Beijing–Tianjin–Hebei AQM Policy Report Series

中国清洁空气联盟
Clean Air Alliance of China

# How to Achieve the Air Quality Attainment in the Beijing, Tianjin and Hebei Region?

## Studies on Reaching $PM_{2.5}$ Standard in the Beijing-Tianjin-Hebei Region Based on Scenario Analysis

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CAAC

# CAAC Policy Report

CAAC Policy Reports are a series products to provide insights, analysis and recommendations based on China's air pollution control policies and management practices, to support the clean air work. The CAAC Policy Reports series are compiled by the CAAC secretariat in collaboration with CAAC members and experts.


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## Main Conclusions

In September, 2013, the State Council released "Action Plan on Air Pollution Prevention and Control (2013-2017)", which set the goal that the concentration of fine particulate matter ($PM_{2.5}$) in the Beijing-Tianjin-Hebei Region shall be decreased by 25% by 2017, among which the annual average $PM_{2.5}$ concentration in Beijing shall be controlled at about 60μg/m$^3$. According to the air quality attainment schedule[1] for cities across the country made by the Ministry of Environmental Protection (MEP) in 2013, the Beijing-Tianjin-Hebei Region should make medium and long term air quality attainment plans, and all the cities should strive to reach the national standard (annual average $PM_{2.5}$ concentration equals 35μg/m$^3$)[2] by 2030. Accordingly, Figure 1 shows the phased annual average $PM_{2.5}$ concentration reduction targets for cities in the Beijing-Tianjin-Hebei Region.

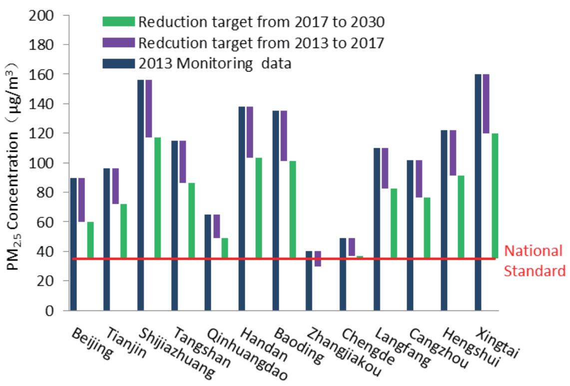


Figure 1. Phased Annual Average $PM_{2.5}$ Concentration Reduction Targets for Cities in the Beijing-Tianjin-Hebei Region

In order to achieve the medium and long term air quality targets for all the cities in the Beijing-Tianjin-Hebei Region by 2030, this study carries out scenario analyses on various air quality levels in 2030 in the Beijing-Tianjin-Hebei Region based on different scenarios. It sets three different scenarios: Business As Usual (BAU), Best Available Technology (BAT, which would strengthen end-of-pipe controls based on the BAU scenario), and Enhanced Energy Structure (EES, which would further energy and industrial structural adjustments on top of the BAT scenario). The study builds air pollutant emission inventories in the Beijing-Tianjin-Hebei Region for 2013 and 2030 under the three scenarios, simulates them with air quality models, and conducts a quantitative assessment on the effects of different air pollution prevention and control measures on reducing $PM_{2.5}$ in the Beijing-Tianjin-Hebei Region. The purpose is to provide a scientific reference for the region to reach the air quality standard by 2030. The simulation results show that all three of the BAU, BAT, and EES scenarios can improve air quality, but only the EES scenario can ensure that the entire Beijing-Tianjin-Hebei Region will reach national standard (see Figure 2). Under the EES scenario, annual average $PM_{2.5}$ concentration in Beijing, Tianjin, and Hebei will decrease from 89.5μg/m$^3$, 96μg/m$^3$, and 108 μg/m$^3$ in 2013 to 23.2μg/m$^3$, 28.0μg/m$^3$, and 28.2 μg/m$^3$ in 2030, a drop of 74%, 71%, and 74%, respectively. Although in this scenario, annual average $PM_{2.5}$ concentration in Beijing, Tianjin, and Hebei would be lower than 30 μg/m$^3$, some cities in Hebei Province, such as Hengshui, Handan and Shijiazhuang would be barely meeting the standard with annual average concentration of slightly lower than 35 μg/m$^3$ (See Figure 3)

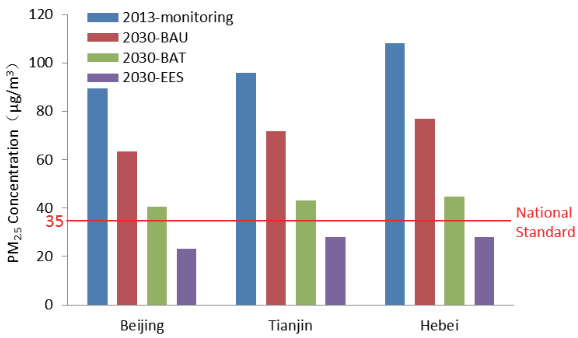


Figure 2 Annual Average $PM_{2.5}$ Concentration Reductions in the Beijing-Tianjin-Hebei Region under Different Scenarios

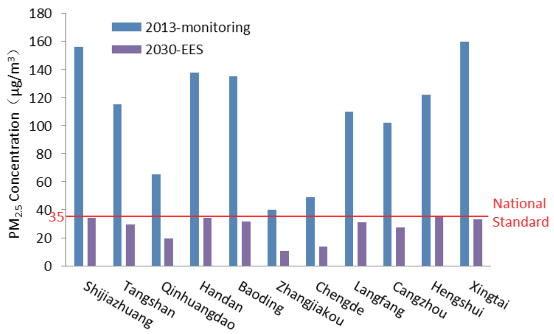


Figure 3 Annual Average $PM_{2.5}$ Concentration Reductions in Cities of Hebei Province under the EES Scenario

Based on the simulated results above, the main changes that are needed to reach air quality standard in all cities across the Beijing-Tianjin-Hebei Region in 2030 are listed below:

1. http://www.chinadaily.com.cn/hqgj/jryw/2013-01-25/content_8124505.html. The MEP Strives for Air Quality Standard Level 2 in All Cities across China by 2030: Cities with excessive major atmospheric pollutants of no more than 15% should strive to achieve the air quality standard by 2015, those with excessive major atmospheric pollutants between 15% and 30% should strive to achieve the air quality standard by 2020, and those with excessive major atmospheric pollutants of more than 30% should make medium and long term plans so that all cities across the country can achieve air quality standard Level 2 by 2030.

2. According to the "Ambient Air Quality Standard (AAQS) (GB3095-2012)", residential areas, commercial, transportation, and residential mixed areas, cultural areas, general industrial areas, and rural areas as defined in town planning should execute secondary standards, whose limit for annual average $PM_{2.5}$ concentration is 35μg/m$^3$. Since the major pollutant in the Beijing-Tianjin-Hebei Region is $PM_{2.5}$, the study takes the achievement of $PM_{2.5}$ attainment as an indicator for the achievement of air quality standard during the analysis.

1. Substantial adjustments to industrial structures: The long-term development pattern of the Beijing-Tianjin-Hebei Region will change according to its overall economic development pattern, which should become increasingly focused on the services industry. The output of high energy consumption industries should remain constant or begin to decrease. The dominance of heavy industries should be transformed before 2030.
   - Beijing should no longer have any industries except for "Urban Industries", which should be environmentally-friendly industries that consume little resources and primarily serve the needs of the city.
   - Tianjin's current large-scale heavy industry should no longer develop, and no similar industries should be established. In 2030, the annual output of iron and steel should be capped at 20 million tons, cement at 40 million tons, and plate glass at 23 million weight cases.
   - Hebei should develop a comprehensive industrial system and control the output of high energy consumption and high pollution industries. In 2030, the output of iron and steel should be capped at 120 million tons, cement at 70 million tons, and plate glass at 280 million weight cases.
2. Cleaner energy structures: The proportion of primary energy consumption that are fueled by coal in the Beijing-Tianjin-Hebei Region should decrease from 73.1% in 2012 to 30.7% in 2030, natural gas should increase from 7.8% to 28.6%, imported electricity from 4.4% to 15.3%, while the proportion from renewable energy sources should rise from 1% to 3.7%. Pollution from bulk coal for civil use should be fully under control, by using methods such as replacing coal with natural gas, renewable energy or clean coal. Meanwhile, coal with sulfur content higher than 0.6% should be completely banned.
   - The proportion of coal in Beijing's local primary energy consumption should decrease from 29.2% in 2012 to 1.9% in 2030, natural gas should increase from 25.2% to 39.7%, imported electricity from 13.6% to 18.8%, and renewable energy from 0.4% to 1.5%.
   - The proportion of coal in Tianjin's primary energy consumption should decrease from 62.0% in 2012 to 24.2% in 2030, natural gas should increase from 9.3% to 30.85%, imported electricity from 2.5% to 10.5%, and renewable energy from 0.3% to 1.1%.
   - The proportion of coal in Hebei's primary energy consumption should decrease from 84.5% in 2012 to 40.8% in 2030, natural gas should increase from 4.0% to 24.9%, imported electricity from 3.0% to 16.0%, and renewable energy from 1.5% to 5.3%.
3. Implementation of end-of-pipe control measures:
   - All coal-fired power stations in Beijing-Tianjin-Hebei Region achieve ultra-low emissions.
   - Iron and steel enterprises in Hebei and Tianjin should implement thorough upgrades such as installing efficient dust collectors, including bag dust collectors, electrostatic-fabric integrated dust collectors and so on, better manage and control unorganized emissions, and install desulfurization equipment on all sintering machines to ensure desulfurization efficiencies of no less than 85%.
   - Industrial boilers in Hebei and Tianjin should be thoroughly upgraded with bag dust collectors or electrostatic-fabric integrated dust collectors. All enterprises in the cement industry should use low $NO_X$ combustion technologies and carry out end-of-pipe denitrification treatment.
   - The Beijing-Tianjin-Hebei Region should completely eliminate medium, small, and obsolete boilers and upgrade the remaining large boilers to improve desulfurization, denitrification, and dust removal processes.
   - The average removal efficiency of volatile organic compounds (VOCs) in coking, external coating, package printing and other key industries should be no less than 70%.
   - Measures to enhance ammonia emission management and control should be effectively enhanced. By 2030, at least 70% of the animal husbandry industries in Tianjin and Hebei should be intensified, fertilizer consumption should be effectively controlled, and new fertilizer technologies with slow and controlled release should be widely promoted.
4. Effective Control on Transportation Pollution:
   - By 2030, vehicle-use gasoline and diesel oil upgrades should be fully completed, and all in-use vehicles should reach the "national VI" or stricter emission standards.
   - By 2030, the number of registered vehicles in Beijing should be capped at 6.76 million, and public transportation ratios in urban areas should be over 41%. Energy-saving cars should account for over 50% of Beijing's vehicle fleet, and electric vehicles over 40%.
   - By 2030, the number of registered vehicles in Tianjin should be capped at 4.49 million, and public transportation ratios in urban areas should be over 41%. Energy-saving cars should account for over 50% of Tianjin's vehicle fleet, and electric vehicles over 35%
   - By 2030, the number of registered vehicles in Hebei should be capped at 20.53 million, and public transportation ratio in urban areas should be over 36%. Energy-saving cars should account for over 50% of Hebei's vehicle fleet, and electric vehicles over 35%.

**Other Findings and Suggestions:**

1. Industrial and energy structures must be substantially adjusted in order to achieve air quality targets. By comparing different scenarios, the study found that if only end-of-pipe treatments were used, the Beijing-Tianjin-Hebei Region could not achieve the goal in 2030 even with all the best available technologies applied . Instead, regional industrial and energy structures must be adjusted at the same time. Adjusting industrial structures will change energy demand patterns accordingly. And as the Beijing-Tianjin-Hebei achieves more advanced economic models, energy demand would correspondingly reach a peak in 2030.
2. Science-based air quality attainment plans should be made and implemented as soon as possible. This report has presented related policies, measures, and suggestions for the Beijing-Tianjin-Hebei Region to reach air quality standard in 2030. However, when looking at specific management systems, all local governments would still need to make more detailed measures and plans based on local conditions. With the help of the pollutant emission inventories, air quality models, and other scientific methods and tools, Beijing, Tianjin, Hebei, and their surrounding areas should make regional air quality attainment plans after thoroughly reviewing the cost and effects of various emission reduction strategies to further establish systematic air quality attainment management mechanism.
3. Energy, industrial, and transportation planning should be consistent with air quality attainment plans. One important conclusion of this report underlines the fact that unless major adjustments are made to regional energy, industrial, and transportation structures, air quality goals cannot be accomplished. Therefore, plans in those fields should be ensured to be consistent with the requirements in the air quality attainment plan.
4. Environmental supervision and punishment for illegal operations should be strengthened, and pollutant discharge permitting system should be established as part a core component managing stationary pollution sources. This study assumes that all relevant measures under each scenario will be fully implemented, but in reality, there are still major challenges on the implemenation and supervision. By reforming pollutant discharge permitting system, environmental impact assessments, operational requirements, pollutant discharge supervision and declaration, environmental information disclosure, pollution surveys, environmental statistics, pollution rights trading, environmental rating, and other mechanisms should all be combined together, so that permitting system becomes the core mechanism for enterprises' environmental management and for government's supervision. Permitting system would ensure that enterprises fulfill their environmental liabilities and encourage the public to supervise the enterprises' pollutant discharges in the same time.
5. Areas around the Beijing-Tianjin-Hebei Region also need to vigorously improve air quality. If these areas maintain the status quo, the Beijing-Tianjin-Hebei Region could not achieve air quality targets even if it adopts the EES scenario. While assessing the emission reduction effects in the Beijing-Tianjin-Hebei Region, the study has also taken the air quality improvement in other areas across the country into consideration. But if the emission levels in other areas of the country are the same with those under the BAU scenario, the $PM_{2.5}$ annual average concentration of Beijing, Tianjin, and Hebei would increase by 22 $\mu g/m^3$, 21 $\mu g/m^3$, 16 $\mu g/m^3$ in 2030 respectively. Specifically, the annual average $PM_{2.5}$ concentration reduction in Beijing, Tianjin, and Hebei would be slashed by 15% to 25%.
6. Development of environmental protection service industry should be supported and input of private capital should be encouraged. The implementation of the measures proposed in this study depends on personnel and capital investment. In terms of personnel, both central and local governments are experiencing an extreme shortage of people engaged in air quality research, management, and enforcement. In order to solve this problem, on one hand, governments' personnel and capital input should be increased; on the other hand, third-party advisory bodies should be entrusted to do some management and support work. In terms of capital, governments can increase stable and diversified funds (including pollutant discharge fees, paid access to emission permits, resource taxes). Moreover, governments can also play a more active role in guiding private investments to increase their effects on air pollution treatment.
7. Air pollution prevention and control in the Beijing-Tianjin-Hebei Region would also reduce greenhouse gases emissions. Under the EES scenario, by 2030, $CO_2$ emissions in the Beijing-Tianjin-Hebei Region would be reduced by 210 million tons from 2013 emission levels, a drop of 19%. Among the emission reduction measures, energy restructuring (including replacing coal with gas, using transmitting power from external areas, developing non-fossil fuels, etc.) and industrial restructuring (including reducing production capacity of iron and steel, cement, and coking, etc.) contributes to 78% and 22% of the $CO_2$ emission reduction respectively
8. We should try our best to achieve air quality targets before 2030. Although this study takes 2030 as the target year, if the implementation of measures mentioned under the EES scenario can be realized in advance, and considering the possibility of technological advance in the future (for example, the accelerated development of renewable energy, etc.), the Beijing-Tianjin-Hebei Region can reach the air quality standard earlier than 2030.

# Contents

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# 1. Methodology

We began by simulating the base year (2013) air quality using the Community Multi-scale Air Quality (CMAQ[3]) based on the base year emission inventory and then verifying the simulation results; next, we set up three scenarios after considering various restructuring measures and end-of-pipe control measures, and adopted the IPAC-AIM / technical model[4] when forecasting the energy demand. Additionally, we derived the emission inventory of the target year (2030) based on the base year emission inventory and the analysis of end-of-pipe control measures, economic and social developmental level, energy consumption, product yield and transporation scenarios under different scenarios; and finally, we conducted air quality simulation to obtain air quality improvement effects in the target year under different scenarios (see Figure 1-1).

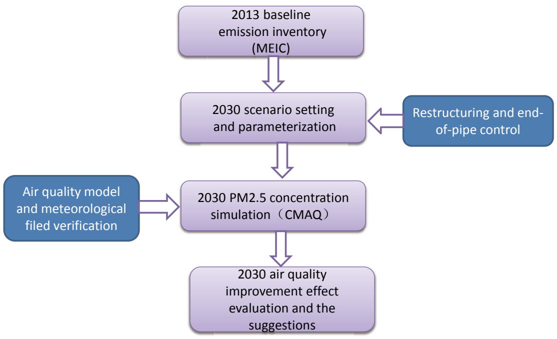



Figure 1-1 Methodology

We input the emission inventory of the base year[5] into CMAQ to simulate Beijing-Tianjin-Hebei Region′ s air quality in 2013. Using the meteorological field data in 2013 in the simulation, we compared and verified the simulation results with the monitoring data of 2013 (see Figure 1-2)[6]. Overall, the model can accurately simulate the absolute value of $PM_{2.5}$ concentrations and their spatial distribution, and can be used as a tool to assess the effectiveness of air pollution control measures.

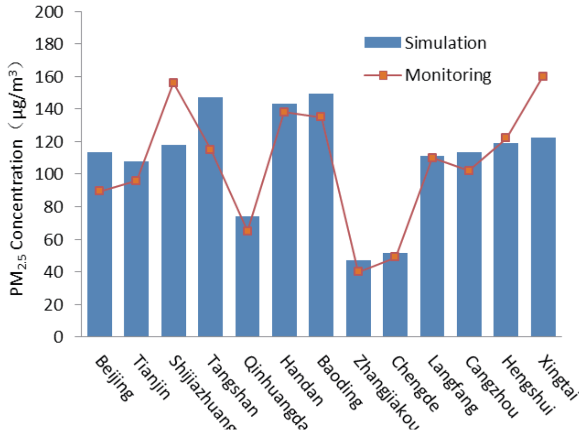



Figure 1-2 Comparison of Simulation Values and Monitoring Values of Base Year Annual Average $PM_{2.5}$ Concentration in Cities of the Beijing-Tianjin-Hebei Region

3. Community Multi-scale Air Quality (CMAQ) is a third-generation air quality model developed by the US Environmental Protection Agency and it mainly focuses on tropospheric ozone, acid deposition, visibility and particulate matter and other pollutants, and describes chemical reactions and transport of these pollutants in regional and urban scales.

4. IPAC-AIM / Technical model was developed by the Energy Research Institute of National Development and Reform Commission, for the purpose of describing the status quo and future development of energy services and their equipment in detail, and simulating the process of energy consumption.

5. The Chinese Multi-resolution Emission Inventory (MEIC) was developed by Tsinghua University, available through: http://www.meicmodel.org).

6. The data is sourced from the monitoring data in the urban air quality monitoring points of National Ambient Air Quality Monitoring Network.

## 2. Scenario Setting

For the quantitative analysis of pollution control effects and air quality improvements in the target year (2030), based on different energy and industrial structures and end-of-pipe control measures in the Beijing-Tianjin-Hebei Region, this study sets up three scenarios and forecasts the distribution of activity levels and control technologies related to energy consumption, production yield, and establishes three sets of corresponding emission inventories of air pollutants in the target year.

Air pollution prevention and control measures can be divided into two categories: restructuring measures and end-of-pipe control measures. Industrial restructuring and energy restructuring are the two standpoints of structural adjustment, which are measures that can reduce emissions from the source. End-of-pipe control measures refer to the measures used to reduce pollutant emissions prior to their emissions to the atmosphere.

Accordingly, the study sets up three scenarios based on two key factors of structural adjustment and end-of-pipe control. First, the study quantifies restructuring measures and end-of-pipe control measures of 2030 and sets them as the BAU scenario based on energy consumption, product yield and end-of-pipe control technologies in 2013 and according to the implementation of existing control measures. Second, the study establishes a database of best available technologies and replaces the original BAU end-of-pipe control technologies with the best available technologies, thus building the BAT scenario. Finally, the study strengthens energy restructuring and industrial restructuring based on the BAT scenario, to establish the EES scenario. Through setting these three scenarios, the study evaluates the effects of end-of-pipe control measures as well as the energy and industrial restructuring (see Figure 2-1). In this study, the target area is the Beijing-Tianjin-Hebei Region. But due to the fact that the air quality improvement is greatly influenced by other surrounding areas, this study applies the three scenarios in other areas as well. Scenario setting programs and reference data are shown in Figure 2-1.

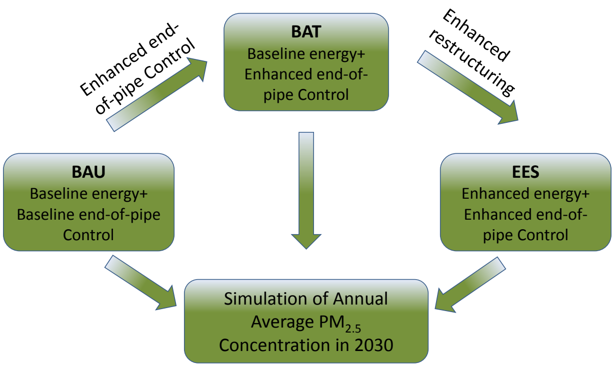



Figure 2-1 Scenario Setting

Table 2-1 Scenario Setting Programs and Reference Data

| Scenario | Setting | | Reference data |
|---|---|---|---|
| BAU | Baseline energy | Beijing-Tianjin-Hebei Region | The Business as usual scenario described in "Scenarios Study of Low Carbon Development in 2050"[7] |
| | | Other areas | |
| | Baseline end-of-pipe control | Beijing-Tianjin-Hebei Region | "Air Pollution Prevention and Control Action Plan" |
| | | Other areas | Air emission standard for key industries specified by the MEP and relevant compilation instructions |
| BAT | Baseline energy | Beijing-Tianjin-Hebei Region | Same to the BAU scenario |
| | | Other areas | |
| | Enhanced end-of-pipe control | Beijing-Tianjin-Hebei Region | "Guideline on Best Available Technologies of Pollution Prevention and Control" |
| | | Other areas | EU: BREFs[8]<br>USEPA: AirControlNET[9] |
| EES | Enhanced energy | Beijing-Tianjin-Hebei Region | "Beijing-Tianjin-Hebei aerosol haze emissions scenario study"[10] |
| | | Other areas | Low-carbon development scenario described in "Scenarios Study of Low Carbon Development in 2050" |
| | Enhanced end-of-pipe control | Beijing-Tianjin-Hebei Region | Same to the BAT scenario |
| | | Other areas | |

### 2.1 BAU

Energy and industrial restructuring measures in the Beijing-Tianjin-Hebei Region and other areas in the BAU scenario shall refer to the "Scenarios Study of Low Carbon Development in 2050".

The main structural adjustment measures include:

a. Optimize industrial structure: Strictly control the growth of production capacity of "high pollution and high energy-consuming" industries, fully phase-out outdated production systems; accelerate the exit of outdated production systems, and implement new production capacity to replace eliminated systems.

b. Control total coal consumption.

c. Develop clean coal-fired power: By 2030, the coal-fired power technology will be mainly supercritical and ultra-supercritical technologies in the Beijing-Tianjin-Hebei Region.

d. Promote clean coal and briquettes in civil sectors, make full use of clean energy, popularize energy-saving household appliances, and commercial energy to serve as the main energy in rural life.

e. Control total vehicle amount, enhance fuel economy, and reduce consumption of diesel and gasoline.

7. Jiang Kejun et al., Scenarios Study of Low Carbon Development in 2050. The report gives the overall national energy scenarios, and energy scenarios of Beijing-Tianjin-Hebei Region mentioned in this study are based on energy consumption proportions in the region in 2013.

8. European Commission: Reference Document on Best Available Techniques.

9. U.S. Environmental Protection Agency: Air Control NET Documentation Report (Version 4.1), which is used to support the database of pollutant emission control strategy and cost analysis.

10. Jiang Kejun et al., Beijing-Tianjin-Hebei aerosol haze emissions scenario study.

The end-of-pipe control measures of Beijing-Tianjin-Hebei Region and other areas in the BAU scenario shall refer to the "Action Plan on Air Pollution Prevention and Control" and air emission standards for key industries specified by the MEP and relevant compilation instructions, mainly including:

a. Desulphurization facilities should be installed in all coal-fired power plants, and the flue gas bypass in the flue-gas desulphurization facilities should be cancelled according to relevant regulations, and the integrated desulfurization efficiency of coal-fired power plants should reach 90% or more. Denitrification facilities should be installed in all coal-fired units except circulating fluidized bed (CFB) boilers. Dust removal standards should be upgraded for coal-fired power plants so that the concentration limit of particulate matter emissions should be reduced from 50 $mg/m^3$ down to 30$mg/m^3$, and the combination of electrostatic precipitation, wet flue gas desulfurization, and bag de-dusting should be promoted.

b. Desulfurization facilities should be installed in sintering machines and pellet production equipment of iron-steel enterprises. Dust removal standards of iron and steel industries should be upgraded, the converter secondary flue gas and furnace flue gas should implement a limit on particle matter emission concentration at 20$mg/m^3$, and high-efficiency bag dust collectors should be comprehensively promoted.

c. Desulphurization facilities should be installed in coal-fired boilers. Existing dust removal facilities should be upgraded and transformed, and new boilers should implement a limit on flue gas particulate matter emission concentration at 50$mg/m^3$, mainly using bag de-dusting, electrostatic precipitator, electrostatic bag de-dusting and other high-efficiency dust removal technologies. Low NOx combustion technology should be applied in new boilers.

d. Low NOx combustion technology should be applied and denitrification facilities should be installed in new dry cement kilns. Dust removal standards of iron and steel industry should be upgraded, implementing the concentration limit of particle matter emissions at 20$mg/m^3$ - 30$mg/m^3$, and high-efficiency electrostatic precipitator and bag dust collectors should be further promoted.

e. Existing dust removal facilities should be upgraded and transformed in industrial stoves.

f. Promote emission control standards for motor vehicles, implement China V Standards and gradually implement the China VI Standards; hasten the elimination of yellow label cars and old vehicles; accelerate efforts to upgrade and replace low-speed vehicles; and vigorously promote new energy vehicles.

g. Comprehensive VOCs control should be implemented in petrochemicals, organic chemicals, surface coating, packaging, printing and other industries. 'Leak Detection and Repair' (LDAR) should be conducted in the petrochemical industry. Oil and gas vapor recovery should be done in petrol stations, oil storage tanks and oil tank trucks in the near future. Improve VOCs emission limits for coatings, adhesives and other products; promote the use of water-based paint; and encourage the production, sale and use of low toxicity, low volatile organic solvents.

### 2.2 BAT

Energy and industrial restructuring measures in the BAT scenario are the same with those in the BAU scenario.

Enhanced end-of-pipe control measures under the BAT scenario in the Beijing-Tianjin-Hebei Region and other areas shall refer to the "Action Plan on Air Pollution Prevention and Control", BREFs of the EU and Air Control NET of USEPA, specifically including:

a. Ultra-low emission in coal-fired power plants: advanced technologies to treat flue and gas should be adopted to help coal-fired power plants emissions reach or become lower than the emission level of natural gas power plants. Emission concentrations of dust, $SO_2$ and NOX should be lower than 5$mg/m^3$, 35$mg/m^3$, and 50$mg/m^3$, respectively.

b. Industrial boilers: Based on the instructions of the "Emission Standards of Air Contaminations of Boilers (draft)", industrial boilers should mainly use high-efficiency dust removal technologies including bag de-dusting, electrical de-dusting and electrical bag de-dusting. Desulphurization should be fully completed in coal-fired boilers, low NOx combustion technological transformation should be conducted in the Beijing-Tianjin-Hebei Region, and facilities should be installed in industrial boilers.

c. Cement industry: Low NOx combustion technology should be applied and denitrification facilities should be installed in new dry cement kilns. According to the "Emission standards for Air Pollutants of the Cement Industry (GB 4915-2013)", high-efficiency electrostatic precipitators and bag dust collectors should be applied in the cement industry.

d. Iron & steel industry: Desulfurization facilities should be installed in all sintering machines of iron-steel enterprises, with desulfurization efficiency of no lower than 85%. Referring to the standard levels of United States, Japan, and UK and the EU control level, emission levels of flue gas particulate matters of the steel industry should be controlled within 0.05kg/t.

e. Motor vehicles: Upgrade from the "Euro - V" to "Euro - VI". The "China VI Standard" ("Beijing Standard VI") will be implemented in Beijing in 2016 and the "China VI" will be implemented in Tianjin and Hebei Province in 2022.

a. VOCs related emission sources: By 2030, VOCs emissions will be significantly reduced in coking, surface coating, packaging, printing and other key industries compared to that of 2013, with a decline of 90%~95% in the oil and gas storage and transportation related industries, and a decrease of more than 50% in the coking and chemical industries.

b. $NH_3$ related sources: In 2030, at least 70% of the animal husbandry industries in Tianjin and Hebei will be intensified, fertilizer consumption will be effectively controlled and new slow and controlled release fertilizer technologies will be promoted widely.

### 2.3 EES

Based on the BAT scenario, the EES scenario will further adjust the energy and industrial structures in the Beijing-Tianjin-Hebei Region and other areas.

The industrial and energy structures under the EES scenario in the Beijing-Tianjin-Hebei Region should refer to the report of the "Beijing-Tianjin-Hebei aerosol haze emissions scenario study". The long-term development pattern of the Beijing-Tianjin-Hebei Region will change to focus on the services industry in the future. The development of high energy consumption industries would have peaked and outputs would remain constant or begin to decrease. The dominance of heavy industries will be shifted before 2030.

Specific structural adjustment measures involved in the Beijing-Tianjin-Hebei Region mainly include:

a. Adjust and optimize industrial structures. Beijing should no longer have any industries except for "Urban Industries"[11]. Tianjin's current large-scale heavy industry should no longer develop, and no similar industries should be established. Hebei should continuously develop a comprehensive industrial system, further reduce the production of crude steel, flat glass, cement, coke and other products, and industrial technologies should be improved.

b. Control total coal consumption. Hebei Province should focus on cutting coal use in power generation and heating, coking and energy-intensive industries (metallurgy, building materials, etc.). Tianjin and Beijing should also slash coal use and focus on reducing coal use in coal-intensive industries, as well as power generation and heating industries.

c. Clean energy alternatives. Increase the supply of natural gas, liquefied petroleum gas, solar and other clean energies, and gradually improve urban proportions of clean energy use.

d. Increase the proportion of purchased electricity and energy from new sources.

e. Restrict the total vehicles, vigorously promote new energy vehicles, establish a more convenient transportation network, and improve the load factor of urban public transport.

The industrial and energy structure under the EES scenario in the Beijing-Tianjin-Hebei Region and other areas shall refer to the low-carbon development scenario described in the "Scenarios Study of Low Carbon Development in 2050", and major restructuring measures shall be strengthened on top of the BAU scenario:

a. Further optimize industrial structures and rapidly develop new industries and the tertiary industry.

b. Further control total coal consumption.

c. In 2030, advanced energy technologies will be widely used. Chinese industry and alternative energy technologies will become the world leader; while China will also become a world leader in developing advanced energy-saving technologies, with approximately a 40% improvement in technical efficiency.

d. Low-carbon and environmentally friendly housing will be widely used.

e. Fuel efficiency will be further improved.

11. Urban industries refer to the environmentally-friendly and low-resource-consumption industries that take urban areas as their ultimate service group. The urban industries have a wide range, mainly including electronic information product research, development and assembly, software development, manufacturing, apparel, advertising, printing, packaging, arts and crafts and travel goods, watches and clocks, glasses, model and mold design and manufacturing, food processing, design, development and assembly of interior decoration products, cosmetics and household cleaning supplies

## 3. Analysis on Pollutants Emission Reduction in Beijing-Tianjin-Hebei Region in 2030

### 3.1 Main Sources of $PM_{2.5}$ in the Beijing-Tianjin-Hebei Region

According to the base year emission inventory in the Beijing-Tianjin-Hebei Region, industrial processes and civil sectors are the major sources of regional primary $PM_{2.5}$, contributing to 51% and 30% of the total, respectively. As for industrial process, emissions mainly come from the iron and steel, cement, coke, and other industries. For civil sectors, emissions mainly come from domestic coal combustion and biomass burning. In addition, electricity, heating, industrial boilers and transportation sectors contribute to 4%, 4%, 7% and 4% of the total primary $PM_{2.5}$ emissions, respectively.

Precursors of secondary $PM_{2.5}$[12] mainly include $SO_2$, NOx, VOCs, and $NH_3$. According to the base year emissions inventory in the Beijing-Tianjin-Hebei Region, $SO_2$ emissions are mainly sourced from industrial boilers, industrial processes (mainly the iron and steel sintering and industrial furnaces), electricity, civil and heating sectors, contributing to 38%, 19%, 17%, 16% and 9% respectively; NOx emissions mainly come from transportation, industrial boilers, electricity, heating and industrial processes (mainly the cement industry), contributing to 28%, 28%, 23%, 11% and 6% respectively. VOCs emissions are mainly sourced from solvent use, industrial processes, and civil and transportation sector, contributing to 38%, 29%, 17% and 8% respectively. $NH_3$ is mainly sourced from chemical fertilizer and livestock in the agricultural sector.[13]

### 3.2 Emission Reductions of Pollutants in the Beijing-Tianjin-Hebei Region under Different Scenarios

The study focuses on the changes in emission of four pollutants: $SO_2$, NOx, primary $PM_{2.5}$ and VOCs. The emission reductions of the four pollutants in 2030 under different scenarios were derived based on the 2013 emission inventory of the Beijing-Tianjin-Hebei Region and through analyzing restructuring and end-of-pipe measures under the three scenarios (see Figure 3-1). Among the three provinces, Hebei contributes most to the emission reductions of pollutants in the Beijing-Tianjin-Hebei Region due to its higher emissions quantities than that of the other two regions. Under the EES scenario, Hebei contributes to 83%, 75%, 82%, and 64% of emission reductions of $SO_2$, NOx, primary $PM_{2.5}$, and VOCs, respectively.

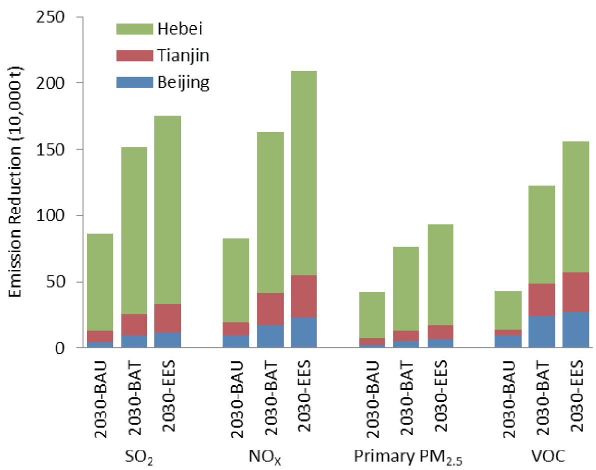


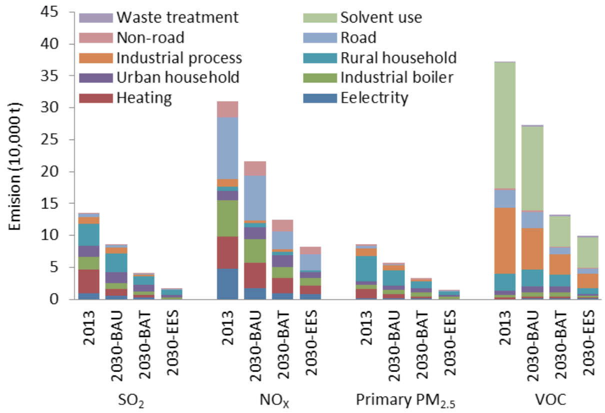

Figure 3-1 Emission Reductions of Pollutants in the Beijing-Tianjin-Hebei Region under Different Scenarios

12. Secondary $PM_{2.5}$ includes sulfates, nitrates, ammonium salts and other inorganic particles and secondary organic aerosols and it is composed of particulate matters changing from various gaseous pollutants (precursors) such as $SO_2$, $NO_X$, VOC, $NH_3$, etc., through complex chemical reactions in the atmosphere.

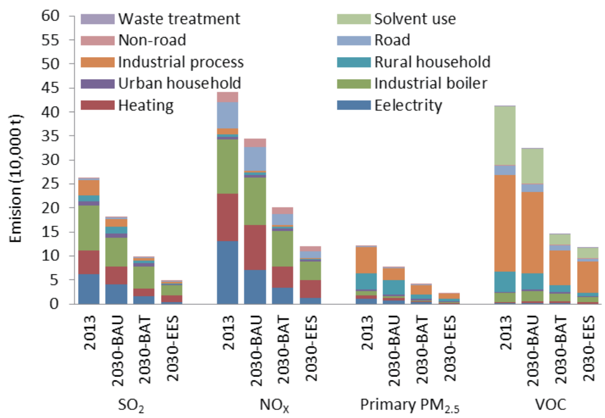
13. Huang X, Song Y, Li M, et al. A high-resolution ammonia emission inventory in China [J]. Global Biogeochemical Cycles, 2012, 26 (1).

### 3.3 Emissions of Pollutants in Different Industries in the Beijing-Tianjin-Hebei Region under Different Scenarios

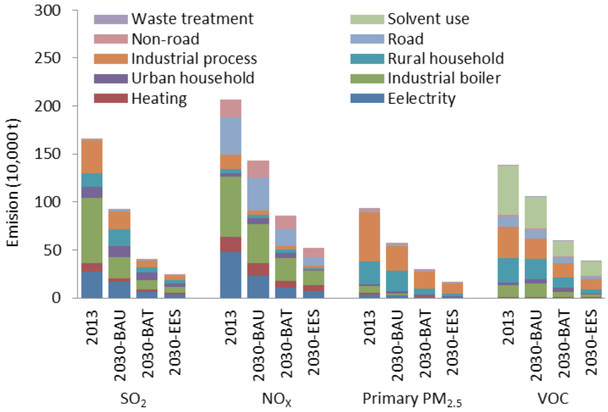
See Figure 3-2 for the emissions of four pollutants in different industries in the Beijing-Tianjin-Hebei Region under different scenarios.




(a) Beijing




(b) Tianjin




(c) Hebei

Figure 3-2 Emissions of Pollutants in Different Industries in the Beijing-Tianjin-Hebei Region under Different Scenarios

It can be seen in Figure 3-2 that existing policies will help reduce emissions of $SO_2$, NOx, primary $PM_{2.5}$ and VOCs in 2030 by around 1/3 on the basis of 2013. Enhancing end-of-pipe control measures under the BAT scenario can help reduce the emissions of $SO_2$, $NO_X$, primary $PM_{2.5}$, and VOCs by about 73% 58%, 67% and 57%, respectively, from 2013 levels. Further adjusting energy and industrial structures in the Beijing-Tianjin-Hebei Region, which is the EES scenario, can help reduce emissions of $SO_2$, $NO_X$, primary $PM_{2.5}$ and VOCs by about 85%, 74%, 82% and 72%, respectively, from 2013 levels.

It can also be seen from Figure 3-2 that structural adjustments have significant effects on the reduction of $SO_2$ and primary $PM_{2.5}$ emissions, and enhanced end-of-pipe control has obvious effect on $NO_X$ and VOCs emissions

### 3.4 Contributions of Different Measures on Emission Reduction under the EES Scenario

Figure 3-3 shows the contributions of emission reduction from different measures under the EES scenario. It can be seen that the desulfurization of industrial boilers contributes maximally to the emission reduction of $SO_2$ (35%), followed by energy restructuring (26%); the emission control of motor vehicle, power plant denitrification and industrial boiler contributes to the emission reduction of NOx almost the same, respectively 25%, 24% and 22%; industrial stove de-dusting upgrade contributes maximally to the emission reduction of primary $PM_{2.5}$ (27%), followed by the energy restructuring (23%); solvent contributes the greatest to emission reduction of VOCs (39%), followed by VOCs end-of-pipe control of key industries (26%).

### 3.5 Co-benefits on Greenhouse Gas Emission Reductions under the EES Scenario

The air pollution treatment in the Beijing-Tianjin-Hebei Region also has the effect of reducing the emission of greenhouse gases. Under the EES scenario, the emission of carbon dioxide in the Beijing-Tianjin-Hebei Region in 2030 will be reduced by 210 million tons on the basis of the emission in 2013, a drop of 19%. Among the emission reduction measures, energy restructuring (including "replacing coal with gas", using externally transmitted power, developing non-fossil fuels, etc.) and industrial restructuring (including reducing the production capacity of iron and steel, cement and coking, etc.) contribute to 78% and 22% of the carbon dioxide emission reductions inthe Beijing-Tianjin-Hebei Region respectively.

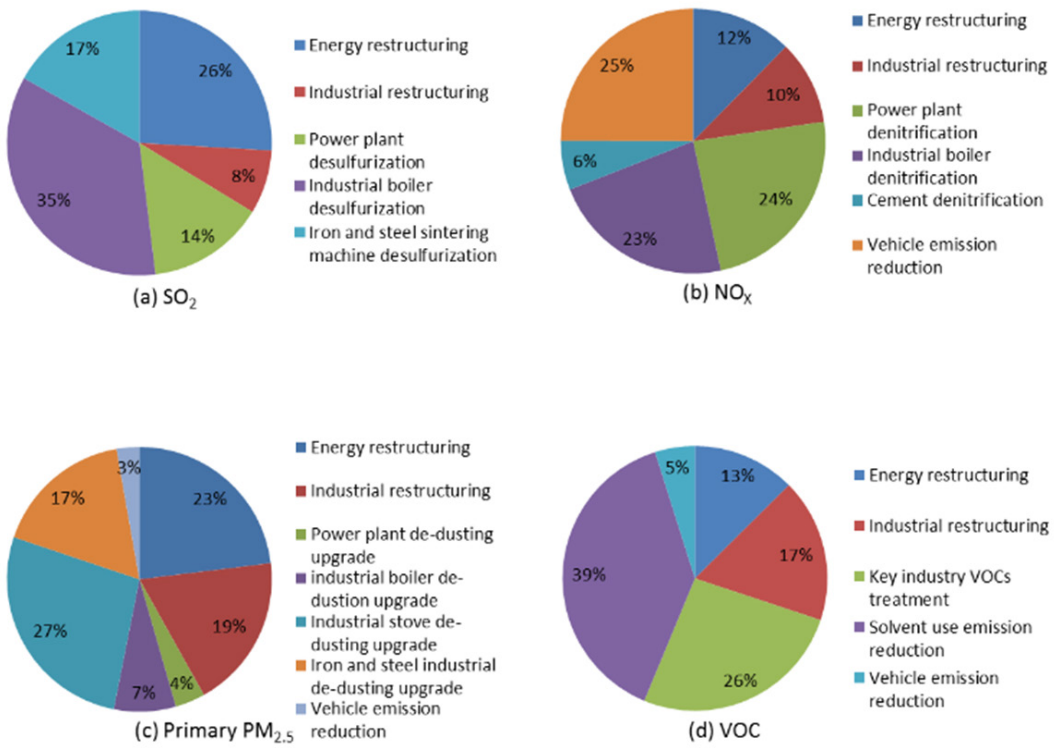



Figure 3-3 Contribution of Different Measures on Emission Reduction of Major Pollutants under the EES Scenario

# 4. Analysis on Air Quality Improvement Effect in the Beijing-Tianjin-Hebei Region in 2030

### 4.1 Annual Average $PM_{2.5}$ Concentration in the Beijing-Tianjin-Hebei Region in 2030 under Different Scenarios

Based on the establishment of the emission inventories for 2013 and 2030, CMAQ model is used to simulate $PM_{2.5}$ pollution situation under different scenarios in the Beijing-Tianjin-Hebei Region in 2030, and the results are shown in Figure 4-1. The same meteorological data (2013) are used in the target year and the base year.

The simulation results show that the BAU, BAT, and EES scenarios can obviously improve the air quality in the Beijing-Tianjin-Hebei Region, but only the EES scenario can ensure the whole Beijing-Tianjin-Hebei Region to reach the standard. In the EES scenario, the annual average $PM_{2.5}$ concentration in Beijing, Tianjin, and Hebei will decrease from 89.5μg/m³, 96μg/m³, and 108 μg/m³ in 2013 to 23.2 μg/m³, 28.0 μg/m³, and 28.2 μg/m³ in 2030, a drop of 74%, 71%, and 74% respectively. However, due to great difference of annual average $PM_{2.5}$ concentration in different cities in Hebei Province, improvement effects are also different. See Figure 4-2 for the results of annual average $PM_{2.5}$ concentration in different cities in Hebei Province under the EES scenario in 2030. It can be seen from the Figure that all cities can meet the standard, but there is still risk for some cities to achieve the target because they are extremely close to the standard limit.

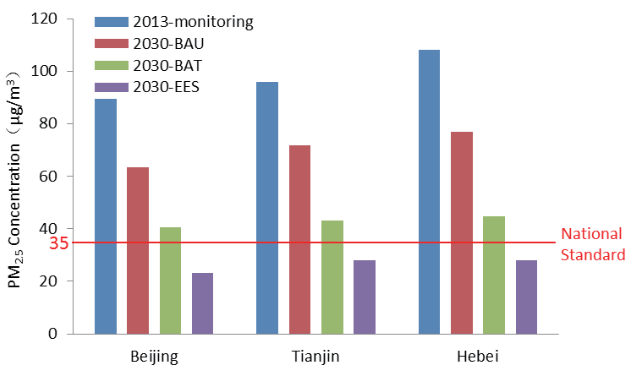



Figure 4-1 Annual Average $PM_{2.5}$ Concentration Reduction in the Beijing-Tianjin-Hebei Region under Different Scenarios

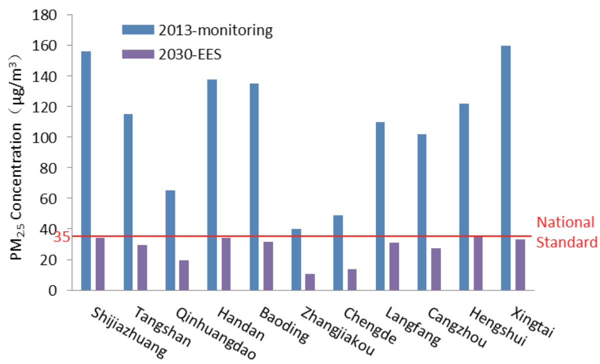



Figure 4-2 Annual Average $PM_{2.5}$ Concentration Reduction in Cities of Hebei Province under the EES Scenario

### 4.2 Contributions of Different Components to the Decline of Annual Average $PM_{2.5}$ Concentration in the Beijing-Tianjin-Hebei Region under Different Scenarios

Particulate matters have different components, including elemental carbon (EC), nitrate ($NO_3^-$), sulfate ($SO_4^{2-}$), ammonium ($NH_4^+$), organic components (OM), and other components (others), whose contributions to the reduction of annual average $PM_{2.5}$ concentration in Beijing, Tianjin and Hebei are shown in Figure 4-3. It can be seen that organic components and other components contribute maximally to the decline of annual average $PM_{2.5}$ concentration in the Beijing-Tianjin-Hebei Region, the contributions of sulfate and nitrate are relatively obvious; and the contribution of elemental carbon in Beijing is also obvious.

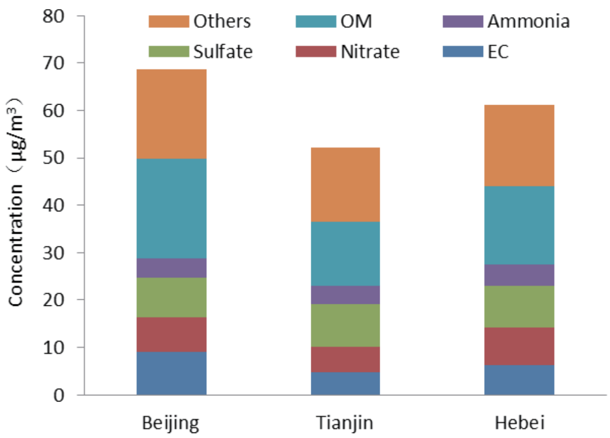



Figure 4-3 Contributions of Different Components to the Decline of Annual Average $PM_{2.5}$ Concentration in the Beijing-Tianjin-Hebei Region under the EES Scenario

From further analysis and comparison of absolute and relative changes of different components of $PM_{2.5}$ (Figure 4-4) as well as the pollutant emission changes of $SO_2$, NOx, VOCs and other pollutants (Figure 3-2) in 2030 and 2013, it can be seen that:

1. Sulfate concentrations falls significantly in three provinces, at 66.9%, 64.2%, and 65.1% respectively, but lower than the decline of $SO_2$ emissions (about 80%).
2. Nitrate concentration falls significantly in the three provinces, at 44.3%、37.4% and 41.9% respectively, but far lower than the decline of NOx emission (70~75%).
3. The decline of different organic component concentrations in the Beijing-Tianjin-Hebei Region is basically the same with the decline of VOCs emissions, around 70%.

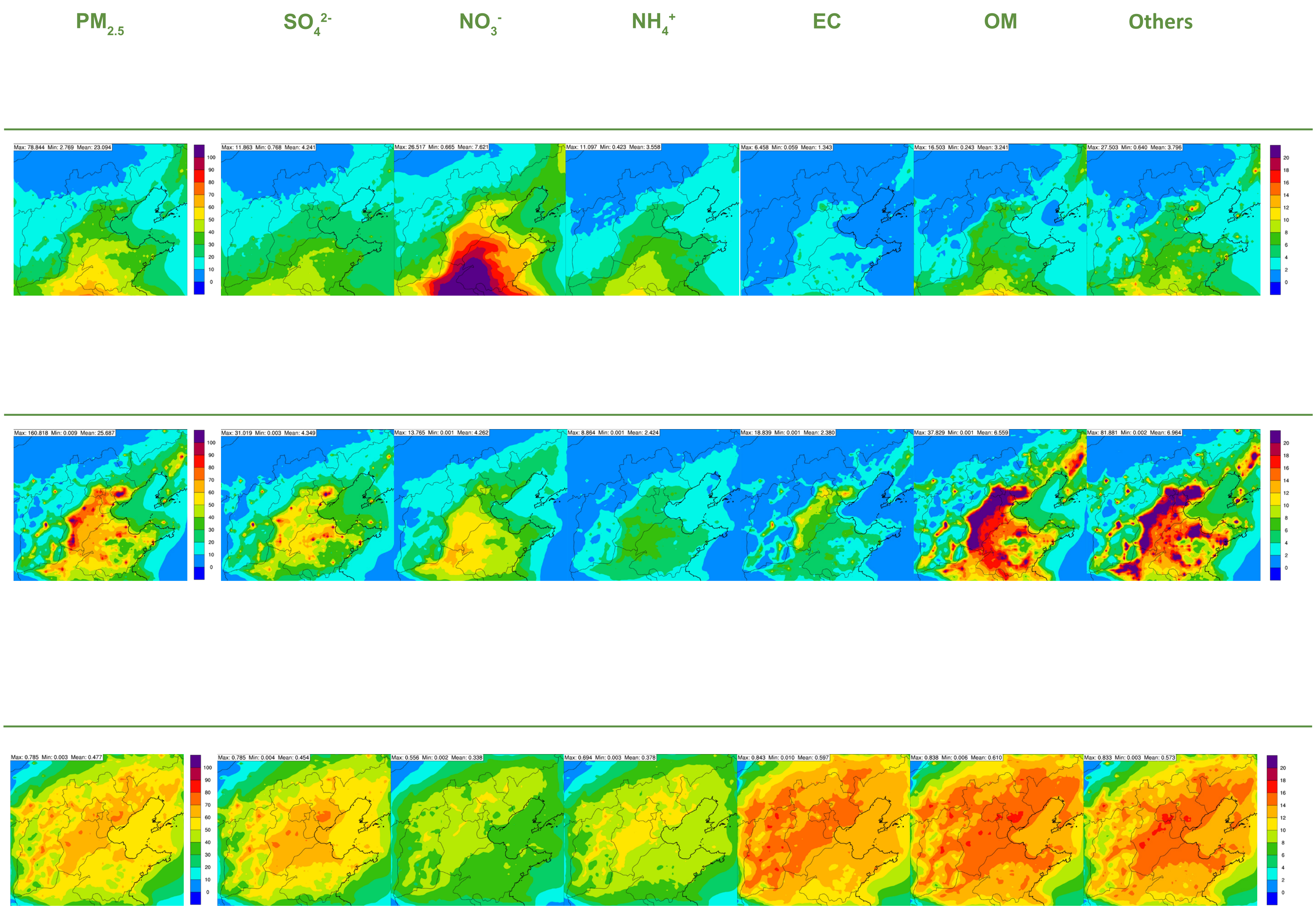



Figure 4-4 Spatial Distribution of the Annual Average Concentrations of $PM_{2.5}$ and Its Components in the Beijing-Tianjin-Hebei Region in 2030 under the EES Scenario and the Absolute and Relative Changes Compared to 2013

## 5. Suggestions on Policies & Measures

The main changes that are needed to reach air quality standard in all cities across the Beijing-Tianjin-Hebei Region in 2030 are listed below:

1. Substantial adjustments to industrial structures: The long-term development pattern of the Beijing-Tianjin-Hebei Region will change according to its overall economic development pattern, which should become increasingly focused on the services industry. The output of high energy consumption industries should remain constant or begin to decrease. The dominance of heavy industries should be transformed before 2030.
   - Beijing should no longer have any industries except for "Urban Industries", which should be environmentally-friendly industries that consume little resources and primarily serve the needs of the city.
   - Tianjin's current large-scale heavy industry should no longer develop, and no similar industries should be established. In 2030, the annual output of iron and steel should be capped at 20 million tons, cement at 40 million tons, and plate glass at 23 million weight cases.
   - Hebei should develop a comprehensive industrial system and control the output of high energy consumption and high pollution industries. In 2030, the output of iron and steel should be capped at 120 million tons, cement at 70 million tons, and plate glass at 280 million weight cases.
2. Cleaner energy structures: The proportion of primary energy consumption that are fueled by coal in the Beijing-Tianjin-Hebei Region should decrease from 73.1% in 2012 to 30.7% in 2030, natural gas should increase from 7.8% to 28.6%, imported electricity from 4.4% to 15.3%, while the proportion from renewable energy sources should rise from 1% to 3.7%. Pollution from bulk coal for civil use should be fully under control, by using methods such as replacing coal with natural gas, renewable energy or clean coal. Meanwhile, coal with sulfur content higher than 0.6% should be completely banned.
   - The proportion of coal in Beijing's local primary energy consumption should decrease from 29.2% in 2012 to 1.9% in 2030, natural gas should increase from 25.2% to 39.7%, imported electricity from 13.6% to 18.8%, and renewable energy from 0.4% to 1.5%.
   - The proportion of coal in Tianjin's primary energy consumption should decrease from 62.0% in 2012 to 24.2% in 2030, natural gas should increase from 9.3% to 30.85%, imported electricity from 2.5% to 10.5%, and renewable energy from 0.3% to 1.1%.
   - The proportion of coal in Hebei's primary energy consumption should decrease from 84.5% in 2012 to 40.8% in 2030, natural gas should increase from 4.0% to 24.9%, imported electricity from 3.0% to 16.0%, and renewable energy from 1.5% to 5.3%.
3. Implementation of end-of-pipe control measures:
   - All coal-fired power stations in Beijing-Tianjin-Hebei Region achieve ultra-low emissions.
   - Iron and steel enterprises in Hebei and Tianjin should implement thorough upgrades such as installing efficient dust collectors, including bag dust collectors, electrostatic-fabric integrated dust collectors and so on, better manage and control unorganized emissions, and install desulfurization equipment on all sintering machines to ensure desulfurization efficiencies of no less than 85%.
   - Industrial boilers in Hebei and Tianjin should be thoroughly upgraded with bag dust collectors or electrostatic-fabric integrated dust collectors. All enterprises in the cement industry should use low $NO_X$ combustion technologies and carry out end-of-pipe denitrification treatment.
   - The Beijing-Tianjin-Hebei Region should completely eliminate medium, small, and obsolete boilers and upgrade the remaining large boilers to improve desulfurization, denitrification, and dust removal processes.
   - The average removal efficiency of volatile organic compounds (VOCs) in coking, external coating, package printing and other key industries should be no less than 70%.
   - Measures to enhance ammonia emission management and control should be effectively enhanced. By 2030, at least 70% of the animal husbandry industries in Tianjin and Hebei should be intensified, fertilizer consumption should be effectively controlled, and new fertilizer technologies with slow and controlled release should be widely promoted.
4. Effective Control on Transportation Pollution:
   - By 2030, vehicle-use gasoline and diesel oil upgrades should be fully completed, and all in-use vehicles should reach the "national VI" or stricter emission standards.
   - By 2030, the number of registered vehicles in Beijing should be capped at 6.76 million, and public transportation ratios in urban areas should be over 41%. Energy-saving cars should account for over 50% of Beijing's vehicle fleet, and electric vehicles over 40%.
   - By 2030, the number of registered vehicles in Tianjin should be capped at 4.49 million, and the public transportation ratios in urban areas should be over 41%. Additionally, energy-saving cars should account for more than 50% of Tianjin's vehicle fleet, and electric vehicles more than 35%.
   - By 2030, the number of registered vehicles in Hebei should be capped at 20.53 million, and the public transportation ratio in urban areas should be over 36%. Additionally, the energy-saving cars should account for more than 50% of Hebei's vehicle fleet, and electric vehicles more than 35%.

## 6. Uncertainty Analysis

Based on the structural adjustment and end-of-pipe control, this study sets up three different scenarios (BAU, BAT, and EES) and qualifies to obtain the levels of energy consumption, industrial structure and end-of-pipe control under different scenarios; this study uses CMAQ model to simulate the reduction of annual average $PM_{2.5}$ concentrations in the Beijing-Tianjin-Hebei Region in 2030 under different scenarios, and a conservative method is used to access the air quality improvement effect. To identify other factors that might have important impact on the $PM_{2.5}$ pollution in the Beijing-Tianjin-Hebei region, this study conducts a simple uncertainty analysis, mainly including:

1. Inter-annual variability of meteorological conditions

In this study, the meteorological conditions in 2013 are adopted for the simulation, and some previous studies show that the meteorological conditions in 2013 were extreme. It′s suggested that correction coefficient of meteorological conditions should be used in the assessment; or according to international experience, a three-year average air quality assessment should be used as the assessment basis, so as to reflect the degree of pollutant emission reduction more objectively.

2. Influence of emission reduction in other areas

While assessing the emission reduction effects in the Beijing-Tianjin-Hebei Region under different scenarios, the study has also taken the air quality improvement in other areas across the country into consideration. But if the emission levels in other areas of the country are the same with those under the BAU scenario, the annual average $PM_{2.5}$ concentration of Beijing, Tianjin, and Hebei will increase by 22 $\mu g/m^3$, 21 $\mu g/m^3$, and 16 $\mu g/m^3$ in 2030 respectively, namely the reduction of annual average $PM_{2.5}$ concentration in Beijing, Tianjin, and Hebei will drop by 15% to 25%..

3. Difficulty in quantifying the VOCs emission reduction measures

Industrial processes and solvent use are the main sources of VOCs, this study strengthens VOCs emission control in key industrial processes and solvent use in the process of scenario analysis, but the sound emission standards and monitoring systems are still lack in our country, and therefore poor execution and difficulty in quantification appear. To guarantee the improvement of $PM_{2.5}$ concentration, VOCs emissions standards for key industries should be developed and on-line monitoring system should be improved.

4. Difficulty in conducting $NH_3$ emission reduction measures

Chemical fertilizer and animal husbandry are the key sources of NH3 emissions. Currently, there are no specific programs or standards in agricultural non-point source control, and therefore it′s difficult to conduct NH3 emission reduction measures for agricultural non-point sources and hard to assess the improvement effect. It′s needed to pay attention to and strengthen the pollution treatment of agricultural non-point sources, so as to ensure the effectiveness of $NH_3$ emission reduction measures implemented and to achieve the PM2.5 reduction target.

## Clean Air Alliance of China

Clean Air Alliance of China (CAAC), initiated by 10 key Chinese academic and technical institutions in clean air field, aims at providing an integrated clean air collaboration platform in China for academic and technical institutions, provinces and cities, Non-profit organizations and enterprises. The overarching goal is to improve air quality in China and mitigate the negative impacts on public health due to air pollution. The members of CAAC include academic institutions, provinces & cities, as well as other nonprofit organizations and enterprises that care about clean air.

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