Air Quality Management Achievements, Challenges and the Way Forward in China: Including $PM_{2.5}$ and Other Major Air Pollutants

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Abstract

In China, rapid economic development accompanied by complex air pollution issues has resulted in a need for innovative solutions simultaneously addressing these complex pollution issues that lack well-developed solutions, since no country has ever faced a similar battle before. To seek innovative solutions, efforts have been made under the Five Sphere Integrated Plan to carry out development under a new concept. In air pollution prevention and control, the Action Plan on Air Pollution Prevention and Control was implemented in 2013–2016. This article provides a brief description of its achievements, with an emphasis on atmospheric quality conditions in 2016. Major air pollutants such as $PM_{2.5}$ and PM_{10} have decreased, achieving the Action Plan's target in advance. Furthermore, international cooperation at the global, regional and bilateral levels related to supporting air pollution prevention and control was also been introduced. Air pollution prevention and control has entered a crucial stage, with great challenges from development and new emerging issues such as ozone. At this stage, to improve air quality further, the Three Year Plan on Defending the Blue Sky was published, serving as a guide for the upcoming three years. The major strategy and objectives of this Three Year Plan are introduced. To improve air quality further with substantial effects, technology cooperation is recommended for facilitating progress toward achieving air pollution prevention and control targets among countries under the guidance of air-related SDG goals and targets.

Key words: action plan, air pollution, blue sky, China, international cooperation, technology cooperation

1. Introduction

China has been developing on a more sustainable path during the past few years under the vision of the Five Sphere Integrated Plan and Four-Pronged Comprehensive Strategy. The rapid economic growth of the past few decades has been rebalanced and restructured (World Bank, 2018). The gross domestic product (GDP) has increased from 54 trillion Chinese yuan in 2012 to 82.7 trillion Chinese yuan occupying a share of from 11.4 to 15% of the global economy and accounting for over 30% of the world economic growth (NBS, 2018). The green innovation and related new sectors have served as a new engine for sustainable development. An annual average of 11% of the increased revenue has been invested in research and development. As a result, the innovation sectors, including e-commerce, mobile payment and the sharing economy, have achieved significant progress and lead global trends.

The growth outlook has been reshaped by ecological innovation in each and every aspect of sustainable development. "Green is Gold" is regarded as a vision dealing with the relationship between economic growth and environmental protection. The ecological environment has been gradually improved with efficient implementation of the action plans for prevention and control of air pollution, water pollution and soil pollution achieving a 20% decrease in energy consumption for per capita GDP, a decrease of around 50% in the number of days with heavy pollution and a continuous decrease in key environmental pollutants.

Along with greater involvement of China in global environmental governance, more Chinese ideas have been shared for the formulation of a sustainable development modality for the world. However, under the current international economic situation of anemic world economic recovery and volatile international financial markets, protectionism is on the rise globally and will cause more downward economic pressure on China. Furthermore, the lack of an internal growth engine and limited capacity for innovation will affect structural optimization toward a more environmentally friendly development modality.

Under the above mentioned economic and macro

circumstances, this article will focus on air pollution prevention and control issues in China by analyzing achievements, challenges and the way forward.

2. Achievements

Since the 1930s, most developed countries have experienced severe atmospheric pollution and have accordingly solved air pollution challenges during the past century (Wang, 2016). In China, rapid economic development accompanied by complex air pollution issues has brought a need for innovative solutions simultaneously addressing these complex pollution issues that lack well-developed solutions, since no country has ever faced a similar battle before. To seek innovative solutions, under the Five-in-one General Strategy (the overall plan for promoting economic, political, cultural, social and ecological progress), efforts have been made to implement a new concept of development.

2.1 Air Pollution Status

In general, the six major air pollutants in 338 cities at or Above Prefecture Level (APL) in 2016 were as indicated in Fig. 1. Among the 338 APL cities, 24.9% of these cities met national ambient air quality standards, i. e., 254 cities failed to meet national ambient air quality standards in 2016 (Fig. 1). The average percentage of days on which air quality standards were attained in 2016 was 78.8%, which was 2.1% higher than the average in 2015. In the 338 APL cities, the number of days with heavy pollution (Air Quality Index (AQI) between 201–300) and very heavy pollution (AQI greater than 300) were 2,464 days and 784 days, respectively. Among these days, 80.3% had $PM_{2.5}$ as the primary pollutant (when AQI>50, the pollutant with the biggest individual AQI is the primary pollutant), 20.4% had PM_{10} as the primary pollutant, and 0.9% had ozone as the primary pollutant. (MEP, 2017)

2.1.1 $PM_{2.5}$

The $PM_{2.5}$ concentrations in three major regions, Beijing-Tianjin-Hebei (BTH), Yangtze River Delta (YRD) and Pearl River Delta (PRD), decreased by 33.0%, 31.3% and 31.9% respectively compared with those in 2013, achieving the Action Plan for Prevention and Control of Air Pollution (Action Plan) goals in advance.

$PM_{2.5}$ concentrations in the APL cities improved in 2016 compared to 2015, decreasing by 6.0%. $PM_{2.5}$ concentrations ranged from 12 to 158 μg/m^3 with an average of 47 μg/m^3; and the percentage of days exceeding the standard was 14.7% (MEP, 2017).

2.1.2 PM_{10}

In 2016, the national PM_{10} concentration decreased by 15.5% from 2013, and in 2017, the national PM_{10} concentration was 75 μg/m^3, down by 22.7% from the 2013 level. The PM_{10} concentration improved in 2016, decreasing by 1.7% from 2015. PM_{10} concentrations ranged from 22 to 436 μg/m^3 with an average of 82 μg/m^3, down 5.7% from 2015; and the percentage of days exceeding the standard was 10.4% (MEP, 2017).

2.1.3 Other Major Air Pollutants

The air quality in China has improved significantly. In 2017, SO_2 in the APL cities decreased by 41.95% compared with 2013, and the 74 cities under stage Ⅰ monitoring based on the newly amended ambient air quality standards showed the percentage of days meeting air quality standards to be 73.4%, up by 7.4% from 2013. These 74 cities had 51.8% fewer heavy pollutions days.

In 2016, the annual average concentrations of SO_2 ranged from 3 to 88 μg/m^3, with an average of 22 μg/m^3, down by 12.0% from 2015. As for NO_2, the annual average concentrations ranged from 9 to 61 μg/m^3 with

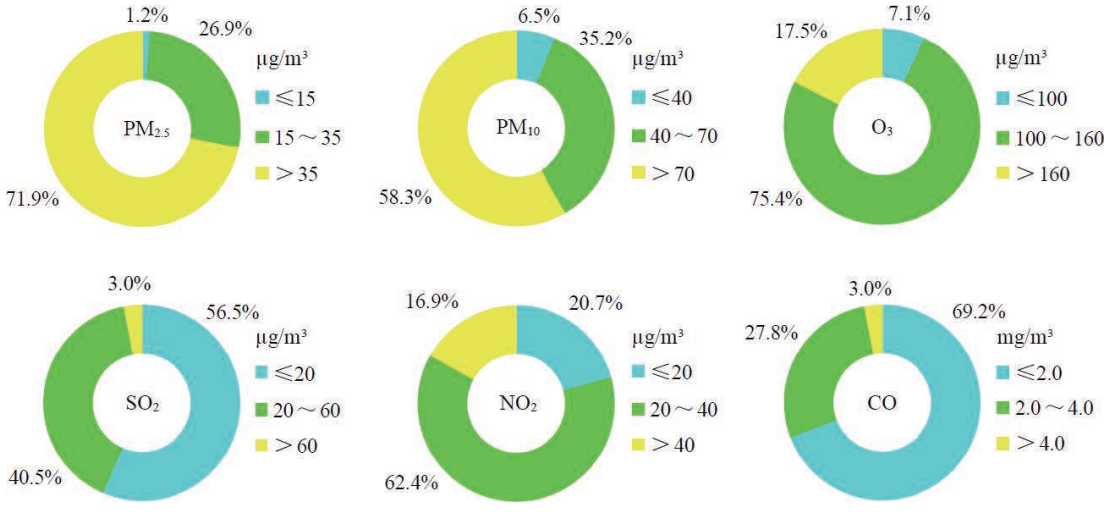

Fig. 1 Percent of 338 APL cities with different concentrations of six pollutions in 2016 in China. The national standards for the six major air pollutants are X for $PM_{2.5}$, X for PM_{10}, X for O_3, X for SO_2, X for NO_2 and X for CO. (MEP, 2017)

an average of 30 μg/m^3, which was equal to the average in 2015. The 95$_{th}$ percentile concentration of the daily CO average decreased by 9.5% from 2015, with an average of 1.9 mg/m^3 and a range of 0.8 to 5.0 mg/m^3. O_3 alone differed from the above-mentioned pollutants, increasing by 3.0% from 2015, with an average of 138 μg/m^3 and a range of 73 to 200 μg/m^3 for 90$_{th}$ percentile concentration of the daily maximum eight-hour average (MEP, 2017).

2.2 Action Plan Implementation

As one of China's three campaigns for prevention and control of pollution, Air Pollution Prevention and Control was guided by the Action Plan for Prevention and Control of Air Pollution. In the budget for the 13$_{th}$ Five-Year Plan on Eco-Environmental Protection, 11.2 billion Chinese Yuan from the central budget were allocated for prevention and control of air pollution.

2.2.1 Air Quality Targets Achieved

The Action Plan targets were fully achieved regarding air quality improvement (Fig. 2), both at the national level and in the key regions. Ambient air quality improvement targets were specified for the index in Part 2.1 of this article. The three major regions achieved the Action Plan goals in advance, especially for $PM_{2.5}$ concentrations. Heavy pollution days in the BTH region decreased and fine days in the YRD region increased on an annual basis. As the city of most intense focus, Beijing achieved an average $PM_{2.5}$ concentration of 58 μg/m^3, down by 34.8% from 2013 to 2017.

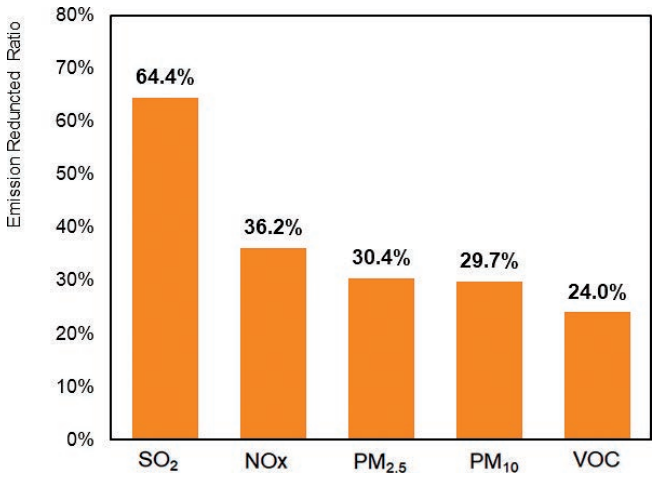

Fig. 2 Emission reduction ratios in 2013–2016 in China.

2.2.2 Structural Adjustments Breakthrough

The structures of three major sectors, i.e., industry, energy and transportation, have been adjusted. In this industrial structure adjustment, backward capacity was eliminated and excess capacity was resolved. From 2013 to 2017, capacities of 200 million tons in steelmaking, 500 million tons in coal, 250 million tons in cement (including at grinding stations), 113 million weight cases in glass, 25 million KWs in coal-fired power units, and 140 million tons in substandard steel were eliminated, getting rid of backward and excess capacity. Other industrial restructuring included "unplanned, illegal and polluting" (UIP) enterprise renovation. As a result, the "2 + 26" cities (Beijing, Tianjin and 26 other cities in the smog-plagued provinces of Hebei, Shandong, Henan and Shanxi) renovated up to 62,000 UIP enterprises contributing to air pollution.

The energy restructuring included ultra-low-emission and energy-saving renovations in coal-fired power plants. Nationwide 700 KWs of ultra-low-emission renovation were completed for coal-fired power plants and 460 million KWs of energy-saving renovation were completed. Furthermore, the world's largest scale coal power supply system meeting ultra-low-level standards was built. The energy structure was also improved, with coal consumption decreasing from 2013 to 2016 (Fig. 3), a major feat considering China's coal consumption had doubled in the decade before 2013.

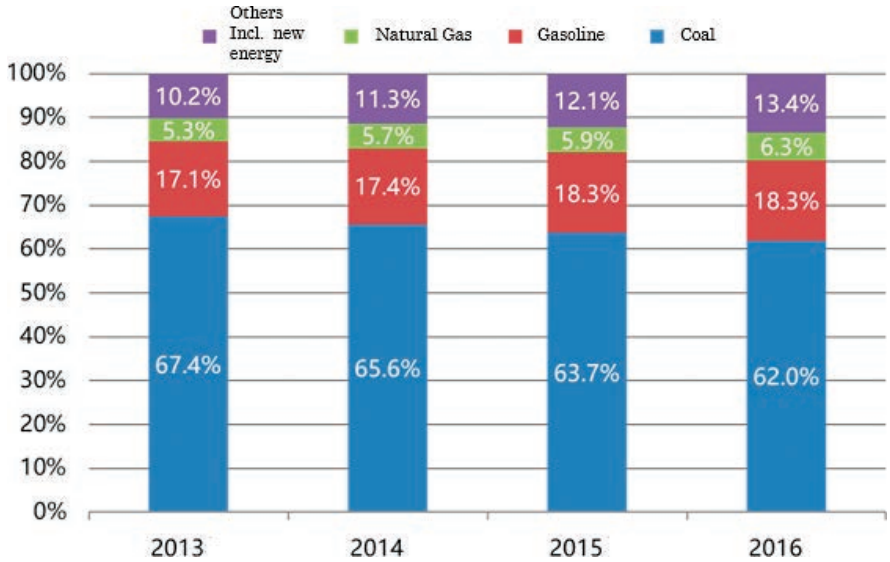

Fig. 3 Energy structure in China, 2013–2016.

As for the transportation structural adjustment, all together 20 million yellow labelled vehicles were eliminated and the China V vehicle emission standards and clean oil product standards were published. China's VI vehicle oil product standards and light vehicle emission standards were also published. Since heavy truck emissions have been a significant issue to be resolved, supervision and management of those were strengthened. At the same time, diesel and gasoline production inspections were carried out. The "2 + 26" cities had fixed and mobile remote sensing monitoring devices installed, covering major crossings, with a focus on diesel trucks and high-emission gasoline vehicles.

2.2.3 New Pattern Formulated

The multi-sector Joint Control Pattern was formulated with central environmental inspections in 31 provinces and quantitative accountability was implemented with responsibility for air quality improvement shared at various levels. Different ministries closely cooperated together to carry out differentiated tasks. In key regions, regional Joint Prevention and Control has achieved great innovation by introducing prevention and control policies and measures without boundaries between administrative divisions.

The Law on Environmental Protection and the Law on Prevention and Control of Atmospheric Pollution were revised and republished. Among these laws, new instruments such as daily penalties, production termination / restriction, seizure and sequestration were also introduced.

2.2.4 Environmental Economic Policies Improved

Financial support from both central and local governments has provided a sound basis for air pollution prevention and control. Around 60 billion Chinese yuan were allocated from the central government during the period of the Action Plan. The Air Pollution Prevention and Control Special Fund was established and a diversified investment mechanism involving governments, enterprises and society was formulated. Funds for special sectors were also set up, such as cleaner heating funds in the BTH region, with 0.5−1 billion Chinese yuan allocated per city. Furthermore, counterpart funds were also provided by provincial-, city- and county-level local governments.

Pricing policies and subsidy policies were developed to provide economic incentives for air pollution prevention and control, such as a graded electricity pricing system, that differentiates among electricity sources and users. Subsidies were utilized to phase out yellow labelled vehicles and promote cleaner energy in the residential sector.

Environment taxes, replacing emission fees, and other environment fees were also introduced as an economic instrument, and included elevated rates of emission fees, VOC emission fees, and other measures.

2.2.5 Heavy Pollution Response System Established

The capacity for heavy pollution weather was enhanced and the response working mechanisms were improved. The capacity for heavy air pollution monitoring and early warning was formulated to realize accurate three-day forecasting and seven-day potential analysis at the regional, provincial and municipal levels.

A technical support system was established for heavy air pollution response, including processes for air quality forecasting, consultation for decision making, releasing of early warning alerts, emergency response, episode evaluation, plan revision and so on. This response system has effectively reduced peak concentrations of heavy air pollution and protected the public health accordingly.

The early warning system set up classification standards for alerts, including blue alerts with a forecasted daily mean AQI of more than 200, yellow alerts with a forecasted daily mean AQI of more than 200 lasting two more days past the alert, orange alerts with a forecasted daily mean AQI of more than 200 lasting three more days or with a forecasted daily mean AQI of more than 300, and red alerts with a forecasted daily mean AQI of more than 200 lasting four more days or with a forecasted daily mean AQI of more than 300 lasting two more days or a forecasted daily mean AQI of more than 500. By classifying the alerts, pollution emission reduction ratios could be set for each alert level and emergency emission reduction ratios could be defined for each alert level. Furthermore, regional emergency linkages were also strengthened for implementing emergency response measures.

2.3 International Cooperation

The world is more inter-linked than ever before in its long history. In China the "New Normal" of seeking a sustainable development path is undergoing a transition from fast economic growth to a more balanced sustainable growth. As for international cooperation strategies, the Belt and Road Initiative is the major initiative for strengthening international cooperative relationships.

Air pollution issues in China currently are a combination of traditional air problems that developed countries have experienced, and new emerging issues such as ozone pollution, for which nobody can provide a well-developed solution yet. Under such circumstances, international cooperation is of crucial significance in sharing experiences, discussing new issues jointly and strengthening technology cooperation among enterprises as a substantial way to improve air quality (CCICED, 2014). In the past decade, global, regional and bilateral cooperation on atmospheric issues was carried out in a variety of ways.

2.3.1 Global Cooperation

Air pollution has gained the attention of the United Nations for the past decade. In light of the emphasis on the Sustainable Development Goals (SDGs) in the 2030

Agenda for Sustainable Development, adopted by the United Nations General Assembly in 2015, these 169 targets underpinning 17 goals provide 169 ways to explain how no one is to be left behind in sustainable development. In responding to the emerging concerns regarding atmospheric issues, air-related targets among the SDGs are mainly covered by Goal 3 — Ensure healthy lives and promote well-being for all at all ages and Goal 11 — Make cities and human settlements inclusive, safe, resilient and sustainable. Among these goals, major air pollution targets are:

▶ Target 3.9 — By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil production and contamination;

▶ Target 11.6 — By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.

Additionally, Goal 12 — Ensuring sustainable consumption and production patterns also covers air issues with a short-term expected timeline as follows:

▶ Target 12.4 — By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

In 2017, the third session of the UN Environment Assembly (UNEA-3), with the theme of "Towards a Pollution-Free Planet," adopted the Resolution on Preventing and Reducing Air Pollution to Improve Air Quality Globally. This resolution calls for member states to take action across sectors to reduce all forms of air pollution and consider joining or cooperating with, as appropriate, relevant global initiatives. The Resolution also stresses the need for further sharing of existing knowledge by engaging in regional cooperation on science, technology, policy, measures and best practices related to addressing air pollution.

2.3.2 Regional Cooperation

Regional cooperation has been initiated through several mechanisms of regional environmental cooperation. Several sub-regional-level mechanisms also set air pollution as a prioritized cooperation area, such as the Tripartite Environmental Ministers' Meeting (TEMM). Since 2010, the TEMM has adopted the five-year Tripartite Joint Action Plan (TJAP) to systematically manage cooperation projects. Under the current TJAP, Air Quality Management is the first among nine cooperation areas and has two sub-areas of air pollution and dust and sandstorms (DSS). The air pollution cooperation mechanism is one of the newest tripartite environmental cooperation mechanisms. The Tripartite Policy Dialogue on Air Pollution is under the technical support of two working groups: Scientific Research on Prevention and Control, and Technology/Policy on Air Quality Monitoring and Prediction.

The APEC Cooperation Network on Green Supply Chain (GSCNET) was endorsed by the 2014 APEC Economic Leaders' Meeting in Beijing. Leaders from 21 APEC economies made the following declaration on GSCNET: "We positively value the APEC High-level Roundtable on Green Development and its declaration, and agree to establish the APEC Cooperation Network on Green Supply Chain. We endorse the establishment of the first pilot center of APEC Cooperation Network on Green Supply Chain in Tianjin, China, and encourage other economies to establish pilot centers and advance related work actively." The GSCNET was established to combine the green aspects of APEC with the global supply chain while focusing on green production and consumption and green transportation sectors to encourage reduction of emissions and more sustainable development. To fulfill these tasks, it enabled pilot centers to be set up at city, enterprise and institution levels.

2.3.3 Bilateral Cooperation

Bilateral cooperation has been developed with neighboring countries such as Japan and Korea. As for bilateral cooperation with Japan, an inter-city cooperation has been implemented with an MOU signed by the ministers from the Ministry of Ecology and Environment of China and the Ministry of the Environment of Japan on cooperation in research and demonstration of an improved atmospheric environment. Cooperation on demonstration has been developed at the city level, focusing on major and urgent atmospheric topics in each participating city. This cooperation was characterized particularly by topic setting for different cities that was based thoroughly on the respective demands of the cities involved in their own air pollution prevention and control activities, such as for VOCs, vehicle emission control, technology assessment methodology and so on. Therefore such cooperation has accordingly strengthened the capacity of each city in response to urgent atmospheric issues and helped improve local work on air pollution prevention and control. Under bilateral cooperation between China and Korea a joint laboratory for joint research of mutual interested topics was established. This cooperation modality provided a platform for researchers of different countries to work together to substantially enhance communication with joint efforts toward mutually beneficial research outputs.

3. Challenges

3.1 Development Challenges

China is still the biggest developing country in the world. Under the comprehensive reform agenda in the 13th Five-Year-Plan (2016–2020), the ongoing economic transition will be facilitated toward a higher quality, more balanced growth that is both economically and environmentally sustainable. With this transition in growth modality, air pollution prevention and control work will face more challenges than before. The ambient

air quality is far from fulfilling the goal of building a society moderately prosperous and meeting people's ever-growing demands for a beautiful environment.

3.2 New Crucial Stage

Air pollution prevention and control has entered a crucial stage. The current industrial, energy and transportation structures lead to high emissions. Decoupling between economic growth and air pollutant emissions has not yet been achieved. Especially in the BTH and surrounding region, the air pollutant emission intensity (emission rate of a given pollutant relative to the intensity of emission) reached four times the national average intensity. Thus air pollution prevention and control work is a long-term task requiring joint efforts from regions and sectors so as to promote continuous improvement in air quality (Brimblecombe *et al*., 2001).

3.3 Ozone Pollution

Additionally, new emerging issues such as ozone pollution have become a major cause of the air pollution replacing $PM_{2.5}$ and PM_{10} in some regions especially during summer. Tropospheric ozone is an air pollutant and a greenhouse gas, with origins in stratospheric ozone and photochemical reactions of NOx and VOCs. Tropospheric ozone is a secondary pollutant arising from a complicated series of chemical reaction in the presence of sunlight. Deeper understanding of its reaction mechanisms and modality will facilitate policy design for ozone pollution prevention and control (Akimoto, 2015).

During the Action Plan period of 2013 to 2016, major air pollutant concentrations decreased expect for the eight-hour 90 percentile concentration of ozone. Among 338 cities, ozone exceeded the standard in 59 cities, most of which were in the BTH, YRD and PRD regions. Both the concentration and percentage exceeding the standard increased continuously. In 74 cities, the annual number of days with ozone pollution exceeding the standards increased by three days. Record-high concentrations occurred increasingly, reaching 139 $\mu g/m^3$, 145 $\mu g/m^3$, 150 $\mu g/m^3$ and 154 $\mu g/m^3$ in 2013 to 2016.

4. The Way Forward

The Three Year Plan on Defending the Blue Sky was launched with a work plan for the subsequent three years on air pollution prevention and control. The Three Year Plan will be implemented to promote structural adjustments continuously in industry, energy, transportation and land use, to respond to weather with heavy air pollution, to carry out deep measures for air pollution prevention and control, and accordingly to improve environmental quality. The Three Year Plan differs from the Action Plan for Air Pollution Prevention and Control in the following four aspects. The Three Year Plan focuses more on the accuracy of policy objectives, including the objectives with regard to air pollutants, regions, seasons and measures. It also focuses more on source control by various forms of restructuring. Meanwhile it emphasizes the design of scientific measures and technical feasibility. Last but not least, it calls for establishment of a long-term mechanism.

4.1 Strategy and General Tasks

In the working areas, the following four priorities will be emphasized. The priority regions will be BTH and the surrounding area, YRD, the Fen-Wei Plains (FWP) and others. Among these regions, Beijing is the major target. The priority indicator is $PM_{2.5}$ and the priority seasons are autumn and winter, when heavy air pollution occurrs most frequently. The priority sources are industry, loose coal, diesel trucks, dust and others.

Four structures will be optimized including industrial, energy, transportation and land use restructuring. This is necessary to protect the environment while pursuing development and to achieve development in a well-protected environment.

The mechanism is designed to enhance, support from the four aspects of regional joint prevention and control, enforcement and supervision, technology innovation, and publicity and guidance. Society is encouraged to participate in the joint efforts of defending the blue sky.

4.2 Objectives

The overall objectives are to achieve a clear decrease in air pollutant emissions, to decrease greenhouse gas emissions with co-control measures, to decrease the $PM_{2.5}$ concentrations notably, to achieve a marked decrease in the number of days with heavy air pollution, to achieve sharp improvements in the atmospheric environment, and to enhance the blue-sky happiness of the people remarkably.

As for concrete indicators, the following goals are to be achieved: a decrease in CO_2 and NOx emissions by 15% from 2015, a decrease of more than 18% in $PM_{2.5}$ concentrations in APL cities that have failed to meet the standards, an 80% ratio of air quality attainment days reached in APL cities, and a decrease in the ratio of days with heavy air pollution or very heavy air pollution by 25% from 2015.

4.3 Other Highlights

Co-control of $PM_{2.5}$ and ozone will also be implemented. The major actions to control ozone in the Three-Year Plan include control of NOx and VOC emissions, enhancement of objective air quality management and improvement in management and control capacities. As the next step, a guidance document will be drafted on ozone pollution prevention and control to promote VOC and NOx emission control so as to co-control ozone with $PM_{2.5}$.

The monitoring network will be further strengthened. By the end of 2020, county-level monitoring sites will all be widely covered and operated in east, central and western China. These sites will also be linked to the China National Environmental

Monitoring Center (CNEMC) for data reporting. The cities in major regions and other severe ozone pollution cities will carry out VOC monitoring. The launching of an atmospheric environment monitoring satellite will be studied.

5. Conclusions

5.1 Key Points

In conclusion, the air pollution prevention and control issue was handled in China by unprecedented strengthening of measures, guided by a series of laws, regulations, standards and polices. Due to downward economic pressure, however, the challenge of seeking a win-win solution towards sustainable development is a great concern. Rather than limiting the discussion to the relationship between economic growth and environmental protection, it would be more worthwhile to discuss how to generate new creativity from green engines for development of broader green production and consumption beyond traditional environmental protection industries. To describe the key function of further efforts towards the final goal, there is a Chinese traditional saying: the last 10% is half of the total work load. This description could fit the current blue sky actions. In this regard, going forward will require further global collaboration and introduction of the best available experience and technologies.

5.2 SDG Mechanism

In a world undergoing profound change, interlinked threats and challenges in environmental issues require everyone to share responsibility and contribute to a common vision. In this context, to implement the related targets, it will be more important than ever to have multilateral structures and institutions, as well as international cooperation.

As for specific means of implementation, a global technology facilitation mechanism is highlighted for providing better access to science, technology and innovation, as well as knowledge sharing to formulate a global partnership for sustainable development of SDGs.

5.3 Technology Cooperation

The Three-Year Plan also emphasizes the importance of green industry technology cooperation. Technology cooperation is the new modality of green international cooperation on the environment. Traditional technical cooperation with ODA financial support from developed countries to China does not fit the current situation and demands. The transition from technical to technology cooperation, with win-win technology cooperation, will be the new trend in air pollution cooperation during the current period. Demand is increasing for the best available clean air technology from the Chinese market in order to solve air pollution issues and attain atmospheric emission standards. Accordingly, more and more concrete, substantial cooperation in technology cooperation will contribute to target implementation for air pollution prevention and control.

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