Executive Summary

Black Carbon (BC) and Organic Carbon (OC) are particulate matter formed from incomplete combustion of carbonaceous matter such as fossil fuels, biofuels and biomass. Both are short-lived climate forcers (SLCFs) which have relatively short lifetime in the atmosphere, for particles on the order of days. BC has a warming effect while OC has a cooling effect on the atmosphere. As important components of atmospheric aerosols, BC and OC aerosols have important impacts on ambient air quality, human health, and regional and global climate change.

1. Overview of the ChiNorBC project

According to the memorandum of understanding (MOU) regarding Economic and Technical Cooperation signed by the Government of the people's Republic of China (China) and the Government of the kingdom of Norway (Norway), as well as the memorandum of understanding signed by the Ministry of Ecology and Environment of the People's Republic of China (MEE) and the Norwegian Ministry of Climate and Environment (MCE). The Ministry of Commerce of the People's Republic of China (MOFCOM) and the Norwegian Ministry of Foreign Affair (MFA) have entered into the Agreement (Chinese-Norwegian Project on Emission, Impact and Control Policy for Black Carbon and its Co-benefits in Northern China) dated 29 November 2019. The main implementing agencies for the project are the Chinese Research Academy of Environmental Sciences (CRAES) and the Norwegian Environment Agency (NEA), in partnership with the Chinese Academy of Environmental Planning (CAEP), the Norwegian Institute of Public Health (NIPH) and Center for International Climate Research (CICERO), with financial support from the Norwegian Ministry of Foreign Affairs.

The implementation period of the project was 3.5 years (from October 2019 to June 2023). The aim was to:

- Review Norwegian relevant polices and counter-measures and experiences of BC/OC emissions reduction,
- Develop or update BC/OC emission inventories in northern China,
- Assess the impacts on air quality and climate using global and regional models,
- Assess the impacts of current BC/OC concentrations in the atmosphere on human health,
- Make recommendations for the development of BC/OC abatement measures in China.

2. Key results of the ChiNorBC project

（1）Review of the Chinese path to dealing with air pollution

In order to improve ambient air quality, the Chinese government has since 2013 successively promulgated and implemented a series of important policies, such as the Action Plan on Prevention and Control of Air Pollution and the Three-Year Action Plan to Fight Air Pollution (Table 1). Supporting

policies including elimination of outdated production capacity, in-depth control of pollution in key industrial sectors (e.g. thermal power, iron and steel, cement), control of coal-fired boilers, clean heating, and prevention and control of mobile source pollution have been implemented. The policies involve the industrial, residential, transportation, and many other sectors. During the 14th Five-Year Plan period (2021–2025), China will accelerate the transformation and upgrading of industrial structure and strictly control the construction of high energy-consuming and high-emission projects. At the same time, China will strengthen the collaboration between different ministries. and conduct unified policy planning and standard setting, along with unified monitoring and assessment, unified supervision and enforcement, and unified inspection and accountability, in order to provide support and guarantees for achieving the synergistic effect of pollution and carbon reductions.

Major relevant polices and counter-measures:

Since 2013, China has released a series of air pollution prevention and control policies, significantly reducing the emission of particulate matter (PM), sulfur dioxide (SO_2) and other pollutants, which has achieved synergies with BC emission reduction. The policies included improving legal frameworks, standards and action plans on air quality improvement, upgrading industrial standards and companies, restructuring industry, optimizing energy structure, prevention and control of mobile source pollution and treatment of non-point source pollution. In 2020, China announced carbon peak and carbon neutrality action in China, that included carbon peaking before 2030 and carbon neutrality before 2060.

Table 1 A series of released air pollution prevention and control policies

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<tr><th>2013</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2025</th><th>2030</th><th>2060</th></tr>
<tr><td colspan="5">The Action Plan of Air Pollution Control and Prevention Tier I (Action Ten, 2013–2017)</td><td colspan="9"></td></tr>
<tr><td colspan="3"></td><td colspan="5">The 13th Five-Year Plan</td><td colspan="6"></td></tr>
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<tr><td colspan="7"></td><td colspan="6">Carbon Peak</td><td></td></tr>
<tr><td colspan="7"></td><td colspan="7">Carbon Neutrality Action</td></tr>
<tr><td colspan="8"></td><td colspan="4">The 14th Five- Plan</td><td colspan="2"></td></tr>
<tr><td colspan="9"></td><td colspan="3">The Action Plan For Eliminating Heavy Pollution, Controlling Ozone Pollution and Diesel Truck Pollution</td><td colspan="2"></td></tr>
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Achievement of air quality improvements:

Since 2013, China has achieved positive results in air pollution prevention and control, with the overall ambient air quality seeing substantial improvement (Figure 1). The annual average measured $PM_{2.5}$ concentration of 337 cities at or above prefecture level (hereinafter referred to as the "337 cities") in

2020 was 33 μg/m^3, down by 29.1% from 2015. From 2015 to 2020, The annual average measured concentration of $PM_{2.5}$ in Beijing dropped by more than 50%..

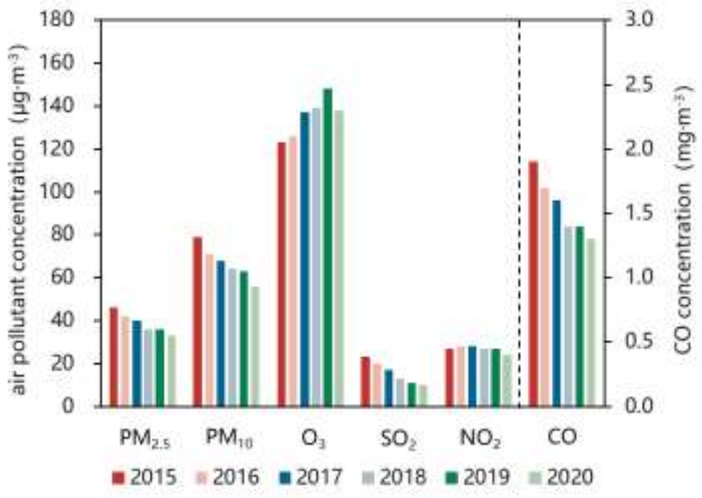

Figure 1 Changes in national annual average measured concentrations of major air pollutants from 2015-2020 in the 337 cities

（2）Development of new emission inventories and scenarios

Existing Black Carbon emission inventories were reviewed and emission factors from literature obtained. Measurements and in-situ investigation were done for mobile and residential sectors to collect activity levels and derive emission factors. Based on a publicly available emission inventory established by Tsinghua University, ChiNorBC-2018 BC/OC and other air pollutants emission database and inventories for Northern China have been established. This was done by updating the information of two key sectors (residential and mobile sectors) and optimizing the others. Total BC emissions of Northern China in the ChiNorBC-2018 inventory and the sector distribution are shown in Figure 2.

The residential sector contributed the most, accounting for more than half of the emissions, followed by industrial sector, accounting for 25%, the mobile (including on-road and off-road mobile sources) sector, accounting for about 13%.The residential sector contributed the most, accounting 56% of the emissions, followed by industrial and mobile (including on-road and off-road mobile sources) accounting for 26% and 13% respectively. In view of the dominance of the residential sector, more focus should be directed towards reducing these emissions in Northern China, not leaving other sectors like industry and mobile unattended.

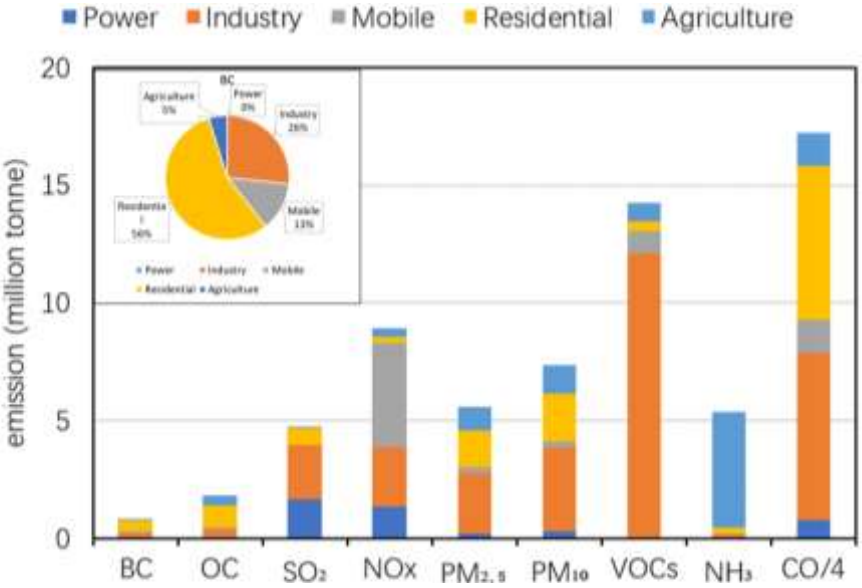

Figure 2 BC emissions of Northern China and the sector distribution in the ChiNorBC-2018 inventory

（3）The co-benefits of mitigating BC/OC emissions in China

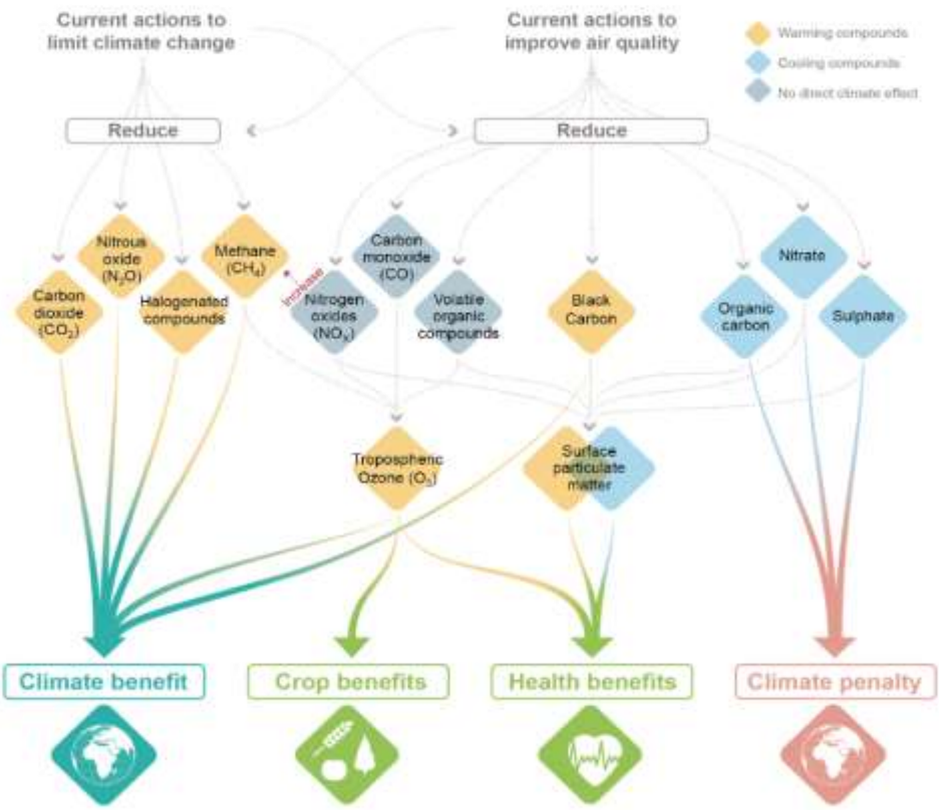

Figure 3 Links between actions aiming to limit climate change and actions to improve air quality (FAQ 6.2 from IPCC, 2021)

BC/OC constitute important parts of atmospheric fine particulate matter ($PM_{2.5}$) and is always co-emitted.

By reducing the emissions, we can obtain air quality, climate and health benefits. Emission control measures will in many cases also mitigate other harmful pollutants, thus many co-benefits can be achieved by optimizing reduction strategies.

1) Emission reduction potential

The ChiNorBC project conducted scenario analyses of BC and OC mitigation pathways using an integrated modeling framework to support policymaking. With the consideration of structural adjustment, end-of-pipe control, and industrial layout optimization, three scenarios with increasing stringency, namely business as usual scenario (BAU), strengthened end of pipe control scenario (EOP) and ambitious control scenario (ABC), are designed. Structural adjustments and strengthened end-of-pipe control measures are effective in reducing BC and OC emissions across Northern China (Figure 4).

The analysis suggests that by 2035, BC and OC emissions in Northern China could decline by 20-43% and 17-35%, respectively, with varying control strictness. The residential, industrial, and mobile sectors have the greatest potential for emission reduction with effective measures implemented.

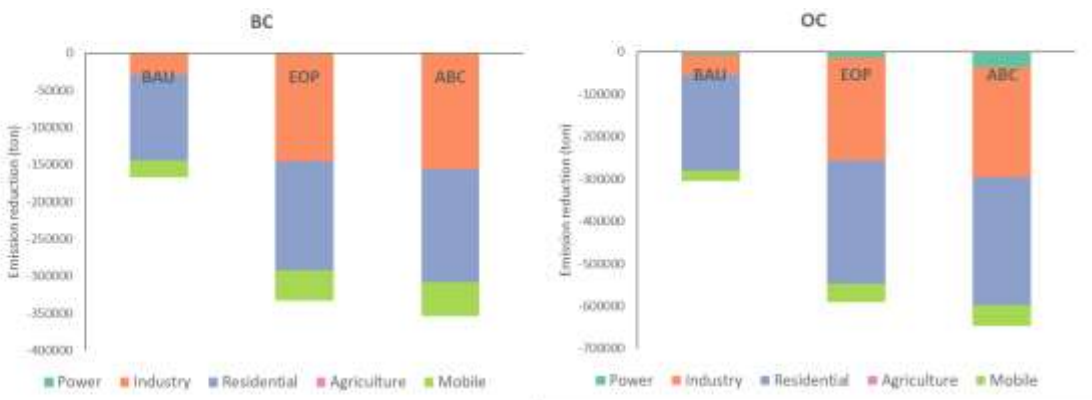

Figure 4　Reductions of BC and OC emissions by 2035 compared with 2018 in the three emission reduction scenarios (Reductions in the agriculture sector is to small to be visible)

2) On air quality

The air quality model simulation performance under the ChiNorBC-2018 emissions inventory has improved considerably compared to the baseline emission inventory. Model results compare much better to the monitoring data, especially for BC/OC.

The air quality modelling results for 2018 show that the concentrations of atmospheric pollutants exhibit clear seasonal variations. The highest pollution mostly occurs during winter, while the summer season generally has the best air quality. The simulated BC/OC concentrations were highest in Beijing, Tianjin, Hebei and surrounding areas and Northeast China. The 2018 concentration of BC and OC during winter is shown in figure 5.

Based on the three scenarios developed in the project, the more pronounced decrease in pollutant concentrations is seen in the ABC scenario. And the maximum decreases in concentrations simulated in the ABC abatement scenario were 60.0% (9.7μg/m^3) and 54.0% (13.8μg/m^3) for BC and OC, respectively. At the same time, the annual average concentrations of other conventional pollutants simulated in this emission reduction scenario are below the concentration limits of the secondary standards in the national air quality standards in 2035.

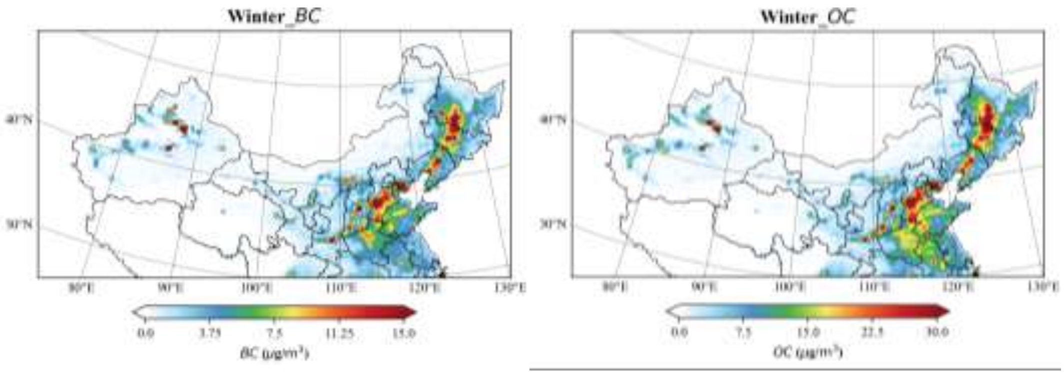

Figure 5 The spatial distribution of the simulated average concentrations of BC/OC in winter (Note that the scales are different for BC and OC)

3) On climate change

Reductions from 2018 to 2035 in the total amount of BC, OC, sulfate, and nitrate aerosols in the atmosphere are simulated for all three scenarios developed in the project. The relative reductions are largest for BC and nitrate (up to 20% for China as a whole in the ABC scenario), and smallest for sulfate (~2-5%). Larger relative reductions in BC and nitrate of up to 40% are found over the regions with the heaviest pollution today.

In the ChiNorBC project, the resulting estimated radiative forcing and impact on global mean temperature is broadly consistent with the current status of scientific knowledge on aerosol-induced climate impacts.

Aerosols can also have important effects on local and regional climate, including on extreme events, through changes in the hydrological cycle and dynamics of the atmosphere. Such effects have not been quantified in the ChiNorBC project, but such quantifications are needed for a more comprehensive understanding of climatic co-benefits or potential trade-offs of BC/OC mitigation.

4) On health

Exposure to $PM_{2.5}$ is a leading environmental risk factor for premature mortality and loss of healthy life years worldwide. BC is the vital component of $PM_{2.5}$, its porous structure is easier to absorb organic compounds, so it has a greater impact on human health. As the sources of $PM_{2.5}$ may vary considerably between regions, knowledge regarding the potential adverse effects of different types of particles is important for implementing effective mitigating measures. The project aimed to perform a health risk assessment of air pollution particles and rank the emissions sectors and sources.

- Our systematic review of the literature showed that long-term exposure to BC was associated with increased total mortality and mortality due to specific diseases. The impact of BC on the respiratory system was higher than on the cardiovascular system.
- Experimental studies in research animals and 2-dimentional (D)/3D cell culture models showed that exposure to BC and $PM_{2.5}$ can cause inflammation, immune cell imbalance, dysregulated gene expression and increased RNA m^6A modification in the lungs, which may reveal the molecular mechanisms underlying the health effects of $PM_{2.5}$ exposure, both in the lung and secondary organs.
- $PM_{2.5}$ sampled in specific cities with representative pollution sources exhibited different inflammatory effects in cell culture models through the release of inflammatory mediators. The results may suggest a higher contribution of industrial emissions and coal burning to PM toxicity than traffic emissions. However, the differences between the samples were small and more experiments and samples must be included to perform an accurate toxicity ranking of the different sources of particles.

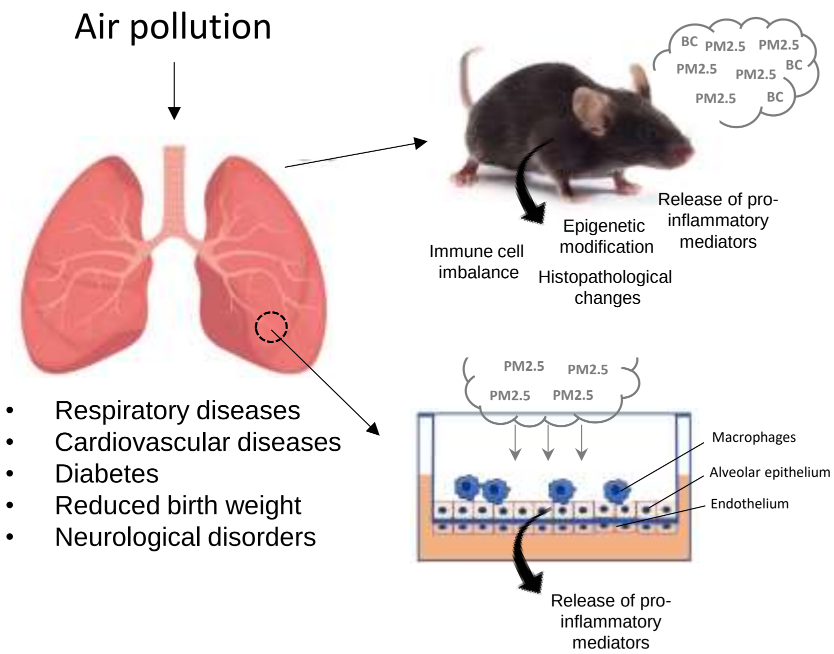

Figure 6 The study of $PM_{2.5}$/BC on health effects. Inhalation of $PM_{2.5}$ can cause a range of diseases. The present study examines the adverse effects of different types of $PM_{2.5}$ using experimental animal models and advanced cell cultures, focusing on the effects on inflammation and epigenetic modifications.

（4）Project dissemination products and outreach

In order to raise awareness and build capacity, the ChiNorBC project has published an extensive number of disseminations products. The publications are aimed at different audiences from policy makers via scientists to the general public.

1) The ChiNorBC web site

All the dissemination products, key results, project history, project participants and contact information can be found at the ChiNorBC web site (http://chinorbc.net/)

2) The final project report

All key results from the project are contained in the final project report. The report has seven chapters and has around 200 pages.

3) Review reports:

Based on the main research content of each of the project outputs, five review reports have been published.

- Review of BC/ OC emissions and control measures in China and Norway.
- Review of BC/ OC emissions inventories.
- Review of impact assessment of BC/OC on air quality and climate change.
- Review of human health effect of BC in air pollution.
- Review of policies of China for the control of BC/OC.

4) Book:

A hard copy book named *A Review of Emissions, Impacts and Policies*(China Environment Publishing Group·Beijing, 2022) has been published based on the review reports:

5) Brochure and Cartoon movie:

A brochure and a cartoon movie for introducing emissions and impacts of BC/OC have been developed.

6) Peer reviewed scientific papers:

Several scientific papers acknowledging the ChiNorBC project have already been published, and we anticipate that there will be more in the coming years. The papers are listed on the ChiNorBC web site.

7) Seminars and workshops

The project was carried out during the covid pandemic, so most of the seminars were digital. The *Final governmental seminar* and an *In-depth seminar* took however physically place in Beijing. The *kick-off meeting*, *two emission workshops* and *a scenario workshop* was carried out. The reports from the meetings are available on http://chinorbc.net/.

3. Uptake of project results in policy making

（1）Fitting BC mitigation programs into China's atmospheric and socio-economic development policies and national policies

Black Carbon is a major air pollutant and climate forcer in China. Reducing BC emissions would help achieve China's strategic target of carbon peaking and carbon neutrality, as well as the target of constructing a "Beautiful China" characterized by clean air. While China has established a policy framework to improve air quality and cope with climate change, tailored mitigation policies specifically targeting BC emissions could be reinforced to better integrate them into China's atmospheric and socio-economic development policies.

Despite that the importance of reducing BC emissions has been widely studied, specific mitigation policies have yet rarely been implemented in China. During the past decade, BC was mainly co-abated by measures that focused on reducing primary $PM_{2.5}$ emissions. While the scientific research should be continued, political will and public awareness are likely to be t important for integrating BC control into China's national policies. The Chinese government is now committing to tackle issues that are of most concern by the general public. Therefore, enhancing the public understanding of the impacts of BC emissions on health and the environment would help form a consensus of targeted mitigation among all parties including the policymakers, scientists, and the general public. This wills likely contribute to the political commitments and social actions and there by emission reductions with benefits for climate, air quality and health.

（2）Exploring the future path for mitigating BC/OC emissions in China

The ChiNorBC-2018 inventory shows that the residential, industrial and mobilesectors are the primary contributors to BC emissions in Northern China. This indicates that abatement actions should focus primarily on these sectors. However, different sectors and types of measures should be focused on when implementing BC control due to the varying emission reduction potential of different control measures across provinces. This can be attributed to the varying industrial and energy structures, as well as the stringency of existing control measures across regions.
Therefore, targeted policies should be developed to address the specific needs and challenges of each province to achieve optimal results in reducing BC emissions.

To further reduce BC emissions in Northern China, with the anticipation of maximizing the air quality, climate, and public health co-benefits, it is suggested to promote the adjustment of energy, industry, and transportation structures in Northern China, as well as maximize the potential of end-of-pipe treatment with a specific focus on key sectors such as residential , industrial, and transportation.

It is also necessary to advocate for the whole society to work together and mobilize all sectors of society to participate in atmospheric environment protection and climate change mitigation. The actions to be taken to achieve reductions in BC/OC and obtain substantial co-benefits for air quality, health, and climate are:

- Implement measures underlying the most ambitious control scenario (that is, the ABC scenario) developed in the ChiNorBC project in key regions to further strengthen the environmental policymaking in China.
- Focus on air pollution control policies that reduce emissions from industrial processes as well as coal burning, particularly in the residential sector, to better protect the public health of Chinese citizens.
- Abate BC emissions from the transportation sector.
- Account for differences in what sectors and types of measure that should be targeted when implementing BC control in different provinces in Northern China.
- Consider both structural adjustments, end-of-pipe control measures, and industrial layout adjustments to substantially reduce emissions and achieve co-benefits.

- Promote a shift from fossil fuels to clean renewable energies by increasing access to wind and solar power, as well encourage construction of hydropower bases.
- Accelerate elimination of unabated coal power plants and coal-fired boilers.
- Limit the development of energy-intensive projects and industrial furnaces using highly polluting fuels.
- Reduce residential coal use by facilitate transition to renewable energy, industrial waste heat, cogeneration, electricity, gas and other applicable ways to substitute coal-fired heating boilers and bulk coal.
- Promote the railway and waterway transportation for the medium and long-distance transportation of bulk commodities.
- Enhance implementation of ultra-low emission standards[1] policies by installation of advanced end-of-pipe control devices in key industries.

[1] For example, a coal-fired power plant meets "ultralow emission standards" when its emission levels of major air pollutants are similar to those from gas-fired power plants.