liu et al. (2009) estimated that the ozone-induced relative yield loss (RYL) for rice ranged from 1.1 to 5.8% between 1990 and 1995 and could reach 10.8% in 2020 in Chongqing while the RYL for winter wheat in that same part of China was estimated at between 0.2 and 9.8% between 1990 and 1995 and projected to reach 12.0% in 2020. For the Yangtze River Delta region of China, they projected that RYL for rice and winter wheat could reach 9.2 and 8.4% respectively in 2020. Another study by van Dingenen et al. (2009) reported that, due to increased ozone concentrations, China had a

⁵⁴ See: <http://www3.cec.org/islandora/en/item/986-north-american-mosaic-overview-key-environmental-issues-en.pdf>

RYL of 19.0, 3.9, 4.7, and 11.4% for wheat, rice, maize and soybean respectively in year 2000. This was equivalent to an estimate of between USD 3.0 and 5.5 billion in economic terms, thereby causing a significant offset in China's Gross Domestic Product in that year.

4.4.2. Methane's Impact on Climate Change

Methane has a direct influence on climate. It is one of the greenhouse gases regulated by UNFCCC and the Kyoto Protocol. Due to human activities, between 1750 and 2011 the concentration of methane in the atmosphere has risen to 1803 ppb, which exceeds pre-industrial levels by approximately 150% (IPCC, 2013). This increased methane concentration in the atmosphere has made it the second most abundant greenhouse gas in the atmosphere after carbon dioxide. The radiative forcing attributed to methane concentration in the atmosphere is estimated as $0.48 \pm 0.05 \text{ Wm}^{-2}$ (IPCC, 2013)⁵⁵. Furthermore, as stated earlier, methane is also an important precursor for tropospheric ozone formation, which is a potent greenhouse gas in its own right. The radiative forcing due to changes in ozone is currently estimated at 0.35 Wm^{-2} (UNEP/WMO, 2011). In addition, there is also strong evidence that tropospheric ozone (especially at the ground-level) has a detrimental impact on vegetation physiology, and therefore on its CO_2 uptake. This reduced uptake leads to an indirect increase in the atmospheric CO_2 concentration (Royal Society, 2008 and references therein).

Given that the lifetime of methane in the atmosphere is about 12 to 17 years, which is far shorter than that of CO_2 (about 100 years or more), the concentration of methane in

⁵⁵ However, the summed value of radiative forcing cause by methane emissions, which includes methane-induced radiative forcing of O_3 , H_2O and CO_2 , is estimated at 0.97 Wm^{-2} .

the atmosphere and consequently the decrease in the global warming effect, will respond faster to emissions reduction than CO_2 and other long lived greenhouse gases (see UNEP/WMO, 2011 for more details).

4.4.3. Methane's Impact on Mining Safety in China

Although not toxic, methane is extremely flammable and could form explosive mixtures with air at levels as low as 5% (Dikshith, 2013). The emission of methane during mining activities has been a major concern and priority in China as it has been the cause of several mining accidents. Harris et al. (2014) reported that explosions caused by flammable gases were responsible for approximately 61% of the approximately 3500 fatalities in China's coal mines between 2006 and 2010. It is therefore not surprising that the recovery and utilization of CMM in China started as a strategy to enhance coal mine safety (OECD/IEA, 2009).

4.5. Potential Sectors for Methane Emission Reduction

The inventory, trend, and projection discussions suggest that opportunities exist to reduce methane emissions from all emissions sector in China. Furthermore, the negative impact on health and crop productivity associated with methane as a precursor for tropospheric ozone formation and the safety issues associated with methane release in China's coal mines further buttress the need for action in all emitting sectors. Within the sectors however, emission reduction efforts would have to focus on sectors with high current and projected emissions so as to maximize emission reduction benefits. As stated in Section 4.1, this would be coal mining, enteric fermentation, rice cultivation and wastewater treatment. Black carbon and methane emission reduction measures are discussed in next chapter.

Chapter 5

Emission Reduction Measures

Chapter 3 and 4 discussed the emissions inventory, trends and projections for black carbon and methane respectively. They also discussed their health, agricultural and climate impacts. This chapter reviews current mitigation measures for reducing black and methane emissions from the various emitting sectors. In presenting the emission reduction measures, the chapter attempts to highlight measures that are already being implemented in China and identify further options. The chapter also provides estimates of emission reduction potential from literature where available.

5.1. Measures to Reduce Black Carbon Emissions

The UNEP/WMO assessment (UNEP/WMO, 2011) proposed nine policy measures for reducing black carbon emissions globally (Table 5.1). Generally, black carbon emission measures in the table can be grouped into those that aim to eliminate or reduce the use of fossil fuels; those that aim to improve fuel combustion efficiency; and those that apply end-of-pipe technologies. All the measures provide air pollution

and climate benefits through reducing black carbon. Below, measures relevant to the China context are discussed.

5.1.1. Reducing Black Carbon Emissions from the Residential Sector

As stated in Chapter 3, the residential sector⁵⁶ accounts for the largest share of China's black carbon emissions, with estimates of between 40-83% of the total (Figure 5.1). The high emissions from the residential sector can be attributed to the relatively low combustion efficiency of fuel type and the combustion equipment.

In rural and suburban China, most people still choose coal for heating and cooking (with a smaller proportion using biomass), on small stoves which are unlikely to be equipped with expensive particle-removal devices. Even in Beijing, where the municipal government has been striving

⁵⁶ Emissions from the domestic sector here include fuel (coal and biomass) combustion in households for cooking and heating but exclude emissions from municipal or district heating systems which are classified under the industrial sector.

Table 5.1. UNEP/WMO (2011) measures for black carbon emission reduction

Measure ¹	Sector
BC measures (affecting BC and other co-emitted compounds)	
Diesel particle filters for road and off-road vehicles	Transport
Elimination of high-emitting vehicles in road and off-road transport	
Replacing coal by coal briquettes in cooking and heating stoves	Residential
Pellet stoves and boilers, using fuel made from recycled wood waste or sawdust, to replace current wood-burning technologies in the residential sector in industrialized countries	
Introduction of clean-burning biomass stoves for cooking and heating in developing countries ^{2,3}	
Substitution of clean-burning cookstoves using modern fuels for traditional biomass cookstoves in developing countries ^{2,3}	Industry
Replacing traditional brick kilns with vertical shaft kilns and Hoffman kilns	
Replacing traditional coke ovens with modern recovery ovens, including the improvement of end-of-pipe abatement measures in developing countries	
Ban of open field burning of agricultural waste ²	Agriculture

¹ There are measures other than those identified in the table that could be implemented. For example, electric cars would have a similar impact to diesel particulate filters but these have not yet been widely introduced; forest fire controls could also be important but are not included due to the difficulty in establishing the proportion of fires that are anthropogenic.

² Motivated in part by its effect on health and regional climate, including areas of ice and snow.

³ For cookstoves, given their importance for BC emissions, two alternative measures are included.

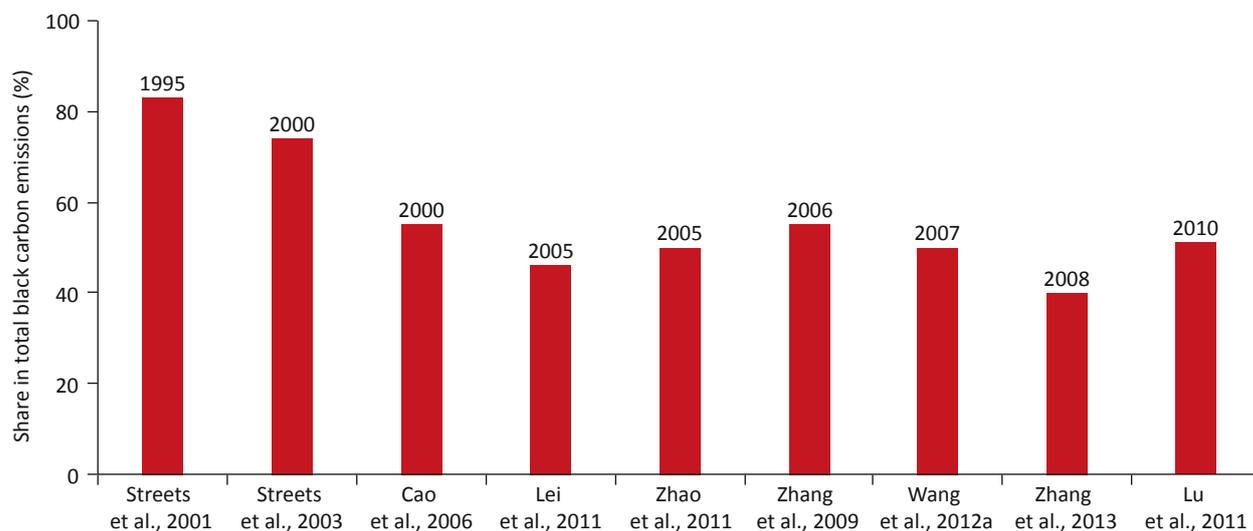


Figure 5.1. Share of black carbon emissions from residential sector in China



Figure 5. 2 A simple lump coal stove
photo credit: Guorui Zhi

to reduce coal consumption, actual coal consumption in the bungalow areas of suburbs and rural villages was still nearly 4 million tons in 2013, equivalent to 17% of Beijing's total coal consumption⁵⁷. Only a small but increasing proportion of the households in rural and suburban China use electricity and gas. Many coal users use coal briquettes, although use of low quality chunks (coal lumps) in simple stoves (Figure 5.2) is still common (Wang et al., 2012a).

The challenge in reducing black carbon emissions from households is therefore three pronged: meeting the need for cleaner fuels, fuel combustion efficiency, and affordability. Hence, emission reduction measures need to focus on these challenges. Measures for meeting these three challenges are discussed below.

Installation of stoves with better combustion efficiency

Improved stoves for cooking and heating are designed to increase fuel use and combustion efficiency during coal or biomass burning for cooking and heating. This results in the use of a smaller amount of fuel and proportionately fewer emissions as compared to traditional stoves. China has been active in implementing cookstove programmes but more effort is still needed to ensure wider expansion (See Box 5.1).

Improve the cleanliness of coal and biomass

Anthracite coal and other bituminous coals, such as low-volatile-bituminous coal (LVB), and high-volatile bituminous coal (HVB) have been shown to have lower emission factors (hence lower black carbon emissions) as compared to medium-volatile-bituminous (MVB) coal (Figure 5.3; Chen et al., 2006; Zhi et al., 2008). Hence, one option is to exclude MVB coals from the residential sector and to use more anthracite, LVB and HVB coal. The second option is to change bituminous coal to semi-coke (or Lan Tan)⁵⁸ which burns with less smoke (Chinese National Standard, GB16171-2012). It is believed that semi-coke releases much less PM_{2.5}, SO₂ and NO_x than original raw coal; hence the possibility of its deployment especially in Northern China during the cold season, to help reduce pollutants including black carbon, deserves further study. The third option is to convert raw coal into briquettes which have higher combustion efficiency especially when burnt in an improved stove.

The combination of improved stoves and clean fuel can produce significant emission reductions. For example, Zhi et al (2009) show that emissions of particulate matter, organic carbon and black carbon were significantly reduced when briquette coal was burnt in an improved stove as compared

⁵⁷ See : http://govfile.beijing.gov.cn/Govfile/front/content/22013045_0.html

⁵⁸ Semi-coke is a product of the dry carbonization of non-caking coal, weakly-caking coal and long-flame coal at a low or medium temperature (≤ 750 oC) (Chinese National Standard, GB16171-2012).

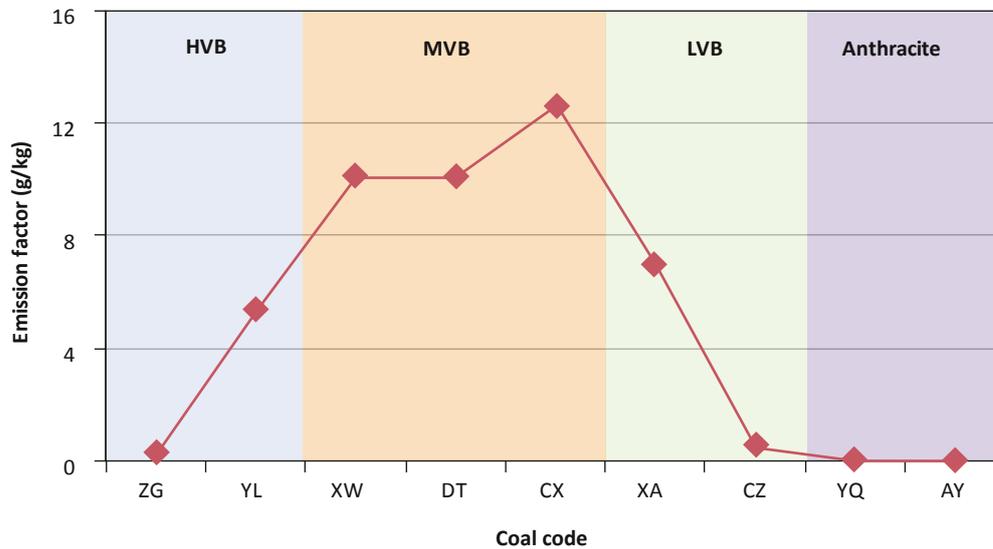


Figure 5.3 Emission factors for different coal maturities burned in lump style.
 Source: derived from data in Chen et al. (2006) and Zhi et al. (2008)



Figure 5.4 Coals and stoves used by Zhi et al. (2009)
 photo credit: Guorui Zhi

to three other combinations involving a traditional simple stoves, an improved stoves and lump coal (Figure 5.4 and 5.5). Their results suggest that particulate matter, organic carbon and black carbon could be reduced annually by 63, 61 and 98% respectively in China's residential sector by using improved stoves and briquette coal. They also found that the combination reduced the black carbon to organic carbon ratio which is beneficial to climate warming. As for biomass (including straw and firewood), research by Shen et al. (2012) also shows that use of improved stoves and briquetted biomass (biomass pellet) results in significant reduction in black carbon emissions.

Extension of district heating systems in suburbs and villages

In China, district heating in winter is an effective way to abate particulate pollution in urban areas. Through use of large combustion facilities, such as industrial coal boilers, district heating can ensure good ventilation, excellent particle trapping and regular maintenance, and thus result in reduced black carbon emissions (Streets et al. 2001). Extension to suburbs and villages could help reduce black carbon emissions from the residential sector. This is expected to happen with rapid urbanization; however effort may be needed to achieve quicker success.

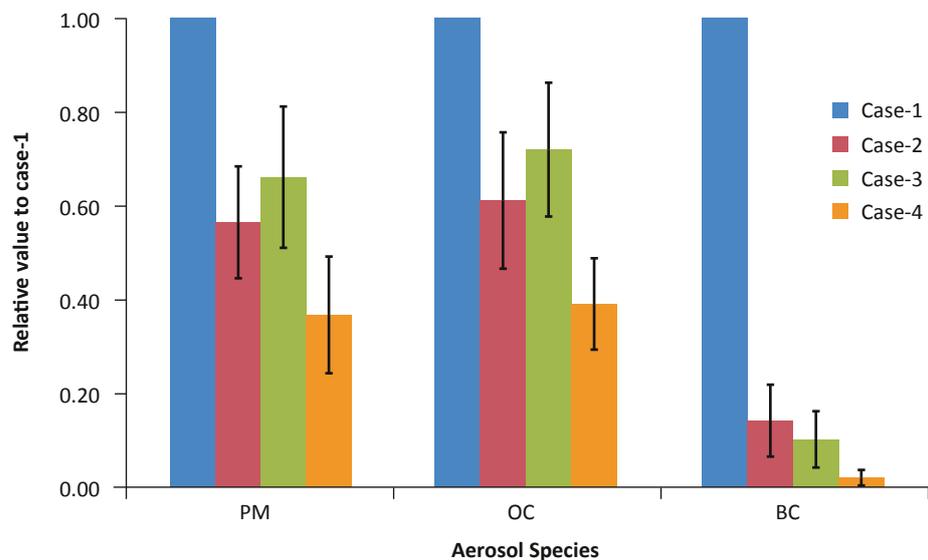


Figure 5.5 Effects of different stove and coal types on emission reduction
case-1: lump/simple stove; Case-2: lump/improved stove; Case-3: briquette/simple stove; Case-4: briquette/improved stove.
 Source: Zhi et al. 2009.

Financial support for increased use of clean stoves

China is already making efforts to improve the cleanliness of the coal used in both the residential and industrial sector. For example, new government directives indicate that the use of coal in Beijing will be banned by 2020⁵⁹ and the import of low-grade coal with 30% or more ash content and 1.5% or more of sulfur content will be banned from January 2015 with stringent requirements for coal use in cities in the southern Pearl River Delta, the eastern Yangtze River Delta, the Hebei province and two northern cities, Beijing and Tianjin⁶⁰. While the directives are steps in the right direction, implementing the directives may require a careful consideration of financial support, possibly in the form of subsidies, in order to ensure success.

With respect to black carbon emission reduction potential in the residential sector, Chen et al. (2009) reported that eliminating MVB from residential use could reduce black carbon emissions by 50%. Additionally, they stated that by eliminating MVB and increasing the use of briquette to 80% from 40%, black carbon emissions could be annually reduced by 80% relative to emissions in 2000.

There are however barriers to successful implementation, especially for improved stove initiatives (see Box 5.1). According to the World Bank (2011), millions of stoves have been introduced globally, including in China; but a sustainable change seems difficult in many regions due to cultural barriers and financial obstacles at the household level. Furthermore, unsuccessful previous programs (often because of poor continuity in cook stove performance – that is, good performance during laboratory testing or when first installed, but then a quick deterioration in performance, often with the stoves breaking down within a year) could discourage adoption of improved cook stoves (World Bank 2011). There

59 http://www.huffingtonpost.ca/2014/08/05/beijing-coal-ban_n_5650607.html

60 See: <http://online.wsj.com/articles/china-coal-ban-highly-polluting-types-banned-starting-in-2015-1410852013> and <http://www.cnbc.com/id/102002818#>

is therefore a need for quality standards in the design of improved stoves and in the implementation of programmes.

The UNEP/WMO Assessment proposes four win-win measures for reducing black carbon emissions from the residential sector (Table 5.1). The main difference between the UNEP/WMO recommendations and the suggestions here is the proposal for a ban on residential access to MVB coals and the wider extension of district heating systems in suburbs and villages. The UNEP/WMO Assessment indicates that whilst technical measures are available, there is a need for improvement in implementation. This calls for continuous involvement of government and the private sector. Stricter policy enforcement for better ambient and indoor air quality and greater investment in stove innovation and clean stove dissemination are vital to success.

5.1.2. Reducing Black Carbon Emissions from the Industrial Sector

Figure 5.6 shows the share of black carbon emissions from the industrial sector in 2007, based on data in Wang et al. (2012a). It shows that coke production generates more than half of the emissions, followed by brick production, industrial diesel use, and other industrial coal. Together, these sources account for about 98% of black carbon emissions from the industrial sector in China. It therefore means that mitigation measures should target these sources, as discussed below.

Coke Production

China is the largest coke producer in the world, accounting for more than 60% of global production in 2010. The coke industry is the third largest coal consumer in China after power generation and manufacturing industry, and it is the most important coal-based chemical industry in China, representing more than 70% of non-fuel uses of coal (Huo et al. 2012).

The UNEP/WMO Assessment identified the coke industry as one of the sources where there are realistic prospects of reducing black carbon with benefits for both climate

Box 5.1. China: A Case Study of Initial Success and Need for More Action⁶¹

China set an example of probably the most impressive organized rural deployment of cook stoves through the Ministry of Agriculture's National Improved Stove Program (NISP) (Smith and Keyun, 2010). According to Smith et al (1993), 129 million stoves were installed in rural China through the project with more than 60% being a replacement of traditional household stoves with improved stoves. They further stated that 90% of improved stoves that were installed globally were installed in China. All introduced stoves had chimneys and some had manual or electric blowers to promote combustion efficiency. According to Li (2005), the new cook stoves resulted in 900 kg saving of coal per each cook stove per year in Shaanxi, China. Sinton et al. (2004) also found that the program improved indoor air quality although not sufficiently to meet China's air quality standards. It must be noted however that NISP did not have indoor air quality improvement as a major objective⁶² (Zhang and Smith, 2005)

According to the Climate Institute (2009), coordination by central government (including provision of some forms of subsidy) and the cooperation of the local government were instrumental in the success of the program. The government also provided funds for research and development, training, product demonstration and public outreach – which help in easing public anxiety about using new products.

The project however suffered from sustainability issues. According to the Climate Institute (2009), some rural families shifted back to using traditional cook stoves because of deterioration of the stoves and because improved fuel was more costly than coal and wood.

Stove improvement initiatives are now commonly implemented at the city and provincial levels and the private sector is also taking a leading role (Climate Institute, 2009).

For new initiatives to be successful, lessons would need to be learned from the failure of past initiatives. Such lessons could include ensuring adequate acceptance of cook stove technology, ensuring the quality standard of new stoves, and providing technical and financial support to households for the use of new stoves. This is particularly important as China seeks to achieve its national target of a minimum of 40 million households adopting clean and efficient cook stoves by the year 2020, and phasing out all lower-efficiency cook stoves by the year 2030⁶³.

61 Partly adapted from Climate Alert, a publication of the Climate Institute: <http://climate.org/PDF/climatealertautumn2009.pdf>

62 The main objective of the NISP is to increase fuel-use efficiency such as to assist rural welfare. See: http://www.cleancookstoves.org/resources_files/a-chinese-national-improved.pdf

63 Ministry of Agriculture (MOA) and the National Development and Reform Commission (NDRC). China Cookstoves and Fuels International Conference, Jointly hosted by the Global Alliance for Clean Cookstoves (GACC), Beijing, China, May 19-20, 2014, http://english.agri.gov.cn/service/ce/201405/t20140528_22035.htm

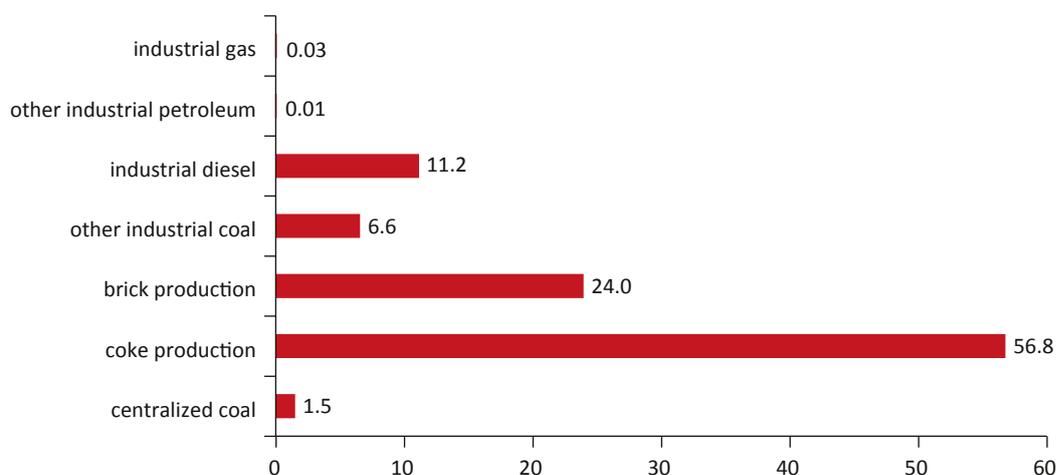


Figure 5.6. Percentage share of black carbon emissions from the industrial sector in 2007

Source: Derived from Wang et al. (2012a)

change mitigation and air quality. It recommended the “replacement of traditional coke ovens with modern recovery ovens, including the improvement of end-of-pipe abatement measures in developing countries” (Table 5.1). Huo et al. (2012) indicated that China has successfully replaced old, inefficient, and polluting indigenous coke ovens with mechanical ovens through the implementation of industrial policies such as phase-out of indigenous/modified coke ovens and change in market entry criteria. They estimated however that the coking process still contributed 5.5% and 14% of total PM_{2.5} and black carbon emissions respectively in 2010, compared to 2.5 and 6% in 1990. The increase in these percentages was attributed to low efficiency in the removal of PM_{2.5} and black carbon and

may also be due to increase in the amount of coal used for coke production. Their results therefore indicate the need for more efficient coke ovens. It must be noted however that the authors stated that their estimates have several uncertainties due to limited emission measurement data in China. To improve black carbon removal efficiency, China may need to mandate the use of technologies with more emission reduction and energy saving such as coke dry quenching⁶⁴ and fine particles removal.

64 In coke dry quenching system, red-hot coke is cooled by gas circulating in an enclosed system, thereby preventing the release of airborne coke dust. Thermal energy from the system is collected and reused as steam in the system. This is in contrast to conventional systems in which airborne dust is released into the atmosphere and thermal energy is lost (see: http://www.jcoal.or.jp/eng/cctinjanpan/2_3A5.pdf).

New Entry Criteria for the Coking Industry, issued by the Ministry of Industry and Information Technology came into force in April 2014⁶⁵. They require the use of coal gas cleaning measures (including desulfurization and ammonia removal) in coke ovens. While this may improve the removal efficiency of PM_{2.5} and black carbon, the implementation would need to take into consideration the cooling effects of sulfate since large scale sulfur removal could discount the climate benefit (Section 3.4.2). However, sulfur reduction is also a valid goal for human and ecological health; hence, the penetration of desulfurization technology would need to be balanced with a matching reduction in black carbon and other SLCP emissions from other sources, if climate benefits are to be maximized.

Brick Kilns

China is a major brick producer with more than 70,000 brick enterprises. It dominates global brick production manufacturing about 700 billion to 1 trillion bricks per year and consuming about 100 million tons of coal per year (Baum, 2010; Murray et al., 2010). Although almost 90% of all bricks produced in China are from efficient kilns (Baum, 2010; Schmidt, 2013), the rest is dominated by small scale enterprises using high black carbon-emitting annular

kilns, with outdated production processes, equipment and technology. It is estimated that soot and SO₂ emissions from brick kilns were 916 Kt and 1770 Kt in 2010, representing 11.0% and 8.1% of each total, respectively⁶⁶.

The UNEP/WMO Assessment recommends “replacing traditional brick kilns with vertical shaft kilns and Hoffman kilns of small scale” (Table 5.1). But in addition to this and in order to meet China’s pollution control objectives, another alternative could be to replace the widely used small annular kilns with modern tunnel kilns. Apart from reducing black carbon emissions, this option will provide the added benefit of improved energy and resource efficiency. Tunnel kilns are not common for brick production in China at present (Luo, 2009). However, its adoption may require overcoming financial and technological barriers including high capital cost, inadequate access to finance and lack of technical information.

Another option could be the installation of end-of-pipe particulate matter control devices such as electrostatic precipitators and fabric filters which could remove black carbon as a part of PM_{2.5}. The power industry provides a good example that can be emulated (See Box 5.2).

65 See: <http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/15919529.html>

66 See: http://www.cenews.com.cn/xwhy/201309/t20130917_747706.html

Box 5.2. Air Pollutant Control in Power Plants in China and Lessons to Learn

As highlighted in Section 3.1, power plants contribute the least to black carbon emissions in China. The low emissions reflect the vigorous measures taken by the Chinese Government. While the measures taken were originally targeted at other air pollutants such as dusts and sulfates, it has helped in significantly reducing black carbon emissions from the power sector. It is believed that without these measures, coal-fired power plants would probably have been a major black carbon emission source in China.

One of such measures is the use of end-of-pipe dust removal technologies. The dust removal efficiency of these technologies has been increasing steadily in China especially as the most recent technique, fabric filters, is gradually introduced into this sector (Table 5.2). This increasing efficiency assists reduction in particulate matter and black carbon emissions.

Meanwhile, China has continued to introduce tighter emission standards for air pollutants from thermal power plants which also provide the opportunity for further reducing black carbon emissions. The latest emission standard for air pollutants for thermal plants (GB13223-2011) sets a particulate matter emission limit of 30mg/m³ for most areas and a special emission limit of 20mg/m³ for some key areas.

Table 5.2 Efficiency of PM Controlling Technologies (%)

Dust Control Technology	>PM ₁₀	PM _{2.5-10}	PM _{2.5}
Cyclones	90	70	10
Wet scrubbers	99	90	50
Electrostatic precipitators	99.5	98	93
Fabric filter	99.9	99.5	99

Source: Lei et al. 2011

In addition to dust removal measures, the past decade has also seen the expansion of flue gas desulfurization and denitrification. Dust removal can reduce black carbon emissions and therefore reduce warming, whereas desulfurization and denitrification can have the opposite effect (that is increase warming) since sulfates have cooling effect (IPCC 2013). In fact, some scientists have given credit for the 10 year global temperature stabilization (1998-2008) to China’s doubled coal consumption in power plants and resultant increase in SO₂ emissions (Kaufmann et al. 2011). If it is true, the ongoing desulfurization and denitrification campaign in China’s thermal power industry could have negative impact on climate. Yet reduction of sulfate emissions is important for improving air quality and reducing negative human health impact. It therefore means that possible negative impacts on climate need to be taken into consideration when selecting measures for black carbon emission reduction. This suggests that reduction in sulfate emissions would need to be balanced with matching reductions in black carbon and other SLCPs from other sources, if climate and environmental benefits are to be maximized.

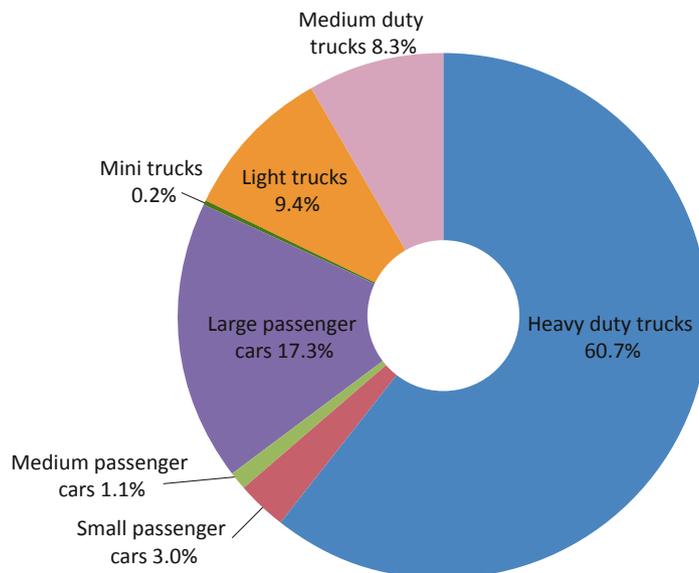


Figure 5.7. Particulate matter emissions from different vehicle types
 Source: China Motor Vehicle Pollution Prevention Annual Report (2013)

As the largest developing country, China is striving for “energy saving and emission reduction” in all fields⁶⁷. Its brick industry is therefore not likely to stop at kiln replacement and dust removal, but to develop further in response to progressively tighter emission standards. According to a May 2013 paper from the China Brick and Tile Industry Association (CBTIA), the development of the brick and kiln industry will be led by emerging industrial policy, high-tech equipment, new technological support projects and new standards, targeted particularly at large firms and groups⁶⁸.

Industrial diesel and other industrial coal use

Industrial diesel black carbon emission sources include heavy duty diesel engines used in industry (off-road equipment). Emission reduction measures for this source are discussed under the transportation sector (Section 5.1.3). Other industrial sources include industrial boilers, coal-fired boilers, small scale furnaces and manufacturing processes such as cement and iron and steel production. Emission reduction measures for these sources include fuel switching, fuel cleaning prior to use, optimization of combustion processes, and use of end-of-pipe technologies such as cyclones, electrostatic precipitators, wet scrubbers and fabric filters (CLRTAP, 2012). The new government directives on the ban of low-grade coal with 30% or more ash content and 1.5% or more sulfur content from January 2015⁶⁹ provide policy support for measures such as fuel switching and fuel cleaning. But as in the case of coke ovens, implementing some of the measures, for example fuel cleaning, may discount the climate benefit of black carbon reduction; hence, reduction in SO₂ emissions would need to be balanced with matching reductions in black carbon and other SLCPs from other sources, if climate benefits are to be maximized.

67 See: <http://www.china-un.org/eng/zt/sdreng/P020120608816288649663.pdf>

68 See: <http://www.brick-tile.com/news/show-1774.html>

69 See: <http://online.wsj.com/articles/china-coal-ban-highly-polluting-types-banned-starting-in-2015-1410852013> and <http://www.cnbc.com/id/102002818#>.

5.1.3. Reducing Black Carbon emissions from the Transport Sector

Emissions from vehicles have become an important source of air pollution in China. According to the Chinese Ministry of Environmental Protection, the vehicle fleets in China reached 244 million in 2012⁷⁰. Black carbon emissions from diesel engines account for the majority of black carbon emissions from mobile sources (Wang et al., 2012a&b)⁷¹ (Figure 5.7).

In addition, there has been considerable growth in off-road mobile machinery, a sector that is characterized by low regulatory standards. The management of emissions from this sector is made even more intractable due to poor diesel quality and unstable working conditions. Research suggests that the quantity of diesel used by off-road machinery is increasing and its particulate matter emissions have surpassed those from vehicles (Zhang et al., 2006).

Measures for reducing black carbon emissions from mobile sources could therefore focus on heavy-duty trucks, large passenger cars and off-road machinery. The proposed measures here, which very much align with the ones proposed in the UNEP/WMO Assessment, are discussed below.

Emission Controls for New Vehicles and Off Road Machinery

At present, China IV emission standards are in use in China for heavy-duty diesel engines⁷². The move from China III to China IV reduced the standard emission of particles from diesel engines by 80%, from 0.1g/kWh to 0.02g/kWh⁷³, resulting in an estimated emission reduction of 40-50 thousand tons of black carbon⁷⁴. However, China’s heavy

70 Ministry of Environmental Protection, China Motor Vehicle Pollution Prevention Annual Report, 2013.

71 See also Ministry of Environmental Protection, China Motor Vehicle Pollution Prevention Annual Report, 2013.

72 SEPA GB 17691-2005 Limits and measurement methods for exhaust pollutants from compression ignition and gas fuelled positive ignition engines of vehicles (III, IV, V)

73 Source: GB17691-2005: Compression Ignition Engines, Gas Ignition Engines and the Exhaust Gas Emission Limits and Measurement Methods (China III, IV, V).

74 Based on data of the National Bureau of Statistics of China

duty vehicle emission standards have lagged behind those in the EU and US. The implementation of the China V emission standard (equivalent to those already implemented in EU V) was delayed and is expected to be implemented nationwide in 2018 (Shao et al., 2014) and there is currently no clear timetable for China VI (equivalent to the already implemented EU VI). Yet, cost-benefit analysis by Shao et al. (2014) demonstrated that implementing China V alone may not be sufficient to achieve long term black carbon emissions reduction in the Guangdong province of China and called for quick implementation of China VI. Their results also show that quick implementation will yield public health benefits with overall benefits outweighing the total implementation cost by 1.4 billion RMB in 2015 alone, providing a case for quick implementation of stricter emission standards.

For off-road mobile machinery, China still applies the phase II emission standards⁷⁵, while the EU and US have adopted the phase IV emission standards. The gap between China and the EU and US therefore remains very large. It is therefore important for the reduction of black carbon emissions in China to move as quickly as possible to the best international standards for off-road mobile machinery.

Emission Controls for In-use Heavy Duty Vehicles

Accelerating the elimination or upgrading of old and high-emission vehicles is an important measure to reduce black carbon emissions from mobile sources. The “Airborne Pollution Prevention Action Plan” of the State Council of China required the elimination of all yellow label vehicles (cars registered before 2005 and which do not meet the China I emission standard and heavy duty vehicles whose emissions do not meet the China III standard – a total of about 14.5 million) by 2017⁷⁶. The particle emissions from yellow label vehicles were 485,000 tons in 2012⁷⁷, hence the action plan could reduce black carbon emissions by 78% from these fleets in 2017⁷⁸.

For diesel vehicles, an effective black carbon reduction measure is to install the wall-flow diesel particulate filter (DPF) on tailpipes. The wall-flow DPFs are very efficient in capturing particles and black carbon emissions from diesel engines, and can reduce more than 85% of particles and more than 90% of black carbon emissions. At present, most of the vehicles in China have no particulate filter, including the new heavy-duty vehicles (because the particulate matter standard requirement is lower than the EU standards). However, DPF is a new technology for China and has financial implications. Hence, research is still needed on their performance, efficiency and reliability as well as cost-effectiveness under Chinese climatic conditions. Furthermore, national or regional promotional activities might be needed for public acceptance especially considering the possible financial barrier against DPF implementation.

75 SEPA GB 20891-2007 Limits and measurement methods for exhaust pollutants from diesel engines of non-road mobile machinery (I, II)

76 See: <http://www.reuters.com/article/2014/05/26/us-china-pollution-idUSKBNOE60AN20140526>

77 MEP, China Motor Vehicle Pollution Prevention Annual Report 2013

78 About 78% of particulate matter emissions are from vehicles, and broadly speaking, 65% of particles emissions are black carbon. Hence 315,000 tons of black carbon can be reduced, representing more than 78% of black carbon emissions from vehicles.

Improving the way heavy-duty trucks are operated can also help to reduce black carbon. Guangdong province has carried out a ‘Green Freight’ program, designed to improve efficiency of freight services and to reduce fuel consumption. This includes use of fuel-saving engines, low resistance tyres and installing components with less wind resistance. A public freight information platform to promote information exchange on freight efficiency was launched for this purpose⁷⁹. While it is believed that the program has helped to reduce black carbon emissions, no quantitative data is yet available.

China is now implementing a Vehicle Inspection and Maintenance (I/M) programme designed to maintain good emissions performance. The percentage of vehicles under inspection is about 50% nationally, with cities like Beijing, Tianjin, Chongqing and Qingdao having over 80% of their vehicles under inspection.⁸⁰ Quantitative data on emission reductions through this measure are however not yet available. Other techniques, such as remote-sensing are being piloted to support I/M policies in areas such as Beijing, Shandong, and Liaoning.

Emission Reduction in Heavy Duty Vehicles through Fuel or Energy Switching

The particle emissions of the diesel vehicle are positively correlated with the quality of fuels, especially their sulfur content. Clean diesel containing lower olefins and aromatics can help to reduce the emission of particles and black carbon. The use of low-sulfur diesel can be a precondition for various advanced technologies, such as passive regeneration DPF. At present, the limit for sulfur content in diesel in China is 350ppm. The “Airborne Pollution Prevention Action Plan” proposes that, by the end of 2014, the national IV standard (50ppm sulfur content or less) should apply throughout the country. By the end of 2015, major Chinese cities will supply gasoline and diesel which accords with national V standard (10ppm sulfur content or less) and this will extend to the whole country by the end of 2017, which is in line with practice in the EU and US. This could reduce black carbon emissions from vehicles in China by more than 20% at that time. Using low-sulfur diesel fuel and requiring all new diesel vehicles to have particulate filters could help China to reduce black carbon emissions from heavy duty vehicles by more than 10% in 2030⁸¹.

Another black carbon controlling technology for diesel vehicles is the use of clean fuels, such as natural gas⁸². The price of natural gas has greatly declined because of large-scale exploitation of shale gas in the United States. China is also exploring its domestic shale gas. This is making Compressed Natural Gas powered engines increasingly popular in China. Other measures include discouraging the use of high black carbon-emitting diesel vehicles by promoting electric hybrid vehicles or electric vehicles to replace traditional diesel engine buses. According to the Development Plan for Energy-saving and New Energy Automotive Industries (2012-

79 See: <http://cleanairinitiative.org/portal/taxonomy/term/1866>

80 China Motor Vehicle Pollution Prevention Annual Report 2013

81 Based on research at Tsinghua University.

82 However, it has to be ensured that methane leakage is mitigated from natural gas production systems. If not, leakage could result in higher warming discounting the climate benefits of replacing diesel with clean fuels

2020), issued by the State Council in 2012, the number of EVs is planned to reach 500,000 units in 2020.

5.1.4. Reducing Black Carbon Emissions from Open Biomass Burning

As highlighted in Chapter 3, biomass burning contributes between 4 and 6% to total black carbon emissions in China, much less than the global average of about 40% (Bond et al. 2004; Bond 2009). In addition, approximately 70% of biomass black carbon emissions are from agricultural biomass burning, whereas savannah and forest fires contribute little (Cao et al. 2006, Streets et al. 2001, Wang et al. 2012a).

China has been making great efforts to curb open burning of biomass. The implementation of regulations to ban open-biomass burning is supported by a website (<http://hjj.mep.gov.cn/stjc/>), through which satellite-derived images are used to identify fire spots on a day-to-day basis during harvest seasons. Figure 5.8 is an example of a satellite-derived image of fire spots on June 11, 2014, showing numerous fire spots. If strictly and consistently enforced, the regulation would be effective at reducing crop residue burning around large cities.

Specific measures for reducing black carbon emissions from biomass burning generally involve seeking alternatives to burning and include returning straw to field by shattering the stalks, turning biomass to briquette, biomass gas, or biodiesel, and deep ploughing, that is burying biomass deep underground. It must be noted however that the effectiveness and feasibility of these measure are not yet well established.

5.2. Measures to Reduce Methane Emissions

As stated in Chapter 4, coal mining activities (coal mine methane production), agricultural production (enteric fermentation, rice cultivation and livestock manure/waste management) and waste management (landfills and wastewater treatment) are the main sources of China's methane emissions. The UNEP/WMO Assessment proposed seven measures for reducing methane emissions globally (Table 5.3). Below, measures relevant to the China context, including those not suggested in the UNEP/WMO Assessment, are discussed.

5.2.1. Reducing Methane Emissions from Coal Mine Methane (CMM)

Increase the Drainage Volume of CMM

A starting point for emission reduction is to increase the volume of CMM that is drained in Chinese coal mines. Drainage volume (the volume of CMM that is drained from the coal seams) increased by about 10.4 billion m³ between 2005 and 2013⁸³; and a drainage rate of 50% was reported for 2010⁸⁴. However, a lot of potential still exists for extraction of more CMM in China and should therefore be explored.

Increase the Utilized Volume of Extracted CMM

As stated in Chapter 4, China has been relatively successful in capturing and utilizing CMM and the rate of utilization has been on an increasing trend. The volume utilized increased to 4.3 billion m³ in 2013. Currently, CMM is used as a residential and industrial fuel and for electricity generation. However, as shown in Figure 5.9, about 8.3 billion m³ of gas was unutilized in 2013, representing about 66% of total extracted gas in that year. To reduce methane, it is therefore important that China increase the use of extracted gas across all relevant sectors.

Enhance the Utilization of Low-concentration (<30%) CMM

Due to safety concerns and economic feasibility, CMM utilization in gas power generation has mainly focused on high methane concentration CMM (that is CMM with greater than 30% methane), with little utilization of CMM with low concentrations of 6% to 25%. On the other hand, China has been successful in utilizing low concentration gas in power generation. The Shengli Power Machinery Company successfully developed a low-concentration gas generator that could use CMM gas with concentrations of 6% for power generation (OECD/IEA, 2009). Caterpillar has also engaged in low-concentration gas power generation and has developed a low-concentration gas generator set that can use CMM with concentrations of over 10%⁸⁵. Currently,

83 See: <https://www.globalmethane.org/documents/news-item-440/3-China-060314.pdf>

84 See: http://www.nios.com.cn/common/files/File/13.Shengdong_EN.pdf

85 See https://www.globalmethane.org/expo-docs/canada13/coal_18_Lui_Presentation.pdf

Table 5.3. UNEP/WMO (2011) measures for methane emission reduction

Measure ¹	Sector
Methane measures	
Extended pre-mine degasification and recovery and oxidation of CH ₄ from ventilation air from coal mines	Extraction and transport of fossil fuel
Extended recovery and utilization, rather than venting, of associated gas and improved control of unintended fugitive emissions from the production of oil and natural gas	
Reduced gas leakage from long-distance transmission pipelines	
Separation and treatment of biodegradable municipal waste through recycling, composting and anaerobic digestion as well as landfill gas collection with combustion/utilization	Waste management
Upgrading primary wastewater treatment to secondary/tertiary treatment with gas recovery and overflow control	
Control of CH ₄ emissions from livestock, mainly through farm-scale anaerobic digestion of manure from cattle and pigs	Agriculture
Intermittent aeration of continuously flooded rice paddies	

¹ There are measures other than those identified in the table that could be implemented.

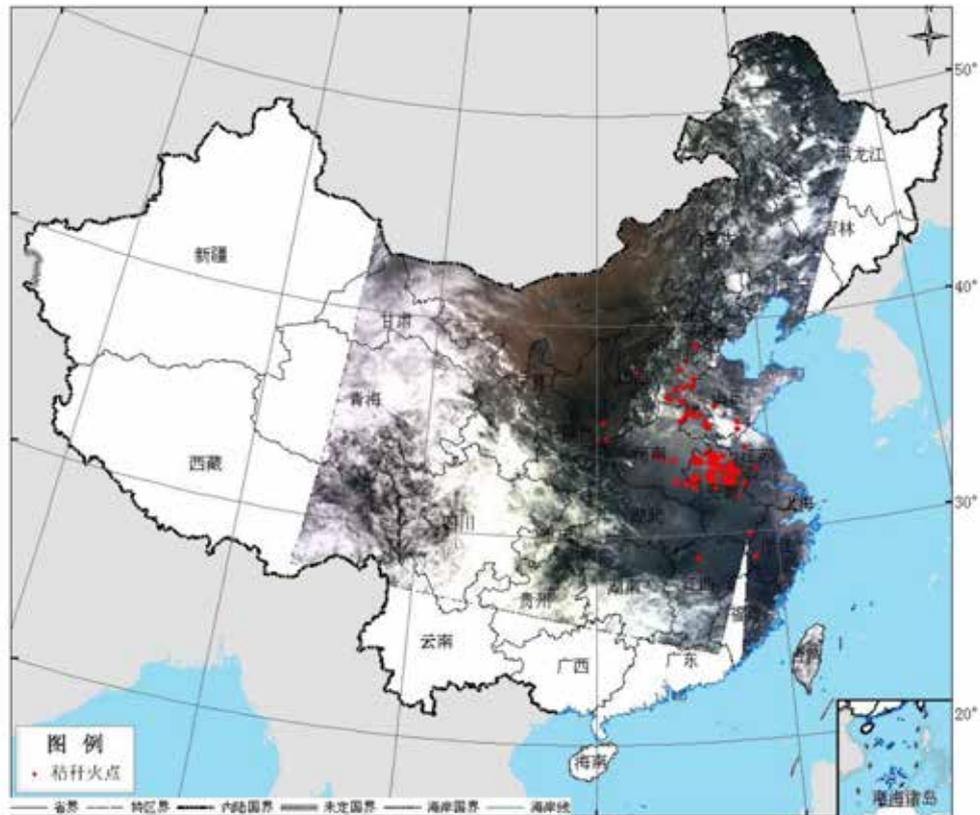


Figure 5.8. Fire spots observed by satellite on June 11, 2014
 Source: <http://hj.mep.gov.cn/stjc/>

other techniques for utilizing low-concentration CMM are at the industrial demonstration phase, and include the purification and catalytic oxidation power generation of low-concentration CMM. The utilization of low-concentration CMM will be one of the main highlights in “the 12th Five Year Plan” period and a further expansion in the use of low-concentration CMM could significantly reduce methane emissions from coal mining activities.

Promote the Utilization of Ventilation Air Methane (VAM) and CMM Liquefaction

Due to the low extraction ratio of CMM, methane is usually emitted from coal mine ventilation. This emitted methane,

normally referred to as Ventilation Air Methane (VAM), has a low methane concentration which is less than 0.75%. VAM can be potentially utilized to generate heat through thermal and catalytic oxidation, with a potential of reducing 97% of methane from ventilation air (Yusuf et al., 2012). Thermal oxidation has been applied at the industrial scale in China including, for example, on the Gao Cheng coal mine project and the Da Tong mine project. There is however scope for applying these technologies in all applicable coal mines in China.

Another option is CMM liquefaction, which involves using cryogenic distillation at low temperature conditions for the separation and liquefaction of oxygen-containing

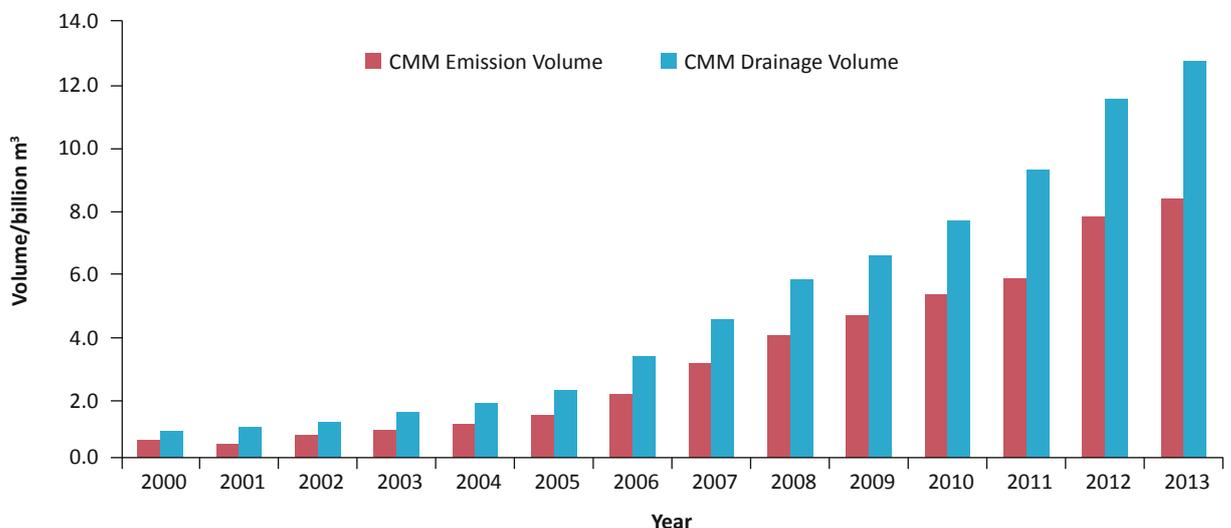


Figure 5.9. Direct emission (unutilized) and drainage volume of CMM in China, 2000-2013
 Source: China Coal Information Institute

CMM resulting in production of purified liquefied coal-bed methane. This method can purify the concentration of CMM from 35-50% to 99.8% liquefied natural gas. The application of this technology could help reduce methane emissions while also providing safety benefits, since 70 to 80% of coal mine accidents in China are caused by coal-bed methane explosions⁸⁶.

Leakage from Oil and Natural Gas Production

Presently, methane emissions due to leakage from oil and natural gas production are very low in China (Brink et al., 2013); hence emission mitigation measures for this source are not discussed in this report.

5.2.2 Reducing Methane Emissions from Agriculture

Reducing Methane Emission from Enteric Fermentation

Measures that have been proposed for methane emission reduction from enteric fermentation generally focus on livestock management strategies including use of dietary supplements, selection of high quality feeds, increase in grain level, and increasing feed conversion efficiency (Ominski and Wittenberg, 2004; Yusuf et al., 2012). Other measures that have been suggested include genetic selection, animal vaccination, methane inhibition, and use of probiotics and prebiotics (Yusuf et al., 2012). However, achieving emission reduction from enteric fermentation still remains a formidable challenge, which requires international cooperation in research and experimentation.

Reducing Methane Emission from Rice Paddies

Irrigation management is the most significant measure for controlling methane emissions from rice paddies. Research has indicated that mid-season paddy drainage can reduce methane emissions by 30-40%, compared with continuously flooded irrigation from a meta-analysis (Shi et al., 2010). Li et al. (2002) show that methane emissions were reduced by 5 Tg of methane per year by implementing this practice, which has already been adopted by some Chinese farmers because it also has a co-benefit of increased yield and water savings⁸⁷.

Fertilization management also shows great potential for decreasing methane emissions in rice paddies. Compared to application of farmyard manure, green manure, and straw, application of compost and biogas residue could reduce 45%-62% of methane emissions (Shi et al., 2010). This management option is however labor intensive, and this barrier needs to be overcome.

Rice variety selection is another option to reduce methane emission from rice paddies. Experiments have indicated that methane emissions from some hybrid rice varieties are lower than other rice varieties (Wang et al., 2013; Jiang et al., 2013). Hybrid rice is already planted in about 50% of the harvest area for Chinese rice. However, the selection of rice varieties by farmers is usually not solely based on methane emissions reduction but on potential yield.

Reducing Methane Emissions from Animal Manure Management

Recovery and utilization of biogas from digested manure in a biogas digester will reduce methane emissions from manure management. In addition, the biogas can be used to provide electricity or thermal energy, thereby reducing CO₂ emissions through the displacement of fossil fuel by biogas. It is estimated that an 8 m³ household biogas tank can treat manure from 4 to 6 pigs, yielding 385 m³ of biogas annually, with a reduction of greenhouse gas of 1.5 – 4.1 tons CO₂ equivalent (Dong, 2008). Another option is the covered anaerobic lagoons which can be used to collect and transmit lagoon-generated biogas for domestic or industrial use⁸⁸.

A series of national laws and regulations including the “Agricultural Law”, “Law of the People’s Republic of China on Energy Conservation”, and “Law of Renewable Energy” clearly specify the development of biogas. In 2007, the Ministry of Agriculture released the “Agricultural Bio-energy Industry’s Development Program (2007–2015)” and the “National Rural Biogas Program (2006–2010),” which set out the principles and objectives for the development of biogas. The 12th Five-Year Plan for National Economic and Social Development also emphasized the need to boost biogas development. At the end of 2010 biogas digesters in China had reached 40 million rural households, the annual total output of biogas being 15.5 billion m³ and it is expected that biogas digesters could reach 60.0 million households⁸⁹.

Analysis by Brink et al. (2013) suggests that it is possible for methane emissions from animal manure in China to be reduced by between 17 and 36 MtCO₂e by 2030 relative to 2010 values. They indicated that this represents an emission reduction of 17-36%.

5.2.3 Reducing Methane Emissions from Waste Management

As discussed in Chapter 4, emission from the waste sector comes from wastewater treatment plants and from MSW landfills. Wastewater treatment plant accounts for the greater part of emissions from this sector. Emission reduction measures as described by the Global Methane Initiative include use of anaerobic sludge digestion, biogas capture at existing open air anaerobic lagoons, installing centralized aerobic treatment facilities or anaerobic lagoons where they do not exist and installation of gas capture and combustion systems to utilize methane⁹⁰. Another option as proposed in the UNEP/WMO Assessment is the upgrading of existing primary wastewater treatment plants to secondary/tertiary treatment plants with gas recovery and overflow controls.

For MSW landfills, emission reduction measures include extracting generated methane for utilization and the separation and treatment biodegradable waste. Furthermore, the reduction, reuse and recycling of waste is an important strategy for ensuring that waste does not reach landfills in the first place. Along this line, the current move of the Chinese government towards a circular economy model⁹¹

88 See: https://www.globalmethane.org/documents/analysis_fs_en.pdf

89 Second China’s National Assessment Report on Climate Change 2011

90 See: https://www.globalmethane.org/documents/analysis_fs_en.pdf

91 See: <http://www.theguardian.com/sustainable-business/china-recycling-waste-circular-economy>

86 See: http://www.ivt.ntnu.no/ept/fag/tep4215/innhold/LNG%20Conferences/2007/fscommand/PO_37_Lin_s.pdf

87 <http://www.nature.com/news/2009/090818/full/news.2009.833.html>

which encourages the design of products in a manner that allows materials to be recycled, reused or remanufactured is a step in the right direction.

Overall, emission reduction strategies should focus on measures that reduce the emissions of all greenhouse gases, not just methane. It is also important that adopted technologies and measures take into consideration China's socio-economic situation.

In terms of emission reduction potential, analysis by Brink et al. (2013) indicates that China's methane emission from wastewater treatment and MSW landfills could be reduced by 20-58 MtCO₂e and 47-90 MtCO₂e respectively by 2030 as

compared to 2010 values, which is equivalent to a 23-66% and 24-45% reduction respectively.

For overall methane emission reduction across all sectors, Høglund-Isaksson et al. (2012) projected that emissions can be reduced by about 31 Mt of methane by 2030, equivalent to approximately 650 MtCO₂e. Their analysis shows that coal mining, waste management and rice cultivation provides a significant proportion of this emission reduction potential.



Chapter 6

Implications for Policy

Chapter 5 shows that China is already making significant efforts towards black carbon and methane emissions abatement in a number of sectors. Black carbon emissions from its coal-burning power stations are very low. China is successfully replacing inefficient and polluting indigenous coke ovens with more efficient and less polluting ones. It has set an example in monitoring and enforcement systems to control agricultural biomass burning. It is a leader in the recovery and use of coal mine methane and in the reduction of methane emissions from rice paddies, and its programme to introduce improved heating and cooking stoves in rural communities has been the largest in the world.

Such measures will cumulatively achieve a great deal, but more will be needed if the health and climate gains highlighted in Chapter 1 are to be achieved. Radical action on SLCPs could offer the best prospect for securing these benefits while also mitigating climate change, but the window of opportunity for action is relatively short. At the same time responses to the smog episodes in Chinese cities clearly showed the rising public and political concern at the impacts of air pollution, and the importance of responding to it. In light of the Chinese experience reviewed in this report, this chapter draws together policy actions that could further assist China, and other countries, to tackle air pollution challenge, while at the same time delivering climate benefits.

6.1. Options for Further Action

The previous chapter identified many opportunities for scaling up current policy responses and for adopting new ones. These opportunities would also represent a major contribution to international effort on air quality improvement and climate change mitigation. Some of the principal options in various sectors that have been discussed in this report are summarized below.

6.1.1. Domestic heating and cooking

Expanding the grid for the delivery of cleaner fuels such as natural gas, for example for district heating in urban and rural China, remains an important priority for air pollutant reduction. In rural areas, increased efforts are needed to extend the penetration and sustainability of China's clean cook stove programme through more government advice, support and subsidy, and to ensure that the stoves promoted are tested varieties that actually reduce black carbon

emissions. Controlling black carbon emissions from domestic stoves presents great difficulties for all governments because of the dispersed character of the emission source, the diversity of fuels used and strong cultural influences. China's programme has arguably been the largest and most effective in the world but further effort is needed (see Box 5.1). Such effort would have the added benefit of helping to control other pollutants, reduce indoor pollution, improve health and provide other economic benefits. At the same time, considerations could be given to the recommendation in this report for a ban on residential access to MVB coals and the wider extension of district heating systems in suburbs and villages.

6.1.2. Industry

By contrast with the domestic sector, the centralized organization of industrial production makes it easier to control emissions through good management practices such as ensuring that machineries are operated efficiently and that pollution control requirements are properly observed.

In China, the control of black carbon emissions from industry has already had some successes. In particular black carbon emissions from coal use in the electricity supply industry are very low, because of the high combustion efficiency of power plants, and the tightening of smoke and dust emission standards. However, there remain serious challenges with the brick industry and with coke ovens. Black carbon emissions from the brick industry can be reduced by technology change – essentially moving from the traditional annular kilns to modern tunnel kilns. Almost all small scale enterprise brick kilns in China use traditional annular kilns, with outdated production processes, equipment and technology. With more than 70,000 brick enterprises and many operators wedded to traditional practices, it is clearly going to be a major challenge to change all traditional kilns to modern ones. This may require some form of financial, technological and capacity building support.

In the case of coke ovens, China has largely achieved the shift from traditional coke ovens to modern recovery ovens with end-of-pipe abatement measures. Further benefits could however be secured by mandatory use of more advanced technologies for energy saving and emission reduction, such as coke dry quenching and fine particles removal.

With ordinary industrial boilers, coal-fired boilers and small scale furnaces, the problem is different. Mandatory pollution control equipment, once installed, may be operated only partially or not at all, and in some cases may not be installed at all. This indicates a need for better government supervision, stronger regulation and heavier punishment for violators as has been recommended in the Policy Research Report on Environment and Development of the China Council for International Cooperation on Environment and Development (CCICED, 2013).

6.1.3. Transport

Black carbon emissions from diesel engines account for the majority of emissions from mobile sources. The UNEP/WMO Assessment highlighted the benefits of introducing standards for the reduction of pollutants from vehicles (including diesel particle filters) equivalent to those included in Euro VI standards, for on-road and off-road mobile machinery; and the elimination of high-emitting vehicles in road and off-road transport.

In this area there is widespread agreement – nationally and internationally – on what needs to be done, and the issue is primarily the speed with which it can be achieved. At present, China has implemented National III standards on light diesel vehicles. If the National IV emission standards could be implemented earlier, then reduction in particle emission would increase. Implementing the National V emission standard could further decrease black carbon emissions. For heavy-duty diesel engines, if the National V emission standard can be implemented as soon as possible, the particles emission of diesel would also decrease. Considering the size and rate of increase of the vehicle fleet in China, earlier implementation of more stringent requirements on the control of particle emissions could bring significant air pollution benefits.

For new off-road mobile machinery, China still implements the National II emission standards, while Europe, the U.S and other developed countries have begun to implement Euro VI standards. Raising the limit value for particle emissions from the off-road mobile machinery in China to those applicable in developed countries will yield increased air pollution and climate benefits.

As for the UNEP/WMO recommendation on high-emitting vehicles, China has put some measures in place. It is estimated that by 2017 the elimination of yellow label cars (cars registered before 2005 and which do not meet the China I emission standard and heavy duty vehicles whose emission do not meet the China III standard) could reduce the emission of black carbon by 78% as compared to 2012 levels. Further progress could come from fitting more recent diesel vehicles with effective particle capture technology, such as the wall-flow diesel particulate filter.

Finally, the use of low-sulfur diesel fuel can help to reduce the emission of particles and black carbon, and can also make the application of various after-treatment technologies possible. As highlighted in chapter 5, using low-sulfur diesel, and requiring all new diesel vehicles to install particulate filters could help China reduce its total black carbon emissions by more than 10% by 2030. Furthermore, China could also consider discouraging the use of high black

carbon-emitting diesel vehicles by promoting electric hybrid vehicles or electric vehicles (EV) to replace traditional diesel engine.

6.1.4. Open Burning

Although in China, biomass burning contributes only 4-6% to total black carbon emissions (Cao et al. 2006, Streets et al. 2001, Wang et al. 2012), which is much less than the global average, there exist opportunities for further emission reduction. Reduction can be achieved through the suppression of natural fires, the implementation of field burning bans, and the protection of forests and vegetation.

Currently, implementation of regulations to ban open-biomass burning is supported by a website and satellite-derived images which can identify fire spots on a day-to-day basis during harvest seasons, therefore providing information that can be used for law enforcement. When strictly enforced, the regulation has been effective in reducing crop residue burning around large cities, but extension of the systems and enhanced enforcement could offer even greater gains.

6.1.5. Agriculture

The introduction of mid-season drainage has already reduced methane emissions from rice paddies, compared with traditional farming practice, but there are other options which could yield further benefits, such as rice variety selection. Management of fertilization also has potential: compared to application of farmyard manure, green manure, and straw, application of compost and biogas residue can reduce 45-62% of methane emissions from rice paddies (see chapter 5; Shi et al., 2010). Reducing methane emissions from manure management has made less progress, but regulations which had led to installation of biogas digesters in 40 million rural households by 2010 provide a good foundation for further policies. Finally, methane emissions from enteric fermentation continue to represent a formidable problem which requires international cooperation in research and experimentation.

6.1.6. Coal Mine Emissions

China is a leader in the use of CMM as an industrial and domestic fuel. As a high-quality, clean, inexpensive industrial fuel, it is widely used in industrial boilers, and ceramic and other industries. As a residential fuel, it can be used in low pressure pipe networks in mining areas, and in recent years pricing structures have made this more economical. Total utilization was estimated at 4.3 billion m³ in 2013, but this still leaves some 8.3 billion emitted to air, offering scope for expanded utilization programmes.

A further option would be to increase utilization of low-concentration gas (<30%), an option which has tended to be avoided outside China due to safety concerns. However there has been substantial technical progress on the issue in China and the option has now found a place in the 12th Five Year Plan.

6.1.7. Waste Management

As China modernizes and upgrades its treatment facilities, for both solid waste and wastewater, there are major

opportunities to mitigate methane emissions, and these will be made more attractive by the recognition of beneficial after-uses, such as use of landfill gas to generate electricity. They will also be supported by widening acceptance that, during treatment, technologies beneficial for greenhouse gas emission reduction need to be given priority; and that at the end of the process, measures should be implemented to prioritize the reduction, reuse and recycling of wastes.

6.2. Delivering Change

Although extensive and successful action is already being taken on many of the main sources of SLCPs in China, there are still major opportunities for widening and scaling-up policies to achieve the health, climate and ecosystem benefits offered by radical emission reductions.

However, the availability of proven technologies and policies is not sufficient. It is important that strategies and processes are in place to ensure that radical expansion of black carbon and methane emission reduction measures fit comfortably into the wider context of atmospheric policy in China. It is also important that such strategies align with the continuing narrative of China's socio-economic development.

Further, many of the measures that have delivered black carbon and methane emissions reduction were not designed primarily with that benefit in view. Often the benefits are secondary, indeed sometimes incidental or unrecognized. It will be important therefore to ensure that, at both the policy and the project level in the wide range of sectors and industries discussed in this report, the potential impact of new projects on SLCPs emissions is wherever possible, quantified and taken into account in the decision process.

Additionally, achieving the multiple benefits that SLCP mitigation offers and the current scale of air pollution and climate change makes necessary a more aggressive, targeted and integrated strategy. This would allow decision makers to look across the range of relevant sectors and mitigation options and set optimal policy priorities, targets and timescales. Achieving this more coherent and action-oriented approach to SLCP mitigation may however require a number of changes, in China as well as in other countries, as discussed in the next sections.

6.2.1. Strengthen the Information Base for Policy Formulation

Expand the Emission Inventory of SLCPs

Although, methane is one of the greenhouse gases controlled under the Kyoto Protocol and its emissions in 2000 and 2005 were described in China's Second National Communication on Climate Change, problems in obtaining official statistics based on time series create difficulties for research and policymaking. Statistical data on black carbon emissions comes from the reports and papers of different agencies and is unsystematic and difficult to compare. There are also differences in the methods of collection and assessment. A comprehensive emission inventory of SLCPs therefore needs to be developed to provide scientific data support for the formulation and implementation of policies as well as to make the policy-making process and outcomes

more measurable, reportable and verifiable. However, in order to be implement an integrated multi-pollutant approach, such SLCPs emission inventory needs to be part of, and consistent with, an overall air pollution and climate change emission inventory.

Establish and Complete an SLCPs Monitoring Network

China's environmental monitoring network is being continuously developed. At present, the atmospheric environmental quality monitoring system, which covers 113 key environmental protection cities and national environmental protection model cities, monitors SO₂, NO₂ and PM₁₀. Since 2013 CO, PM_{2.5} and O₃ have also been measured in Jing-Jin-Ji, the Yangtze River Delta, the Pearl River Delta, municipalities and provincial capital cities and 74 other cities, and the MEP publishes an Air Quality Report every month. There is a case now for reviewing the environmental monitoring network to make sure that it can objectively reflect the real situation, in view of changes in China's atmospheric environmental quality. This could include expanding the scope of monitoring PM_{2.5} and putting black carbon, methane and other SLCPs into a unified environment monitoring network.

Strengthen Research

One of the strengths of SLCPs, as illustrated by the UNEP/WMO Assessment, is that measures and techniques are already available which can deliver cost-effective mitigation in all the relevant sectors. Nevertheless more attention needs to be given to research on SLCP monitoring methods, the analysis of emission streams, the application of mitigation technologies, the health-climate-ecology impacts of SLCPs, estimation of emissions mitigation potential, and other relevant issues in both the natural and social sciences. Some of the matters requiring research are specific to Chinese conditions and culture, but others are international and cross-cultural and may be best pursued through cooperative international programmes (Section 6.2.4).

Ensure Cost-Benefit Analysis of Measures

The clear evidence from the UNEP/WMO Assessment that the principal SLCP mitigation measures are cost-effective and yield net benefits, provides a firm economic foundation for a mitigation strategy. Nevertheless this does not remove the need to ensure that cost-benefit assessment procedures are in place at the project level as strategies are implemented. In particular, it is important that such analysis is done before project implementation so as to provide the economic case for action needed for policy decision and public acceptance.

6.2.3. Develop a Regulatory and Planning Systems for SLCPs

China has already established a series of standards, laws and regulations for air quality management, but they do not yet fully cover the control of SLCPs. It would now be timely to complete the framework of standards, law and regulations for SLCPs, and ensure compliance through strict enforcement. Environment monitoring and data publication should also be subject to stricter quality control.

Such standards and regulations could be a catalyst for development of novel technologies for tackling air quality challenges.

At present, the coverage of SLCPs in air quality and climate plans and programmes is fragmented. The existing elements now need to be brought together in an integrated SLCP planning and implementation process, so that overall targets for mitigation can be set and progress measured, and in particular so that it is possible to assess the relative feasibility and cost-effectiveness of alternative SLCPs mitigation measures. This may require the development of national action plans or strategies that could help integrate SLCP strategies into broader national policies and actions⁹².

However, any integrated SLCP strategy needs to be included in an overarching integrated planning and implementation process for atmospheric issues including air pollution and climate change so as to avoid further fragmentation. Doing this would also ensure that antagonistic policies or strategies that could favour air quality objectives at the expense of climate change or other sustainable development objectives, or vice versa, are avoided. An integrated SLCP planning process will need to be tied into broader atmospheric policy systems, and linked to the main programmes (such as transport, industry and waste management) through which most mitigation initiatives will need to be implemented. In addition, although action on SLCPs may yield potentially the highest overall benefit, it is important that action should not negatively impact other areas of air pollution control. SLCPs policies and planning processes therefore need to link seamlessly with the broader sweep of air pollution and climate policy. While a coherent free-standing strategy for SLCPs is needed, it should also be seen as a means of promoting a broader multi-pollutant strategy. Similarly, in climate policy, while the mitigation of SLCPs can yield major near-term climate benefits, it is important that this is pursued alongside deep cuts in CO₂ emissions.

6.2.4. Strengthen International Communication and Cooperation

New SLCP mitigation programmes could be strengthened by enhanced international cooperation and communication on such issues as environmental monitoring, mitigation technology and system design. While China has made innovative and internationally significant contributions to SLCPs mitigation policy and technologies, it has much to gain from international practice in those areas where it currently has less experience and capacity. This suggests that, in developing its own strategy, China could consider taking full advantage of the various alliances and multilateral cooperation mechanisms on SLCPs, which have emerged recently, both to have access to international support in funding and techniques and to allow other countries to benefit from its own experience. China is already a member of the Global Methane Initiative⁹³ and joining or increasing cooperation with other similar initiatives could provide a further avenue for strengthening its ability to develop

coherent and action-oriented SLCP mitigation strategies and policies⁹⁴.

Regional and international initiatives which address issues of transboundary air pollution and its link with climate change, could also provide effective support to national action on SLCPs, for instance the Tripartite Environmental Ministers' Meeting (TEMM) among China, Japan and the Republic of Korea and the ASEAN+3 Meeting. In the Joint Communiqué from the 16th TEMM held in April 2014, Ministers from China, Japan and Korea noted 'the need for information sharing and joint research on the control techniques and policies regarding short-lived climate forcers with the purpose to promote co-control⁹⁵ of air pollutants and greenhouse gases so as to create co-benefits.' Aside from immediate benefits, stronger Chinese engagement with this process would help to ensure that any conclusions emerging from the work takes the Chinese context into consideration.

6.3. Next Steps

While some of the measures discussed above may take some time to implement, others are straight forward and could be implemented immediately. It is important that the latter are implemented as soon as possible while policy changes are being put in place for the former. There is, for example, a case for ensuring that, when environment and indeed other policies are developed and reviewed, consideration is explicitly given to the possibility of adjustments and adaptations which could assist SLCPs mitigation. For example, as policies for control of PM_{2.5} are developed, priority could be given to control of sources of black carbon in view of the greater health and environment benefits that this may offer. Such an approach could also be considered in respect of transport emissions. A comprehensive strategy is needed for control of vehicle emissions, but within this there is a case for targeting diesel vehicles in particular because of the particularly harmful impact of their emissions.

Recent developments have meanwhile, shown that SLCP mitigation is important for tackling the challenge of poor air quality in China and globally, and have provided a foundation for its implementation. For instance, 'co-control' has become an important theme of Chinese policy. This could make an important contribution to developing an SLCPs strategy linking the climate and air pollution policy domains because of the practical experience it has already offered of integrating such domains and optimizing outcomes across a range of policy fields.

It will also be greatly assisted by recent policy decisions by the Chinese Government and the significant financial investments that have been associated with them. These include the government directive to MEP to revise laws and regulations, and develop a system of compensation for environmental damage within a wider strategy to strengthen environmental controls, as part of an effort to control PM_{2.5} emissions. They also include a slate of policy reforms such as the "Airborne Pollution Prevention and Control Action

92 This type of national action plans is being supported by the Climate and Clean Air Coalition (CCAC). See: <http://www.unep.org/ccac/Initiatives/SupportingNationalPlanningforactiononSLCPs/tabid/130325/language/en-US/Default.aspx>

93 <https://globalmethane.org/partners/china.aspx>

94 One example of such initiative which China could consider joining or cooperating with is the Climate and Clean Air Coalition (CCAC). (<http://www.ccacoalition.org/>).

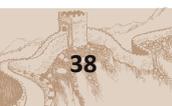
95 a strategy that replaces single pollutant abatement by abatement of two or more pollutants together to maximize overall benefits

Plan” in September, 2013. Last but not least, they entail a commitment of 5 billion Yuan for air pollution control in Beijing and Tianjin, the provinces of Hebei, Shanxi and Shandong, and the Inner Mongolia Autonomous Region in 2013 and 10 billion Yuan in 2014⁹⁶.

More generally there is the evidence that, as illustrated in Chapter 2, the focus of air pollution control in China

has already moved forward successfully, widening from a concentration on the ‘traditional’ pollutants to embrace monitoring and policy-development on particulate matter, ozone, and other pollutants. Developing coherent policies and targets for SLCP mitigation could now be the bridge to a comprehensive multi-pollutant strategy taking account of climate as well as pollution concerns.

⁹⁶ See: http://www.china.org.cn/environment/2013-10/28/content_30425833.htm



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