Can China replicate the miracle of particle pollution control for ozone pollution control?

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In January 2013, a rare and continuous heavy haze pollution episode occurred in central and eastern China, causing the fine particulate matter ($PM_{2.5}$) concentrations in multiple cities to increase. Heavy pollution has impacted 30 provinces, and the affected population has reached more than 800 million.[1] The average monthly haze days in Jiangsu, Beijing, Zhejiang, Anhui, and Shandong Provinces are 23.9 days, 14.5 days, 13.8 days, 10.4 days, and 7.8 days, respectively, all of which are the highest in the same period since 1961.

Immediately after serious air pollution occurred, the Chinese government successively issued and implemented the "Action Plan for Air Pollution Prevention and Control (2013-2017)" and "Three Year Action Plan for Winning the Blue Sky Defense War (2018-2020)". During this process, China has followed the actions conducted by European and American countries to control the emission of air pollutants through end-treatment measures. Consequently, compared with those in 2013, the total number of industrial waste gas treatment facilities (dedusting, desulfurization, and denitration) increased by 23.7 times in 2022, and the emissions of particulate matter, sulfur dioxide and nitrogen dioxide (NOx) decreased by 61.4%, 86.7% and 59.8%, respectively (https://www.mee.gov.cn/hjzl/sthjzk/sthjtjnb/). The smoke plumes emitted from chimneys has also improved from black smoke to white smoke.

Owing to the superiority of macroeconomic policies, China has completed the decade's long process of reducing emissions in foreign countries within just a few years, and the national concentration of $PM_{2.5}$ decreased by 59.7% in 2022 compared to 2013 (https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/). Erik Solheim, former Secretary General of the United Nations, praised China, stating that "China reduced air pollution in 7 years as much as the US did in three decades".[2] The United Nations Environment Programme (UNEP) published a themed article titled "Beijing air improvements provide a model for other cities" (https://www.unep.org/news-and-stories/press-release/beijing-air-improvements-provide-model-other-cities).

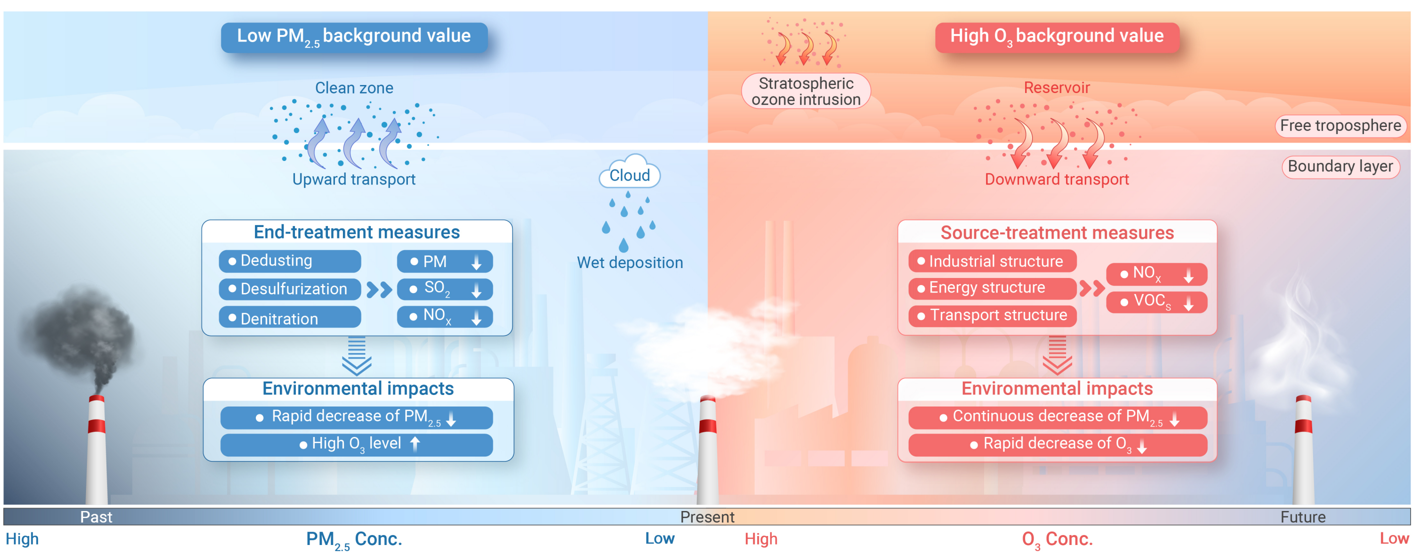

Figure 1. Processes of $PM_{2.5}$ and O_3 pollution control in China from the past to the future.

However, due to the lack of volatile organic compounds (VOCs) governance and the decrease in NOx, the ozone (O_3) concentration has rebounded and fluctuated greatly (https://www.mee.gov.cn/hjzl/sthjzk/zghjzkgb/). Therefore, the Ministry of Ecology and Environment of the People's Republic of China issued the "Action Plan for Continuous Improvement of Air Quality" in 2023. Notably, the United States took more than 80 years to gradually achieve the emission reduction targets of NOx and VOCs and basically eliminate O_3 pollution. The reason for long-term ozone control is the significant differences in the causes and spatiotemporal distributions of ozone and particulate matter pollution. Therefore, it is extremely difficult for China to achieve ozone concentration standards in a short period, and the main reasons are as follows.

COMPLEXITY

The $PM_{2.5}$ and O_3 pollution levels are closely related to the concentrations of these precursors, but there are significant differences in the responses of $PM_{2.5}$ and O_3 to these precursors. Although the relationship between $PM_{2.5}$ and its precursors is nonlinear, a reduction in emissions from the main precursors (NOx, sulfur dioxide, ammonia, and VOCs) rarely leads to an increase in the concentration of $PM_{2.5}$. However, a decrease in NOx in urban areas may lead to a significant increase in O_3 concentration, which increases the difficulty of O_3 pollution control due to this strong nonlinear relationship. The current high ozone concentration in China is also due to the side effects of NOx reduction (Figure 1). To completely control O_3 pollution, it is necessary to reduce NOx and VOCs emissions at an appropriate proportion, which increases the complexity of ozone pollution prevention and control.

LONGEVITY

Coarse particles are affected by gravity and can be quickly deposited on the ground. The aitken mode particles condense or coagulate and then grow into fine particles, most of which are removed by wet deposition. The effects of emission and deposition result in a significantly greater concentration of particulate matter in the boundary layer than in the free atmosphere. Therefore, the $PM_{2.5}$ concentration can be significantly reduced by controlling anthropogenic emissions. However, the area with the strongest O_3 formation capacity is usually not near the ground but within a certain area at high altitudes.[3] In addition, stratospheric O_3 frequently invades the troposphere through stratospheric and tropospheric exchanges. The above two aspects induce a reservoir of O_3 in the free atmosphere, resulting in a background O_3 concentration of 20-55 ppbv in the troposphere in China[4] (Figure 1). Therefore, low-dose and small-scale emission reductions have difficulty reducing the total amount of ozone in the entire troposphere, and long-term and sustained reductions in emissions are the only way to control ozone pollution.

UNCERTAINTY

In July 2023, the United Nations announced that the Earth had entered an era of global boiling from global warming. As global warming enters a new stage, the prevention and control of ozone pollution will inevitably increase. First, global warming will increase the emissions of VOCs from plants and NOx from soil, but decreased cloud ice and liquid numbers will lead to a reduction in NOx emissions from lightning.[5] In addition, an increase in the global temperature will lead to enhanced chemical reactions between ozone precursors. Both of the above aspects will lead to changes in the global background value of ozone, thereby increasing the uncertainty of ozone pollution control.

Given the above issues, ozone pollution control is definitely not as simple as particulate matter pollution control, and China is currently facing a more severe and complex global atmospheric environment. If we want to shorten the process of O_3 pollution control, the experience of particle pollution control cannot be simply replicated, and we need to explore more ways to reduce emissions in addition to drawing on experience in European and American countries.

The essence of China's ecological and environmental problems is the issue of a high-carbon energy structure, high energy consumption, and high-carbon industrial structure. With the advancement of ecological environmental protection, the emission reduction space of traditional end-treatment measures is gradually being reduced. In 2020, China clearly stated the goals of "carbon peaking" by 2030 and "carbon neutrality" by 2060, which indicated that green and low-carbon development is the fundamental solution for air pollution. Therefore, to support the continuous improvement of air quality, it is necessary to explore greater potential for pollutant reduction through source-treatment means beyond traditional end-treatment means.

In recent years, China has gradually increased its efforts in structural reform, achieving positive results in energy structure transformation, industrial structure optimization, and transportation structure adjustment. However, the industrial structure dominated by the heavy chemical industry, the energy structure dominated by coal, and the transportation structure dominated by road freight have not undergone fundamental changes, and there is still significant room for improvement in structural reform. Specifically, it is necessary to "optimize the industrial structure, promote the green upgrading of industrial products", "optimize the energy structure, accelerate the clean, low-carbon, and efficient development of energy", and "optimize the transportation structure and vigorously develop the green transportation system". These factors will contribute to the reduction of source-treatment emissions. Consequently, with the promotion of the green and low-carbon transformation of industries, energy, and transportation, a win–win situation involving environmental, economic, and social benefits will be achieved naturally (Figure 1).

However, sustained and in-depth structural reforms still require technological advancement and profound changes in development methods. At the scientific level, it is necessary to further clarify the main driving forces of pollution emissions in key industries, providing theoretical guidance for identifying transformation priorities and formulating governance strategies. At the technical level, it is necessary to focus on breaking through key technologies such as low-carbon process reengineering (steel, cement, and petrochemicals), as well as industrial ecological linkages and recycling, to provide a new impetus for green and low-carbon development. In terms of optimizing regulations, we will develop fine control technologies for air pollution targeting complex multiobjective processes, enhance the comprehensive decision-making ability and collaborative governance efficiency of the economic climate environment, and provide smart hubs for green transformation. Through the aforementioned breakthroughs in science, technology and policy, we believe that China can curb the deterioration of O_3 before the carbon peak (2030) and basically eliminate O_3 pollution before 2040. From this perspective, China will take no more than 20 years to achieve the 80 year journey that European and American countries have gone through, and provide a model for global air pollution control again.

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DECLARATION OF INTERESTS

The authors declare no competing interests.