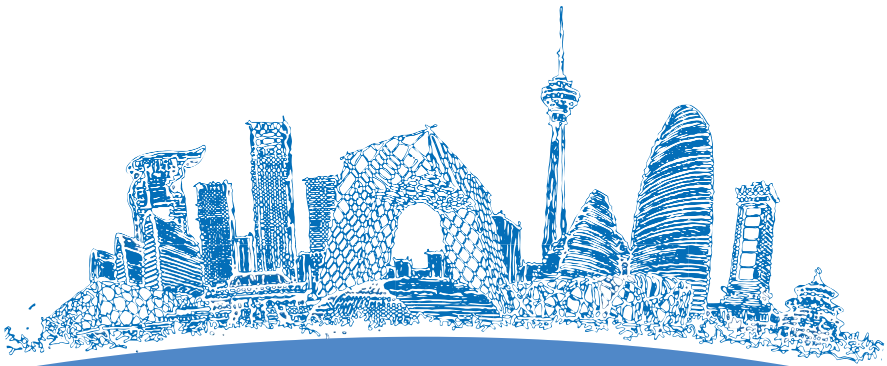
UN environment

A REVIEW OF 20 YEARS'
Air Pollution Control in Beijing



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FOREWORD

For years, Beijing had the unhappy distinction of being a polluted city. How quickly things can change. In just five years, from 2013 to 2017, fine particle levels in Beijing and the surrounding region fell by around 35% and 25% respectively. No other city or region on the planet has achieved such a feat.

This didn't happen by accident, of course. It was the result of an enormous investment of time, resources and political will, including President Xi's vision of an Ecological Civilization, "wars on pollution control" launched by the State Council, a substantially revamped Air Quality Law, new penalties for non-compliance, local clean air action plans, and Beijing's own cutting-edge initiatives. It was a long and arduous journey, and many important lessons were learned along the way.

Understanding Beijing's air pollution story is crucial for any nation, district or municipality that wishes to follow a similar path. Indeed, as this report makes clear, the city's experiences offer lessons that can apply in almost any context:

- Heavy industrialization leaves a long legacy of tainted water, soil and air. Diversifying one's domestic economy is a wise move at any state of development.
- Vehicle emission control is of key importance for clean air. Especially, old cars and trucks disproportionately contribute to urban air pollution.
- Private enterprises have little incentive to install emission controls until they are mandated to do so. Governments should consider other ways to induce companies to do the right thing.
- Information is power. Data transparency enables all elements of society to participate in achieving environmental objectives.
- Air pollution crosses every jurisdictional boundary: international, national, regional and local. Cooperation across borders is critical to forging effective and lasting solutions.
- There are deep reserves of scientific knowledge and air quality management experience around the world, and they are available to anyone who wishes to draw upon them.

This is the third time that UN Environment organizes assessment on Beijing's air quality programmes. In 2009, we published an independent analysis of the 2008 Summer Olympics, highlighting the city's success in guarantee good air quality during the Games. In 2016, we reviewed Beijing's air quality interventions from 1998 to 2013, recognizing the substantial achievement and made several recommendations for what the city could do next. We are grateful to see that all of those ideas have been put to good use.

This report is somewhat different, and takes a much longer view. Part I, which is aimed at students of public policy, describes how Beijing's air quality management programme has evolved over the past quarter century: the fits and starts, the trials and the triumphs, the evidence of what worked and what did not. Part II is for those interested in the ultimate goal, air that is truly healthy, and that meets global standards. In this section, we consider the challenges ahead and suggest some near-, medium- and long-term steps that Beijing can take to maintain its momentum toward clean air. We believe the fresh experience and lessons from Beijing could be of help for many cities suffering air pollution.

We at UN Environment have been honoured to work with the former Beijing Municipal Environmental Protection Bureau over the past few decades. We look forward to many more years of collaboration with the newly created Beijing Municipal Ecology and Environment Bureau as we strive together towards a planet that is, finally, free of pollution.

Joyce Msuya,
Acting Executive Director
UN Environment Programme

FOREWORD

(Photograph credit: Liu Jiawei)

Winter of 2017 was a moment of triumph and milestone for the city of Beijing in our war against air pollution. Decades of hard work and mounting investments by the municipal government paid off with a dramatic reduction in air pollution. In five years (2013-2017), annual average $PM_{2.5}$ concentrations in Beijing fell from 89.5 to 58$\mu g/m^3$, surpassing the 60 $\mu g/m^3$ target set by the State Council. Moreover, the entire region of Beijing-Hebei-Tianjin shared in this achievement, cutting fine particle pollution by 25% overall from the 2013 baseline. It was the single biggest step forward in more than a quarter century of steady progress. The war was officially launched by the city in 1998, air quality has kept improving trends in 20 years with hundreds of measures implemented in phases. The five years during 2013 to 2017 was the period of most significant improvement.

We are proud of being one party of the war and the deserved result. What makes us more happy is that this air quality improvement has been achieved under the rapid social and economical development in the capital city. Over the past 20 years, Beijing's gross domestic product (GDP) has maintained a growth rate over 6.5% each year, increased by 10.8 times totally. In 2017, per capita GDP has exceeded 20 thousand dollars. Meanwhile, energy intensity and carbon dioxide emission per unit GDP (kg CO_2 per 10 thousand Yuan) has maintained downward tendency. Clean air actions contribute to the high quality social economical sustainable development. As well, environmental sector is the sector encouraged to develop and are creating more job opportunities in Beijing.

As we all know, there is much more work to do. $PM_{2.5}$ in Beijing's ambient air still exceeds China's air quality standards and the World Health Organization's recommended "safe" levels. Also, ozone (O_3) pollution is not falling by the same amount. This troubling development is partly due to complex chemical processes in the atmosphere, but also due to uncontrolled precursor emissions. Finally, heavy pollution episodes frequently occur during autumn and winter in the capital city mainly attributed to the remaining quantities of local pollutants emissions. Solving all these air quality issues will be a long-term process.

President Xi's Ecological Civilization vision has become the guiding theory for building a beautiful China and realizing harmony between human being and the nature. Good environmental quality is taken as the most important benefit for the people. Blue sky is considered as a kind of happiness for the people in Beijing. In 2018, the State Council released new blue sky action plan for 2018-2020, which requires Beijing lower $PM_{2.5}$ concentrations and reduce the frequency of heavy pollution days, to improve air quality substantially. The Beijing Blue Sky Action Plan 2018-2020 was published subsequently, with more detailed goals and actions planned.

We would like to thank UN Environment for its deep and continuing interest in Beijing's air quality management program, as evidenced by this and previous joint reports. Thanks to the support of Climate and Clean Air Coalition, this report helps to recount Beijing's efforts over the past 20 years, it's a milestone summary for Beijing. If it could be of help as fresh experience and lessons for other cities struggling to control air pollution, we are happy to share with them through UN Environment platform.

While the level of complexity of air pollution is unique to Beijing's stage of development, the achievement may be attributed to its governmental structure in some extent, there are several commonalities. We have found that the keys to local sustainable development are the strong willingness, clear goal, supportive legislation, plan and policies, implementation and enforcement arrangement. Engaging the public in these objectives will strengthen environmental protection even further and increase social harmony.

The former Beijing Municipal Environmental Protection Bureau, recently reformed into Beijing Municipal Ecology and Environment Bureau (BEE) has integrated with more missions on promoting ecological civilization. We will continue the efforts for blue sky, better environment, and happy life for the people of the city. We will practice at local level with full efforts – to turn that inspiring vision of 2030 sustainable goals into reality.

Chen Tian
Director General
Beijing Municipal Ecology and Environment Bureau

EXECUTIVE SUMMARY

A Review of 20 Years' Air Pollution Control in Beijing

As the capital of China and an international metropolis, Beijing has experienced a rapid development in the past two decades. Compared with 20 years earlier, the GDP, population and vehicles of Beijing sharply increased by 1078%, 74% and 335% respectively at the end of 2017.

The great economic prosperity and urban growth have also resulted in the deterioration of the city's environment, especially air quality. The characteristics of combined coal-vehicle pollution are unceasingly apparent and heavy-pollution episodes occurred regularly, with negative effects on public health. To tackle severe air pollution, Beijing has launched comprehensive air pollution control programs in phases since 1998. With the constant efforts in air pollution control, emission intensity has decreased year by year and air quality has improved significantly. On-ground observation data shows that the annual average concentrations of SO_2, NO_2 and PM_{10} decreased by 93.3%, 37.8% and 55.3% respectively (Fig1).

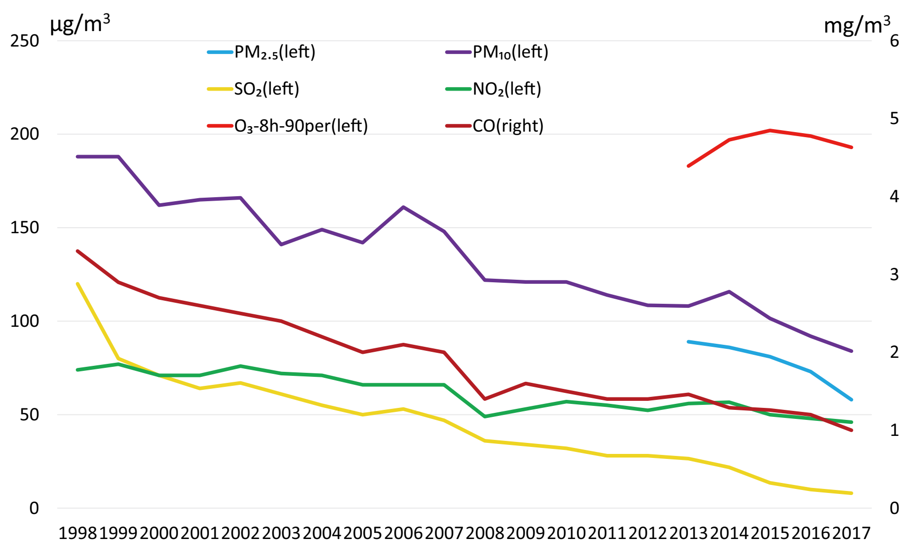


Figure1 Changes in annual average concentrations of air pollutants in Beijing, 1998-2017

Source: *Former Beijing Municipal Environmental Protection Bureau*

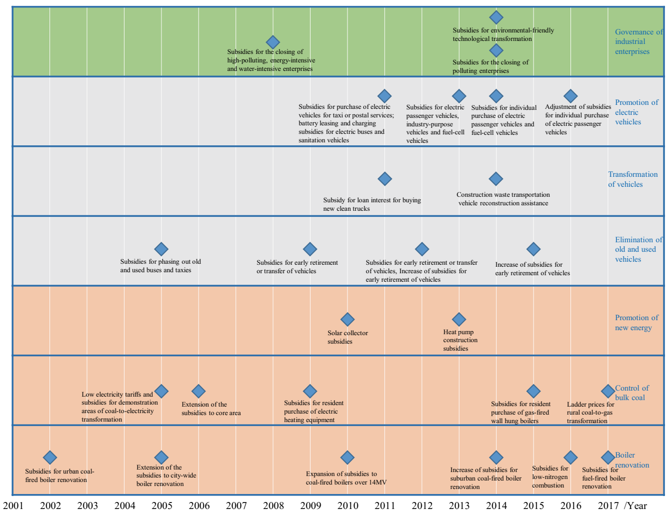
To better understand the air pollution control process in Beijing and provide worthy insights for cities of developing countries facing similar challenge, a systematic review of 20 years' clean air actions in Beijing has been commissioned by UN Environment, focusing on pivotal control points and major pollution sources.

An effective air quality management system

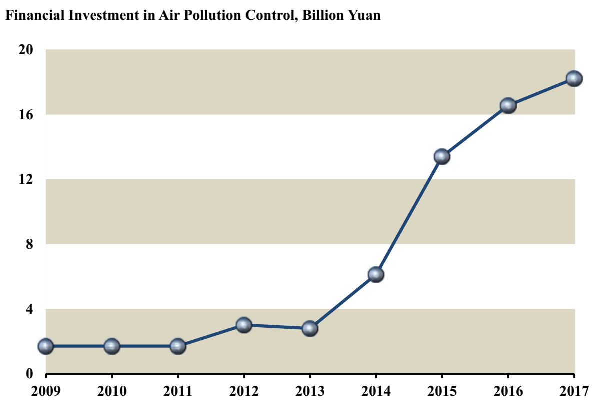
A comprehensive and increasingly effective air quality management system has gradually taken shape over 20 years' practice. The system is characterized by:(a) Complete legislation and enforcement mechanism; (b) Systematic planning; (c) Powerful local standards; (d) Strong monitoring capacity; (e) High public environmental awareness.

Economic incentives and financial support

In the past 20 years, Beijing has gradually established a number of local environmental-economic policies, including subsidies, fees, pricing, and other financial practices, to provide economic incentives for the effective implementation of various measures (Fig2a). Meanwhile, the spending on air pollution control has also been increased, especially after 2013 (Fig2b), which manifest great ambitions of the government on air pollution control.



(a)



(b)

Figure2 Major economic policies (a) and financial investment (b) on air pollution control in Beijing, 1998-2017

Source: *Beijing Municipal Research Institute of Environmental Protection, Beijing Municipal Bureau of Finance*

Sophisticated air quality monitoring system

Beijing started to build the air quality monitoring (AQM) system in the 1980s. By 2013, 35 ambient AQM stations which can monitor 6 major pollutants such as $PM_{2.5}$ and O_3, had been established across Beijing. In 2016, combining advanced technologies like high resolution satellite remote sensing and laser radar, a new generation of integrated air quality monitoring network was established. For example, Figure3 shows a high-density $PM_{2.5}$ monitoring network in Beijing, which deployed over 1000 $PM_{2.5}$ sensors throughout the whole city and helped to accurately identify high-emission areas and periods.

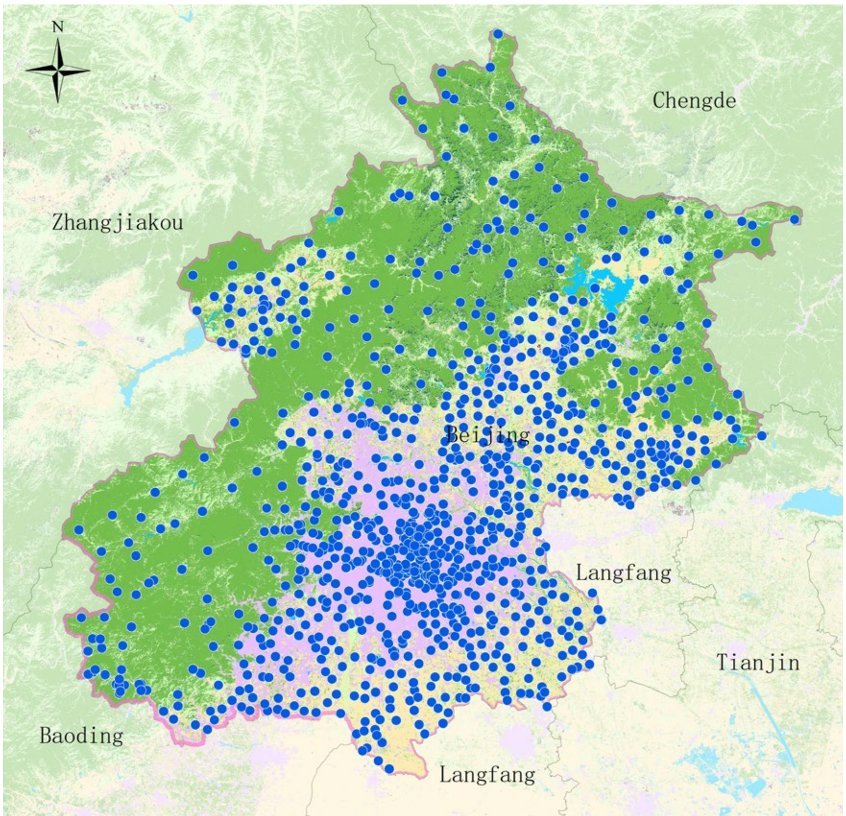


Figure3 Beijing's high-density sensor-based $PM_{2.5}$ monitoring network

Source: Beijing Municipal Environmental Monitoring Center

Emission reductions from coal combustion sources

Coal combustion has always been a major air pollution source in Beijing, and the city has continuously promoted end-of-pipe control and energy structure adjustment over the past 20 years (Fig4). Focusing on power plants, coal-fired boilers and residential coal use, the pollution sources were controlled simultaneously, achieving remarkable progress.

Take coal-fired power plants as an example. Beijing has implemented a "coal-to-gas" policy since 2005 and reduced coal combustion by nearly 11 million tons by 2017. High-efficiency terminal treatment facilities were continuously renovated and ultra-low emission standards were enforced during this period. In 2017, emissions of $PM_{2.5}$, SO_2, and NO_x were reduced by 97%, 98% and 86% respectively compared with 20 years earlier (Fig5), resulting in significant environmental and health benefits.

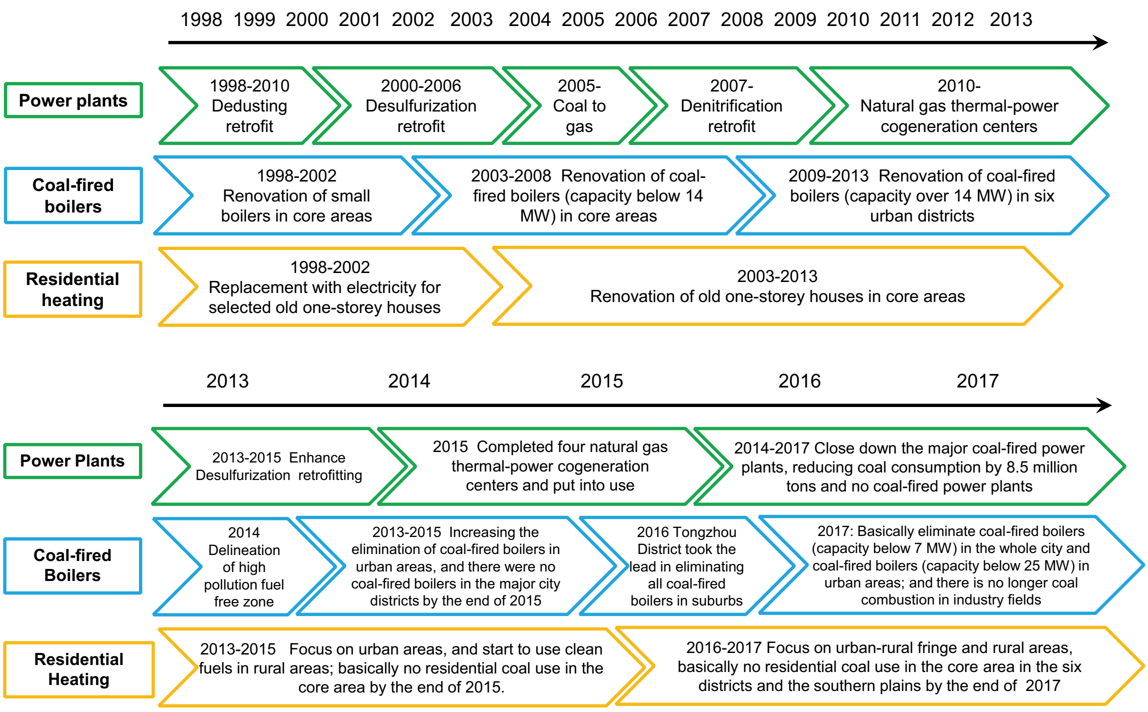


Figure4 Coal combustion control process and specific measures in Beijing, 1998-2017

Source: Former Beijing Municipal Environmental Protection Bureau, Tsinghua University

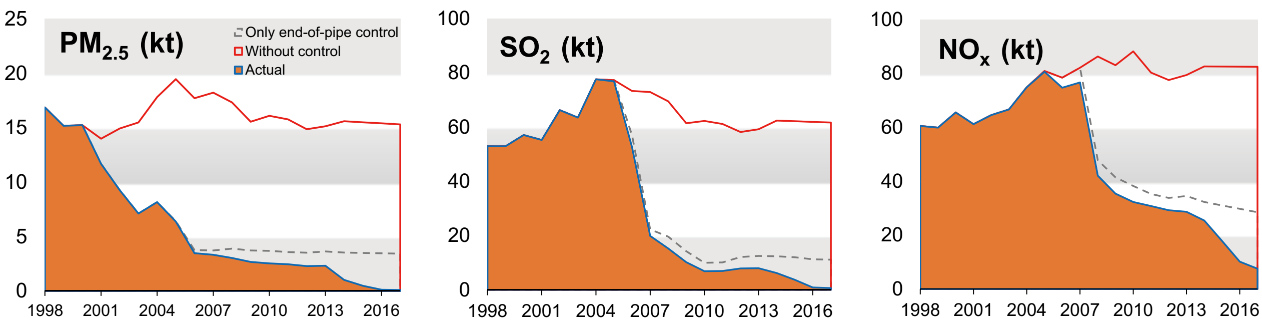


Figure5 Changes of major pollutants emission from coal-fired power plants in Beijing, 1998-2017

Source: Tsinghua University

Vehicle emission control

The prevention and control of vehicle pollution have long been a critical task in Beijing's air pollution control. Focusing on new vehicles, in-use vehicles and fuel quality, Beijing has implemented a series of local emission standards and comprehensive control measures; as well as strengthened traffic management and economic incentives continuously (Fig6). The integrated "Vehicle-Fuel-Road" framework (Fig7) was developed. More important, a large scale public transport system has been built to allow gradual formation of a green and low-carbon in-city travel habit by the people.

Although the number of vehicles increased three-folds in Beijing during the last two decades, the total pollutants emissions decreased remarkably (Fig8). Compared with 1998, CO, THC, NO_x and $PM_{2.5}$ emissions from the transportation sector were reduced by nearly 1,105kt, 94kt, 71kt and 6kt in 2017 (Fig8, green parts), with a decrease rates of 89%, 64%, 55% and 81% respectively. Phasing out older vehicles made the most significant contributions during this period.

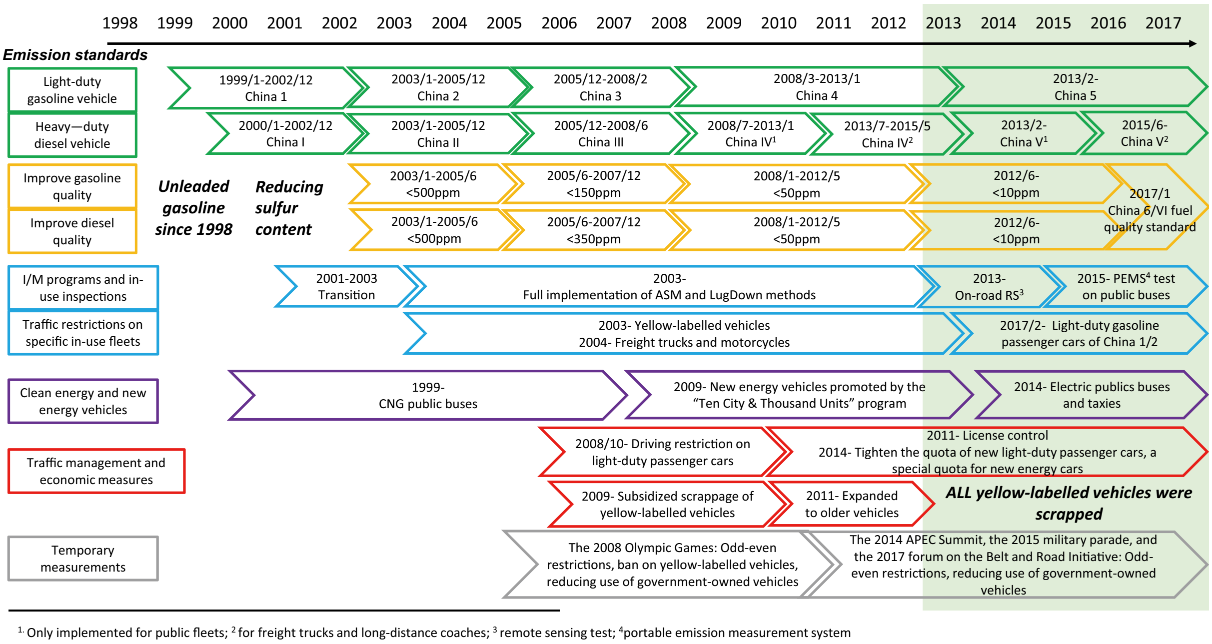


Figure 6 Review of main emissions control measures for motor vehicles in Beijing, 1998–2017

Source: Former Beijing Municipal Environmental Protection Bureau, Tsinghua University

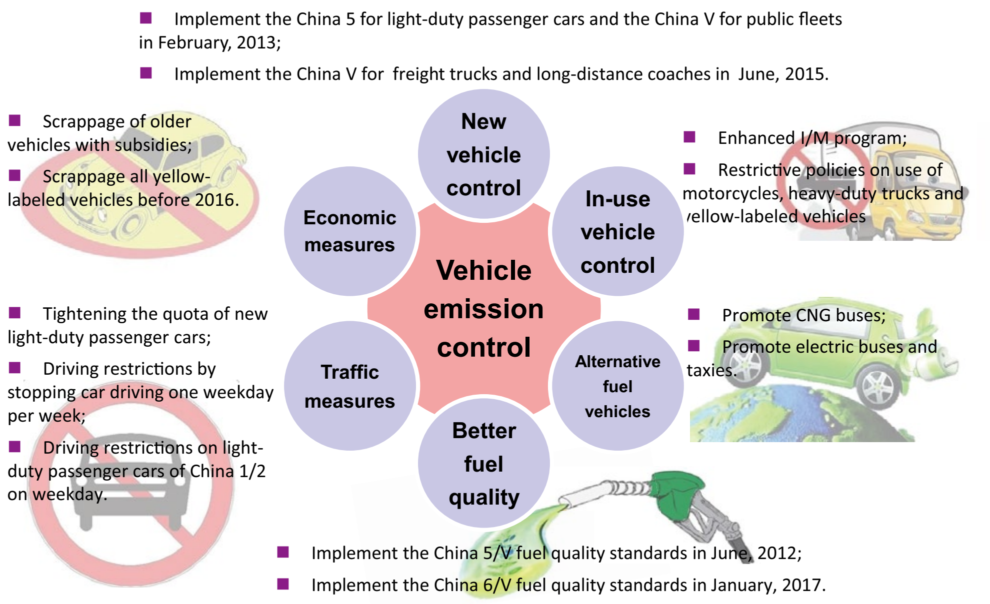


Figure 7 Vehicle-fuel-road integrated control system

Source: Former Beijing Municipal Environmental Protection Bureau, Tsinghua University

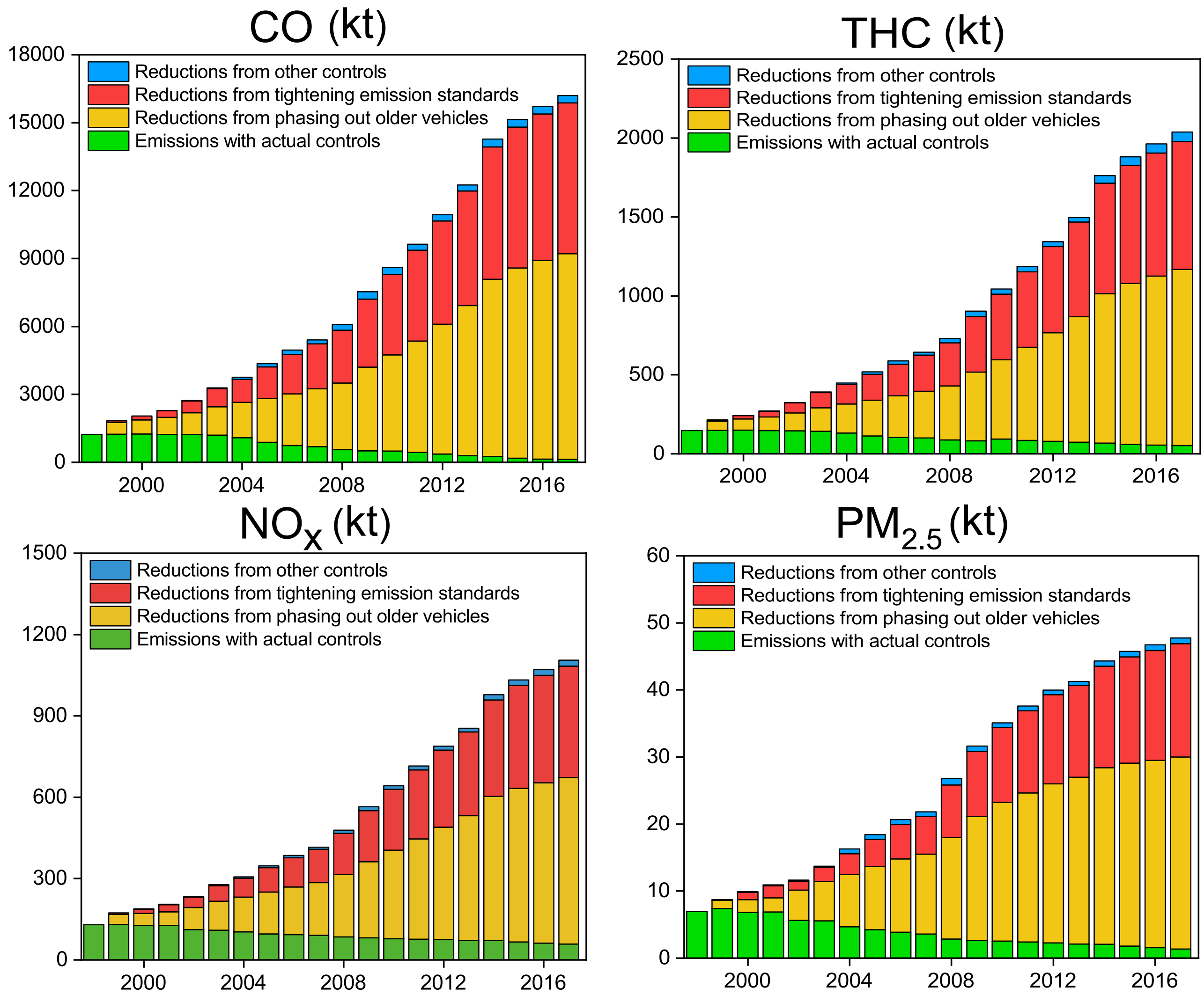


Figure8 Actual mobile source emissions and emission reduction effects of control measures in Beijing, 1998–2017

Source: *Tsinghua University*

Intensive pollution control during 2013-2017

The "Beijing 2013-2017 Clean Air Action Plan" was the most comprehensive and systematic pollution control program in Beijing. In 2017, Beijing's annual average $PM_{2.5}$ concentration lowered to 58μg/m^3 and decreased by 35.6% compared with 2013, achieving the enhanced air quality goal which was generally considered difficult at home and abroad.

Estimation of emission reductions by major control measures found that coal-fired boilers control, clean fuels in residential sectors, and optimization of the industrial structure were the top three effective measures (Fig9a). During 2013-2017, the emissions of SO_2, NO_x, VOCs and $PM_{2.5}$ decreased by 83%, 43%, 42% and 55% respectively (Fig9b).

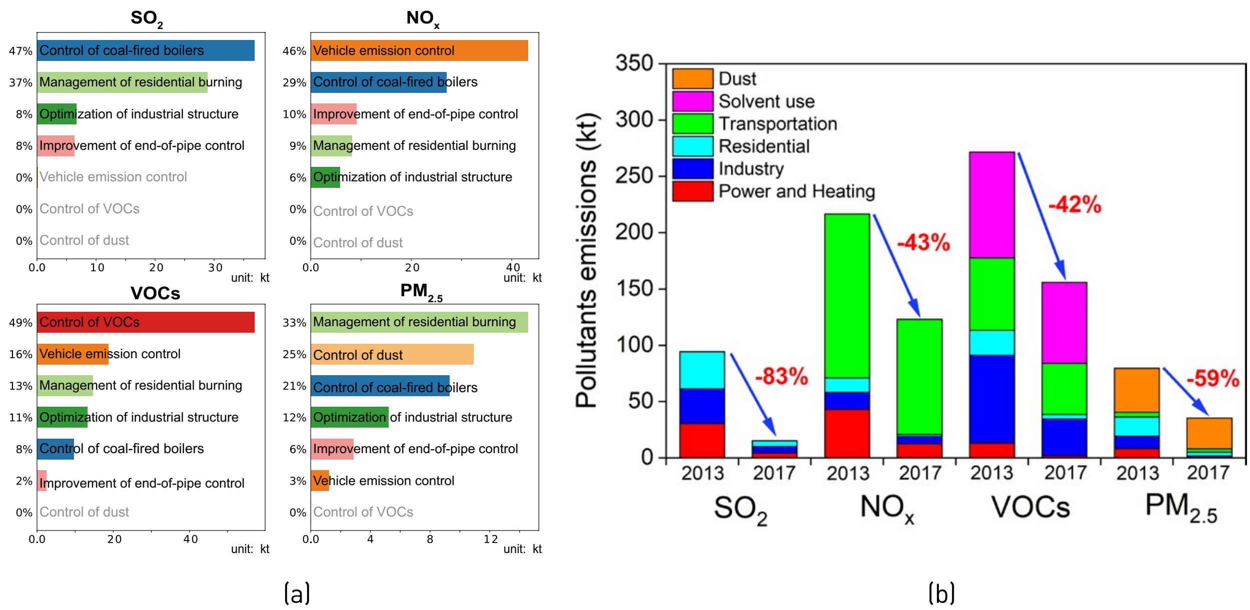


Figure 9 (a) Emission reductions and relative contributions of each control measure in Beijing during 2013-2017; (b) Changes in anthropogenic emissions of SO_2, NO_x, VOCs and primary $PM_{2.5}$ in Beijing during 2013-2017.

Source: *Tsinghua University; J Cheng et al., ACPD, 2019*

Coordination between Beijing and Its Surrounding Areas

Besides enhancing local air pollution control, Beijing also actively sought to co-ordinate air pollution control measures with the surrounding areas. At the end of 2013, Beijing was asked to lead the establishment of the Mechanism for Coordinated Prevention and Control of Air Pollution in Beijing-Tianjin-Hebei and Surrounding Areas with the support of China's State Council. In 2017, the former Ministry of Environmental Protection identified the 28 cities (as Fig10 shows) in the Beijing-Tianjin-Hebei and Surrounding Areas as air pollution transportation channel. Through collaborative planning, unified standards, joint emergency response, and information sharing, the air quality of the whole region has significantly improved. As figure 11 shows, the annual average $PM_{2.5}$ concentrations of the Beijing-Tianjin-Hebei and surrounding areas decreased by nearly 25% during 2013-2017.

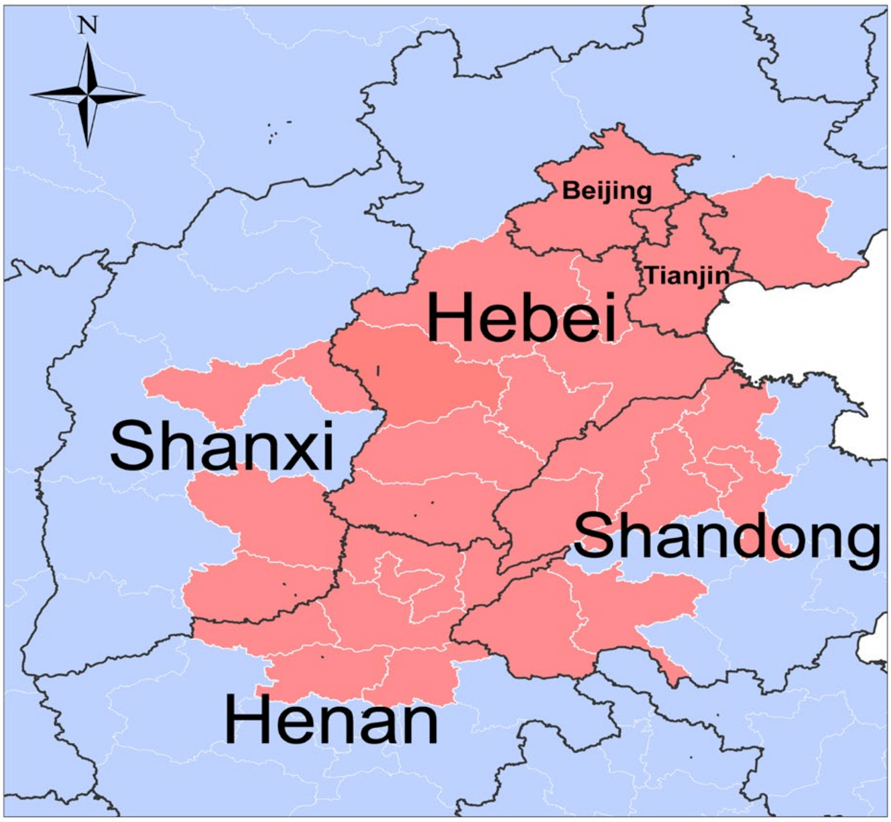


Figure10 Distribution of the "2+26" cities (the red areas) in Beijing-Tianjin-Hebei and Surrounding Areas

Source: Former Beijing Municipal Environmental Protection Bureau, Tsinghua University

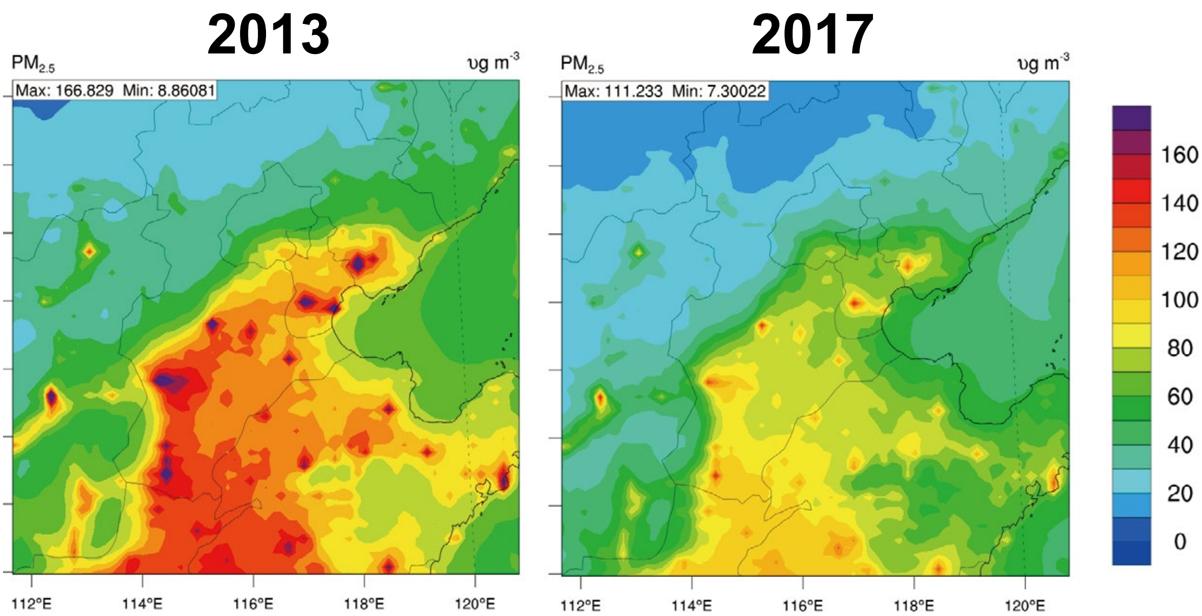


Figure11 Spatial distribution of annual average $PM_{2.5}$ concentrations in Beijing-Tianjin-Hebei and Surrounding Areas (2013, 2017)

Source: Tsinghua University

Experience, challenges and prospects

This substantial air quality improvement has been made under the rapid social and economic development in the capital city. Over the past 20 years, Beijing's gross domestic product (GDP) has maintained a growth rate over 6.5% each year, increased by 10.8 times totally. In 2017, per capita GDP has exceeded 20 thousand dollars. Meanwhile, energy intensity and carbon dioxide emission per unit GDP (kg CO_2 per 10 thousand Yuan) has maintained downward tendency. Clean air actions contributed to the high quality social economic sustainable development. Environmental sector, including service for monitoring, pollution control, engineering consultancy keeps growing along with the intensified pollution control campaign in China. Total output of Chinese environmental sector reached 1.35 trillion Yuan in 2017 with over 20% contributed by environmental enterprises in Beijing (China Association of Environmental Protection Industry, 2018). Environmental industry is listed as priority sector for development in Beijing, and is creating more job opportunities.

While the complexity of air pollution in Beijing is unique to its stage of development, the achievement may attributed to its governmental structure in some extent, there are several commonalities. We have found that the keys to local sustainable development are the strong willingness, clear goal, supportive legislation, plan and policies, implementation and enforcement arrangement. Engaging the public in these objectives will strengthen environmental protection even further and increase social harmony.

Even though great air quality improvement has been made, Beijing and the surroundings still face pressures and challenges in future air pollution control. In 2017, $PM_{2.5}$ concentration in Beijing was 66% higher than the National Ambient Air Quality Standard of China, and even more higher than the World Health Organization guideline (10μg/m^3 for $PM_{2.5}$). In addition, ozone (O_3) pollution has not been effectively controlled in recent years. The continuous improvement of the atmospheric environment still needs unremitting and extra efforts in the future.

What's next for future options: (1) Considering synergistic control of $PM_{2.5}$ and O_3 pollution; (2) Optimizing energy structure and energy efficiency simultaneously for a low-carbon development, to meet both air quality and climate target in future; (3) Working on vehicle emission control and transportation structure optimization to build a low-emission, high-efficiency transport system; (4) Strengthening the control of non-point source pollution; (5) Enhancing the coordination of Beijing-Tianjin-Hebei and Surrounding Areas; (6) Integrate city level environmental goal with 2030 sustainable development goals.

CONTENTS

ACRONYMS AND ABBREVIATIONS

AQI	Ambient Air Quality Index
BCM	billion cubic metres
BEE	Beijing Municipal Ecology and Environment Bureau
BRT	Bus Rapid Transit
CNG	compressed natural gas
CO	carbon monoxide
DPF	diesel particle filter
ESP	electrostatic precipitator
FGD	flue gas desulphurization
GDP	gross domestic product
HDDV	heavy-duty diesel vehicle
LNG	liquefied natural gas
MEIC	Multi-resolution Emission Inventory for China
NAAQS	National Ambient Air Quality Standard
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
PEMS	portable emissions measurement system
$PM_{2.5}$	particle matter with aerodynamic diameter of 2.5μm or less
PM_{10}	particle matter with aerodynamic diameter of 10μm or less
QA/QC	quality assurance and quality control
SCR	selective catalytic reduction
SNCR	selective non-catalyst reduction
SO_2	sulfur dioxide
tce	tonnes of coal equivalent
THC	total hydrocarbons
TSP	total suspended particulate matter
UN Environment	United Nations Environment Programme
VOCs	volatile organic compounds
WHO	World Health Organization

CHAPTER I
BACKGROUND

Beijing, the capital of China, is a fast-growing megacity covering an area of 16,400 square kilometers (km^2). At the end of 2017, the permanent resident population reached 21.7 million and Gross Domestic Product (GDP) per capita surpassed 20,000 US dollars; registered vehicle ownership was 5.99 million and annual energy consumption reached 71.0 million tons of coal equivalent (tce) (Figure 1.1). Relative to 1998 levels, growth of these indexes were 1078%, 74%, 335%, and 86% respectively. These indicators reflect rapid economic growth accompanied by significant pressures on environmental governance in the capital city of the largest developing country.

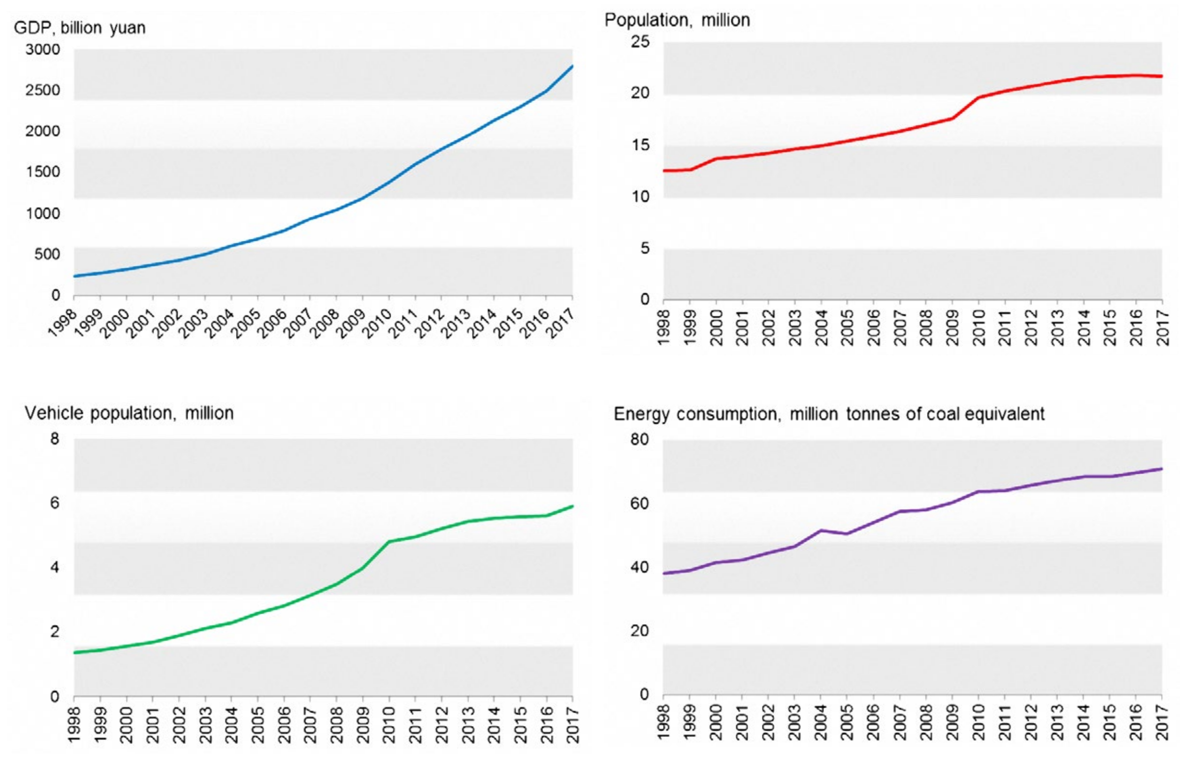


Figure 1.1 Socio-economic development of Beijing in 20 years (1998–2017)

Source: *Beijing Municipal Statistics Bureau*

Similar with other large cities in industrialized countries, for instance, London, Los Angeles and Tokyo, Beijing experienced the rapid emergence of air pollution. Environmental protection started in the late 1970s in China and Beijing. At local level, end-of-pipe pollution control measures (mainly on industrial sources) were implemented following government regulations until the late 1990s.

By the late 1990s, the ambient concentrations of pollutants including sulfur dioxide (SO_2) and total suspended particles (TSP) in Beijing seriously exceeded Chinese national air quality standards. Against the background of "China Speed" (rapid economic and social development), air quality continuously deteriorated. In response, in 1998 the Beijing Municipal Government published *Announcement of Urgent Measures to Control Air Pollution of People's Government of Beijing Municipality,* which was the first local government declaration in China on air pollution control. This document announced Beijing's war against air pollution. Twenty years old now, this "war" can roughly be divided into three stages for a review.

The first stage was from 1998 to 2008. In 1998, Beijing launched the first local government air pollution control program in China. Hundreds of concrete measures were implemented targeting at key pollution sources of particulate matter (PM) and soot, namely coal consumption, industrial emissions, motor vehicle emissions, and dust. With these measures, the annual average concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), inhalable particular matter (PM_{10}) and carbon monoxide (CO) were significantly reduced. The 29th Summer Olympic Games held in Beijing in 2008 was a catalyst for Beijing's air pollution control, which accelerated the implementation of more intense measures, and marked the conclusion of the first stage.

The second stage was from 2009-2012, the post-Olympic period and a transitional period. End-of-pipe air pollution control measures were gradually replaced by integrated measures related to structural adjustment. The increased pollution from continued growth of the economy and population was offset by pollution reductions from these control measures. Air quality continued to be improved.

The distinct characteristics of these 2 stages were: 1) targeting at primary pollutants (SO_2, NO_2, PM_{10}, and CO; 2) government playing the main role and taking primary responsibility in the air pollution campaign; 3) Beijing stood alone at the early stages, and began regional cooperation during the 2008 Olympic Games period. The 2008 Beijing Olympic Games proved to be a successful test for regional cooperation on air pollution control.

The third stage was from 2013-2017. Secondary pollutants, primarily $PM_{2.5}$, became the main focus for control, and a regional coordination mechanism was developed. During the autumn and winter of 2012, heavy $PM_{2.5}$ pollution episodes frequently occurred in Beijing and the surrounding region. These episodes aroused serious concerns among the media and public about the health impacts. The Chinese central government took immediate actions to address the challenge. The Chinese national *Ambient Air Quality Standard* was revised, the threshold of $PM_{2.5}$ was added, and the limits for other pollutants were tightened. In the middle of 2013, Beijing unveiled the *Beijing Clean Air Action Plan 2013–2017* in accordance with the requirements of the national *Action Plan for Air Pollution Prevention and Control.* The Beijing action plan focused on controlling $PM_{2.5}$ pollution to protect public health, In this five year period, aiming at $PM_{2.5}$ pollution control, comprehensive measures of legal, economic, technical, and administrative were implemented, focusing on coal consumption reduction, vehicle emission control, industrial emission control and fugitive dust mitigation.

By the end of 2017, the annual average $PM_{2.5}$ concentration in Beijing decreased to 58μg/m^3 from 89.5μg/m^3 in 2013, and the frequency and level of heavy pollution episodes declined drastically. Similar air quality improvements also occurred in the surrounding region.

During this 20-years air pollution control process, Beijing established a comprehensive air quality management system that suits its own circumstances. In the context of unprecedented socio-economic development over nearly two decades, a continuous air pollution control campaign was successfully implemented, including energy structure optimization, vehicle emission controls, industrial structure upgrading, city management enhancement, ecological restoration, and raising public environmental awareness. In these 20 years, Beijing achieved continuous improvements of air quality. Annual average concentrations of SO_2, NO_2, and PM_{10} decreased by 93.3%, 37.8%, and 55.3% respectively, and, with SO_2 and CO concentrations stably in compliance with current national standards. In addition, the annual $PM_{2.5}$ concentration was reduced by 35.6% in the 5 years since monitoring of $PM_{2.5}$ began (former Beijing Municipal Environmental Protection Bureau, 1998-2018).

Taking advantage of the fruitful, long-term cooperation between United Nations Environment (UN Environment) and China as well as Beijing, UN Environment produced independent environmental evaluations for the Beijing 2008 Green Olympics and for air pollution control in the period 1998-2013. These two reports, well appreciated worldwide, provide a good basis upon which to evaluate the past 20 years of air pollution control progress in Beijing. An updated quantitative assessment of air pollution control measures can give fresh examples for emerging cities suffering from serious air pollution, in China and beyond. With this in mind, UN Environment invited international experts, along with an expert team from Tsinghua University, to undertake an updated quantitative assessment.

This report reviews the air quality management system set up in Beijing, conducts quantitative assessments of the pollution reduction effects in selected areas, and analyzes the new challenges Beijing faces, and provides recommendations for further improvement of air quality.

CHAPTER II
AIR QUALITY IMPROVEMENT IN BEIJING IN 20 YEARS

2.1 Ambient Air Quality Trends

Beijing's annual coal consumption hit 28 million tons (equivalent to nearly 40 million tce) in 1998 with the coal-dominated energy structure causing severe smoke pollution. At the same time, the vehicle fleet size began to increase dramatically in the 1990s while the technologies for vehicle emissions control in China were equivalent to the 1970s level of those in the developed countries in Western Europe and North America. As a result, air pollution caused by vehicle emissions emerged as a distinct and growing challenge. As shown in Figure 2.1, in 1998, the annual average ambient concentrations of CO, SO_2 and NO_2 in Beijing climbed to 3.3 mg/m^3, 120μg/m^3 and 74μg/m^3 respectively, and the concentrations of total suspended particles (TSP) in the heating and non-heating seasons were as high as 431μg/m^3 and 348μg/m^3 respectively.

To address the issue of severe air pollution, the Beijing Municipal Government issued the *Announcement of Urgent Measures to Control Air Pollution of People's Government of Beijing Municipality* in 1998, launching the intensified efforts on air pollution control in the city. Monitoring data shows that annual average concentrations of major air pollutants in Beijing maintained a decreasing trend (Figure 2.1). Except for some fluctuations during 2005-2007, concentrations of SO_2, CO, and NO_2 declined linearly over the 20 years. Concentrations of CO has constantly met the national standards; SO_2 met national ambient air quality standards in 2004 and declined even further since then. The levels of CO and SO_2 were further reduced to 1.0 mg/m^3 and 8μg/m^3 respectively in 2017, well below the national air quality standards. Concentration of $PM_{2.5}$ continued to decline since monitoring began in 2013.

Summer Palace under blue sky (Photograph credit: Beijing Municipal Environmental Publicity Center)

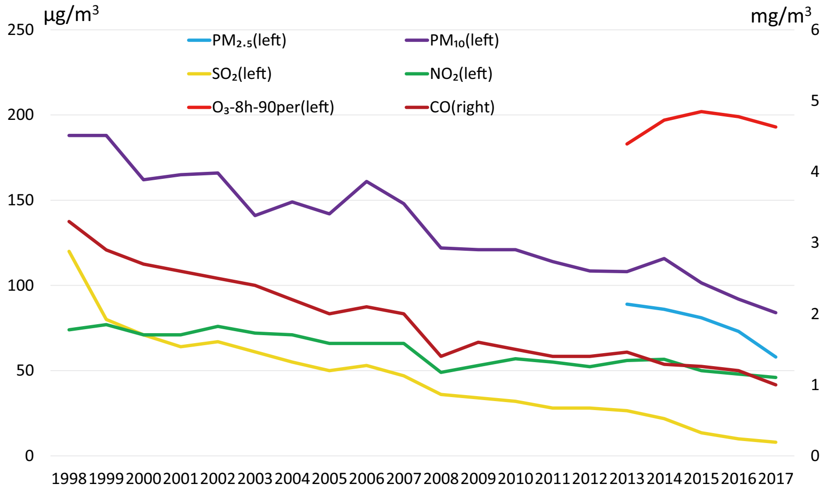


Figure 2.1 Changes in annual average concentrations of major air pollutants in Beijing, 1998–2017

Source: Former Beijing Municipal Environmental Protection Bureau

During the five years from 2013 to 2017, air quality improved at a faster pace in Beijing, with an increase in good air quality days, decrease in heavy pollution episodes, and drastic reduction of major pollutant concentrations (Figure 2.2). From 2013 to 2017, the ambient concentrations of SO_2, CO, NO_2, $PM_{2.5}$ and PM_{10} fell by 70.4%, 38.2%, 17.9%, 35.6% and 22.2% respectively.

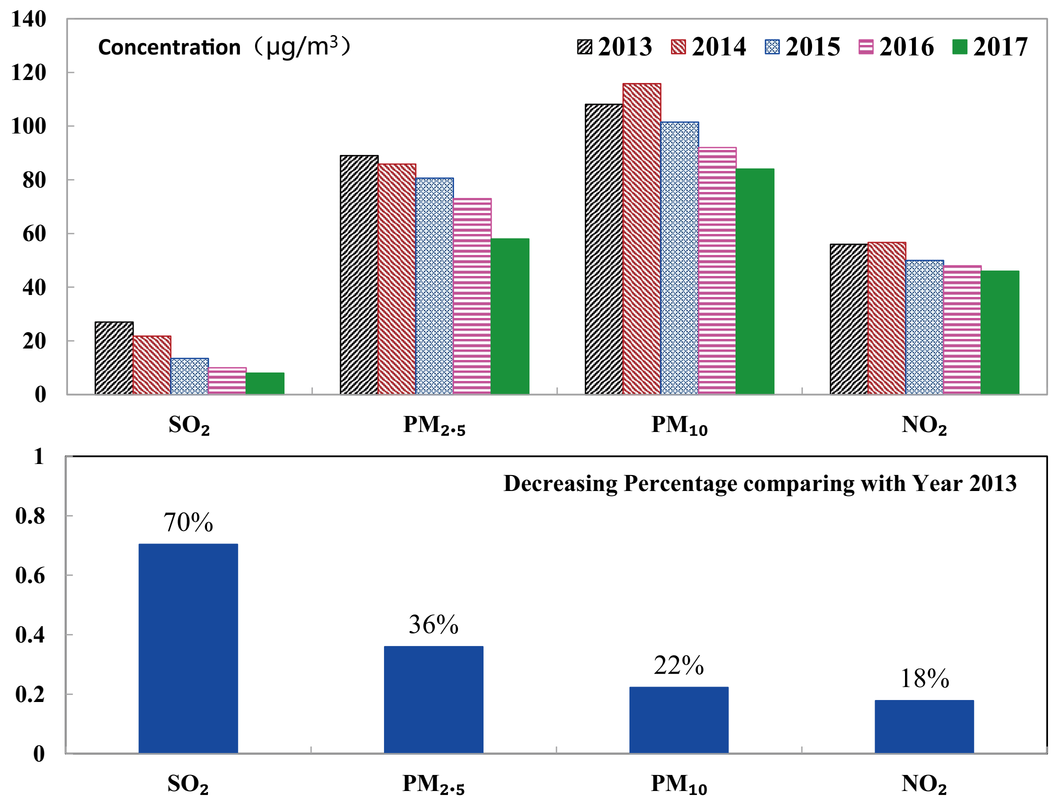


Figure 2.2 Annual average concentrations of air pollutants and percentages of decline in Beijing, 2013–2017

Source: *Former Beijing Municipal Environmental Protection Bureau*

2.2 $PM_{2.5}$ Source Apportionment Results

After new national air quality standards came into force in 2012, Beijing launched a systematic study on $PM_{2.5}$ source apportionment to support the control of $PM_{2.5}$ pollution, and released the initial results in 2014. These results showed that regional transport contributed about 28% to 36% of the $PM_{2.5}$ pollution in Beijing, while local emissions contributed 64% to 72%. Of the local emissions, motor vehicles, coal combustion, industrial production and fugitive dust accounted for 31%, 22%, 18% and 15% respectively, and emissions related to restaurants, automobile repair, livestock and poultry breeding and construction painting (the "Miscellaneous" category) took up 14% (figure 2.3).

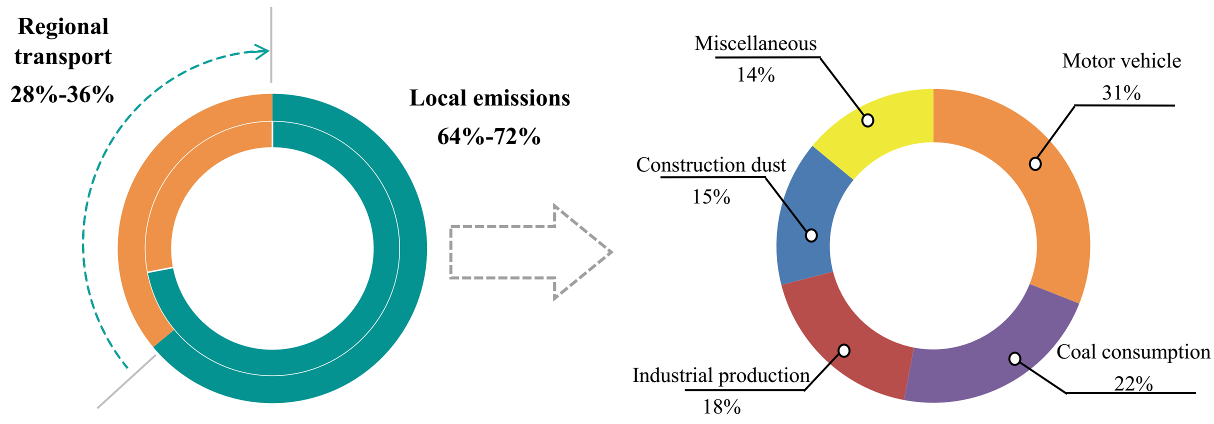


Figure 2.3 $PM_{2.5}$ source apportionment results for Beijing, 2013

Source: Former Beijing Municipal Environmental Protection Bureau

In 2017, a new round of $PM_{2.5}$ source apportionment was carried out based on updated monitoring data, research findings and technical methods. According to the results published in May 2018, local emissions constituted two-thirds (58%-74%) of Beijing's annual $PM_{2.5}$ concentrations in 2017. Among these local sources, mobile emissions, fugitive dust, industrial sources, residential non-point sources and coal combustion contributed 45%, 16%, 12%, 12% and 3% respectively, and agriculture and other natural sources made up about 12% (Figure 2.4). Regional transport was responsible for about one-third (26% to 42%). The contribution of regional transport showed a clear upward trend with pollution intensification and contributed as much as 55% to 75% to Beijing's air pollution on heavily polluted days (with daily average $PM_{2.5}$ concentration > $150\mu g/m^3$) (Figure 2.5).

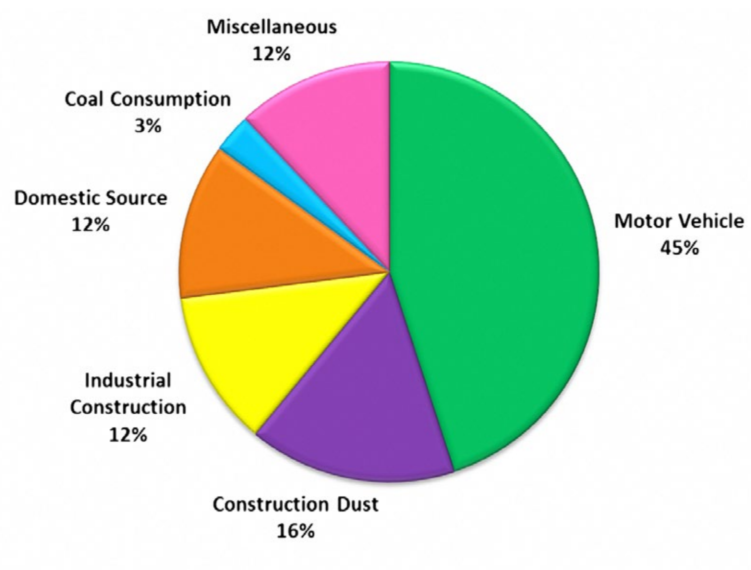


Figure 2.4 Local sources of ambient $PM_{2.5}$ in Beijing, 2017

Source: Former Beijing Municipal Environmental Protection Bureau

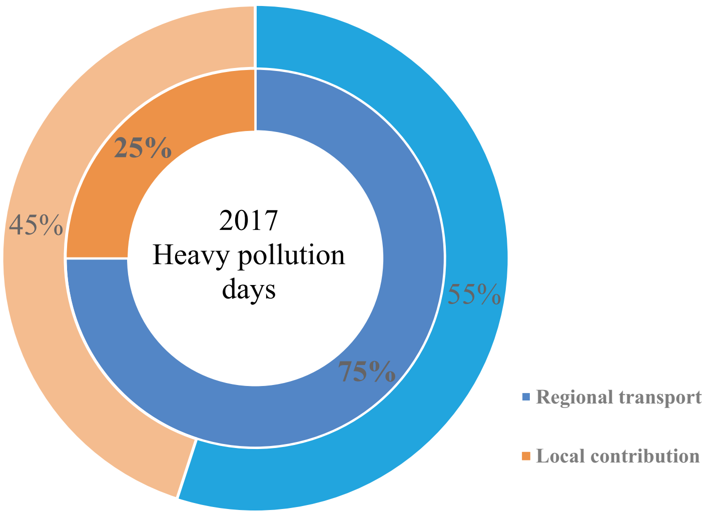


Figure 2.5 Local and regional contribution to $PM_{2.5}$ on heavily polluted days in Beijing, 2017

Source: *Former Beijing Municipal Environmental Protection Bureau*

These two source apportionment results showed significant changes in the contribution of local emissions to $PM_{2.5}$ pollution in Beijing from 2013 to 2017. First, the contribution of each major source, noticeably coal combustion, to the $PM_{2.5}$ concentrations in absolute terms clearly reduced. Second, the contribution of mobile sources and fugitive dust sources rose, while those of coal combustion and industrial sources decreased, and the contribution of residential non-point sources became further highlighted. In addition, on-road diesel vehicles formed the largest part of mobile sources; construction dust and road dust were equally important among fugitive dust sources; volatile organic compounds (VOCs) from petrochemical, automobile and printing industries took a dominant position among industrial sources; solvents accounted for 40% of residential non-point sources.

Despite the significant improvement in air quality, Beijing still fails to meet the national standards for multiple major pollutants: $PM_{2.5}$ exceeds the national standard by 66%, and NO_2 and PM_{10} concentrations still do not meet national standards. Beijing continues to suffer heavy pollution episodes in autumn and winter. In addition, ozone (O_3) pollution during summertime has become a concern in recent years. Air pollution control in Beijing remains a long-term arduous task.

New looks of the Beijing Capital Steel Group Shougang Shijingshan Plant after shutdown and relocation in 2008
(Photograph credit: Beijing Municipal Environmental Publicity Center)

CHAPTER III

DEVELOPMENT OF BEIJING'S AIR QUALITY MANAGEMENT SYSTEM

3.1 Air Pollution Control Plans

(1) Plans of different range

In China, five-year plans for social and economic development have been implemented (every 5 years) since the 1950s. Environmental protection became a part of these plans in the1990s and air pollution control has been the focus in environmental protection section. Accordingly, over the past 20 years, air pollution control has been a part of *Beijing's Five-Year Plan for Environmental Protection* during the recent four five-year plan periods (from 2000-2020).

By the end of 2012, Beijing had implemented 18 phases of the air pollution control programs based on the requirements of the five-year plan for environmental protection, including two phases for some years (heating season and non-heating season) during 1998-2010 and one phase per year during 2011-2012.

The *Action Plan for Air Pollution Prevention and Control,* released by the State Council in 2013, required Beijing to reduce the annual average concentration of ambient $PM_{2.5}$ by 25% in 2017 from the 2012 level and achieve an annual average concentration of around 60μg/m^3. To meet the requirement, the *Beijing Clean Air Action Plan 2013–2017* was released, and under this framework annual work plans were developed for each of the ensuing 5 years.

In 2015, the Chinese government issued the *Plan for Coordinated Development of Beijing-Tianjin-Hebei Region.* To make sure the region's 5-year clean air target could be achieved, several new plans were developed to reinforce this regional coordination strategy and respond to the mid-term assessment conducted by the former Ministry of Environmental Protection. For Beijing, the enhanced measures included the *Beijing Plan for Implementing the Strengthened Measures for Air Pollution Prevention and Control in the Beijing-Tianjin-Hebei Region 2016–2017, and the Beijing Detailed Plan for Implementing the Action Plan for Comprehensive Prevention and Control of Autumn and Winter Air Pollution in Beijing-Tianjin-Hebei and Surrounding Areas 2017–2018.* The process of Beijing's air pollution control planning from 1998 to 2017 is illustrated in Figure 3.1.

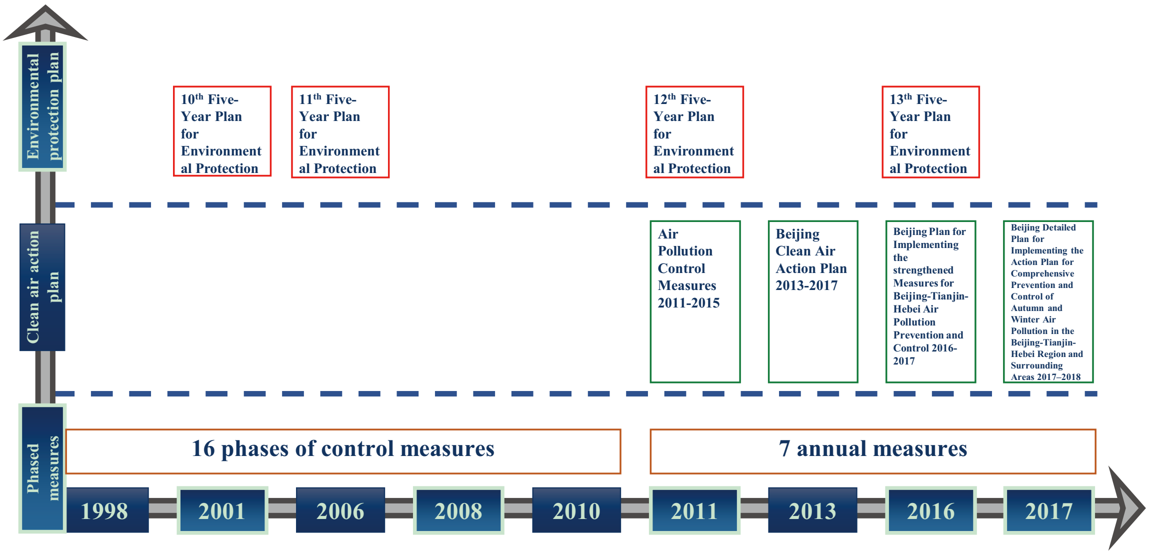


Figure 3.1 Process of Beijing's air pollution control planning, 1998–2017

Source: Beijing Municipal Research Institute of Environmental Protection

(2) Tasks and measures

In general, Beijing's major air pollution sources include the four categories which are similar with many other large cities: coal combustion, vehicle emissions, industrial emissions, and fugitive dust. Over the past 20 years, hundreds of concrete measures were implemented, with the approaches shifting gradually from end-of-pipe single pollutant control to integrated control of multiple pollutants. To control pollution from coal combustion, the measures shifted from using low sulfur coal and retrofitting coal boilers with desulfurization control to converting from using coal to using natural gas, electricity, and other clean and high quality energy alternatives. For mobile sources, Beijing started with tightening of emission standards and fuel quality standards, scrapping old polluting vehicles, and developing a comprehensive public transportation system, which formed an integrated "Vehicle-Fuel-Road" framework. Later, Beijing began promoting new energy vehicles (NEVs) and the focus on vehicle pollution control gradually changed from gasoline vehicles emissions to heavy-duty diesel vehicle emissions. In terms of industrial sources, measures included end-of-pipe retrofitting , more stringent local emission standards, and optimizing the industrial structure. To control fugitive dust, dust control technologies, process, and management rules were promoted to reduce dust from construction sites, roads, and bare land. In recent years, VOCs related to residential life, such as restaurant and auto repair, have also been included in air pollution control.

(3) Scientific support

Scientific research on air pollution and relevant innovative technologies have provided critical support to the development and implementation of air pollution control measures. Beijing has conducted systematic scientific research and technology development by relying on Beijing-based research institutions and universities and its own environmental technical teams. The work mainly covers research on atmospheric science; pollutant generation mechanisms; air quality monitoring, forecasting, and early warning technologies; emission inventory development, and $PM_{2.5}$ source apportionment; research on strategies and technologies for PM and O_3 pollution control; new technologies for pollution control; and decision support systems.

3.2 Local Regulations and Emission Standards

(1) Local regulations on air pollution prevention and control

Beijing follows national environmental laws on air pollution control, mainly *The Law of People's Government of China on Environmental Protection* (Enacted in 1979, revised in 2014), and *The Law of People's Government of China on Air Pollution Control* (enacted in 1987, revised in 2015). To deal with the serious air pollution, Beijing formulated a local law *Ordinances of Beijing Municipality for Prevention and Control of Air Pollution* in 2014 based on the lessons and experience accumulated over the previous 15 years. This local regulation was the first of its kind targeting on $PM_{2.5}$ pollution control in China and to implement comprehensive treatment and integrated control of a wide-range of $PM_{2.5}$ sources. This local law also embodied a shift in air pollution control, from end-of-pipe treatment to process-wide control; from setting concentration limits to controlling both the concentration and total emission amount; and from government control to social governance, with equal emphasis put on corporate governance, sectoral governance, and regional coordination.

(2) Local emission standards

According to related Chinese laws, local government can publish local environmental standards that are more stringent than national ones. Beijing started to build its local emission standards system from 2000 to support its intensified air pollution control campaign. As of 2017, there were 42 prevailing local air pollution control standards, covering combustion sources, mobile sources, industrial sources, and commercial products. A leading local system of the most stringent standards for air pollutant emissions has taken shape and played an important role in accelerating a clean energy mix, tightening pollution controls, transforming and upgrading the

Standards for Air Pollutants Emission of Boilers

To control emissions from coal-fired boilers, Beijing developed its first *Standards for Air Pollutants Emission of Boilers* (DB11/139-1998) in 1998, and revised the standards in 2002, 2007, and 2015. The revisions in 2002 and 2007 were mainly to tighten emission limits for SO_2 and particulate matter, and push end-of-pipe treatment for coal-fired boilers and conversion from coal to gas. The *Standards for Air Pollutants Emission of Boilers* (DB11/139-2015) tighten the concentrations of NO_x emissions from gas-fired boilers newly installed and in use to 30 mg/m^3 and 80 mg/m^3 respectively. In order to promote the implementation of standards, Beijing, among the first in the country, initiated the low-NO_x renovation of gas-fired boilers in 2016 mainly by using low NO_x burners (LNB) or directly install low-NO_x gas-fired boilers. In order to encourage boiler owners to make the renovation, Beijing introduced an incentive and subsidy policy in 2016, which allows performing boiler owners to obtain subsidies up to two-thirds of the total investment from municipal and district level governments. The new boiler standards and supporting financial incentives have effectively reduced NO_x emissions from gas-fired boilers, the emissions per boiler have been more than halved. Throughout the city, a total of 23,800 MW of gas-fired boilers have been transformed, cutting nearly 5,000 tons of NO_x emissions per year.

industrial structure, and promoting lower emissions of motor vehicle models.

(3) Law enforcement

In Beijing, there are two levels of environmental law enforcement, municipal level and district level, with each level having differing responsibilities for cooperation in relation to the other. Enforcement of laws and regulations on stationary sources includes daily supervision, specific inspection, automatic online monitoring supervision, and hotspot grid supervision. A detailed emission inventory for each source has been established, and random on-site investigations and supervision are conducted on a regular basis. The enforcement on mobile sources mainly includes random emission testing for new vehicles, regular emission testing for in-use vehicles, road testing, and inspections. For off-road machinery, on-site testing and specific inspections are performed.

In 2017, an environmental police team was created under the Beijing Municipal Bureau of Public Security. Through joint law enforcement liaison, environmental protection departments can transfer cases of suspected environmental crimes to public security departments according to law, which has greatly enhanced the deterrent power of environmental law enforcement.

Typical Case of Joint Law Enforcement by Environmental Police

Since the formation of the first environmental protection police team in January 2017, environmental protection and public security departments in Beijing have strengthened collaboration and joint actions and launched a year-long Special Law Enforcement Operation to Crack Down Environmental Crimes. As of the end of 2017, a total of 135 cases of administrative detentions and 44 cases of suspected environmental crimes were investigated by the environmental police team. Below is a typical case of crime involving illegal emissions handled by the environmental protection police.

In April 2017, the Environmental Protection Bureau of Tongzhou District found in a law enforcement inspection that a printing company emitted waste gas without treatment. The company continued production in order to meet its production deadline while the two sets of exhaust gas purification facilities were under maintenance and not in operation. According to the *Law of the People's Republic of China on Prevention and Control of Air Pollution,* the Environmental Protection Bureau of Tongzhou District ordered the company to correct the illegal activities within a given time, imposed a fine, and transferred the case to the environmental police team. The police team imposed the penalty of administrative detention on relevant responsible persons according to the law, in accordance with "stopping the operation of pollutant treatment facilities in the course of production or operation" in Article 7 of the *Interim Measures for the Transfer by Administrative Departments of Cases of Environmental Violations that Administrative Detention May Be Applied.*

3.3 Economic Policies

(1) Policies

For the effective implementation of air pollution control plans, Beijing has gradually built a system of local environmental economic incentive policies, which provide financial support to implement pollution control measures covering coal combustion sources, industrial sources, mobile sources, and fugitive dust sources through subsidies, fees, incentives, and pricing.

Among the economic measures for the control of coal combustion pollution, funding is used to subsidize clean energy renovation of coal-fired boilers[1], coal-to-electricity heating renovation[2] for urban bungalows, and rural transformation of bulk coal. For example, urban households can receive subsidies for coal-to-electricity heating renovation equivalent to two-thirds of the equipment acquisition costs and are eligible for a maximum discount of 78% of the heating electricity tariff.

Financial subsidies or incentives are also provided to vehicle owners who scrap old cars, retrofitting heavy-duty diesel vehicles, and buying new energy vehicles. During 2008-2014, subsidies were granted for the retrofitting of heavy-duty diesel vehicles, equivalent to half (no more than 15,000 Yuan) of the total retrofitting costs. During 2014-2017, individual purchasing of new energy vehicles in Beijing were granted subsidies of up to 60% for the purchase price of electric passenger cars.

In terms of industrial pollution prevention and control, incentives or subsidies were granted for high-polluting enterprises that choose to close their production or to implement extensive exhaust gas treatment in their production processes. For those who chose to remain in production, differentiated fees are charged according to the concentration of waste gas emissions. For example, beginning in 2008, subsidies up to a maximum of 3 million Yuan were granted for the closing of high-polluting, energy-intensive and water-intensive enterprises and the upgrading of production processes and equipment.

Economic Policy for Rural Clean Energy Alternatives

In order to promote the control of bulk coal use in rural areas, from 2014 onwards Beijing introduced a number of targeted policies to promote clean energy alternatives. These policies were based on the practice of coal-to-electricity transformation in the urban area. From 2017, a financial subsidy policy system has been in place for main users of bulk coal, such as residential homes, public buildings, agriculture facilities, and livestock and poultry houses. The policy system covers, coal-to-electricity transformation, coal-to-gas transformation, thermal solar utilization, and farmhouse renovation for earthquake-resistance, energy efficiency and thermal insulation. The scope of subsidy covers the whole process from construction of the external pipe (electrical) networks, purchase of clean heating systems, and daily use.

[1] Conversion of coal-fired boiler to gas-fired boiler or electric boiler.

[2] Conversion of small coal-fired stove to electric heater.

To change to gas-fired boilers for heating, a household with a heating area of 120m² and a heating period of 120 days is eligible for a subsidy of two-thirds of the boiler purchase cost (average subsidy per household is 8,000 Yuan) and the lowest natural gas sales price (first ladder) of 2.28 Yuan/m³. If the purchase cost of gas-fired boilers is not taken into account, the annual heating costs after the coal-to-gas conversion are reduced by about 30%.

Driven by the above-mentioned economic policies, the removal of bulk coal use in rural areas of Beijing has progressed smoothly. From 2013 to 2017, bulk coal was removed from about 900,000 households in more than 2,000 villages, and transformation was completed in 1,514 village committees and public venues for villagers' activities and 946,000 m² of agricultural facilities. It is estimated that annual bulk coal consumption during the heating season is reduced by about two million tons.

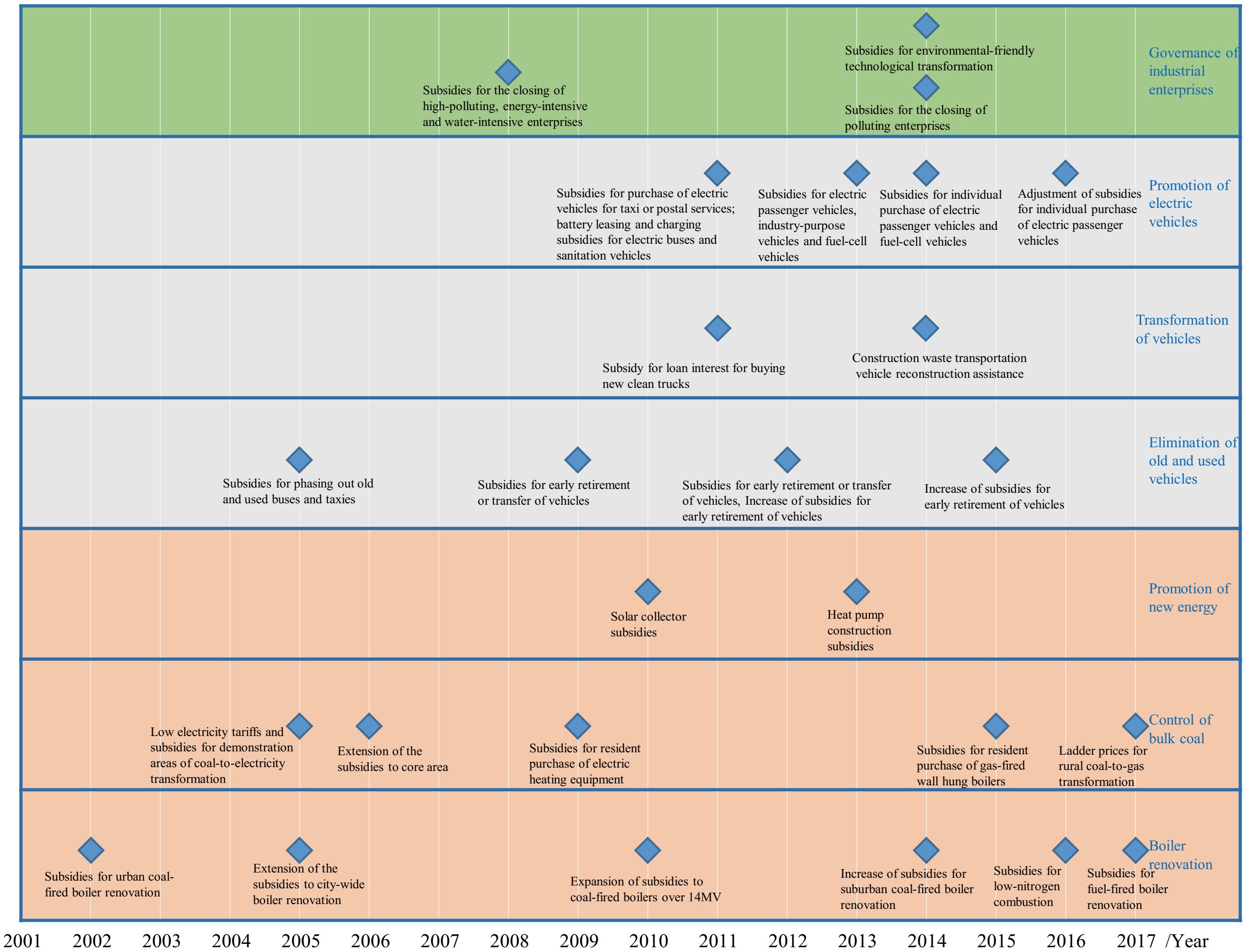


Figure 3.2 Major Economic Policies for Air Pollution Control in Beijing

Source: *Beijing Municipal Research Institute of Environmental Protection*

(2) Financial investment

Beijing has scaled up its financial funding on air pollution control and stimulated environmental protection investment, laying a solid foundation for the implementation of control measures and improvement of air quality. The funding stood at 1.7 billion Yuan in 2009, and climbed to 18.22 billion Yuan in 2017, an increase of nearly ten times in eight years (Figure 3.3). These government funds are mainly used as subsidies for renovation of coal-fired boilers, clean energy alternatives for bulk coal, elimination of old and polluting vehicles, closing of old and polluting enterprises, and construction of green buildings and ecological demonstration zones.

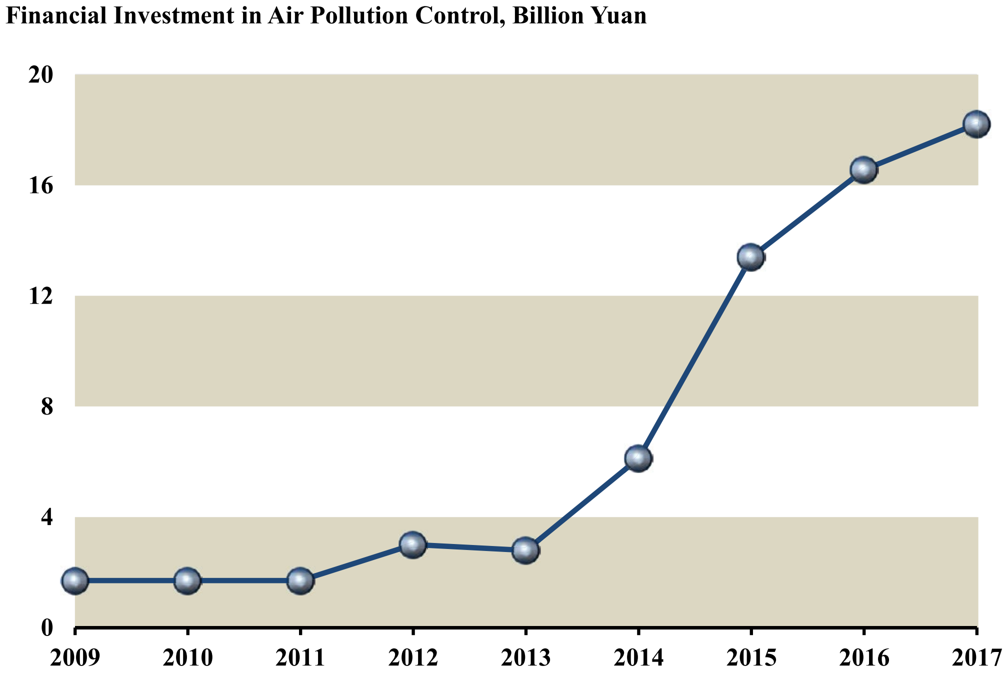


Figure 3.3 Beijing municipal funding for air pollution control in recent years

Source: Beijing Municipal Bureau of Finance

3.4 Enhancement of monitoring capacity

In the early 1980s, Beijing built China's first automatic monitoring system for ambient air quality, which consisted of eight monitoring stations. This system was used to monitor Beijing's ambient air quality and its long-term trends, covering such pollutants as SO_2, CO, NO_2 and TSP. In 1999, with the growing importance, PM_{10} was included in the monitoring as inhalable particulate matter. In 2012, the monitoring network was further expanded to integrate $PM_{2.5}$ and O_3 monitoring capacity. At present, the 35 automatic monitoring stations (Figure 3.4) cover Beijing's entire territory and include urban stations, background stations, traffic stations and pollution trans boundary stations. The monitoring data collected using national standard methods are released to the public, including six pollutants, namely $PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3.

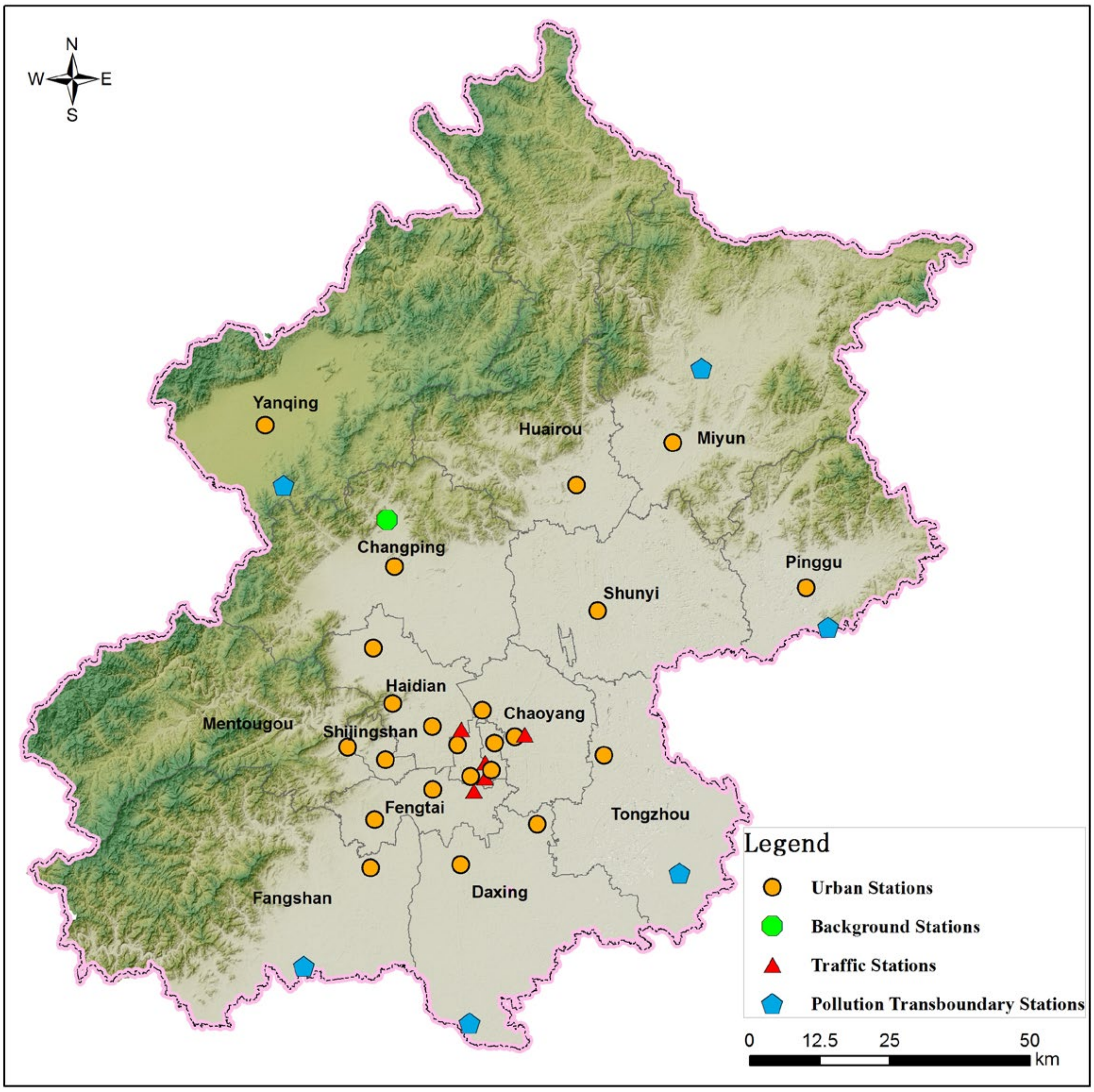


Figure 3.4 Beijing's existing automatic air quality monitoring network

Source: *Beijing Municipal Environmental Monitoring Center*

In 2016, monitoring methods were upgraded and combined with new technologies, such as new generation satellite remote sensing with high spatial and temporal resolution, laser radar vertical network, and high-precision meteorological observation. These new technologies enabled an "air-land" integrated air quality monitoring network with greater analytical capacity. In the meantime, relying on big data technology, Beijing conducted independent research and developed smart air quality sensors, and designed a new model of network operation and quality control. With this technology, Beijing deployed over 1000 $PM_{2.5}$ monitoring sensor stations, and built a low-cost, high-density grid monitoring system. The system can accurately identify the areas and time periods with high $PM_{2.5}$ emissions and provide support for evaluating the air quality of 325 towns in the capital city.

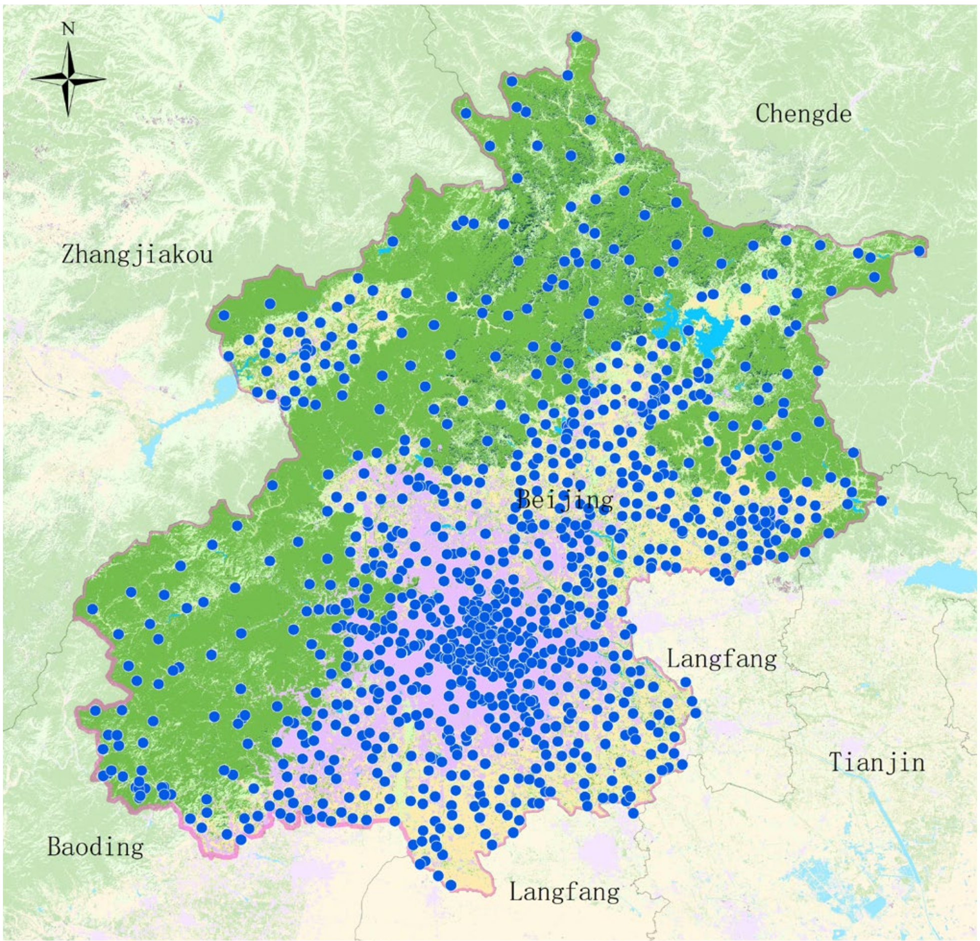


Figure 3.5 Beijing's high-density sensor-based $PM_{2.5}$ monitoring network built in 2017

***Source:** Beijing Municipal Environmental Monitoring Center*

3.5 Heavy Pollution Emergency Response System

In response to frequent heavy air pollution in autumn and winter, Beijing released the *Beijing Emergency Plan for Extreme Air Pollution (Interim)* in 2012, the first of its kind in China. The early warning mechanism was improved over four revisions of the plan, with alert levels and thresholds for initiating actions becoming more scientific. In addition, emergency emission control measures were taken during early warning periods, which effectively reduced the level of pollution under adverse weather conditions. The *Beijing Emergency Plan for Extreme Air Pollution (Revised in 2017)* encompasses alert levels, emergency measures, emergency response, and organizational guarantees.

Beijing relies on the air quality monitoring network for timely forecast of air quality. In case of forecasted heavy pollution, early warnings are issued at least 24 hours in advance by releasing pollution warning notices and health risk warnings through the media. Traditional media like radio, TV, and newspaper, and new media including Weibo, WeChat, and mobile APPs, are all covered to make sure the message can be conveyed to different groups. This not only helps the public to strengthen their own health protection, but also enables the implementation of emergency pollution control measures.

Typical Case of Emergency Response to Heavy Air Pollution

It was forecasted that Beijing and the surrounding region would encounter a long period of heavy air pollution during December 16-22, 2016. In response, with the approval of Beijing Municipal Government, Beijing Municipal Headquarters for Heavy Air Pollution Emergency Response issued an early warning notice (a red alert) at 12:00 of Dec.15, 32 hours in advance of the beginning of the red alert. The notice announced that the red alert measures will be taken from 20:00 Dec. 16 to 24:00 of Dec. 21, including restrictions and controls on motor vehicles, suspended or restricted production of coal-fired facilities and industrial enterprises, construction work suspension, increased road cleaning, staggered production . Meanwhile, extra buses and subway trains were added, kindergarten and primary school classes were suspended, and flexible school hours adopted at secondary schools, and the relevant departments stepped up inspection on compliance with emergency measures within their scope of responsibility. The red alert was relieved when the pollution episode ended. During the same period, 22 cities around Beijing also launched red alert emission reduction measures.

Assessment of the actions taken show that the SO_2, NO_x, $PM_{2.5}$, and VOCs emissions during the red alert period were cut by 30% on average due to the emergency measures, especially motor vehicle restriction and control. According to the results of air quality simulation under two scenarios (with and without red alert measures), the implementation of red alert measures in Beijing and its surrounding areas reduced Beijing's daily average $PM_{2.5}$ concentration by an average of 23% and realized the expected effects in reducing the pollution peak.

3.6 Information release and public participation

(1) Air quality data and forecast release

Since1998, Beijing began to publish weekly air quality reports and gradually improved the quality and frequency of air quality monitoring data released to the public as the air quality monitoring network improved. In 2001, Beijing started to publish daily air quality reports and forecasts, which predicted the pollution index ranges and pollution levels of three major pollutants, i.e. SO_2, NO_2, and PM_{10}. Air quality forecasting became an important task during the preparations for the 2008 Beijing Olympic Games. Taking this opportunity, Beijing significantly expanded the air quality monitoring network and enhanced its monitoring, data utilization and analysis capacity. The technical system developed for air quality forecasting consists of three components: a statistical forecast model, a numerical forecast model, and expert diagnosis and correction, as shown in Figure 3.6.

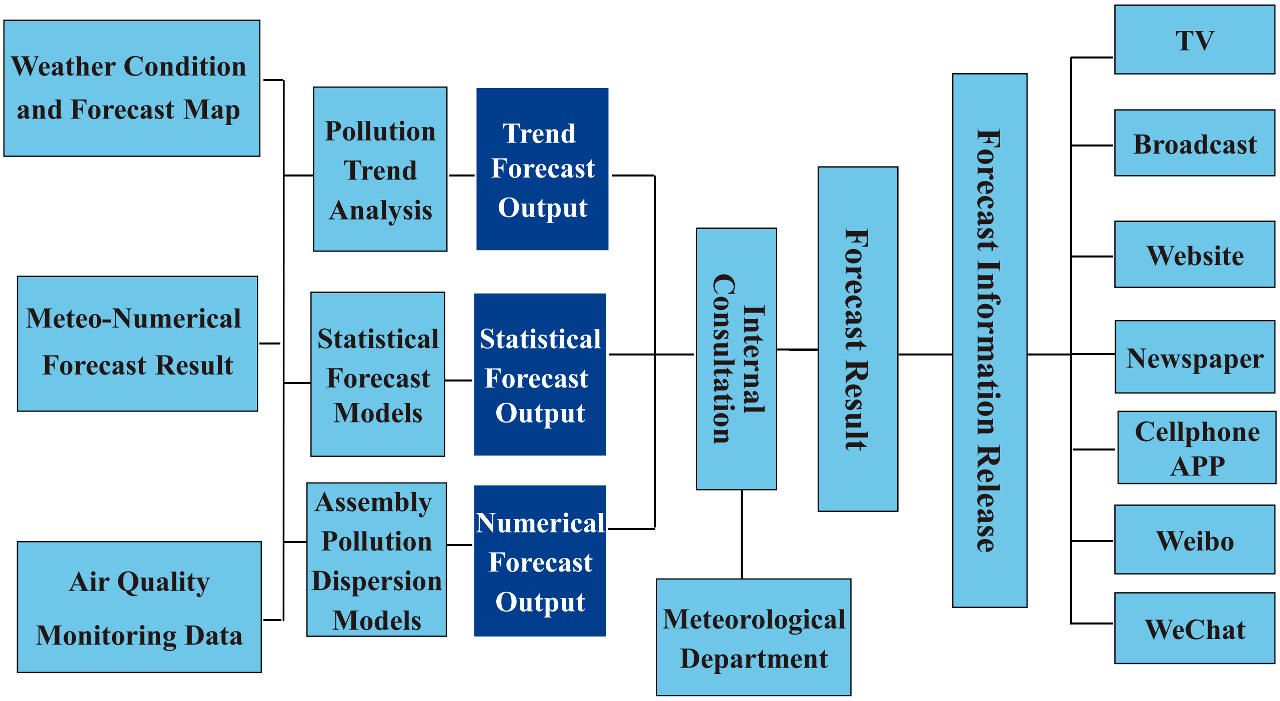


Figure 3.6 Technical and operation framework of ambient air quality forecasting in Beijing

Source: Beijing Municipal Environmental Monitoring Center

Since 2013, Beijing has made public air quality-related information, including real-time concentrations of six major pollutants, i.e. SO_2, NO_2, PM_{10}, CO, $PM_{2.5}$ and O_3, at 35 automatic monitoring sites, and evaluation results, health tips, and air quality forecasts. The information disclosure platforms include new media such as websites, Weibo, WeChat, and mobile apps, in addition to traditional media such as television and radio.

(2) Environmental awareness and public participation

Realizing the importance of public participation in environmental protection, Beijing has gradually enhanced its environmental promotion and education agencies. They worked to set up all-media communications platforms that feature interactions of traditional and new media, including newspaper, radio, television, internet, Weibo, and WeChat; foster online and off-line brand activities with public participation, such as the Beijing Environmental Culture Week and the Beijing Green Communication Conference; and 38 environmental education bases were opened to the public. A variety of forms have been used to report environmental activity updates, interpret environmental policies, popularize environmental knowledge, disseminate green ideas, and significantly improve public environmental awareness. Among these forms are news coverage, popular science books, special television programs, environmental animations, and environmental dramas.

Different activities and campaigns to enhance public participation in environmental protection were developed for specific target groups. For teenagers, a series of environmental protection events were carried out, such as "I Love Mother Earth" Primary and Secondary School Students Speech Competition, Beijing Children's Environmental Protection Art Festival, and so on. For photographers and animation enthusiasts, "Hand in Hand with Blue Sky, You and Me" Environmental Photography Contest, and the Environmental Theme Animation Design Contest were launched. For those who have cars, a series of Green Driving thematic activities were launched. For community residents, promotion activities of environmental knowledge were organized. Beijing began to appoint Beijing Public Environmental Ambassadors since 2013. 10 ambassadors have been appointed up to now, with 5 female ambassadors and 5 male ambassadors, they act as model for the public on living in an environmental way.

Women's volunteer team in Shunyi District publicizes air pollution control

A women's volunteer team in Shunyi District consisting of more than 8,000 volunteers is dedicated to providing services such as environmental promotion and home visits. In recent years, focusing on Air Pollution Control, Conversion of coal-fired heating to electricity or natural gas in rural areas and other work, the women's volunteer team encourages and supports women in villages and communities to participate in the community and village level environmental activities through multiple modes, which has received positive results.

Publicity of policies: In order to publicize the concept of green life, environmental knowledge and policies are provided for residents by means of information columns and electronic screens. The volunteers visit residents to explain the advantages of conversion from coal heating to electricity or gas in rural areas and other policies for women residents to help them understand the policies in detail and participate in rural bulk coal use replacement.

Volunteers pilot actions: Women volunteers regularly carry out environmental cleaning activities in the community/village where they live to encourage the residents to form the habit of environmental protection, and they also carry out the activities like "Turning waste into treasure", which greatly improved the community environment and won the praise of residents.

Regular inspection to find and solve problem: Women volunteers organize regular environmental inspection in community and village. If they find facilities or behaviors that damage or pollute the environment, they persuade and educate people to correct timely. The women volunteers' action helps to make the environment cleaner and tidier, and a healthy and harmonious community/village.

Summer Palace in winter (Photograph credit: Beijing Municipal Environmental Publicity Center)

Figure 3.7 Beijing Public Environmental Ambassadors (2013-2017)

Nie Yijing, Guo Chuan, Cai Xianglin, Li Li, Stephon Marbury, Hai Qing, Li Chen, Yang Yang, Xu Chunni, Bai Yansong

Source: *Beijing Municipal Environmental Publicity Center*

An environmental petition and complaint system have been established, which includes an environmental protection hotline (12369) and an online complaint mailbox. Incentives up to 50,000 Yuan per case is offered to encourage the public to actively report violations related to environmental pollution.

Rising Public Environmental Awareness

Results of Beijing's public environmental awareness surveys conducted by third-party agencies since 2013 show marked improvements in public environmental awareness, understanding of environmental knowledge, sense of environmental responsibility, and participation in environmental actions.

First, the public has become more knowledgeable about that environmental protection is closely related to themselves. People with knowledge of $PM_{2.5}$ increased from 87% in 2013 to 94% in 2016. People showed a high level of awareness of $PM_{2.5}$ sources in 2017, of which 73.6% men and 70.66% women blamed motor vehicle exhaust emissions, and 50.73% men and 49.40% women blamed dust, both being the main $PM_{2.5}$ sources.

Second, the public has a stronger sense of environmental responsibility. The proportion of people who believe that they should play an important role grew significantly, from 65.3% in 2013 to 80.86% men and 80.17% women in 2017. The degree of public satisfaction with Beijing's environmental quality rose from 42% in 2015 to 64% in 2017. The percentage of public participation in environmental protection activities also increased from 30% in 2013 to 49% in 2016. In addition, the public are engaged in more diverse activities, such as "starting with small things," "participating in policy development discussions," "reporting environmental violations and illegal acts," and so on. For example, public awareness of the environmental complaints hotline 12369 rose from 38% in 2013 to 59% in 2016, and in 2017, 43% of the respondents said that they "have proactively reported environmental violations."

CHAPTER IV

QUANTITATIVE ASSESSMENT OF AIR POLLUTION CONTROL MEASURES IN BEIJING

The quantitative effectiveness of pollution control measures taken in Beijing in the 20 years from 1998 to 2017 were evaluated, focusing on two of the most significant sources: coal combustion sources and mobile sources.

4.1 Adjustment of Energy Structure and Control of Coal Combustion Source Emissions

Coal has long been an important source of energy in Beijing. It has been mainly used in sectors closely related to production and people's lives, such as power generation, industrial production, residential cooking and heating. Since 1998, Beijing has made vigorous efforts to upgrade end-of-pipe treatment and adjust the energy structure. These approaches were realized by requiring use of low-sulfur coal and accelerating the development of clean energy such as natural gas and electricity. The measures taken from 1998 to 2017 to control pollution from coal combustion sources are shown in Figure 4.1.

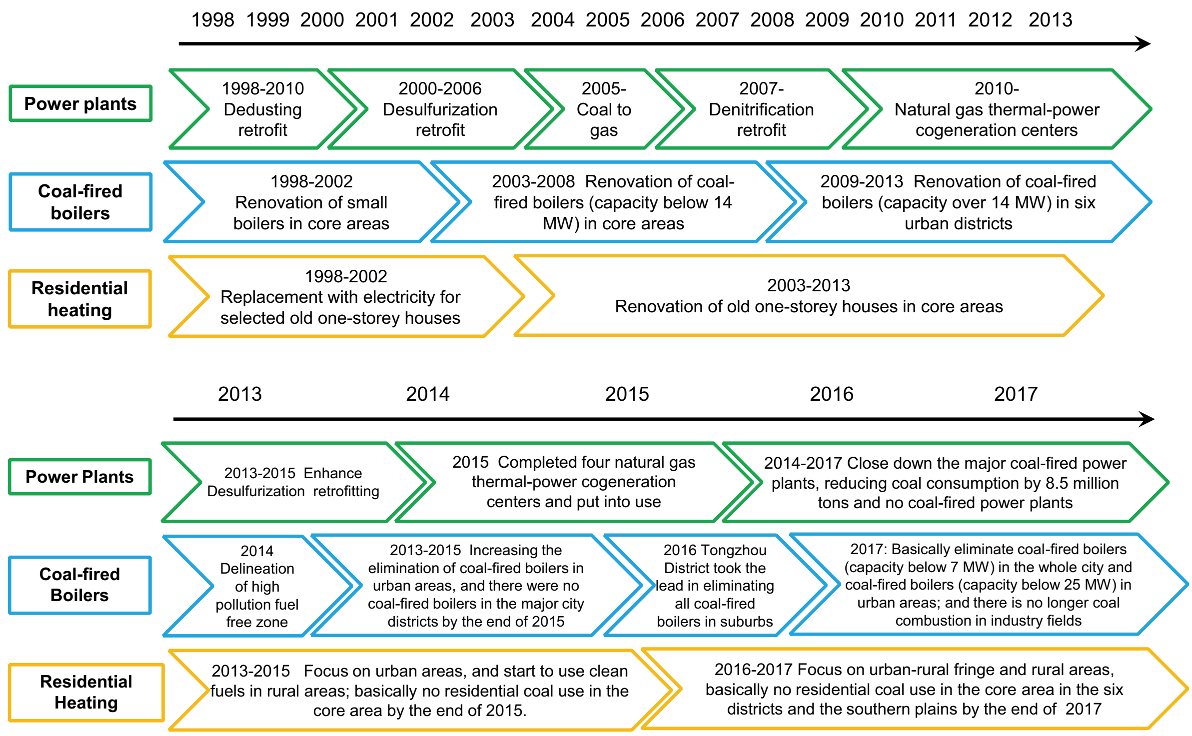


Figure 4.1 A brief history of coal combustion control measures taken in Beijing, 1998-2017

Source: Former Beijing Municipal Environmental Protection Bureau, Tsinghua University

Through these series of measures, Beijing achieved a qualitative leap in its energy mix during a period of rapid growth in energy consumption. From 2013 to 2017, the consumption of coal fell below 5 million tons from 28 million tons and its proportion in total energy consumption dropped from 23.3% to about 5.7%, while the proportion of clean energy (Non-coal energy) rose to higher than 90%.

(1) Ultra-low emission renovation and clean energy alternative in power plants

Coal-fired power plants used to be the main coal consumers. Before 2005, EOP retrofitting projects were implemented in power plants to lower the emissions of SO_2, dust and other pollutants. Beijing began the coal-to-gas transformation in 2005 in power plants, and gradually increased their consumption of natural gas. This contributed to a marked decrease in coal consumption in the power sector while power generation actually expanded. Coal consumption in the power sector tended to decline after peaking in 2005 and fell to 6.43 million tons in 2013, with a total of 2.5 million tons of coal reduced during this period. Meanwhile, natural gas consumption rose to 1.85 billion m^3 in 2013, accounting for 35% of the total consumption of fossil fuels in this sector.

The adjustment of Beijing's energy structure intensified in the power sector after the *Beijing Clean Air Action Plan 2013–2017* was put into practice. From 2013 to 2017, Beijing built four major gas-fired thermoelectric centers to replace coal-fired power plants, which cut nearly 8.5 million tons of annual coal consumption. By 2017, the power sector became almost coal free, and 7.4 billion m^3 of natural gas was consumed. As a result, the share of natural gas in total fossil fuel consumption in the power sector increased to 85%.

(2) Renovation of coal-fired boilers

The renovation of coal-fired boilers has long been an important task for Beijing to control air pollution. Beijing has actively carried out the development of coal-free areas since 1998, and stepped up efforts to transform coal-fired boilers during 2013 to 2017, a total of 27,300 MW of coal-fired boilers were renovated or eliminated, and annual coal consumption was thereby cut by about 8.5 million tons.

The coal-fired boilers in Beijing were renovated in four phases according to areas and priorities, as shown in Table 4.1. By 2017, coal consumption was basically eliminated in the plain areas of the city.

Table 4.1 Four-phases renovation of coal-fired boilers in Beijing during 1998–2017

Phase	Area	Focus	Implementation
I (1998–2002)	Core area[1]	Coal-fired boilers of less than 0.7 MW	10.633 coal-fired boilers involving 15,687 MW eliminated[2]
II (2003–2008)	Core area	Coal-fired boilers of less than 14 MW	5,704 coal-fired boilers involving 15,499Mweliminated
III (2009–2012)	Six urban districts[3]	Coal-fired boilers of 14MW	598coal-fired boilers involving 4,038 MW eliminated
IV (2013–2017)	whole city area	Coal-fired boilers of 7 MW or less	8,312 coal-fired boilers involving 27,416 MW eliminated (not including 27,000 small domestic cookers)

Note: 1. The core area refers to Dongcheng District and Xicheng District; 2. The six urban districts are Chaoyang, Haidian, Fengtai, Shijingshan, Dongcheng, and Xicheng.

Data source: *Compilation from several sources from the former Beijing Municipal Environmental Protection Bureau*

(3) Elimination of civil bulk coal consumption

From 1998 to 2017, Beijing continued to advance heating system transformation to reduce bulk coal consumption based on the availability of natural gas, electricity and other cleaner energy. Beijing completed installation of the clean energy heating alternatives in about 700,000 households, and basically achieved a coal-free core urban area by the end of 2015. In the years after 2015, the control of bulk coal expanded to rural-urban fringes and plain rural areas, coal-burning heating and cooking were replaced with cleaner energy in rural plains villages. These actions reduced annual coal consumption by nearly 1 million tons and basically eliminated coal consumption from the six urban districts and southern plain rural area.

4.2 Adjustment of Transportation Structure and Control of Mobile Source Emissions

Pollution prevention and control of motor vehicles has always been a key task in Beijing's air pollution control. Since 1998, Beijing has formulated and revised more than 30 local vehicle emission standards, involving new vehicles, in-use vehicles, and fuel quality. With more application of traffic control and economic incentives beginning in 2008, an integrated vehicle emission control system covering Vehicle-Fuel-Road was gradually developed and continuously improved during 2013–2017 (Figure 4.2). Figure 4.3 shows the main measures and their timing.

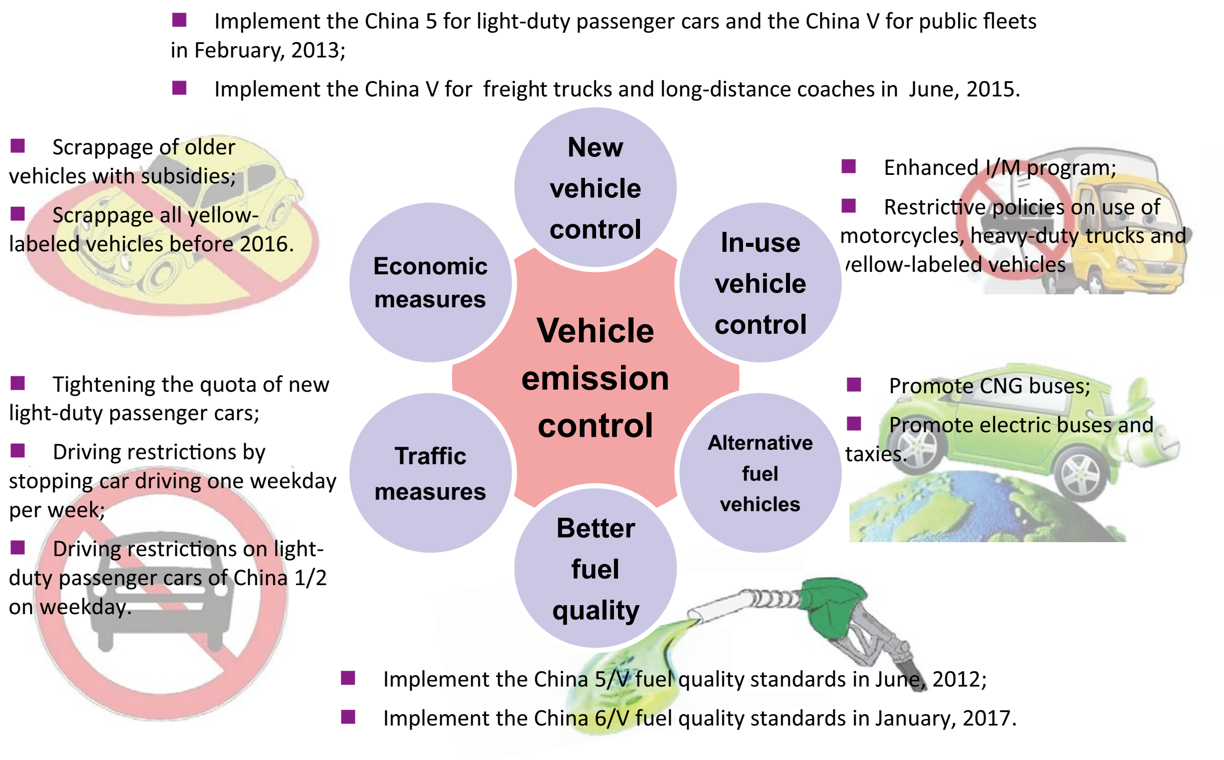


Figure 4.2 Vehicle-fuel-road integrated control system

Source: Former Beijing Municipal Environmental Protection Bureau, Tsinghua University

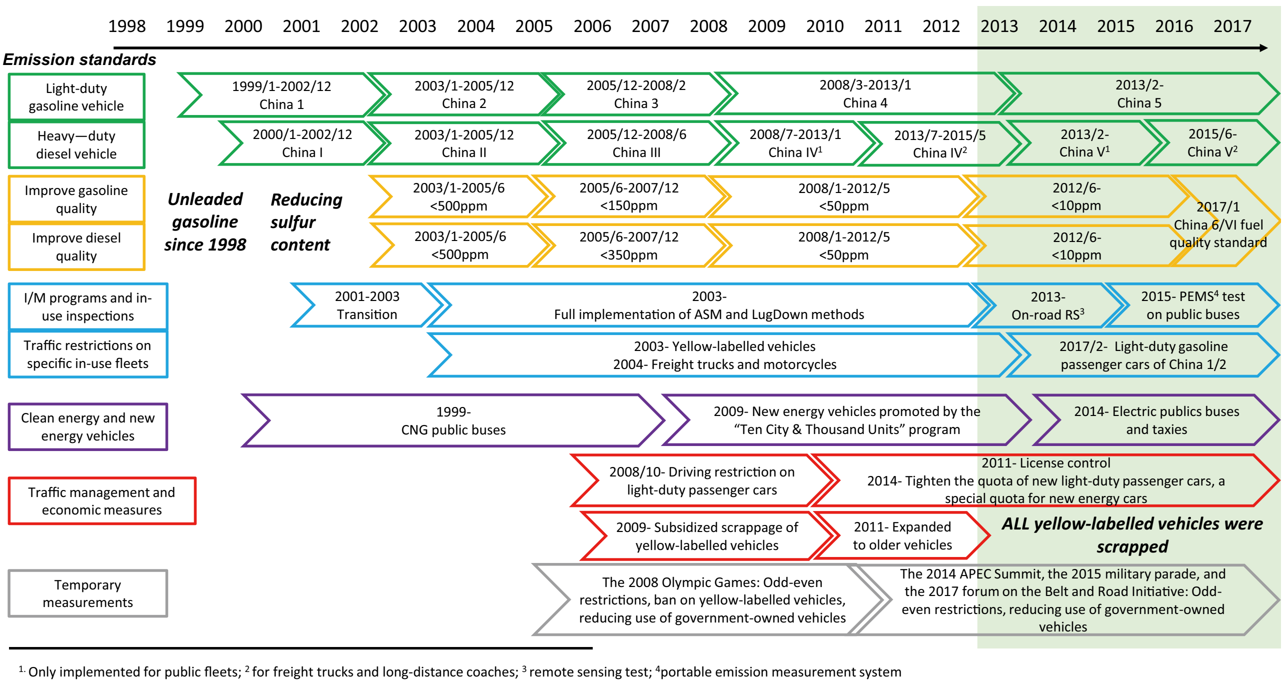


Figure 4.3 Review of main emissions control measures for motor vehicles in Beijing, 1998–2017

Source: *Former Beijing Municipal Environmental Protection Bureau, Tsinghua University*

(1) Stricter emission standards and in-use vehicle retrofitting

In January 1999, Beijing became the first city in China to implement China 1 emission standards for light-duty gasoline vehicles. In February 2013, Beijing took the lead by implementing Beijing 5/V emissions standards, equivalent to Euro 5/V emissions standards, which further narrowed the vehicle emissions control gap with developed countries in Europe and North America. Over the past two decades, Beijing leaped forward in the control of new vehicle emissions, and helped to foster energy-saving technological progress in the Chinese automotive industry.

Along with the tightening of emission standards, Beijing took additional measures to reduce motor vehicle emission. In the past 20 years, In-use vehicles retrofitting was carried out in 4 phases. In 1999, Beijing started the renovation and treatment of gasoline vehicles to reduce the CO, hydrocarbons (THC) and NO_x emission, and nearly 200,000 cars were retrofitted. In 2008, retrofitting by installation of diesel particulate filter (DPF) to reduce particulate matter was launched, a total of 10,000 vehicles were retrofitted. In 2015, 8,800 China IV/V diesel buses were retrofitted to reduce NO_x emission. Starting from 2016, 8 categories of heavy duty public service vehicles, including public transport, sanitation, postal, shuttle, school bus, tourism bus, airport bus, and trucks for muck transport, were equipped with DPF filters. By the end of 2017, a total of 17,000 vehicles of these types have been installed with this equipment.

(2) Scrappage of old and polluting vehicles

In Beijing, yellow-labeled vehicles were first restricted within the Second Ring Road in 2003. During the 2008 Olympic Games period, they were banned in the whole city. In 2010, the scope of the restricted area for yellow-labeled vehicles was extended to within the Sixth Ring Road and then to the whole city in December 2015. For light-duty gasoline vehicles, starting from 2017, those of China 1 and China 2 emission standards have been restricted within the Fifth Ring Road of Beijing; for heavy-duty diesel trucks, those of China III emission standard or less have been restricted within the Sixth Ring Road starting from 2017.

In order to encourage the replacement of high-emission vehicles, Beijing has introduced government subsidies for the scrappage of older vehicles with high emissions since 2009. During 2013-2017, Beijing eliminated a total of 1.7 million old vehicles, far surpassing the planned target.

(3) Other measures

Measures to control mobile source emissions also include upgrading fuel quality, promoting gasoline and diesel detergents, encouraging new energy vehicles and optimizing the transportation structure, restricting purchase of new cars and traffic control measures.

Upgrading fuel quality: Beijing began to improve vehicle fuel quality in the late 1990s and became the first Chinese city with unleaded gasoline in 1998. It was among the first in the country to implement China II to V fuel quality standards, and simultaneously upgrade the standards for fuel quality and new vehicles. In January 2017, Beijing once again led the national implementation of China VI fuel quality standards, which further tightened environmental indicators for gasoline and diesel.

Developing new energy vehicles: In 1999, Beijing introduced compressed natural gas (CNG) to the bus fleet and gradually promoted clean fuels and new energy buses. Among the 2,306 buses that were updated in 2016, 1,368 were electric vehicles, accounting for 59%.

Optimizing transportation structure: By optimizing the urban layout and developing public transport system, including subways and buses, the transportation structure has significantly improved in recent years (Figure 4.4). This effectively cut vehicle trips and emissions, and eased traffic congestion during rush hours.

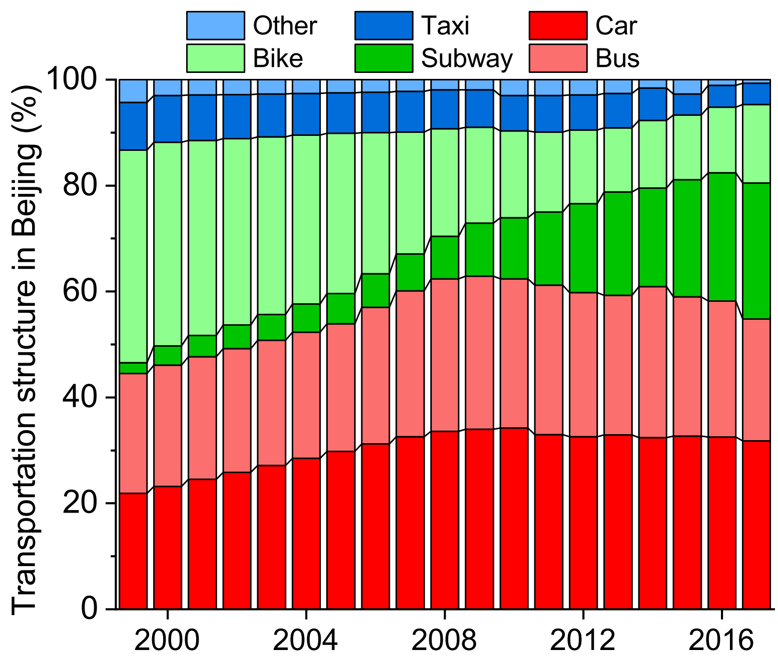


Figure 4.4 Modes of Transportation in Beijing, 1998-2017

Source: Beijing Transportation Research Center

In response to the rapid growth, high use frequency, and increased density in urban area of small passenger cars, Beijing piloted temporary traffic restrictions using odd-and-even number license plates during the Beijing 2008 Olympic Games' period. Based on this experience, traffic management measures that restrict passenger cars in certain areas during weekday rush hours were put into force in October 2008. Furthermore, in 2011 Beijing started to restrict the purchase of new vehicles by limiting the monthly quota to 20,000 new license plates for passenger cars. The quota was tightened in 2014 with the annual total lowered from 240,000 to 150,000. These restrictions have reversed the rapid growth of motor vehicle fleet and contribute to mitigate traffic congestion in Beijing as well.

4.3 Effects of Beijing's 20 Years'Air Pollution Control Measures

(1) Emission reduction by coal combustion source control measures

Owing to strict EOP treatment and coal-to-gas transformation, the total $PM_{2.5}$ emissions from power plants in Beijing continued to decline during 1998–2017 in spite of growing electricity production, while SO_2 and NO_x emissions first rose and then decreased. The most significant reduction of various pollutant emissions took place in 2 phases, including 1 phase from 2004 to 2007, and the other from 2013 to 2017 (Figure 4.5). Relative to 1998, the $PM_{2.5}$, SO_2, and NO_x emission reductions of power plants reached 16,800 tons, 53,000 tons, and 52,300 tons respectively in 2017, representing a decrease of 97%, 98% and 86%. In this regard, the operation of EOP treatment technologies played a key role from 1998 to 2013, including electrostatic precipitators (ESP)/bag filters, wet limestone flue-gas desulfurization (FGD), and selective catalytic reduction (SCR). From 2013 to 2017, as the coal-to-gas transformation advanced, adjustments in the energy mix were able to more fully harness potential emission reductions and further drive the reduction of air pollution from power plants.

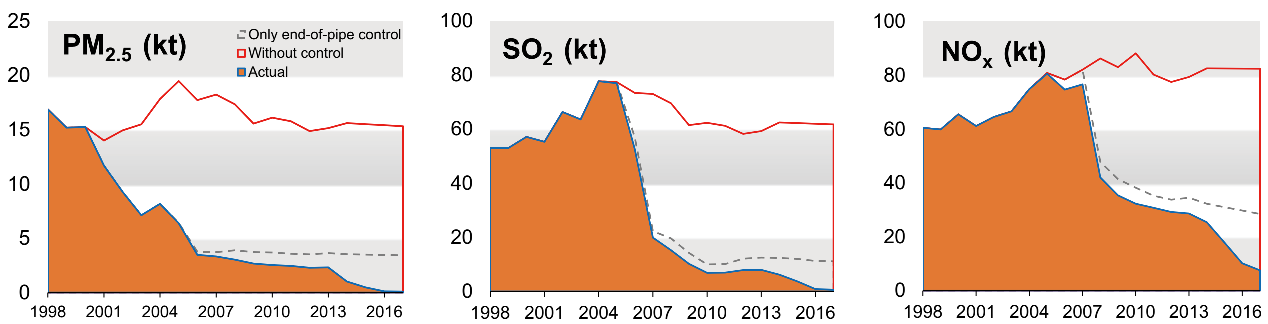


Figure 4.5 Emissions of major air pollutants from power plants in Beijing, 1998–2017

Source: Tsinghua University

Through the renovation of coal-fired boilers in Beijing, the annual emissions of $PM_{2.5}$, PM_{10}, SO_2, and NO_x emissions in 2017 were cut by 21,000 tons, 35,000 tons, 16,500 tons and 56,000 tons respectively as compared with 1998. The pollutant emission reductions in different stages of renovation are as shown in Figure 4.6.

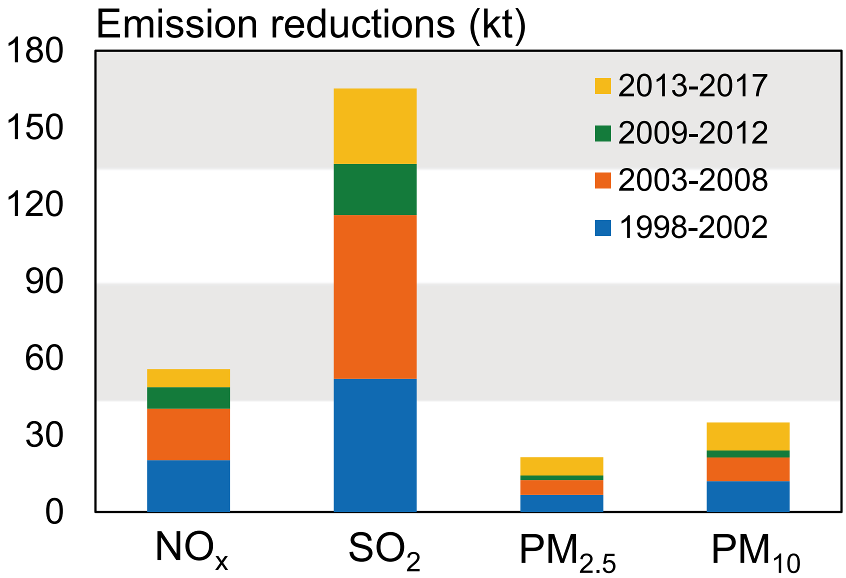


Figure 4.6 Pollutants emission reductions by renovation of coal-fired boilers in Beijing, 1998–2017

Source: Tsinghua University

In terms of civil bulk coal, the annual $PM_{2.5}$, PM_{10}, SO_2, and NO_x emissions in Beijing were reduced by 21,000 tons, 32,000 tons, 46,000 tons and 16,000 tons respectively from 1998 to 2017, owing to the implementation of high-quality coal, coal-to-electricity and coal-to-gas policies. The emission reductions in absolute terms were smaller than those from the control of power plants and coal-fired boilers. However, bulk coal was mainly used in old urban centers with high building and population density, and in villages. Clean energy alternatives renovations significantly improved the air quality of these communities and effectively reduced the concentration of indoor pollutants in old cottage areas and villages during the heating season. This contributed to better living conditions and improved safety in old cottage areas and yielded more significant environmental and health benefits.

(2) Emission reduction by mobile source emissions control measures

After implementing a series of measures, the total emissions from mobile sources in Beijing dropped sharply, though the number of motor vehicles tripled. Compared with 1998, the CO, total hydrocarbon (THC), NO_x, and $PM_{2.5}$ emissions from mobile sources in 2017 declined by 1,105kt, 94kt, 71kt, and 6kt respectively, representing a reduction of 89%, 64%, 55% and 81%. The yearly emissions of the four pollutants are as indicated in green in Figure 4.7. The reduction of CO and THC emissions is mainly attributed to the strict control of emissions from light-duty gasoline vehicles, and the reduction of $PM_{2.5}$ emissions benefits from the control of heavy-duty diesel vehicles. NO_x emission reductions were smaller than those of other pollutants.

The sum of blue, red and yellow sections in Figure 4.7 show what would have occurred in the absence of control measures. Motor vehicle emissions would continue to rise dramatically (and traffic conditions would continue to deteriorate). In this uncontrolled scenario, CO, THC, and NO_x emissions in 2017 are more than 100 times the actual levels and $PM_{2.5}$, 80 times greater. In other words, the motor vehicle control measures removed over 99% of the CO, THC, NO_x, and $PM_{2.5}$ emissions.

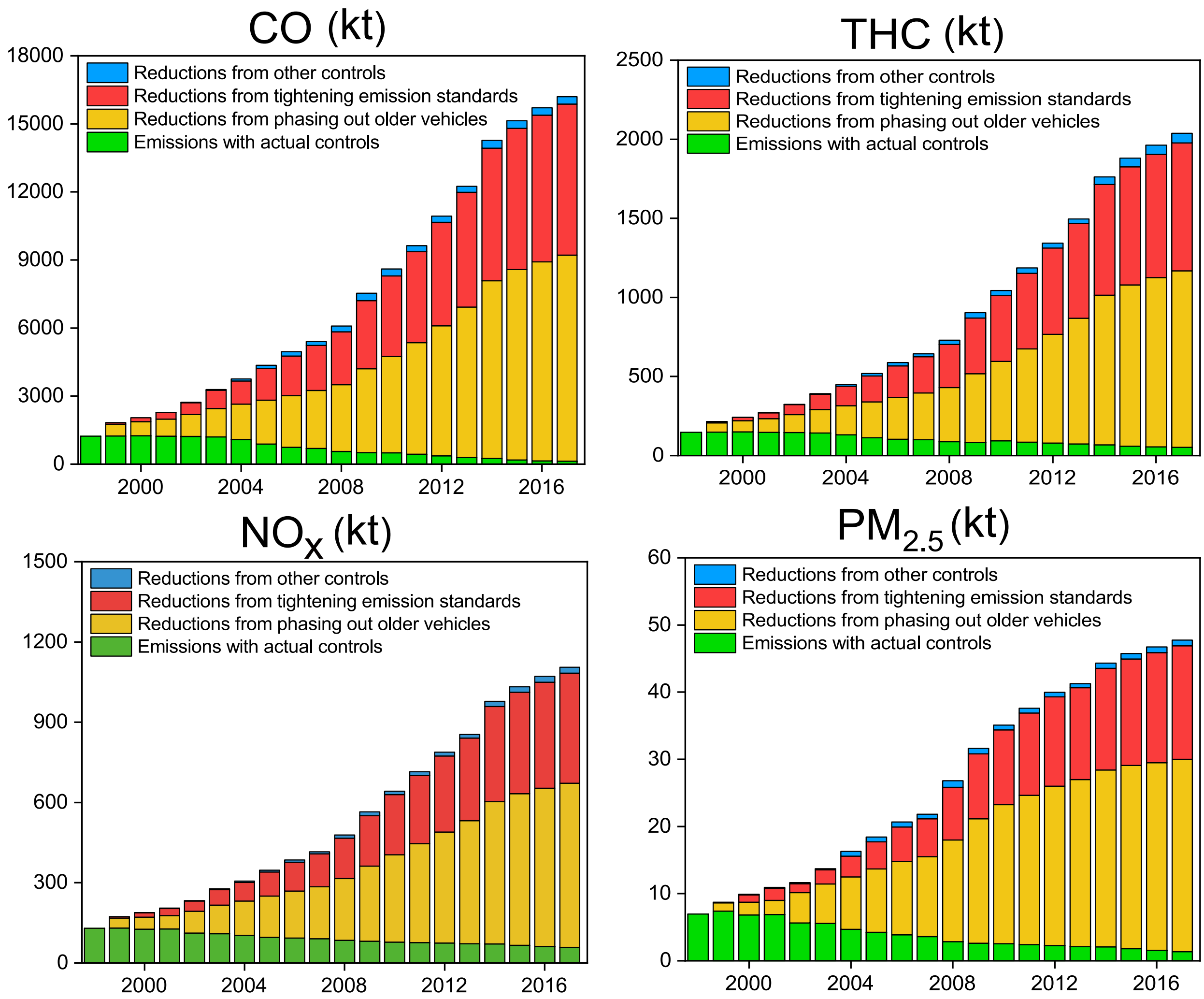


Figure 4.7 Actual mobile source emissions and emission reduction effects of control measures in Beijing, 1998–2017

Source: *Tsinghua University*

The elimination of old and polluting vehicles was a result of a combination of multiple measures. Among all measures for mobile source emissions control in Beijing, regional traffic restrictions and incentives significantly accelerated the elimination of old and polluting vehicles and generated the greatest emission reductions. Compared with the uncontrolled scenario, the elimination of old and polluting vehicles cumulatively accounted for 56%, 56%, 59%, and 63% of the CO, THC, NO_x, and $PM_{2.5}$ emission reductions during 1998–2017 respectively (red section in Figure 7).

Beijing has long been a leader in China in upgrading motor vehicle emissions standards. Results of the analysis showed that the continuous improvement of emissions standards exerted a significant effect on the reduction of mobile source emissions, second only to the elimination of old and polluting vehicles. Compared with the uncontrolled scenario, this measure cumulatively contributed up to 42%, 41%, 39%, and 34% of the CO, THC, NO_x, and $PM_{2.5}$ emission reductions during 1998–2017 respectively (yellow section in Figure 4.7).

The contributions of other measures, indicated in blue in Figure 4.7, was 3%, 3%, 2%, and 2% respectively, during the same period.

4.4 Air Pollution Control in Other Sectors

(1) Industrial restructuring and industrial pollution control

Focusing on the functional orientation of the capital city, Beijing has adopted a combination of measures to further optimize the industrial structure and reduce industrial pollution, including tightening environmental requirements for new development projects, eliminating obsolete production capacity, rectifying polluting businesses and enterprises, promoting cleaner production, and intensifying EOP treatment. Beginning in 2006, a group of large-scale industrial enterprises such as Beijing Coking and Chemical Plant, Beijing Capital Steel Group Shougang Shijingshan Plant, and Dongfang Chemical Plant were closed or relocated; number of cement manufacturer factories was reduced from 19 to 2, and the production capacity of those remaining is used only for integrated disposal of hazardous waste. Since 2013, over 1,900 polluting enterprises from the manufacturing sector, such as printing, casting and furniture, were closed or relocated through adjustment; 11,000 polluting businesses and enterprises were treated according to their different situation and categories immediately after they were identified. More than 400 pollution control renovation projects were implemented, with the focus on NO_x and VOCs control. At the same time, active efforts were made to develop high-tech industries and service industries, raising the proportion of tertiary industries in the economy from 67.4% in 2001 to 80.6% in 2017, on par with the average level of developed countries.

(2) Dust pollution control

Beijing has been under a period of rapid urban expansion during the past 20 years, dust pollution became evident due to an increased number of large-scale and wide-ranging construction activities. Focusing on bare lands, construction sites and road dust, the city continued to improve its dust pollution control system for more precisely pollution control. For construction dust control, video monitoring systems were installed in more than 1,700 construction sites and 155 concrete mixing plants throughout the city. Concrete batching plants that failed to meet requirements were shut down; a green and civilized construction management model was created; and efficient washing facilities and new dust suppression technologies were applied. For road dust control, more than 8,000 demolition waste transportation trucks were retrofitted to have sealed carrying space since 2013; and monitoring of dust on major roads was carried out and the results announced on a monthly basis. New methods for "absorbing, sweeping, scouring, and collecting" road dust have covered more than 88% of the roads in the city, which effectively reduced road dust.

In order to strengthen and expand the capacity of the natural environment, Beijing launched a program to plant trees in 66,667 hectares of plain area (1 million Chinese *mu*), increasing the green coverage rate to over 60% in the city. Also, efforts were made to enlarge the water surfaces in the Yongding River, Chaobai River and the North Canal river systems. A natural ecosystem consisting of green shields in mountains, green buffers in suburban plains, and urban areas with scattered green coverage were formed.

Dust Pollution Control

In order to control construction dust pollution, Beijing set the six-100% guideline for dust control in construction site (100% enclosure around the site, 100% coverage of demolition waste and stacked materials, 100% bare land pavement,100% cleaning of vehicles entering and leaving the site, 100% wet excavation, and 100% closed demolition waste transport vehicles) and continued to improve the standards.

In order to control road dust pollution, Beijing unveiled the *Quality and Operation Requirements for City Road Sweeping and Cleaning* in 2014, which specifies and classifies the management and operation for city roads. Urban trunk roads are washed twice a day; for secondary roads, mechanical scouring and washing are performed on daily base, and during winter washing frequency is increased. In 2017, mechanical sweeping and new cleaning process operations covered 89% and 88% of the roads in Beijing respectively.

For strict control of dust pollution from transporting demolish waste, Beijing released the *Technical Requirements for Marking, Monitoring, and Sealing Construction Waste Transportation Vehicles* in 2014. Meanwhile, vehicles transporting demolish waste in Beijing must meet local vehicle emission standards, i.e. China IV standards for newly-purchased vehicles and China III emissions standards for transformed vehicles. As of 2017, 4,216 demolish waste transportation vehicles had installed satellite positioning systems and achieved confined transportation.

Hanshiqiao Wetland (Photograph credit: Beijing Municipal Environmental Publicity Center)

CHAPTER V

COORDINATED AIR POLLUTION CONTROL IN BEIJING AND ITS SURROUNDING AREAS

5.1 Mechanism for Joint Prevention and Control of Air Pollution in Beijing-Tianjin-Hebei and Surrounding Areas

(1) Coordination agency

With the support of China's State Council, the Coordination Group for Air Pollution Prevention and Control in Beijing-Tianjin-Hebei and Surrounding Areas was established at the end of 2013. Led by the Beijing Municipal Government, the Coordination Group encompasses seven ministries, namely the National Development and Reform Commission (NDRC), Ministry of Finance, former Ministry of Environmental Protection (MEP), Ministry of Industry and Information Technology, Ministry of Housing and Urban-Rural Development, China Meteorology Administration, and National Energy Administration, and six provinces (autonomous regions and municipalities), namely Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, and Shandong. In May 2015, Henan Province and the Ministry of Transport joined the Coordination Group, expanding the members to eight ministries and seven provinces (Figure 5.1). In 2017, according to the characteristics of pollutants transport, MEP identified Beijing, Tianjin, and another 26 cities in Hebei, Shanxi, Shandong, and Henan provinces (collectively referred to as "2+26" cities) as the key cities along the air pollution transport channels in Beijing-Tianjin-Hebei and Surrounding Areas, and prioritized these cities for the purpose of air pollution control.

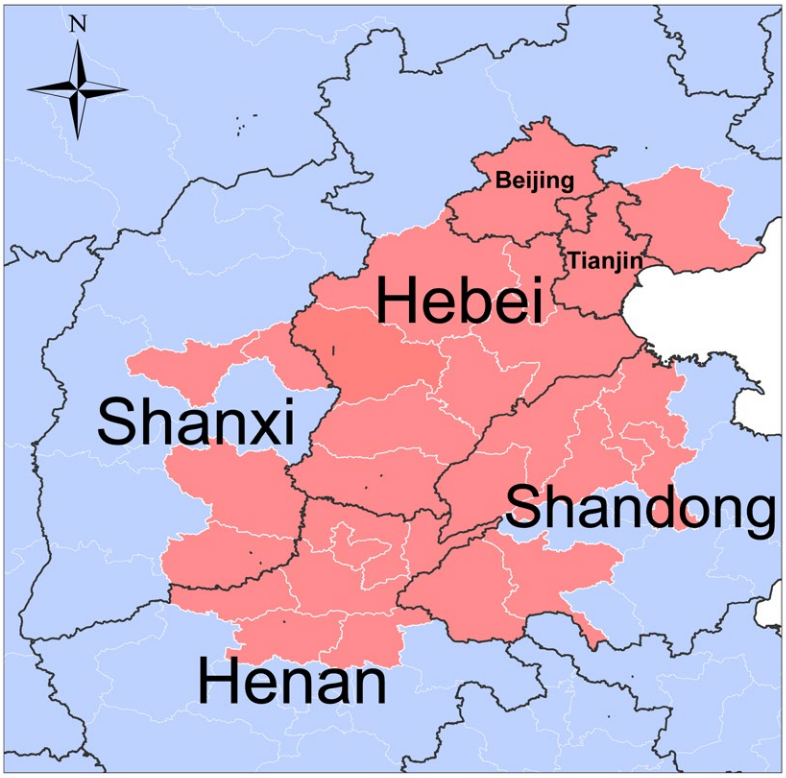


Figure 5.1 Distribution of the "2+26" cities (the red areas) in Beijing-Tianjin-Hebei and Surrounding Areas

Source: Former Beijing Municipal Environmental Protection Bureau, Tsinghua University

(2) Unified planning and policy

Since 2013, the Coordination Group and relevant ministries, such as NDRC and MEP, have successively rolled out multiple plans and annual programes for regional air pollution control, and put forward unified regional requirements for the key tasks of clean heating, comprehensive industrial pollution control, motor vehicle pollution control, and responding to heavy pollution. In 2015, a project was launched to study the medium-long term planning for strengthening air pollution control in Beijing-Tianjin-Hebei and Surrounding Areas. The outcomes of this project provided important support for the analysis, forecasting and early warning for heavy pollution episodes in the region; crucial action for the comprehensive control of autumn and winter air pollution; and the preparation of the 13^{th} five-year plan for air pollution prevention and control in related provinces. In 2016, Beijing, Tianjin and Hebei put into effect the China V emission standards for motor vehicles and the China V standards for fuel quality. In 2017, the "2+26" cities began to supply fuels meeting China VI standards, and Beijing, Tianjin and Hebei jointly issued the *Limits for Volatile Organic Compounds in Building Paints and Adhesives,* which plays an important role in improving overall air quality.

(3) Cooperation mechanism

Twinning cities: A twinning-based cooperation mechanism to control air pollution was established in 2015. Beijing twinned with neighboring Baoding city and Langfang city of Hebei province. Beijing provided financial and technical support for the elimination of small coal-fired boilers and control of large coal-fired boilers, thus setting an example for regional cooperation on air pollution control.

Unified heavy pollution episode response: A joint forecasting and early warning mechanism was also established. In 2016, the alert thresholds for heavy air pollution emergencies were unified across Beijing, Tianjin, and Hebei. In 2017, these standards were extended to the "2+26" cites and the procedures to issue, adjust and lift alerts were also standardized, paving the way for a unified regional response to heavy air pollution and coordinated measures to reduce emissions in Beijing-Tianjin-Hebei and Surrounding Areas.

Joint mobile source control: A special mechanism was also established for regional cooperation in control of vehicle pollution. That includes joint inspections on new vehicle conformity and penalties upon violation outside the vehicle's registration city. An information sharing platform was built for air pollution prevention and control in Beijing-Tianjin-Hebei and Surrounding Areas, which shares real-time information about air quality and key pollution source emissions in seven provinces (including autonomous regions and municipalities).

5.2 Changes of Air Pollutants Emissions in Beijing and Its Surrounding Areas

According to the MEIC model estimates, in 1998, SO_2 emissions in Tianjin, Hebei, Henan, Shandong and Shanxi totaled 6.23 million tons, NO_x 3.24 million tons, $PM_{2.5}$ 3.49 million tons, and VOCs 3.74 million tons. In the next 20 years, the SO_2, NO_x, and $PM_{2.5}$ emissions all grew at first and then declined, while the VOCs emissions continued to increase before stabilizing in recent years. Figure 5.2 shows the spatial distribution of major pollutants emissions in Beijing-Tianjin-Hebei and Surrounding Areas in 1998, 2013 and 2017.Figure 5.3 shows the changes in the past two decades of major pollutants emissions from various sectors in Beijing-Tianjin-Hebei and Surrounding Areas.

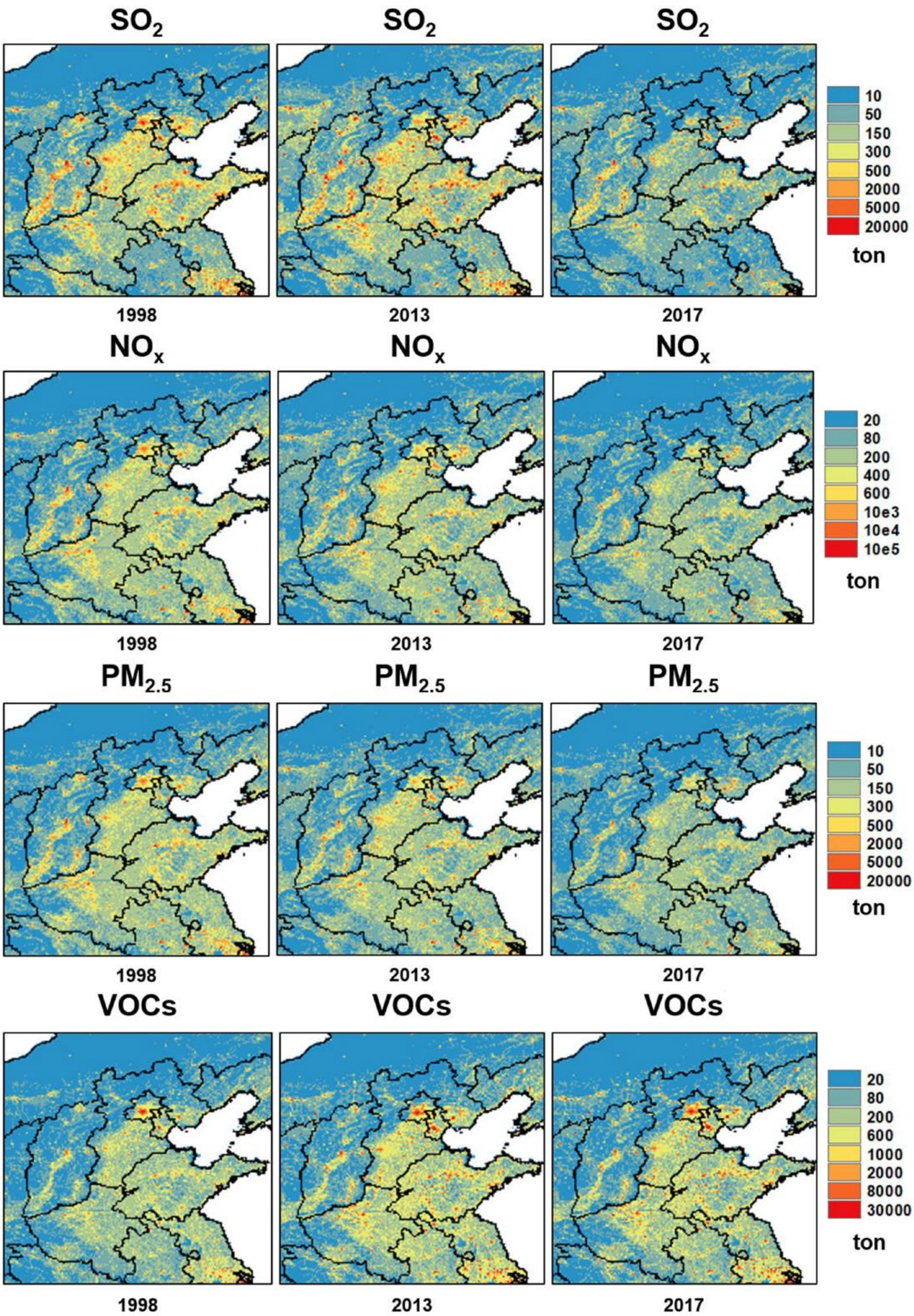


Figure 5.2 Spatial distribution of major pollutant emissions in Beijing-Tianjin-Hebei and Surrounding Areasin 1998, 2013 and 2017

Source: The Multi-resolution emission inventory for China (http://www.meicmodel.org/)

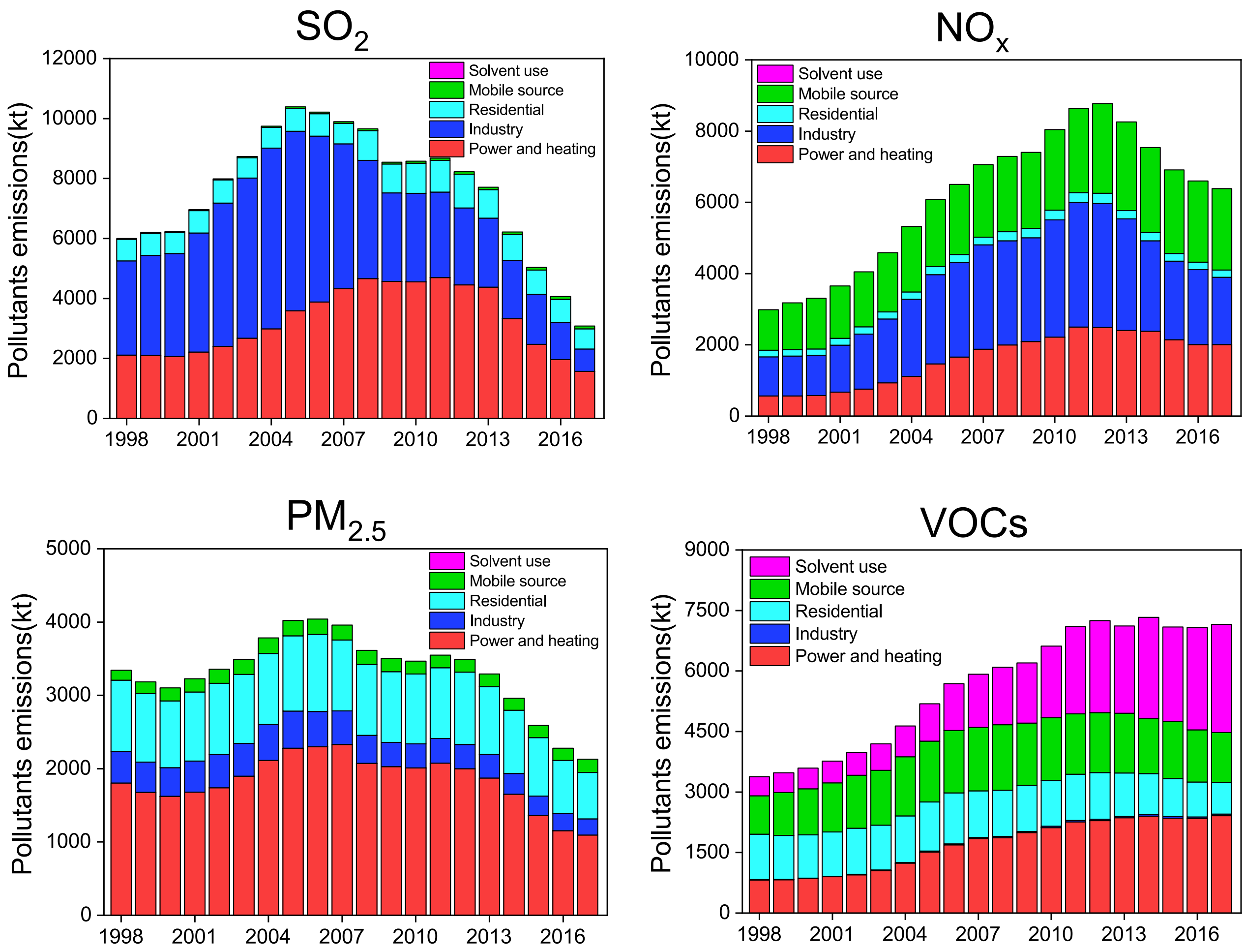


Figure 5.3 Changes in major pollutants emissions from various sectors
In the Areas Surrounding Beijing (including Tianjin, Hebei, Henan, Shandong, Shanxi and Inner Mongolia), 1998–2017

Source: *The Multi-resolution emission inventory for China (http://www.meicmodel.org/)*

Since the national *Action Plan for Air Pollution Prevention and Control* launched in 2013, the emissions of major air pollutants in the Areas Surrounding Beijing (including Tianjin, Hebei, Henan, Shandong, Shanxi and Inner Mongolia) decreased significantly, with changes as shown in Figure 5.4. Except for VOCs, pollutant emissions dropped sharply in 2017 compared with 2013. The SO_2, NO_x and $PM_{2.5}$ emission reductions were 60%, 22% and 42% respectively, while the VOCs emissions basically remained at the 2013 level with a slight increase of 0.2%.

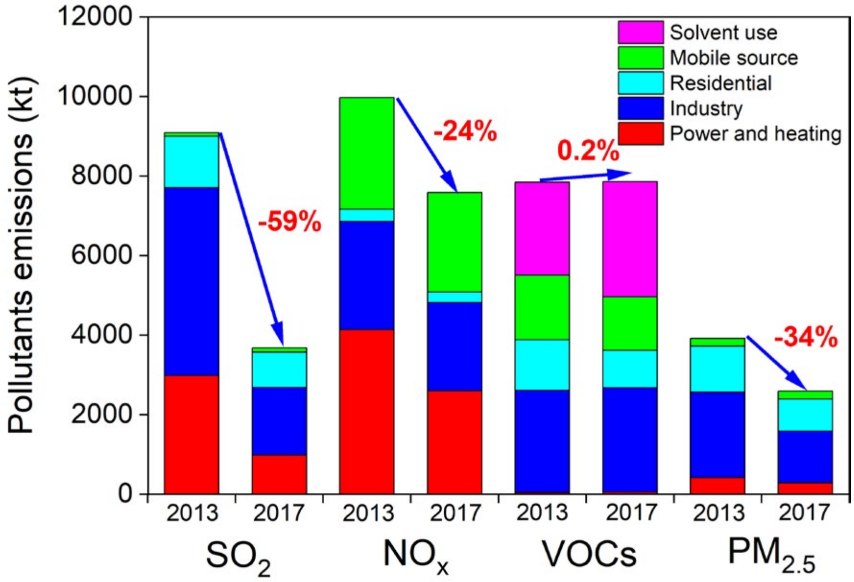


Figure 5.4 Changes in major air pollutant emissions in the Areas Surrounding Beijing (including Tianjin, Hebei, Henan, Shandong, Shanxi and Inner Mongolia), 2013–2017

Source: *The Multi-resolution emission inventory for China (http://www.meicmodel.org/)*

From 2013 to 2017, the power and industrial sectors slashed their SO_2 emissions by 1.221 million tons and 3.145 million tons respectively. This is evidence that the measures in the *Action Plan for Air Pollution Prevention and Control,* such as ultra-low emission of coal-fired power plants, renovation of coal-fired boilers, and transformation of key industries to meet higher standards, have significantly cut SO_2 emissions. For NO_x emissions, the reductions mainly occurred in the power sector, reaching 1.202 million tons during the 2013-2017 period. For $PM_{2.5}$ emissions, the reduction is mainly driven by control of fugitive dust sources and industrial sectors, achieving 937,000 tons and 608,000 tons respectively. Unlike SO_2, NO_x, and $PM_{2.5}$, there has been a slight increase in VOCs emissions in the Areas Surrounding Beijing (including Tianjin, Hebei, Henan, Shandong, Shanxi and Inner Mongolia) during the same period, mainly because of the cumulative emission reductions in the power sector, residential and mobile sources were not enough to offset the incremental increase in emissions from solvent use.


Palace Meseum under blue sky (Photograph credit: Beijing Municipal Environmental Publicity Center)

CHAPTER VI

ASSESSMENT OF *BEIJING CLEAN AIR ACTION PLAN 2013–2017*

The *Beijing Clean Air Action Plan 2013–2017* was one of the most intense programs in Beijing's air pollution control history, with its implementation leading to unprecedented air quality improvement in Beijing. In 2017, the annual average $PM_{2.5}$ concentration in Beijing fell by 35.6% from the 2013 level to 58μg/m^3, representing a major reduction that was considered difficult to achieve both domestically and internationally. Given its significance and results, the following is an impact assessment of the *Beijing Clean Air Action Plan 2013-2017*.

6.1 Effects of Major Measures on Emissions Reduction

Based on the self-examination reports by *Beijing city on the Beijing Clean Air Action Plan 2013-2017* and the appendices, a total of 32 measures in seven categories are sorted out for quantitative assessment. Using the MEIC model, category-specific emission reductions are calculated with 2013 as the base year, in order to analyze the contribution of these measures.

In 2013, the emissions of SO_2, NO_x, VOCs, $PM_{2.5}$, and PM_{10} in Beijing stood at 95,000 tons, 218,000 tons, 273,000 tons, 81,000 tons, 266,000 tons respectively. SO_2 emissions mainly came from the residential sector, industrial sectors, and the power and heating sector; and the NO_x emissions were from mobile sources, and the power and heating sector. VOCs were mainly emitted by solvent use, mobile sources and industrial sectors, and primary PM sources were fugitive dust and the residential sector.

The implementation of the *Beijing Clean Air Action Plan 2013-2017* has evidently brought down the emissions of major air pollutants in Beijing over the five years. The measures taken can be classified into seven categories: Coal-fired boiler control, clean fuels in the residential sector, optimization of the industrial structure, improvements in end-of-pipe control, vehicle emission control, fugitive dust control and integrated treatment of VOCs.

From 2013 to 2017, the emissions of SO_2, NO_x, VOCs, primary $PM_{2.5}$, and primary PM_{10} were reduced by 79,000 tons, 93,000 tons, 116,000 tons, 44,000 tons, and 139,000 tons respectively, a relative decrease of 83%, 43%, 42%, 55%, and 52% compared with 2013.The contribution of each measure to the reduction of major pollutants is shown in Figure 6.1. In terms of SO_2, the renovation of coal-fired boilers and promotion of clean residential fuel played a dominant role by generating reductions of 37,000 tons and 29,000 tons emissions respectively, during 2013-2017, representing 47% and 37% of the total reductions. In terms of NO_x, the control of mobile source emissions contributed the largest share by reducing 43,000 tons, accounting for 46% of the total reductions. This was followed by the renovation of coal-fired boilers and industrial retrofitting, which generated reductions of 27,000 tons and 9,000 tons respectively, accounting for 29% and 10% of the reductions. In terms of VOCs, targeted VOCs treatment was most effective in cutting emissions of 57,000 tons, accounting for 49% of the total reductions. The control of mobile source emissions and industrial restructuring were also important, contributing 16% and 13% of the reductions respectively. In terms of primary $PM_{2.5}$, promotion of clean residential fuel, comprehensive dust control, renovation of coal-fired boilers, and industrial restructuring achieved reductions of 15,000 tons, 11,000 tons, 9,000 tons and 5,000 tons respectively, equivalent to 33%, 25%, 21%, and 12% of the total $PM_{2.5}$ reductions.

In summary, the measures contributing the most to overall reductions of the major pollutants during 2013-2017 include the renovation of coal-fired boilers, promotion of clean residential fuel, industrial restructuring, and control of mobile source emissions. Clean domestic fuel and comprehensive dust control also played a prominent role in reducing primary $PM_{2.5}$ and PM_{10} emissions.

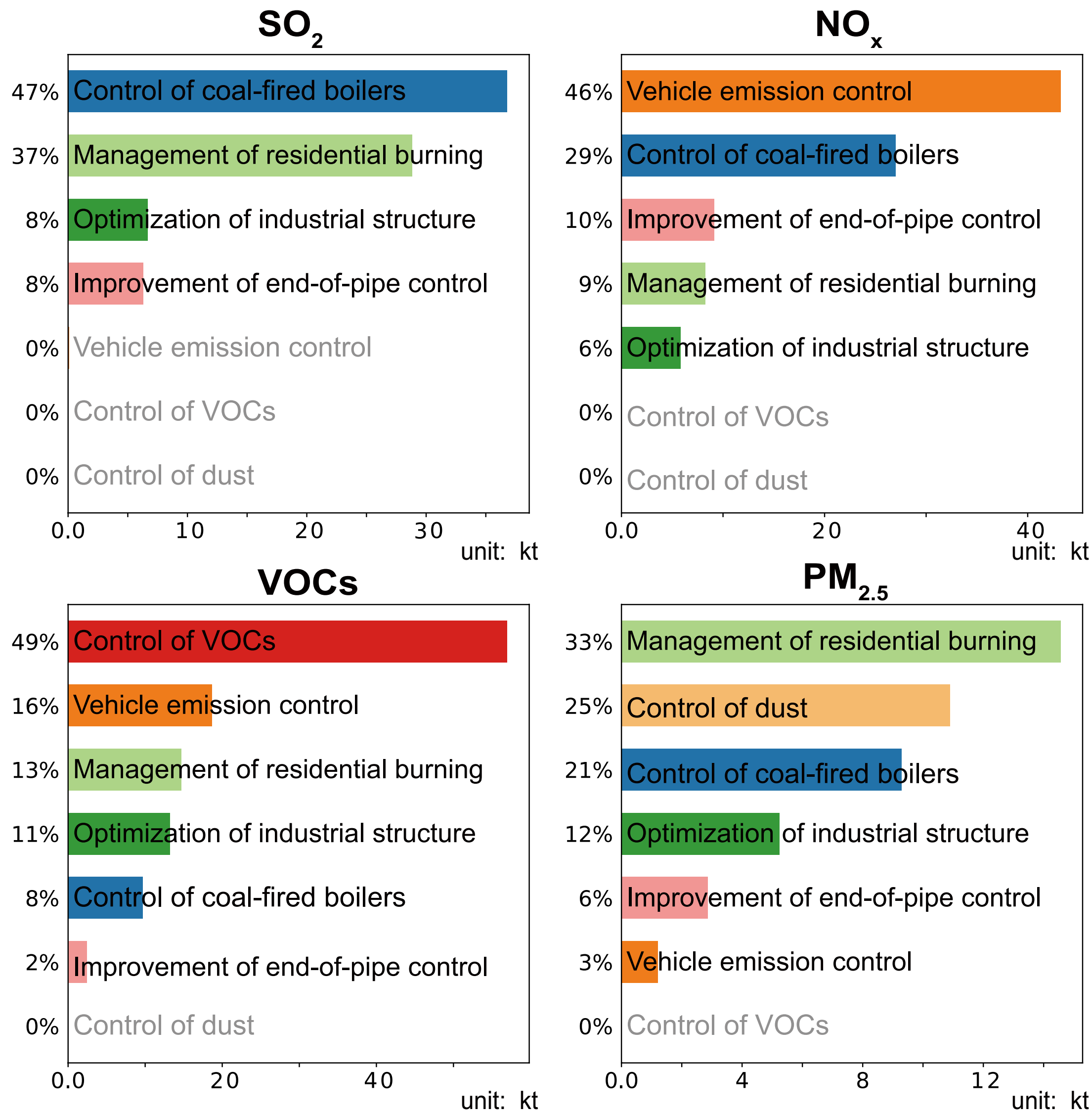


Figure 6.1 Contributions of major measures to reduction of major pollutants emissions in Beijing, 2013-2017

Source: *Tsinghua University; J Cheng et al., ACPD, 2019*

The changes in major pollutant emissions from different sources during 2013-2017 are shown in Figure6.2. Reductions mainly occurred in SO_2 emissions from the power and heating, industrial, and residential sectors, NO_x emissions from mobile sources and the power and heating sector, VOCs emissions from industrial and residential sectors, solvent use, and mobile sources, and $PM_{2.5}$ emissions from residential, industrial, and power and heating sectors, and dust sources.

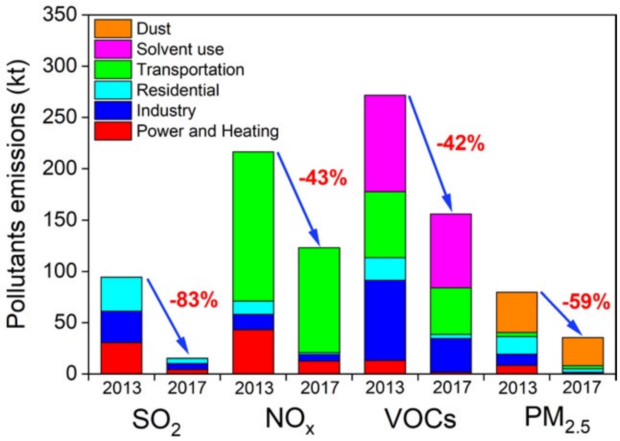


Figure 6.2 Changes in major pollutants emissions from different sources in Beijing, 2013-2017

Source: *Tsinghua University; J Cheng et al., ACPD, 2019*

In 2017, emissions of SO_2, NO_x, VOCs, $PM_{2.5}$, and PM_{10} in Beijing stood at 16,000 tons, 124,000 tons, 157,000 tons, 35,000 tons, and 127,000 tons respectively. SO_2 emissions were mainly produced by fuel combustion in the power and heating, industrial, and residential sectors. The NO_x emissions mainly came from mobile sources, and the power and heating sector, VOCs from solvent use, mobile sources and the industrial sector, and primary PM from dust sources and the residential sector.

6.2 Air Quality Improvements Brought by Major Measures

A three-dimensional atmospheric chemical transport model (WRF-CMAQ) was used to simulate air quality of Beijing and the surrounding region in 2013 and 2017, in order to examine the contributions of the measures in the *Beijing Clean Air Action Plan 2013–2017* to air quality improvement in Beijing, and the impacts of changes in meteorological conditions on air quality in Beijing.

From 2013 to 2017, Tianjin, Hebei, Shanxi, Shandong, and Henan reduced SO_2, NO_x, and $PM_{2.5}$ emissions by 7.71 million tons, 1.869 million tons, and 1.163 million tons respectively through the implementation of the national *Action Plan for Air Pollution Prevention and Control* and their own programs as required. The model simulation results showed that these reductions lowered Beijing's $PM_{2.5}$ concentration by 7.1$\mu g/m^3$, representing 23% of the total decline in the $PM_{2.5}$ level.

Local measures undertaken by Beijing reduced Beijing's $PM_{2.5}$ concentration by 20.6$\mu g/m^3$ during 2013-2017, representing 65% of the total decline. The relative contributions of the various local measures taken are shown in Figure 6.3.

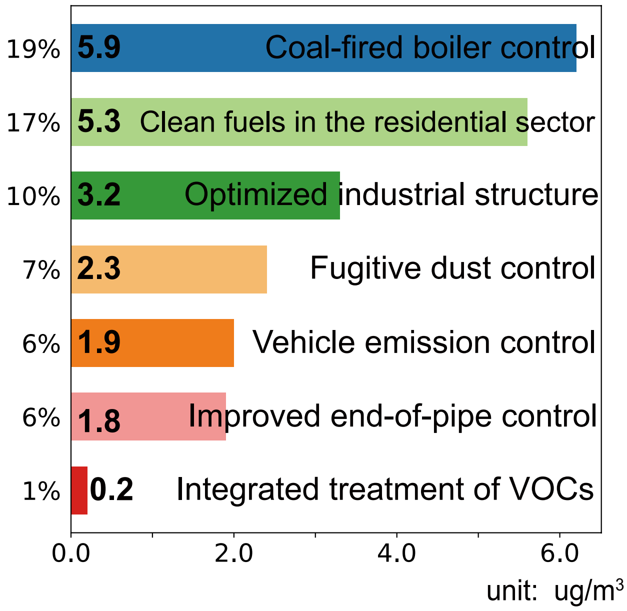


Figure 6.3 Contributions of local measures to reducing the $PM_{2.5}$ concentration in Beijing, 2013-2017

Source: *Tsinghua University; J Cheng et al., ACPD, 2019*

The most significant measure taken was the renovation of coal-fired boilers, which reduced the $PM_{2.5}$ concentrations in Beijing by 5.9μg/m^3, representing 19% of the total decline. The promotion of clean residential fuel and industrial restructuring also made significant contributions of 5.3μg/m^3 and 3.2μg/m^3 respectively, equivalent to 17% and 10% of the total decline. Comprehensive dust control, mobile source emissions control, industrial retrofitting, and VOCs treatment accounted for a smaller proportion of the overall decline in $PM_{2.5}$ concentration,representing7%, 6%, 6% and 1%, respectively.

In terms of emission sources, the contribution of local combustion sources, industrial sources, fugitive dust sources, and locally registered mobile sources 11.2μg/m^3, 5.4μg/m^3, 2.3μg/m^3 and 2.0μg/m^3 respectively, representing 35%, 19%, 7% and 6% of the total decline of $PM_{2.5}$ concentration.

6.3 Impacts of Meteorological Conditions

Meteorological conditions fluctuated in Beijing during the 2013-2017 period. Using the emission levels of 2017, the monthly $PM_{2.5}$ concentrations were simulated under both 2013 and 2017 meteorological conditions. As shown in Figure 6.4, compared with 2013, the meteorological conditions improved by an average of 6% throughout the year 2017. Improvement was noticeable in winter, while some deterioration was observed in spring and summer, specifically April, May, and July. The improved meteorological conditions lowered the annual average $PM_{2.5}$ concentration by 3.8μg/m^3 in 2017, accounting for 12% of the total decline in $PM_{2.5}$ concentrations. Under 2013 meteorological conditions, the annual average $PM_{2.5}$ concentration would fall to nearly 62μg/m^3 in 2017 from 89.50μg/m^3 in 2013, which would be slightly higher than the actual situation in 2017 (58μg/m^3).

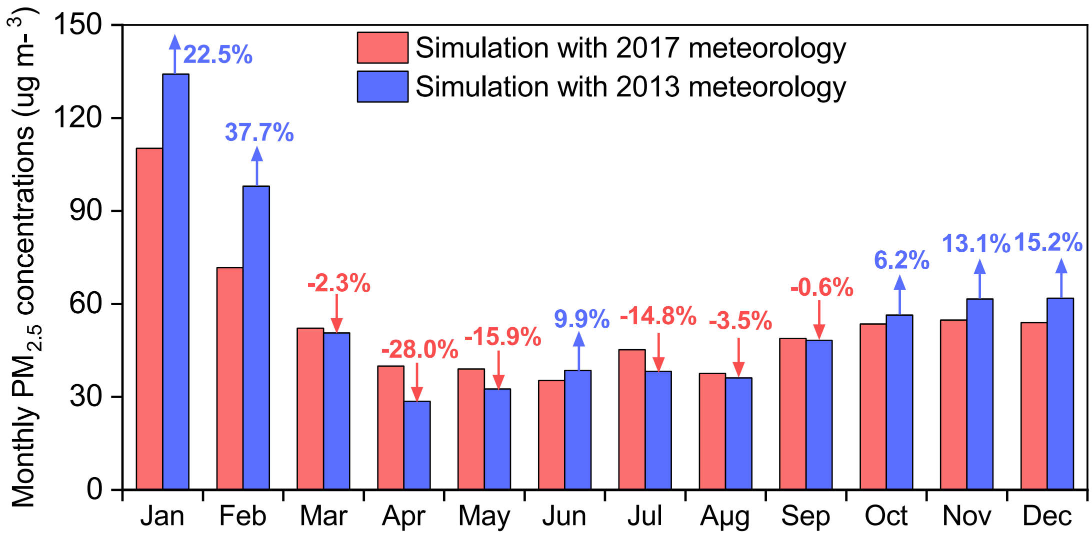


Figure 6.4 Monthly simulation of $PM_{2.5}$ concentration in Beijing under 2013 and 2017 meteorological conditions at 2017 emission levels

Source: Tsinghua University; J Cheng et al., ACPD, 2019

6.4 Summary

The implementation of *Beijing Clean Air Action Plan 2013–2017* produced marked effects. From 2013 to 2017, the annual average $PM_{2.5}$ concentration in Beijing decreased by 31.5μg/m^3. Local emission reductions, regional emission reductions, and meteorological changes contributed reductions of 20.6μg/m^3, 7.1μg/m^3, and 3.8μg/m^3 respectively, accounting for 65%, 23%, and 12% of the overall decline. The most effective local measures taken included the renovation of coal-fired boilers, promotion of clean residential fuels, and industrial restructure, which contributed 19%, 16%, and 11% of the total decline in the $PM_{2.5}$ concentration respectively. From the perspective of emission sources, coal combustion sources, the industrial sector, fugitive dust sources, and mobile sources lowered the $PM_{2.5}$ concentration by 11.2μg/m^3, 5.4μg/m^3, 2.3μg/m^3, and 2.0μg/m^3 respectively, accounting for 35%, 19%, 7% and 6% of the total decline. The spatial distribution of annual average $PM_{2.5}$ concentrations in Beijing and its surrounding areas in 2013 and 2017 are shown in Figure 6.5.

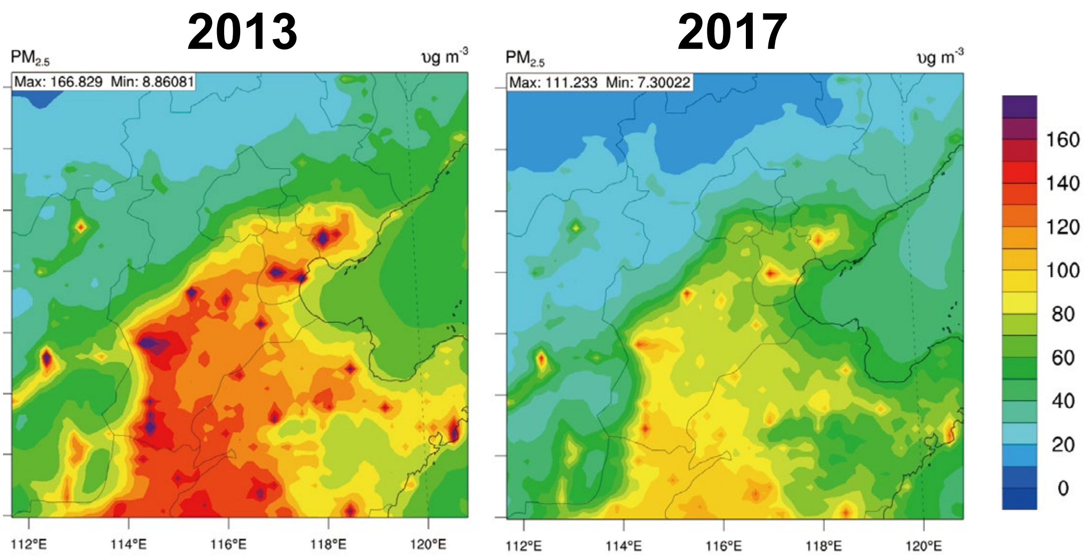


Figure 6.5 Spatial distributions of annual average $PM_{2.5}$ concentrations in Beijing and its surrounding areas (2013, 2017)

Source: *Tsinghua University*

The tallest skycraper of Beijing under construction in clear sky (Photograph credit: Beijing Municipal Environmental Publicity Center)

CHAPTER VII
EXPERIENCE AND OUTLOOK

7.1 Beijing Experience and Lessons

In the past 20 years from 1998 to 2017, Beijing continuously strengthened its efforts to control air pollution through an integrated approach involving legal, administrative, economic and technological instruments, in response to the rapid growth in city size, population, energy consumption, and vehicle fleet. The outstanding air quality improvements achieved in 20 years can be attributed to the optimization of the energy mix and industrial structure, controlling mobile source emissions, and enhanced air quality management system built along the process. Beijing's experience and lessons in development and implementation of air pollution control policies and programs have long been a model for many Chinese cities. As well, Beijing's experience has contributed to the development and formulation of a national emission standards and air quality governance system.

(1) A comprehensive and effective air quality management system has gradually taken shape over 20 years' efforts. The system is characterized by:

(a) Complete laws and enforcement mechanism: A legal system consisting of laws and regulations at national and city level, and a supporting enforcement and supervision mechanism was established. The system gives clear guidance on the mandatory responsibility of city and district level governments in development and implementation of clean air actions.

(b) Systematic Planning: There is a full cycle of clean air action planning system, including medium-long term (5 years and above) plan, annual plan, and temporary plan highlighting enhanced actions. All these plans are connected effectively, resulted in achievement of annual targets and medium-long term targets.

(c)Powerful local standards: Beijing has built a complete local emission standards and products (fuel) quality standards to support its intensified air pollution control programs.

(d) Strong monitoring capacity: Based on traditional monitoring technologies and adopting big data and other emerging new technologies, Beijing has developed a comprehensive air quality monitoring and assessment system consisting of satellite information, remote sensing, and ground stations, as well as a pollution source monitoring and supervision system.

(e) High public environmental awareness: Air quality data and pollution control program information are released through traditional and new media to the public in a timely basis. Public environmental awareness and willingness to join air pollution control activities have been raised to unprecedented levels.

(2) Qualitative optimization of the energy mix has made decisive contribution to the achievement of air quality goals against increased energy consumption. The power sector, district heating boiler, and other major coal burning facilities converted to gas; cooking and heating in countryside villages a converted to natural gas or electricity step by step. Electricity, natural gas, and other cleaner energy accounted for over 90% in the total energy consumption, and the developed urban area and major parts of the suburban plains became "coal free zone" by the end of 2017.

(3) The integrated "Vehicle-Fuel-Road" emissions control system is a model for Chinese cities, and a good example internationally as well. Vehicle emission control started comparatively late in China. Beijing built its vehicle emission control system through adopting international experiences to the local situation. The Beijing model has been widely followed by many other Chinese cities, and provided valuable practical experience for improving China's national vehicle emission control system. It could be a good example internationally.

(4) Successful regional cooperation plays a key role. Development and effective operation of the regional cooperation mechanism provided a fundamental base for the great leap-forward air quality improvement in Beijing and the region in the last 5 years.

This substantial air quality improvement has been made under the rapid social and economic development in the capital city. Over the past 20 years, Beijing's GDP has maintained a growth rate over 6.5% each year, increased by 10.8 times totally. In 2017, per capita GDP has exceeded 20 thousand dollars. Meanwhile, energy intensity and carbon dioxide emission per unit GDP (kg CO_2 per 10 thousand Yuan) maintain downward tendency. Clean air actions contributed to the high quality social economical sustainable development. Environmental sector, including service for monitoring, pollution control, engineering consultancy keeps growing along with the intensified pollution control campaign in China. Total output of Chinese environmental sector reached 1.35 trillion Yuan in 2017 with over 20% contributed by environmental enterprises in Beijing. Environmental sector is listed as priority sector for development in Beijing, and is creating more job opportunities.

While the complexity of air pollution in Beijing is unique to its stage of development, the achievement may be attributed to its governmental structure in some extent, there are several commonalities. We have found that the keys to local sustainable development are the strong willingness, clear goal, supportive legislation, plan and policies, implementation and enforcement arrangement. Engaging the public in these objectives will strengthen environmental protection even further and increase social harmony.

7.2 Reflections and Prospects for the Next Step

Even though great air quality improvement has been made, Beijing and the surrounding region still face major challenges in air pollution. In 2017, Annual average $PM_{2.5}$ concentration in Beijing is still 66% higher than the Chinese national ambient air quality standard of 35$\mu g/m^3$, and far higher than the 10$\mu g/m^3$ set in WHO guidelines. In addition, ozone pollution has become a new concern in recent years. Air pollution control remains a long-term and arduous task that requires ceaseless efforts. Beijing and the surrounding region now are confronted by the "deep water area" of integrated dealing with $PM_{2.5}$ and O_3.

Looking forward, following are recommendations for Beijing in its long term and next step air pollution control strategies:

(1) Strengthening VOCs and NOx control targeting at mitigating both $PM_{2.5}$ and O_3

Both $PM_{2.5}$ and O_3 in the ambient air pose direct threats to human health while they are complex and difficult to control. Control of VOCs, the key precursors of ambient $PM_{2.5}$ and O_3, is of importance to mitigate the level of these two pollutants. VOCs control rests on an emission control system that covers monitoring, emission inventories, and sector-specific policies. Priority for VOCs control should be extended from key industries, such as petrochemicals, printing and dyeing, and furniture manufacturing, to residential non-point sources, including auto repair, restaurant, and dry cleaning.

(2) Highlighting energy structure and energy efficiency in parallel for a low carbon energy mix to reduce greenhouse gases emissions

It's advisable that Beijing continue with its last mile efforts to remove coal from the energy mix to build the city into a coal free city. With the development of new energy technology, there is the opportunity to increase the proportion of renewable energy in the energy mix to reduce both air pollutants emissions and greenhouse gas emission from fossil fuel. Meanwhile, equal importance should be given to improving energy efficiency in energy-intensive industries and activities, including heating, air-conditioning, transportation, and industry. Twinning approaches on energy efficiency and cleaner energy strategy, will help to reduce the demand for fossil fuels at the source, and decouple social and economic development from the growth of fossil fuel energy consumption.

(3) Working on mobile sources emission control and transportation structure optimization to build a low emission transport system

To control emissions from mobile sources, the well-established Vehicle-Fuel-Road emission control system should be further extended to off-road machinery. When technically and economically feasible, it could be a wise choice to raise the proportion of electric vehicles in public fleets like buses, taxis and passenger cars on a large scale to build ultralow emission public fleets. Given the size of Beijing city, it could afford to build low emission zones in different functional parts of the city. Big data and intelligent technologies will soon become available for precise monitoring of high-emission diesel vehicles operating in and travel to Beijing. Further study needs to be carried out on bulk freight transport, and raise the proportion of rail transportation to a comparatively higher level to build a low-carbon and more efficient cargo transportation system.

(4) Tightening control on non-point source pollution

After very successful point emission sources control, to achieve further air quality improvement, control of non-point sources should be brought into consideration. Non-point sources include small scattered sources, like urban service sectors (restaurants, car repair, paint use, etc.), and farming activities, which may require more precisely designed solution for a specific type of source.

(5) More actively promote regional cooperation mechanism

Beijing should participate actively in the regional cooperation mechanism now headed by the central government, and make necessary contribution to its operation and improvement, including promoting a region-wide air pollution control decision support system, region-level energy structure optimization, and upgrading industrial structure and transportation (especially freight transportation) structure. With these key issues planned and implemented at regional level, cities in the region jointly taking action through coordinated steps, can help to reduce the total pollutants emission in the region and lay a sound base for the substantial improvement of air quality in Beijing and the region.

(6) Integrate local environmental goal with 2030 Sustainable Development Goals

The United Nations announced 2030 Sustainable Development Goals for the planet in 2015, covering 17 goals, including good health and well-being, climate change, gender equality, sustainable cities and communities, affordable and clean energy, etc. Good practice and model at city level is of key importance to realize global sustainability. As a model for dealing with pollution issues along with rapid economic and social development, we would advise Beijing to design its environmental goals and actions under the framework of 2030 sustainable development goals. That would be the right choice to deal with the challenge of population, resources, and environment, and move forwards to city's high quality development to realize both local and global environmental goals.

A glimpse of the Palace Museum in sunny winter (Photograph credit: Beijing Municipal Environmental Publicity Center)

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Beijing Beihai Park (Photograph credit: Beijing Municipal Environmental Publicity Center)


Summer Palace in Winter


Palace Museum under Blue Sky


Guajiayu Village with Solar Power


Hanshiqiao Wetland

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