The Modeling Study about Impacts of Emission Control Policies for Chinese 14th Five-Year Plan on PM$_{2.5}$ and O$_3$ in Yangtze River Delta, China

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1. Introduction

Ozone (O$_3$) and PM$_{2.5}$ (fine particles refer to particles with aerodynamic equivalent diameter less than or equal to 2.5 μm) are important pollutants of the troposphere due to their large impacts on air quality, human health and climate [1–4]. Both O$_3$ and PM$_{2.5}$ originate from complex sources and chemical reactions, and are very difficult to control [5,6]. The air pollution in China is the consequence of diverse and high primary emissions (e.g., NO$_x$, NH$_3$, SO$_2$ and VOCs), and efficient secondary productions [7]. As a result of the rapid urbanization in the past decades, most regions in China have experienced heavy and even increasing O$_3$ and PM$_{2.5}$ pollution [8–11]. Despite continued efforts,
the Chinese government has yet to grapple with the issue of air pollution. The densely populated and developed regions experience frequent and severe winter haze and summer O$_3$ pollution episodes, such as the Beijing-Tianjin-Hebei (BTH), Pearl River Delta (PRD) and Yangtze River Delta (YRD) regions [12–15]. It has been shown that primary emissions accumulate in various types of meteorological conditions in each region, suggesting a strong tendency of complex air pollution in China [16,17]. Recent studies show that the changes in O$_3$ concentrations correlated with PM$_{2.5}$ reductions but that decreases in NOx led to unexpected rises in the surface O$_3$ level in China [18,19]. Studies have indicated that O$_3$ levels in eastern China show an obvious upward trend, with most of its urban agglomerations located in the YRD region [20,21]. The YRD region has 41 cities with the mega-city of Shanghai and the provinces of Jiangsu, Zhejiang and Anhui. The area accounts for only 2% of the national land area, but accounts for more than 20% of China’s gross domestic product (GDP) [22]. It is one of the most densely populated and high-ground emission areas in China. Therefore, the region urgently needs control measures to curb the intensification of air pollution.

The Five-Year Plan, or FYP, is a comprehensive policy blueprint released by China every five years to guide its overall economic and social developments. During the 11th FYP (2004–2009), efforts were focused on reducing the emissions of SO$_2$ by setting an overarching goal to reduce national SO$_2$ emissions by 10% in the context of severe acid rain [23,24]. Since then, the overarching goal associated with air pollution control policies during each FYP period was repeatedly adjusted and set. For example, during the 12th FYP (2010–2015), the principal goal had been set to reduce 10% and 8% of the national NOx and SO$_2$ emissions, respectively. The main objectives of the 12th FYP were contextualized by the sharp increases in NOx emissions from motor vehicles in China which led to the intensification of air pollution [25,26]. After that, the overarching goal of the 13th FYP (2016–2020) was set to reduce 15%, 15%, and 10% of the national NOx, SO$_2$, and VOCs (volatile organic compounds) emissions, respectively. The 13th FYP marked the beginning of the overall emission reductions in VOCs. This is the first time that VOCs have been included in the overall emission reduction targets in the FYP. With the sharp rises in industrial products in China, there has been an increasing trend in domestic non-methane volatile organic compounds (NMVOCs) emissions [27]. VOCs are precursors to both surface-level ozone and secondary organic aerosols [28]. Meanwhile, due to the rise in industrial productions and the continuous promotion of urbanization, the continuous control of NOx and SO$_2$ emissions with the increased intensity of energy consumption are inevitable. The National People’s Congress (NPC) of China formalized the “Outline for the 14th FYP and Long-Term Targets for 2035” in March, 2021. The outline of the 14th FYP sets the goal of reducing “energy intensity” by 13.5% between 2021 and 2025. This refers to China’s long-term climate goal in the FYP and introduces the concept of “Capping Carbon Emissions” for the first time. The outline of the 14th FYP promulgates and implements the relevant emission reduction targets of comprehensively accelerating the controls of VOCs emissions and reducing the emissions of NOx and VOCs by more than 10%. With this background, this can represent possible emission reduction measures in China in the next five years. In general, the implementations of China’s FYP ensures the stability of emission reductions at the national level.

In addition to the FYP, China has achieved remarkable results in air pollution controls with the implementation of the clean air policies. The detailed major clean air policies are summarized in Figure 1. For example, the “Air Pollution Prevention and Control Action Plan” (APPCAP, covering 2013–2017) was the most stringent air pollution prevention and control action plan promulgated in China. During this period, the PM$_{2.5}$ concentrations in the BTH, YRD, and PRD regions in 2018 relative to 2013 decreased by 25%, 20% and 15%, respectively [29]. In the five years, China had taken a series of strict air pollution control actions. However, there was a lack of control measures for the NMVOC emissions. Since then, China’s State Council has promulgated the “Three-Year Action Plan for Winning the Blue Sky Defense Battle”. By 2020, the total emissions of SO$_2$ and NOx would be reduced
by more than 15% relative to those in 2015. It is expected that air quality can be significantly improved through the implementation of air quality policies. Despite China’s efforts to reduce emissions, China’s air quality was still far below the requirements of residents and the targets promised by the government. Therefore, flexible and scientific emission reduction policies are needed to prevent the deterioration of air pollution in China.

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The advanced chemical transport model can be used to estimate the level of air pollutants and provide strong support for the simulation of air pollution control policies. However, there is still a lack of relevant studies reflecting on the actual ground emission status and the effective emission reduction strategies in the FYP. This study systematically evaluated the impacts of the implementation of the air quality policies in the 14th FYP in the YRD by 2025. The simulation periods mainly focused on the summer season (June-July-August) with the ozone pollution and the winter season (January and December) with the haze pollution in the YRD. The significance of this study is to provide the reference and basis for the future air pollution policy-making. We comprehensively analyzed the formation of O3 and PM2.5 during the “14th FYP” period and under the background of

| Year | Period of 12th FYP | Period of 13th FYP | Three year Action Plan² |  
|------|-------------------|-------------------|-------------------------|
| 2011 | A national goal set to reduce 10%, 8% of emission of NOx and SO₂ respectively  
Emission standards for air pollutants for Thermal Power Plan (2011)  
“China 4” Standard for heavy duty gasoline vehicle (2011)  
New standards for industry sectors of sinter, coking, iron and steel (2012)  
APP CAP² (2013–2017)  
• New Standards for industry sectors of brick, cement, and boiler (2013–2014)  
• “China 4” Standard for heavy duty gasoline vehicle and applied nationally (2015)  
• “Ultralow emission” standards for power plants (2014)  
• “China 5” Standard applied nationally (2016)  
• Coal substituted by natural gas and electricity in households (2012–2017)  
2012 | The aim of air pollution control policies in China have switched from “Emissions Reduction” to “Air Quality”  
2013 |  
2014 |  
2015 |  
2016 | A national goal set to reduce 15%, 15% and 10% emission of NOx, SO² and VOCs, respectively  
2017 | Three year Action Plan³ (2018–2021)  
• Overarching goal: ambient PM2.5 concentrations reduced by -18% on the basis of 2015  
• Accelerating the adjustment of the energy mix and establishing a clean, low-carbon, and efficient energy framework  
• Adjusting the transportation structure and developing green transport system  
• Optimizing and adjusting the land use structure and press ahead with the control of pollution from non-point sources  
• Launching major campaigns to substantially reduce pollutants  
• Strengthening regional cooperation on controls of heavy air pollution  
2018 | A national goal set to reduce 10%, 10% emission of NOx and VOCs, respectively  
2019 |  
2020 |  
2021 | Figure 1. Timeline summarizing major air pollution control strategies in China. 1 The 12th Five Year Plan (2010–2015), the overarching goal was set to reduce 10% and 8% national NOx and SO2 emission with a result of 18.6% and 18% reductions in national NOx and SO2 emissions, respectively. 2 Air Pollution Prevention and Control Action Plan (2013–2017) aimed to reduce 25%, 20% and 15% PM2.5 in Beijing-Tianjin-Hebei region (BTH), YRD (YRD) and Pearl River Delta (PRD), respectively. 3 The 13th Five Year Plan (2016–2020), the overarching goal was set to reduce 15%, 15% and 10% national NOx, SO2, and VOCs emission, respectively. 4 Three-Year Action Plan for Winning the Blue Sky Defense Battle (2018–2021). The Action Plan puts forward six measures with quantifiable indicators and timelines. After that, the overarching goal was set to reduce 10% and 10% national NOx and VOCs emission in the 14th Five Year Plan (2021–2025), respectively.
“Capping Carbon Emissions” for the first time. The results reveal the specific targets of emission reductions in the YRD in the future, and will also provide enlightenments for the formulation of China’s future emission reduction policies.

2. Methods

2.1. Model Configurations and Emission Inventory

The offline Weather Research and Forecasting (WRFv3.9.1) and Community Multi-scale Air Quality Modeling (CMAQv5.3.2) model was applied to simulate spatiotemporal variations in meteorological and chemical fields. The CMAQv5.3.2 (released in 2020) is the latest version and its major science advances in detail can be found in Murphy et al. [30], and Appel et al. [31]. In this study, the Carbon Bond 6 (CB6) schemes and AERO7 module were responsible for gas and aerosol chemistry simulations, respectively. More advanced scientific calculation functions were embedded into CB6 and AERO7 for improving organic aerosol simulation performance of CMAQv5.3.2. Compared to CB5 with 74 species and 182 reactions, CB6 contains 90 species and 227 reactions for the gas-phase precursors [32,33]. Fewer species are required for AERO7 with more robust predictions which require less computation time than AERO6. Scientific improvements in AERO7 include [34]: (1) improvements in consistency in terms of secondary organic aerosol (SOA) between carbon bond and SAPRC-based mechanisms; (2) updates of monoterpene SOA from photooxidation (OH and ozone); (3) uptakes of water onto hydrophilic organics; (4) reorganization of anthropogenic SOA species and (5) formations of inorganic sulfate when IEPOX organosulfates are formed.

A 1-way domain covering mainland China with a horizontal resolution of 12 km × 12 km was built, which had 345 rows and 395 columns of grid cells (Figure S1). The projection mode was Lambert for the domain. The inorganic components were computed by the ISORROPIA II module [35]. The WRFv3.9.1 model was used to provide meteorological fields for chemical simulations [36]. The model configurations and components for the WRF model used in this study were the same as those in Yu et al. [37], Zhang et al. [38] and Wang et al. [39].

To study the impacts of emission control policies of the 14th FYP on the air quality in the YRD in 2025, the meteorological initial conditions (IC) and boundary conditions (BC) for the WRF model were derived from the model results on the basis of the “Representative Concentration Pathways” (RCP) Database (version 2.0) for the RCP 8.5 in 2025 simulated by the MESSAGE modeling team [40]. The underlying scenario drivers and resulting development paths for the RCP 8.5 were based on the A2r scenario detailed in Riahi et al. (2007) which characterized increasing greenhouse gas emissions over time representative of scenarios in the literature, leading to high greenhouse gas concentration levels [41]. RCP8.5 is consistent with the policy background under the Paris Agreement and the timeline of large-scale economic change and focuses on the total cumulative CO₂ emissions between 2005 and 2030 [41,42]. China is expected to achieve its commitment of “Capping Carbon Emissions” before 2030. In the context of “Capping Carbon Emissions” background, RCP8.5 was chosen in the study. The RCP database is available from the open-source website [43].

The gridded anthropogenic emissions for China from the Emission Inventory of Air Benefit and Cost and Attainment Assessment System (EI-ABaCAS) in 2018, developed by Tsinghua University [44], were used. The EI-ABaCAS includes 16 emission sectors listed in Table S1. The EI-ABaCAS dataset includes the annual gridded emissions on a Lambert projection grid with 12 km resolution, which is consistent with the resolution of the model domain. The emissions for CO, NH₃, NOx, PM₁₀, PM₂.₅, SO₂, and VOCs with speciation were contained in the dataset. The total annual emissions for various industry sectors for each province in the YRD were summarized in Figure 2 and Table S2. The natural sources for biogenic emissions were calculated inline using the Biogenic Emission Inventory System version 3.14 (BEISv3.14) [45].
Figure 2. The histogram of 16 sectors of annual emissions in 2018 for each species (CO, VOCs, NOx, NH₃, PM₁₀, PM₂.₅, SO₂, POC and EC) in Shanghai, Anhui, Jiangsu, and Zhejiang in the YRD. The unit of emission is tons/year (t/a). The descriptions of 16 emission sectors were listed in Table S1.
The YRD urban agglomerations includes 26 cities, as shown in Figure S1, with city names listed in Table S3. Hourly observed PM$_{2.5}$ and O$_3$ concentrations in 26 cities between 2016 and 2021 were obtained from China National Environmental Monitoring Center [46]. The monthly average and maximum concentrations of PM$_{2.5}$ and O$_3$ for each city in the YRD in the past 6 years (2016–2021) were shown in Figures S2 and S3, which provided insight into the historical air pollutions in YRD. Based on the results of the pollution situation in the past 6 years (Figures S2 and S3), the high concentrations of PM$_{2.5}$ and O$_3$ in the YRD occurred in the 2 winter months (i.e., January and December) and the 3 summer months (i.e., June, July, and August), respectively. Hence, we chose two winter months (January and December) to represent the haze formation period and three summer months (June, July, and August) to represent the O$_3$ pollution period in the YRD in this study.

2.2. Descriptions of Emission Control Scenarios

Our study designed two types of experiments, namely baseline and sensitivity scenario simulations. In the baseline scenario simulations (case: Base), the original emission inventory without any emission controls were used. We designed 4 sets of sensitivity scenario simulations (S1, S1_E, S2_E and S3_E) to quantify the potential impacts of emission control policies in the 14th FYP on both PM$_{2.5}$ and O$_3$ in the YRD as listed in Tables 1 and 2. These four emission control scenarios are described in detail below.

The Chinese government sets targets for the performance of its economy in every Five-Year Plan (FYP), which include energy- and pollution-related targets from the National Total Emissions Control (NTEC) Program. In the 13th FYP, the national SO$_2$, NOx and VOCs targets were set to achieve 15%, 15%, and 10% emission reductions, respectively. Nevertheless, the actual reduction varied across the country. Local governments all over the country had reported their emission reduction results of NTEC to Ministry of Ecology and Environment of China by 2020 since this was the last year of the 13th FYP. The emission control scenario 1 (S1) was designed on the basis of the reported emission reduction results in 41 cities in the YRD listed in Table 1. Under the guidance of ecosystem and environmental protections in the 14th FYP [47], the governments of Shanghai, Anhui, Jiangsu and Zhejiang have formulated emission control policies to prevent and control air pollution for protecting the air environment and public health with quantifiable indexes and time nodes [48–51]. The 5 main policies are briefly summarized below [48–51]:

1. Adjustments and optimizations of the energy structures. By 2025, the proportion of non-fossil and clean energies in primary energy production and consumption will reach more than 20%.
2. Implementation of comprehensive managements of industrial boilers and other industries. This policy is the continuation of the “ultra-low emission” work, including the phasing out and renovation of old boilers in the YRD.
3. Integrated management of industrial parks. The policy will gradually promote emission reductions for industries with the high VOCs emissions.
4. Developments of green transportation systems in the YRD. By 2023, the “China 6” standard for motor vehicles will be fully implemented. The share of railway freight transportation will increase to 35%, and the market share of “new energy vehicles” will reach 20% by 2025.
5. Strengths of the comprehensive management of VOCs emissions in the YRD. This includes the substitution of raw materials and the upgrading projects of inefficient treatment facilities with high VOCs emissions. The enhanced emission control scenario (S1_E) was designed by assuming that the above 5 measures would be fully implemented in all cities in the YRD by 2025. To summarize briefly, the total emission reductions are assumed to increase by 1.5, 1.5 and 3 times for NOx, SO$_2$, and VOCs in S1_E relative to those in S1, respectively.
Table 1. The emission control schemes on the basis of National Total Emission Controls.

| Province | City      | Control Scenario 1 (S1) | Enhanced Control Scenario 1 (S1_E) |
|----------|-----------|------------------------|------------------------------------|
|          |           | SO₂ (%) | NOₓ (%) | VOCs (%) | SO₂ (%) | NOₓ (%) | VOCs (%) |
| Shanghai | municipal | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Anqing    | 16.0%   | 14.4%   | 11.4%    | 24.0%   | 21.6%   | 34.2%    |
|          | Bengbu    | 15.4%   | 13.2%   | 10.4%    | 23.1%   | 19.8%   | 31.2%    |
|          | Bozhou    | 11.0%   | 8.8%    | 6.6%     | 16.5%   | 13.2%   | 30.0%    |
|          | Chizhou   | 5.0%    | 6.0%    | 8.8%     | 7.5%    | 9.0%    | 30.0%    |
|          | Chuzhou   | 13.2%   | 15.4%   | 9.1%     | 19.8%   | 23.1%   | 30.0%    |
|          | Fuyang    | 11.2%   | 14.4%   | 7.9%     | 16.8%   | 21.6%   | 30.0%    |
|          | Hefei     | 23.1%   | 24.2%   | 12.2%    | 34.7%   | 36.3%   | 36.6%    |
| Anhui    | Huaihai   | 17.6%   | 16.0%   | 9.9%     | 26.4%   | 24.0%   | 30.0%    |
|          | Huainan   | 17.9%   | 17.6%   | 6.8%     | 26.9%   | 26.4%   | 30.0%    |
|          | Huangshan | 2.0%    | 2.0%    | 10.3%    | 3.0%    | 3.0%    | 30.9%    |
|          | Luan      | 8.8%    | 8.0%    | 8.6%     | 13.2%   | 12.0%   | 30.0%    |
|          | Mananshan | 23.1%   | 24.2%   | 12.4%    | 34.7%   | 36.3%   | 37.2%    |
|          | Suzhou    | 22.0%   | 22.0%   | 22.0%    | 33.0%   | 33.0%   | 66.0%    |
|          | Tongling  | 17.6%   | 17.6%   | 9.8%     | 26.4%   | 26.4%   | 30.0%    |
|          | Wuhu      | 17.9%   | 17.6%   | 11.6%    | 26.9%   | 26.4%   | 34.8%    |
|          | Xuancheng | 8.5%    | 10.0%   | 9.9%     | 12.8%   | 15.0%   | 30.0%    |
| Jiangsu  | Changzhou | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Huaian    | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Lianyungang | 20.0%  | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Nanjin    | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Nantong   | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Suqian    | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Suzhou    | 12.1%   | 11.0%   | 8.4%     | 18.2%   | 16.5%   | 30.0%    |
|          | Taizhou   | 22.0%   | 22.0%   | 22.0%    | 33.0%   | 33.0%   | 66.0%    |
|          | Wuxi      | 22.0%   | 22.0%   | 22.0%    | 33.0%   | 33.0%   | 66.0%    |
|          | Xuzhou    | 22.0%   | 22.0%   | 22.0%    | 33.0%   | 33.0%   | 66.0%    |
|          | Yancheng  | 18.0%   | 18.0%   | 18.0%    | 27.0%   | 27.0%   | 54.0%    |
|          | Yangzhou  | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
|          | Zhenjiang | 20.0%   | 20.0%   | 20.0%    | 30.0%   | 30.0%   | 60.0%    |
| Zhejiang | Hangzhou  | 23.0%   | 23.0%   | 26.0%    | 34.5%   | 34.5%   | 78.0%    |
|          | Huzhou    | 23.0%   | 23.0%   | 20.0%    | 34.5%   | 34.5%   | 60.0%    |
|          | Jiaxing   | 21.0%   | 21.0%   | 18.0%    | 31.5%   | 31.5%   | 54.0%    |
|          | Jinhua    | 21.0%   | 21.0%   | 26.0%    | 31.5%   | 31.5%   | 78.0%    |
|          | Lishui    | 8.0%    | 8.0%    | 24.0%    | 12.0%   | 12.0%   | 72.0%    |
|          | Ningbo    | 17.0%   | 17.0%   | 25.0%    | 25.5%   | 25.5%   | 75.0%    |
|          | Quzhou    | 15.0%   | 15.0%   | 24.0%    | 22.5%   | 22.5%   | 72.0%    |
|          | Shaoxing  | 22.0%   | 22.0%   | 18.0%    | 33.0%   | 33.0%   | 54.0%    |
|          | Taizhou   | 13.0%   | 13.0%   | 3.0%     | 19.5%   | 19.5%   | 30.0%    |
|          | Wenzhou   | 15.0%   | 15.0%   | 15.0%    | 22.5%   | 22.5%   | 45.0%    |
|          | Zhoushan  | 3.0%    | 3.0%    | 10.0%    | 4.5%    | 4.5%    | 30.0%    |
To explore the impact on pollutant generations under the premise that all the induced policies and relevant advanced emission source control technologies will be fully implemented in the high-emission sectors of the YRD by 2025, 2 emission control scenarios (S2_E and S3_E) were designed on the basis of controls schemes for emission sectors as listed in Table 2. These include emission sectors for Agriculture (AGRF (fertilizer application), AGRL (livestock)), Industry (INCB (industry combustion), PRCE (cement), PRIR (steel), PRSO (industry solvent use), PROT (other industry process)), Energy PPCB (power plant) and Transport (TROF (off-road transport), TRON (on-road transport)) (see Table 2). Relative to S1_E, S2_E had more types of pollutants regulated and the control rates of pollutants adjusted within the scope of policy implementation. Relative to S2_E, S3_E maintained the

| Control Scenario | Description | Sectors | Control Percentage (%) |
|------------------|-------------|---------|------------------------|
|                  |             | CO      | NH₃ | NOₓ | PEC | PM₁₀ | PM₂.₅ | POC | SO₂ | VOCs |
| S2_E             | Enhanced control | AGRF    | 10.0% |     |     |     |       |     |     |      |
|                  |             | AGRL    | 10.0% |     |     |     |       |     |     |      |
|                  |             | INCB    | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PPCB    | 30.0% | 30.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PRCE    | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% |
|                  |             | PRIR    | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PROT    | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PRSO    | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% |
|                  |             | TROF    | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% |
|                  |             | TRON    | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% |
| S3_E             | Enhanced control | AGRF    | 20.0% |     |     |     |       |     |     |      |
|                  |             | AGRL    | 20.0% |     |     |     |       |     |     |      |
|                  |             | INCB    | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% |
|                  |             | PPCB    | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% |
|                  |             | PRCE    | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% |
|                  |             | PRIR    | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% |
|                  |             | PROT    | 65.0% |       |       |       |       |       |       |       |
|                  |             | PRSO    | 65.0% |       |       |       |       |       |       |       |
|                  |             | TROF    | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% |
|                  |             | TRON    | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% |
| S2_E_NT          | Enhanced control | No transport control | AGRF    | 10.0% |     |     |       |     |     |      |
|                  |             | AGRL    | 10.0% |     |     |     |       |     |     |      |
|                  |             | INCB    | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PPCB    | 30.0% | 30.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PRCE    | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% | 30.0% |
|                  |             | PRIR    | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PROT    | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% | 20.0% |
|                  |             | PRSO    |       |       |       |       |       |       |       |       |
|                  |             | TROF    |       |       |       |       |       |       |       |       |
|                  |             | TRON    |       |       |       |       |       |       |       |       |
| S3_E_NT          | Enhanced control | No transport control | AGRF    | 20.0% |     |     |       |     |     |      |
|                  |             | AGRL    | 20.0% |     |     |     |       |     |     |      |
|                  |             | INCB    | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% |
|                  |             | PPCB    | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% |
|                  |             | PRCE    | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% | 50.0% |
|                  |             | PRIR    | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% | 35.0% |
|                  |             | PROT    | 65.0% |       |       |       |       |       |       |       |
|                  |             | PRSO    | 65.0% |       |       |       |       |       |       |       |
|                  |             | TROF    |       |       |       |       |       |       |       |       |
|                  |             | TRON    |       |       |       |       |       |       |       |       |

* Emission sectors include Agriculture: AGRF (fertilizer application), AGRL (livestock); Industry: INCB (industry combustion), PRCE (cement), PRIR (steel), PRSO (industry solvent use), PROT (other industry process); Energy: PPCB (power plant); Transport: TROF (off-road transport), TRON (on-road transport).
same control set for the emission sectors but with higher control rates as shown in Table 2. The corresponding reduction rates for each species of each emission sector in Table 2 were derived on the basis of targets for air quality improvement, key air pollutant emission reductions and the optimization of energy and industrial structures for 2025 in the 14th Five-Year Plan. The high emissions of NH$_3$ come from livestock farming and the heavy use of fertilizers. A combination of the aforementioned measures was estimated to reduce China’s NH$_3$ emissions by 30–50%, based on the existing literature and local agricultural practice [52]. In this work, we choose 10% and 20% NH$_3$ emission abatement strategy to examine its atmospheric environmental impacts for S2_E and S3_E, respectively.

The controls of O$_3$ precursors were mainly focused on NOx emissions, whereas less emission control strategies have been implemented on VOCs in the past few decades in China. However, along with the vigorous promotion of a green public transportation system, and new energy automobile in YRD, the NOx emissions from transportation will fall further in the future. In addition, NOx emissions in China have decreased by 23% since 2016, in which emission reductions from power plants were the predominant contributor [19]. Hence, China will continue to implement NOx emission abatement policies. In this study, 30–50% NOx emission reductions for industry and transportation sectors were chosen in S2_E and S3_E. A percentage of 50% can be taken as upper bound of NOx emission reductions via feasible control policies in the 14th FYP in Table 2.

The large-scale regulations in VOCs emissions in China started in 2018. These regulations had been included in the Three-Year Action Plan for Winning the Blue Sky Defense Battle (covering 2018–2021). The regulations include: (1) Remediation plans for key VOC-emitting industries; (2) Banning the production and use of high-VOC solvent-based inks, adhesives, etc.; (3) Enforcement actions to reduce the total environmental emissions of certain VOCs by more than 10 percent between 2015–2020. In March 2020, China released 4 mandatory national standards on VOCs in coatings, adhesives, inks, and cleaning agents [53]. These standards, which come into effect on 1 December 2020, include: (1) GB 30981-2020, “Limit of harmful substances of industrial protective coatings”; (2) GB 33372-2020, “Limit of volatile organic compounds content in adhesives”; (3) GB 38507-2020, “Limits of volatile organic compounds (VOCs) in printing inks”, and (4) GB 38508-2020, “Limits for volatile organic compounds content in cleaning agents”. On the basis of this information, high VOCs control rates with 30–65% in industry and transportation sectors were used under the S2_E and S3_E control scenarios in this study (see Table 2). From 2013 to 2017, significant declines in PM$_{2.5}$ concentrations occurred nationwide [29]. Therefore, we chose comparatively low control rates (20–35%) of primary particulate pollutants (PEC, PM$_{10}$, PM$_{2.5}$ and SO$_2$) from industry sectors under the S2_E and S3_E control scenarios in this study (see Table 2). In the context of “Carbon Peaking and Neutrality”, the comprehensive carbon emission control should be promoted in China. The CO control rates were kept the same as primary particulate pollutants with 20–50% (see Table 2). As shown in Table 2, the S3_E case can be considered as the enhanced emission control scenario of S2_E.

On the other hand, the S2_E_NT and S3_E_NT scenarios were created to test the sensitivities of O$_3$ to VOCs and NOx emissions from the transportation sector by completely removing the transportation emission sources (TROF and TRON) in the corresponding emission control scenarios of S2_E and S3_E (see Table 2).

3. Results and Discussions

3.1. Impacts of the Emissions Control Scenarios on PM$_{2.5}$ in the YRD

The potentials of emission control scenarios for air quality improvement in the YRD region were evaluated by comparing the simulations of surface concentrations of city mean PM$_{2.5}$ in 41 cities under the 4 control and 1 baseline scenarios in the 2 winter months (January and December) in 2025. Table 3 summarizes the predicted average decreases in city mean PM$_{2.5}$ concentrations in 41 cities under the 4 different emission control scenarios relative to the base case in the 2 winter months, while Tables S4 and S5 listed the monthly mean results for each month. The spatial distributions of the predicted average
changes in concentrations and percentages of mean PM$_{2.5}$ in the 2 winter months were shown in Figure 3 and Figure S4, respectively. Figure 3 indicates that although the scenarios of enhanced emission controls (S1_E and S3_E) show further decreases in mean PM$_{2.5}$ concentrations in line with expectations, the decrease values were different in the different regions.

Table 3. Predicted average decrease values of winter PM$_{2.5}$ concentrations under the 4 control scenarios relative to the baseline in 41 main cities of YRD in 2025.

| Province | City   | Concentrations * (µg/m$^3$) | Decrease Values * (µg/m$^3$) |
|----------|--------|-----------------------------|-------------------------------|
|          |        | Base                        | S1-Base, S1_E-Base, S2_E-Base, S3_E-Base |
| municipal | Shanghai | 30.0 ± 27.7                 | −0.3 ± 1.7, −1.1 ± 2.5, −4.8 ± 4.7, −9.1 ± 8.7 |
|          | Anqing  | 63.7 ± 59.7                 | −0.2 ± 1.6, −4.0 ± 12.0, −8.7 ± 10.2, −8.0 ± 13.6 |
|          | BengBu  | 38.1 ± 38.8                 | −0.6 ± 2.7, −0.5 ± 2.0, −9.0 ± 10.0, −11.5 ± 12.4 |
|          | Bozhou  | 42.4 ± 41.8                 | −0.2 ± 1.8, −3.0 ± 9.7, −10.0 ± 10.4, −13.1 ± 14.7 |
|          | Chizhou | 23.8 ± 25.1                 | −0.3 ± 1.2, −1.7 ± 5.1, −12.3 ± 13.8, −9.6 ± 12.1 |
|          | ChuZhou | 53.6 ± 53.0                 | −0.1 ± 1.0, −2.1 ± 5.7, −8.2 ± 7.3, −9.9 ± 12.6 |
|          | Fuyang  | 34.9 ± 34.2                 | −0.2 ± 0.8, −1.3 ± 3.2, −10.5 ± 10.8, −10.6 ± 14.1 |
|          | Hefei   | 32.9 ± 28.9                 | −0.8 ± 2.8, −0.7 ± 2.6, −10.2 ± 10.7, −12.9 ± 17.5 |
|          | Huabei  | 35.0 ± 39.4                 | −0.2 ± 1.2, −1.5 ± 4.8, −9.1 ± 9.6, −9.2 ± 11.5 |
|          | Huainan | 29.8 ± 34.6                 | −0.2 ± 0.9, −0.7 ± 2.3, −9.6 ± 10.8, −6.3 ± 9.2 |
|          | Huationshan | 38.3 ± 37.4            | 0.0 ± 1.0, −1.7 ± 6.4, −11.2 ± 13.2, −7.0 ± 6.4 |
|          | Luan    | 46.0 ± 46.3                 | −0.1 ± 0.4, −0.8 ± 1.6, −9.0 ± 9.5, −8.4 ± 7.1 |
|          | Manzhan | 48.9 ± 50.4                 | 0.1 ± 1.0, −3.9 ± 9.1, −6.8 ± 6.8, −10.8 ± 15.4 |
|          | Suzhou  | 33.0 ± 30.3                 | −0.1 ± 0.9, −2.1 ± 9.3, −9.2 ± 9.1, −10.2 ± 11.5 |
|          | Tongling | 51.3 ± 46.9                | −0.1 ± 0.9, −2.6 ± 8.1, −7.1 ± 7.2, −8.4 ± 10.5 |
|          | Wuhu    | 53.7 ± 50.0                 | −0.5 ± 1.5, −2.2 ± 7.1, −5.9 ± 5.5, −6.4 ± 6.2 |
|          | Xuancheng | 49.9 ± 47.0                | −0.2 ± 1.7, −2.0 ± 6.4, −11.1 ± 12.7, −7.6 ± 9.2 |
|          | Changzhou | 57.2 ± 54.9               | −0.3 ± 1.9, −2.6 ± 7.3, −10.8 ± 11.6, −6.5 ± 9.2 |
|          | Huaian  | 48.6 ± 44.7                 | −0.2 ± 1.0, −2.1 ± 7.9, −11.6 ± 12.5, −11.2 ± 12.9 |
|          | Lianyungang | 41.2 ± 41.4              | −0.2 ± 0.9, −1.5 ± 5.7, −7.1 ± 6.5, −7.3 ± 8.6 |
|          | Nanjing | 39.3 ± 38.8                 | −0.4 ± 1.9, −2.4 ± 9.8, −11.4 ± 10.8, −10.1 ± 11.2 |
|          | Nantong | 35.1 ± 33.8                 | −0.2 ± 0.3, −1.6 ± 5.4, −10.6 ± 10.6, −9.2 ± 9.8 |
|          | Suzian  | 38.6 ± 37.2                 | 0.1 ± 1.1, −2.2 ± 6.1, −11.9 ± 12.1, −9.9 ± 12.3 |
|          | Suzhou  | 59.1 ± 55.9                 | −0.2 ± 0.3, −1.7 ± 5.1, −13.1 ± 13.9, −10.7 ± 12.9 |
|          | Taizhou | 51.4 ± 47.0                 | −0.1 ± 0.9, −1.8 ± 5.6, −6.8 ± 7.7, −11.0 ± 11.8 |
|          | Wuxi    | 43.3 ± 41.7                 | −0.5 ± 1.7, −1.2 ± 4.9, −4.6 ± 4.9, −9.7 ± 10.7 |
|          | Xuzhou  | 54.4 ± 55.4                 | −0.3 ± 1.8, −0.3 ± 0.9, −8.7 ± 8.5, −11.0 ± 12.0 |
|          | Yangzhou | 47.0 ± 44.2                | −0.1 ± 0.3, −3.3 ± 9.3, −5.9 ± 5.9, −10.5 ± 12.3 |
|          | Yancheng | 31.0 ± 28.1                | −0.1 ± 1.2, −1.7 ± 5.5, −9.8 ± 10.2, −7.8 ± 14.5 |
|          | Zhejiang | 49.2 ± 44.6                | −0.4 ± 1.8, −3.0 ± 8.2, −10.1 ± 10.6, −4.9 ± 5.0 |

Concentrations *: monthly mean concentrations ± standard deviation. Decrease values *: monthly mean decrease values ± standard deviation.
Overall, the PM$_{2.5}$ decreases in these 41 cities in December were larger than those in January for the same control scenarios. Compared to the S1 scenario, the S1_E scenario had wider decrease areas and higher decrease values of PM$_{2.5}$ concentrations (Figure 3), consistent with the intensities of emission controls (Tables 1 and 2). In January, under the scenarios of S2_E and S3_E, the PM$_{2.5}$ decreases in the central Anhui, southern Jiangsu, northern Zhejiang and Shanghai were relatively large. Under the S1 scenario designed on the basis of the emission reduction scheme reported in the 13th FYP, the average PM$_{2.5}$ decreases in these 41 cities in the YRD in winter were less than 2 µg/m$^3$. Under the S1_E scenario, the monthly average concentrations of city mean PM$_{2.5}$ were predicted to decrease by $-7.6$ µg/m$^3$ in Anqing city of Anhui province, followed by $-5.8$ µg/m$^3$ in Ningbo city of Zhejiang province, $-5.4$ µg/m$^3$ in Zhenjiang city of Jiangsu province, and $-1.4$ µg/m$^3$ in Shanghai in December (see Table S4). Compared with those in December, the decrease values in January were expected to be less due to its lower baseline concentrations. For example, it was predicted that by January 2025, under the S1_E scenario, the maximum values of average decreases in city mean PM$_{2.5}$ in each province in both Suzhou city (in Anhui province) and Yangzhou city (in Jiangsu province) would reach $-3.5$ µg/m$^3$, followed by $-1.1$ µg/m$^3$ in Jiaxing city of Zhejiang province and $-0.7$ µg/m$^3$ in Shanghai. As shown in Figure S4, under the S1 and S1_E scenarios, the decrease percentages of PM$_{2.5}$ in the YRD were predicted to be less than 10%. Although the overall emission reductions in SO$_2$, NOx and VOCs in the YRD were strengthened under the S1_E scenario, the average concentrations of city mean PM$_{2.5}$ were predicted to decrease only by 10% by 2025, indicating that the emission reduction intensities under the S1_E scenario were not enough to meet the requirements of the 14th FYP.

Figure 3. Spatial distributions of PM$_{2.5}$ concentration decrease values under the 4 control scenarios relative to the base case over the YRD region in January (Jan) and December (Dec), 2025.
Compared to the control scenarios of S1 and S1_E, the enhanced emission control scenarios (i.e., S2_E and S3_E) are expected to further reduce PM$_{2.5}$ in each city by more than 20%, depending on the regions and months (see Figure S4). For example, the S3_E control scenario led to a further decrease in monthly average PM$_{2.5}$ concentrations in Shanghai, Anhui, Jiangsu, and Zhejiang in December of 2025 by $-3.1$, $-14.9$ to $-3.6$, $-17.3$ to $-2.6$, and $-12.6$ to $-3.4$ µg/m$^3$ in December of 2025, respectively (Table S4). The predicted decreases in PM$_{2.5}$ in January were different from those in December, with smaller decreases expected in the most areas of the YRD due to their lower PM$_{2.5}$ concentrations (Figure 3 and Table S5). It was clear that when the precursor reductions were high, it would lead to a concentration decrease in more areas with higher reductions (Figure 3). Compared with the S2_E scenario, the monthly average decreases in PM$_{2.5}$ in the YRD region for 2 months under the S3_E scenario were larger. For example, reductions were expected to decrease further by $8.3$ µg/m$^3$ in Hangzhou and Anqing under the S3_E scenario, with more decreases in most other cities (Tables S4 and S5). In summary, the decrease values of the emission control policies predicted by the S1 and S1_E scenarios were not enough, and the decreases in city mean PM$_{2.5}$ concentrations in the most regions of YRD in the winter of the 14th FYP were less than 20%, based on the monthly simulation results (Figure S4). As shown above, the enhanced emission control scenarios (i.e., S2_E and S3_E) will be an effective way for decreasing PM$_{2.5}$ in the YRD region.

### 3.2. Impacts of the Emissions Control Scenarios on O$_3$ in the YRD

Figures 4 and 5 depict the monthly mean changes in hourly and MDA8 (the maximum daily 8-hour moving average) O$_3$ concentrations under the S1 and S1_E scenarios relative to the base case in June, July and August of 2025. Tables 4 and 5 summarize the mean results in all 3 months for each city of the 41 cities in the YRD and the results for each month are listed in Tables S6–S11. The S1 and S1_E control emission reduction policies have completely different emission reduction effects for O$_3$ relative to those of PM$_{2.5}$ in the YRD. Under the S1 scenario, O$_3$ mean concentrations in the most areas of the YRD showed increasing trends with decreases in precursor emissions. It was found that the maximum monthly mean increases in city mean O$_3$ concentrations in Shanghai, Anhui, Jiangsu and Zhejiang in the 3 summer months under the S1 scenario were 7.8 µg/m$^3$ (in July in Shanghai), 15.0 µg/m$^3$ (in August in Bengbu city), 12.9 µg/m$^3$ (in August in Zhenjiang city), and 13.8 µg/m$^3$ (in July in Lishui city), respectively (see Tables S6–S8). The increasing trends were more obvious for the MDA8 O$_3$ concentrations (Figure 5). The maximum monthly increases in city MDA8 O$_3$ concentrations in Shanghai, Anhui, Jiangsu, and Zhejiang in 3 summer months under the S1 scenario were 29.5 µg/m$^3$ (in July in Shanghai city), 39.7 µg/m$^3$ (in August in Fuyang city), 29.5 µg/m$^3$ (in June in Nantong city) and 28.7 µg/m$^3$ (in August in Shaoxing city), respectively (Tables S9–S11).
Figure 4. Spatial distributions of monthly average O₃ concentration change values under the 4 control scenarios relative to the base case over the YRD region in June (Jun), July (Jul) and August (Aug), 2025.
Figure 5. Spatial distributions of MDA8 O$_3$ concentration change values under the 4 control scenarios relative to the base case over the YRD region in June (Jun), July (Jul) and August (Aug), 2025.
Table 4. Predicted average change values of summer O₃ concentrations under the 6 control scenarios relative to the baseline in 41 main cities of YRD in 2025. The results of the base case are also summarized.

| Province   | City         | Concentrations (µg/m³) | Change Values (µg/m³) |
|------------|--------------|------------------------|-----------------------|
| Shanghai   | S1-Base      | 93.2 ± 65.9            | -0.6 ± 12.3           |
|            | S1-E-Base    | 5.5 ± 12.5             | -10.2 ± 11.8          |
|            | S2_E-Base    | 6.0 ± 10.6             | -15.5 ± 16.3          |
|            | S2-E_NT-Base | -20.8 ± 36.6           | -16.2 ± 38.3          |
| Anhui      | Huaibei      | 97.4 ± 56.9            | -5.4 ± 13.7           |
|            | Huainan      | 75.1 ± 48.5            | -7.1 ± 19.5           |
|            | Hefei        | 112.5 ± 69.3           | -10.9 ± 10.0          |
|            | Huaian       | 97.9 ± 56.9            | -7.9 ± 8.5            |
| Anhui      | Huaibei      | 97.4 ± 56.9            | -5.4 ± 13.7           |
|            | Huainan      | 75.1 ± 48.5            | -7.1 ± 19.5           |
|            | Hefei        | 112.5 ± 69.3           | -10.9 ± 10.0          |
| Anhui      | Huaibei      | 97.4 ± 56.9            | -5.4 ± 13.7           |
|            | Huainan      | 75.1 ± 48.5            | -7.1 ± 19.5           |
|            | Hefei        | 112.5 ± 69.3           | -10.9 ± 10.0          |

Table 5. Predicted average change values of summer MDA8 O₃ concentrations under the 6 control scenarios relative to the baseline in 41 main cities of YRD in 2025. The results of the base case are also summarized.

| Province   | City         | Concentrations (µg/m³) | Change Values (µg/m³) |
|------------|--------------|------------------------|-----------------------|
| Shanghai   | S1-Base      | 95.7 ± 64.3            | 2.0 ± 9.5             |
|            | S1-E-Base    | 20.2 ± 19.6            | -5.7 ± 6.4            |
|            | S2_E-Base    | 2.0 ± 9.5              | -18.2 ± 9.3           |
|            | S2-E_NT-Base | -2.2 ± 24.8            | 2.6 ± 21.2            |
| Anhui      | Huaibei      | 96.5 ± 58.5            | -6.6 ± 7.2            |
|            | Huainan      | 97.9 ± 56.9            | -6.6 ± 8.6            |
| Anhui      | Huaibei      | 96.5 ± 58.5            | -6.6 ± 7.2            |
|            | Huainan      | 97.9 ± 56.9            | -6.6 ± 8.6            |

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Under the S1_E scenario, the emission reduction effects of NOx and VOCs on O3 were enhanced with improvements in the O3 control efficiency (Figure 4), in which O3 concentrations in the central areas of the middle and lower reaches of the YRD slightly decreased due to the increases in VOCs emission reduction proportions. It is worth noting that under the S1 scenario, the emission reduction rates for NOx and VOCs were close, while under the S1_E scenario the emission reduction rates for VOCs were higher than those for NOx. The rising trends of O3 concentrations in the YRD under the S1 scenario were alleviated under the S1_E scenario in which there were downward trends for the O3 concentrations in Shanghai, central and Northern Anhui, Central Jiangsu and Northern Zhejiang. In the summer of 2025, the averages of city mean O3 concentrations of the 3 summer months in the YRD under the S1_E scenario were predicted to decline with the maximum values of ~14 µg/m³ (in Anqing city), ~9.3 µg/m³ (in Wuxi city), and ~9.6 µg/m³ (in Taizhou city) in Anhui, Jiangsu, and Zhejiang, respectively (see Table 4). The downward trends were more evident in spatial distributions of monthly mean MDA8 O3 concentrations (Figure 5). It is predicted that the means of city MDA8 O3 concentrations of the 3 summer months of 2025 will have the maximum decrease values of ~17.3 µg/m³ (in Bengbu city), ~15.0 µg/m³ (in Changzhou city), and ~32.1 µg/m³ (in Jiaxing city) µg/m³ in Anhui, Jiangsu, and Zhejiang, respectively (see Table 5). This indicates that emission reduction policies for VOCs were more effective in influencing serious O3 pollution. As pointed out by Simon et al. [54], NOx participated in competing O3 creation and destruction reactions, and the response of O3 concentrations to changes in NOx or VOC emissions relies on their relative concentrations and the intensity of insolation. The effects of NOx are mainly O3 destruction under the condition that either the VOC/NOx ratios are low or insolation is very low (VOC or oxidant limited condition). This means that in the regions with elevated NOx concentrations due to high emissions densities (e.g., urban centers with significant traffic), reductions in NOx will lead to increases in local ozone concentrations. On the other hand, under the condition that the VOC/NOx ratios are high (NOx limited conditions), the main effects of NOx are O3 formation, and reductions in NOx will lead to decreases in local O3 concentrations [54]. The increasing trends of O3 concentrations in the most areas of the YRD with the decreases in precursor emissions under the S1 scenario in Table 4 indicate the VOC limited conditions for the O3 formation. On the other hand, the S1_E scenario under which the emission reduction rates for VOCs were higher than those

Table 5. Cont.

| Province | City     | Concentrations (µg/m³) | Change Values (µg/m³) |
|----------|----------|------------------------|-----------------------|
|          | Base     | S1 Base                | S1_E-Base             | S2_E-Base | S3_E-Base | S2_E_NT-Base | S3_E_NT-Base |
| Jiangsu  | Changzhou| 90.2 ± 62.7           | 11 ± 10.7             | ~15 ± 29.0 | ~15.0 ± 14.0 | ~16.2 ± 7.1 | ~11.9 ± 38.7 | 0.9 ± 13.4 |
|          | Huai'an  | 105.1 ± 59.7          | 8.7 ± 13.0            | ~11.4 ± 34.6 | ~6.2 ± 7.6 | ~22.7 ± 10.4 | 12.9 ± 24.0 | 4.8 ± 30.0 |
|          | Lianyungang| 109.4 ± 57.7       | 7.8 ± 16.6            | ~1.7 ± 22.1 | ~7.9 ± 6.7 | ~22.0 ± 10.6 | ~16.0 ± 31.4 | ~19.4 ± 31.2 |
|          | Nanjing  | 86.9 ± 30.3           | 7.8 ± 7.7             | ~14.4 ± 30.8 | ~5.9 ± 6.3 | ~19.5 ± 12.8 | ~4.5 ± 31.1 | ~28.1 ± 37.4 |
|          | Nantong  | 101.8 ± 59.2          | 11.8 ± 20.4           | 9.4 ± 15.1 | ~10.0 ± 7.9 | ~21.2 ± 18.2 | ~10.1 ± 29.7 | ~15.0 ± 40.6 |
|          | Suzhou   | 85.6 ± 56.7           | 16.2 ± 16.0           | ~19.1 ± 9.9 | ~7.6 ± 8.9 | ~38.0 ± 31.8 | ~3.7 ± 16.7 | ~29.5 ± 32.8 |
|          | Taizhou  | 91.3 ± 38.2           | 8.9 ± 17.7            | ~3.5 ± 13.7 | ~12.5 ± 8.8 | ~28.4 ± 28.2 | ~14.4 ± 38.4 | ~1.6 ± 54.2 |
|          | Wuxi     | 93.0 ± 65.5           | 15.0 ± 17.0           | 12.9 ± 9.6 | ~8.2 ± 9.1 | ~16.6 ± 10.2 | ~18.6 ± 35.1 | ~21.3 ± 12.2 |
|          | Xuzhou   | 120.7 ± 71.1          | 10.1 ± 11.2           | 3.3 ± 13.8 | ~8.1 ± 8.4 | ~16.7 ± 17.6 | 3.5 ± 37.9 | 3.7 ± 26.1 |
|          | Yangzhou | 88.0 ± 37.1           | 11.1 ± 16.2           | ~2.6 ± 20.6 | ~8.6 ± 9.2 | ~18.1 ± 10.5 | 11.8 ± 31.7 | 2.8 ± 23.9 |
|          | Yancheng | 124.6 ± 57.5          | 11.5 ± 8.6            | 2.5 ± 8.4 | ~13.4 ± 10.4 | ~18.9 ± 9.5 | 10.8 ± 21.7 | ~7.9 ± 31.1 |
| Zhejiang | Zhenjiang| 72.5 ± 34.3           | 11.4 ± 11.3           | 10.8 ± 9.1 | ~7.8 ± 11.0 | ~25.6 ± 13.7 | 5.8 ± 18.4 | ~4.2 ± 26.6 |

[54]
for NOx compared to the S1 scenario shows decreasing trends for the O3 concentrations in Shanghai, central and Northern Anhui, Central Jiangsu and Northern Zhejiang (Figure 5), indicating the NOx limited conditions. In summary, the spatial variations of O3 responses to the emission controls under the S1 and S1_E scenarios show that different emission reduction rates for VOCs and NOx may lead to different control effects of O3 in the YRD.

The spatial distributions of O3 change values under the S2_E and S3_E scenarios relative to the base case in Figures 4 and 5 revealed that the decreases in city hourly and MDA8 O3 mean concentrations in almost all the cities in YRD were found by controlling high-emission industries. Under the S2_E scenario, the maximum decreases in city mean O3 concentrations in Shanghai, Anhui, Jiangsu and Zhejiang were predicted to be $-12.2 \mu g/m^3$ (in July in Shanghai city), $-14.3 \mu g/m^3$ (in July in Hefei city), $-15.8 \mu g/m^3$ (in July in Suzhou city), and $-17.6 \mu g/m^3$ (in July in Taizhou city) $\mu g/m^3$, respectively (see Tables S6–S8). Under the S2_E scenario, the average decrease values of MDA8 O3 concentrations in Anhui, Jiangsu and Zhejiang were $-24.5 \mu g/m^3$ (in June in Suzhou city), $-26.3 \mu g/m^3$ (in August in Changzhou city), and $-18.2 \mu g/m^3$ (in July in Jinhua city) $\mu g/m^3$, respectively (see Tables S9–S11). The higher O3 concentration abatements were found under the S3_E scenario relative to the S2_E scenario as shown in Figures 4 and 5. In general, the largest drops of ozone concentrations were predicted under the S3_E scenario because of its highest control strength of precursors. The maximum average decrease values of city mean MDA8 O3 concentrations were $-69.7 \mu g/m^3$ (in August in Huainan city) in Anhui, followed by $-52 \mu g/m^3$ (in June in Suqian city) in Jiangsu, $-51.2 \mu g/m^3$ (in July in Lishui city) in Zhejiang, and $-19.6 \mu g/m^3$ (in July) in Shanghai under the S3_E scenario relative to the base case (see Tables S9–S11). It is noteworthy that the S2_E and S3_E scenarios gained more decreases in city mean MDA8 O3 concentration decreases than those for hourly O3 concentrations.

It was found that O3 concentrations in most areas of the YRD region increased under the S2_E_NT and S3_E_NT scenarios without transportation emissions (see Figures S5 and S6). The MAD8 O3 levels in most areas of the Yangtze River Delta showed an upward trend under the S2_E_NT scenario relative the base case. As shown in Figure S6, the areas with elevated MDA8 O3 concentrations were mainly located in the central parts of Northern Anhui and Zhejiang and most areas of Jiangsu and Shanghai. The maximum monthly average increases in MAD8 O3 concentrations in the 3 summer months under the S2_E_NT scenarios were $12.3 \mu g/m^3$ (in June in Shanghai), $28.8 \mu g/m^3$ (in July in Huainan city), $23.3 \mu g/m^3$ (in July in Wuxi city) and $33.5 \mu g/m^3$ (in June in Quzhou city) in Shanghai, Anhui, Jiangsu, Zhejiang, respectively (see Tables S9–S11). However, in the areas where O3 concentrations decreased under the S1 scenarios, a greater decrease in ozone under the enhanced scenarios will be expected.

4. Conclusions

This study used the WRF/CMAQ model to explore the potential impacts of emission control policies for Chinese 14th FYP on PM$_{2.5}$ and O3 in Yangtze River Delta, China, and aimed to provide a scientific basis for the controls of PM$_{2.5}$ and O3 in the future. The simulation results of the 4 emission control scenarios in the 2 winter months in 2025 indicate that under both S1 and S1_E scenarios, the average concentrations of city mean PM$_{2.5}$ in 41 cities in the YRD were predicted to decrease only by 10%, whereas the enhanced emission control scenarios (i.e., S2_E and S3_E) were predicted to reduce PM$_{2.5}$ in each city by more than 20%, thus being able to meet the targets of air quality improvements in 2025 promised by the government. For example, under the S3_E (S1_E) scenario, the monthly average concentrations of city mean PM$_{2.5}$ were predicted to decrease by $-19.0 \mu g/m^3$ in Chizhou city of Anhui province ($-7.6 \mu g/m^3$ in Anqing city of Anhui province), followed by $-16.5 \mu g/m^3$ in Hangzhou of Zhejiang province ($-5.8 \mu g/m^3$ in Ningbo city of Zhejiang province), $-15.6 \mu g/m^3$ in Suzhou city of Jiangsu province ($-5.4 \mu g/m^3$ in Zhenjiang city of Jiangsu province), and $-10.7 \mu g/m^3$ in Shanghai ($-1.4 \mu g/m^3$ in Shanghai) in December (see Table S4). The model simulation results for O3 in the 3 summer months in 2025 show
that the $O_3$ responses to the emission controls under the S1 and S1_E scenarios show different control effects on $O_3$ concentrations in the YRD with the increase and decrease effects, respectively, although both cannot achieve the control target for $O_3$. The model results also reveal that both enhanced emission control scenarios (S2_E and S3_E) were predicted to decrease $O_3$ in each city by more than 20% with more reductions in $O_3$ under the S3_E emission control scenario because of its higher control strength of both NOx and VOCs, being able to meet the targets of air quality improvements in 2025 promised by the government. This result indicates that if the 14th FYP adopted the same emission control scenarios in the 13th FYP, its effectiveness and compliance would not achieve the targets of air quality improvements in the YRD by 2025. The study found that emission reduction policies for controlling high emission sectors of NOx and VOCs such as S2_E and S3_E were more effective for decreasing both PM$_{2.5}$ and $O_3$ in the YRD. The economic development in China will put heavy demand on the consumption of energy and rapid productivity growth, which result in continuously increasing of precursor emissions. Our study found that $O_3$ controls will benefit from well-designed air pollution control strategies of reasonable control ratios of NOx and VOCs emissions. The reasonable and sustainable emission abatement will ensure the further decline of PM$_{2.5}$ and $O_3$ in the future.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/atmos13010026/s1, Figure S1: a. The model domain covering China with a horizontal resolution of 12 km $\times$ 12 km and 345 $\times$ 395 grid cells. b. The Yangtze River Delta region and districts of Shanghai, Anhui, Jiangsu, and Zhejiang. c. Map of Yangtze River Delta region with marked location of each city; Figure S2: Monthly mean concentrations of PM$_{2.5}$ in Yangtze River Delta urban agglomerations in recent 6 years; Figure S3: Monthly mean concentrations of $O_3$ in Yangtze River Delta urban agglomerations in recent 6 years; Figure S4: Spatial distributions of PM$_{2.5}$ concentration decrease percentages under the four control scenarios relative to the baseline over the Yangtze River Delta region in January and December, 2025; Figure S5: Spatial distributions of decrease values of monthly average $O_3$ concentrations under the four control scenarios relative to the baseline over the Yangtze River Delta region in July and August, 2025; Figure S6: Spatial distributions of decrease values of MDA8 $O_3$ concentrations under the four control scenarios relative to the baseline over the Yangtze River Delta region in June, July and August, 2025; Table S1: Definitions of emission sectors in the inventory; Table S2: Annual emissions for each sector species of each province in YRD (tons/year); Table S3: List of cities in YRD and the abbreviations of city name used in this study; Table S4: Predicted decrease values of PM$_{2.5}$ concentrations under the four control scenarios relative to the baseline case in 41 main cities of YRD in December, 2025. Table S5: Predicted decrease values of PM$_{2.5}$ concentrations under the four control scenarios relative to the baseline case in 41 main cities of YRD in January, 2025; Table S6: Predicted decrease values of $O_3$ concentrations under the six control scenarios relative to the baseline case in 41 main cities of YRD in June, 2025; Table S7: Predicted decrease values of $O_3$ concentrations under the six control scenarios relative to the baseline case in 41 main cities of YRD in July, 2025; Table S8: Predicted decrease values of $O_3$ concentrations under the six control scenarios relative to the baseline case in 41 main cities of YRD in August, 2025; Table S9: Predicted decrease values of MDA8 $O_3$ concentrations under the six control scenarios relative to the baseline case in 41 main cities of YRD in June, 2025; Table S10: Predicted decrease values of MDA8 $O_3$ concentrations under the six control scenarios relative to the baseline case in 41 main cities of YRD in July, 2025; Table S11: Predicted decrease values of MDA8 $O_3$ concentrations under the six control scenarios relative to the baseline case in 41 main cities of YRD in August, 2025.

**Author Contributions:** S.Y. and Z.L. designed this study and wrote the manuscript. Z.L. and S.Y. contributed to observations and data analyses, M.L., X.C., Y.Z., Z.S., J.L., Y.J., W.L., P.L. and X.Z. contributed to the discussions. S.Y. contributed to the manuscript and supervised the research. All authors have read and agreed to the published version of the manuscript.

**Funding:** This work was partially supported by the National Natural Science Foundation of China (Nos. 42175084, 21577126 and 41561144004), Department of Science and Technology of China (Nos. 2018YFC0213506, 2018YFC0213503, and 2016YFC0202702), and National Research Program for Key Issues in Air Pollution Control in China (No. DQGG0107). Part of this work was also supported by the “Zhejiang 1000 Talent Plan” and Research Center for Air Pollution and Health in Zhejiang.
University. Pengfei Li is supported by National Natural Science Foundation of China (No. 22006030), Initiation Fund for Introducing Talents of Hebei Agricultural University (412201904), and Hebei Youth Top Q15 Fund (BJ2020032).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** No new data were created or analyzed in this study. Data sharing is not applicable to this article.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**

1. Knowlton, K.; Rosenthal, J.; Hogrefe, C.; Lynn, B.; Gaffin, S.; Goldberg, R.; Rosenzweig, C.; Civerolo, K.; Ku, J.; Kinney, P. Assessing Ozone-Related Health Impacts Under A Changing Climate. *Environ. Health Perspect.* 2004, 112, 1557–1563. [CrossRef] [PubMed]
2. Ebi, K.; McGregor, G. Climate Change, Tropospheric Ozone and Particulate Matter, and Health Impacts. *Ciência Saúde Coletiva* 2009, 14, 2281–2293. [CrossRef] [PubMed]
3. Fuzzi, S.; Baltensperger, U.; Carslaw, K.; Decesari, S.; Denier van der Gon, H.; Facchini, M.; Fowler, D.; Koren, I.; Langford, B.; Lohmann, U.; et al. Particulate Matter, Air Quality And Climate: Lessons Learned And Future Needs. *Atmos. Chem. Phys.* 2015, 15, 8217–8299. [CrossRef]
4. Meng, S.; Gao, D.; Liao, F.; Zhou, F.; Wang, X. The Health Effects of Ambient PM2.5 and Potential Mechanisms. *Ecotoxicol. Environ. Saf.* 2016, 128, 67–74. [CrossRef] [PubMed]
5. Yang, J.; Zhang, B. Air Pollution and Healthcare Expenditure: Implication for the Benefit of Air Pollution Control in China. *Environ. Int.* 2018, 120, 443–455. [CrossRef]
6. Li, K.; Jacob, D.; Liao, H.; Zhu, J.; Shah, V.; Shen, L.; Bates, K.; Zhang, Q.; Zhai, S. A Two-Pollutant Strategy for Improving Ozone and Particulate Air Quality in China. *Nat. Geosci.* 2019, 12, 906–910. [CrossRef]
7. An, Z.; Huang, R.; Zhang, R.; Tie, X.; Li, G.; Cao, J.; Zhou, W.; Shi, Z.; Han, Y.; Gu, Z.; et al. Severe Haze in Northern China: A Synergy of Anthropogenic Emissions and Atmospheric Processes. *Proc. Natl. Acad. Sci. USA* 2019, 116, 8657–8666. [CrossRef]
8. Li, X.; Song, J.; Lin, T.; Dixon, J.; Zhang, G.; Ye, H. Urbanization and Health in China, Thinking at the National, Local and Individual Levels. *Environ. Health* 2016, 15, S32. [CrossRef]
9. Mou, Y.; Song, Y.; Xu, Q.; He, Q.; Hu, A. Influence of Urban-Growth Pattern on Air Quality in China: A Study Of 338 Cities. *Int. J. Environ. Res. Public Health* 2018, 15, 1805. [CrossRef]
10. Lu, X.; Zhang, S.; Xing, J.; Wang, Y.; Chen, W.; Ding, D.; Wu, Y.; Wang, S.; Duan, L.; Hao, J. Progress of Air Pollution Control in China and Its Challenges and Opportunities in The Ecological Civilization Era. *Engineering* 2020, 6, 1423–1431. [CrossRef]
11. Yi, F.; Ye, H.; Wu, Y.; Zhang, Y.; Jiang, F. Self-Aggravation Effect of Air Pollution: Evidence from Residential Electricity Consumption in China. *Energy Econ.* 2020, 86, 104684. [CrossRef]
12. Fang, D.; Chen, B.; Hubacek, K.; Ni, R.; Chen, L.; Peng, K.; Lin, J. Clean Air for Some: Unintended Spillover Effects of Regional Air Pollution Policies. *Sci. Adv.* 2019, 5, eaav4707. [CrossRef] [PubMed]
13. Liu, M.; Bi, J.; Ma, Z. Visibility-Based PM2.5 Concentrations in China: 1957–1964 And 1973–2014. *Environ. Sci. Technol.* 2017, 51, 13161–13169. [CrossRef]
14. Liang, L.; Wang, Z. Control Models and Spatiotemporal Characteristics of Air Pollution in The Rapidly Developing Urban Agglomerations. *Int. J. Environ. Res. Public Health* 2021, 18, 6177. [CrossRef] [PubMed]
15. Han, H.; Liu, J.; Shu, L.; Wang, T.; Yuan, H. Local and Synoptic Meteorological Influences on Daily Variability in Summertime Surface Ozone in Eastern China. *Atmos. Chem. Phys.* 2020, 20, 203–222. [CrossRef]
16. Xu, J.; Huang, X.; Wang, N.; Li, Y.; Ding, A. Understanding Ozone Pollution in The YRD Of Eastern China from The Perspective of Diurnal Cycles. *Sci. Total Environ.* 2021, 752, 141928. [CrossRef]
17. Sun, M.; Wang, J.; He, K. Analysis on The Urban Land Resources Carrying Capacity During Urbanization-A Case Study of Chinese YRD. *Appl. Geogr.* 2020, 116, 102170. [CrossRef]
23. Terada, H.; Ueda, H.; Wang, Z. Trend of Acid Rain and Neutralization by Yellow Sand in East Asia-A Numerical Study. *Atmos. Environ.* **2002**, *36*, 503–509. [CrossRef]

24. Bhatti, N.; Streets, D.; Foell, W. Acid Rain in Asia. *Environ. Manag.* **1992**, *16*, 541–562. [CrossRef]

25. Yan, X.; Crookes, R. Energy Demand and Emissions from Road Transportation Vehicles in China. *Prog. Energy Combust. Sci.* **2010**, *36*, 651–676. [CrossRef]

26. Xu, P.; Chen, Y.; Ye, X. Haze, Air Pollution, And Health in China. *Lancet* **2013**, *382*, 2067. [CrossRef]

27. Ou, J.; Huang, Z.; Kliment, Z.; Jia, G.; Zhang, S.; Li, C.; Meng, J.; Mi, Z.; Zheng, H.; Shan, Y.; et al. Role of Export Industries on Ozone Pollution and Its Precursors in China. *Nat. Commun.* **2020**, *11*, 5492. [CrossRef]

28. Gao, M.; Teng, W.; Du, Z.; Nie, L.; An, X.; Liu, W.; Sun, X.; Shen, Z.; Shi, A. Source Profiles and Emission Factors of VOCs From Solvent-Based Architectural Coatings and Their Contributions to Ozone and Secondary Organic Aerosol Formation in China. *Chemosphere* **2021**, *275*, 129815. [CrossRef] [PubMed]

29. Zhang, Q.; Zheng, Y.; Tong, D.; Shao, M.; Wang, S.; Zhang, Y.; Xu, X.; Wang, J.; He, H.; Liu, W.; et al. Drivers of improved PM$_{2.5}$ air quality in China from 2013 to 2017. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 24463–24469. [CrossRef]

30. Murphy, B.; Nolte, C.; Sidi, F.; Bash, J.; Appel, K.; Kang, J.; Cao, D.; Kelly, J.; Mathur, R.; Napelenok, S.; et al. The Detailed Emissions Scaling 3.2, Isolation, And Diagnostic (DESID) Module in The Community Multiscale Air Quality (CMAQ) Modeling System Version 5.3.2. *Geosci. Model Dev.* **2021**, *14*, 3407–3420. [CrossRef] [PubMed]

31. Appel, K.; Bash, J.; Fahey, K.; Foley, K.; Gilliam, R.; Hogrefe, C.; Hutzell, W.; Kang, D.; Mathur, R.; Murphy, B.; et al. The Community Multiscale Air Quality (CMAQ) Model Versions 5.3 And 5.3.1: System Updates and Evaluation. *Geosci. Model Dev.* **2021**, *14*, 2867–2897. [CrossRef] [PubMed]

32. Yarwood, G.; Jung, J.; Whitten, G.Z.; Heo, G.; Mellberg, J.; Estes, M. Updates to the Carbon Bond mechanism for version 6 (CB6). In Proceedings of the Annual CMAS Conference, Chapel Hill, NC, USA, 11–13 October 2010.

33. Whitten, G.; Heo, G.; Kimura, Y.; McDonald-Buller, E.; Allen, D.; Carter, W.; Yarwood, G. A New Condensed Toluene Mechanism for Carbon Bond: CB05-TU. *Atmos. Environ.* **2010**, *44*, 5346–5355. [CrossRef]

34. Pye, H.O.T. Overview of AERO7 and AERO7i. Available online: https://github.com/USEPA/CMAQ/blob/a04eb974895cb7b3804dc55aa37f7c12d95b6f/DOCS/Release_Notes/CMAQv5_3_aero7_overview.md (accessed on 3 October 2021).

35. Fountoukis, C.; Nenes, A. ISORROPIA II: A computationally efficient thermodynamic equilibrium model for K+–Ca${}^{2+}$–Mg${}^{2+}$–NH$_4^+$–Na$^+$–SO$_4^{2-}$–NO$_3^-$–Cl$^-$–H$_2$O aerosols. *Atmos. Chem. Phys.* **2007**, *7*, 4639–4659. [CrossRef]

36. Skamarock, W.C.; Klemp, J.B.; Dudhia, J.; Gill, D.O.; Barker, D.; Duda, M.G.; Huang, X.Y.; Wang, W.; Powers, J.G. A Description of the Advanced Research WRF Version. Available online: https://opensky.ucar.edu/islandora/object/technotes:500 (accessed on 3 October 2021).

37. Yu, S.; Mathur, R.; Pleim, J.; Wong, D.; Gilliam, R.; Alapaty, K.; Zhao, C.; Liu, X. Aerosol Indirect Effect on The Grid-Scale Clouds in The Two-Way Coupled WRF–CMAQ: Model Description, Development, Evaluation and Regional Analysis. *Atmos. Chem. Phys.* **2014**, *14*, 11247–11285. [CrossRef]

38. Zhang, Y.; Chen, X.; Yu, S.; Wang, L.; Li, Z.; Li, M.; Liu, W.; Li, P.; Rosenfeld, D.; Seinfeld, J.H. City-level air quality improvement in the Beijing-Tianjin-Hebei region from 2016/17 to 2017/18 heating seasons: Attributions and process analysis. *Environ. Pollut.* **2021**, *274*, 116523. [CrossRef]

39. Wang, L.; Yu, S.; Li, P.; Chen, X.; Li, Z.; Zhang, Y.; Li, M.; Memhoud, K.; Liu, W.; Chai, T.; et al. Significant wintertime PM$_{2.5}$ mitigation in the Yangtze River Delta, China, from 2016 to 2019: Observational constraints on anthropogenic emission controls. *Atmos. Chem. Phys.* **2020**, *20*, 14787–14800. [CrossRef]

40. Moss, R.H.; Edmonds, J.A.; Hibbard, K.A.; Manning, M.R.; Rose, S.K.; Van Vuuren, D.P.; Carter, T.R.; Emori, S.; Kainuma, M.; Kram, T. The next generation of scenarios for climate change research and assessment. *Nature* **2010**, *463*, 747–756. [CrossRef]

41. Schwalm, C.; Glendon, S.; Duffy, P. RCP8.5 Tracks Cumulative CO$_2$ emissions. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 19656–19657. [CrossRef]

42. Riahi, K.; Rao, S.; Krey, V.; Cho, C.; Chirkov, V.; Fischer, G.; Kindermann, G.; Nakicenovic, N.; Rafaj, P. RCP 8.5—A Scenario of Comparatively High Greenhouse Gas Emissions. *Clim. Change* **2011**, *109*, 33–57. [CrossRef]

43. RCP Database (version 2.0). Available online: https://tntcat.iiasa.ac.at/RcpDb/ (accessed on 3 October 2021).

44. Zhao, B.; Zheng, H.; Wang, S.; Smith, K.; Lu, X.; Aunan, K.; Gu, Y.; Wang, Y.; Ding, D.; Xing, J.; et al. Change in Household Fuels for Carbon Bond: CB05-TU. *Atmos. Environ.* **2010**, *44*, 11652–11653. [CrossRef] [PubMed]

45. Schwede, D.; Pouliot, G.; Pierce, T. Changes to the Biogenic Emission Inventory System Version 3 (BEIS3). In Proceedings of the 4th Annual CMAS Models-3 User’s Conference, Chapel Hill, NC, USA, 26–28 September 2005.

46. China National Environmental Monitoring Centre. Available online: http://www.cnemc.cn (accessed on 3 October 2021).

47. National Development and Reform Commission (NDRC) of People’s Republic of China. The 14th FYP for Economic and Social Development of The People’s Republic of China. Available online: http://www.gov.cn/xinwen/2020-03/13/content_5592681.htm (accessed on 3 October 2021).

48. National Development and Reform Commission (NDRC) of People’s Republic of China. The 14th FYP for Economic and Social Development of Shanghai. Available online: https://www.ndrc.gov.cn/fggz/fzzlgh/dffzgh/202104/t20210408_1271913_ext.htm (accessed on 3 October 2021).
49. National Development and Reform Commission (NDRC) of People’s Republic of China. The 14th FYP for Economic and Social Development of Anhui Province. Available online: https://www.ndrc.gov.cn/fggz/fzzlgh/dffzgh/202104/t20210408_1271917 (accessed on 3 October 2021).

50. National Development and Reform Commission (NDRC) of People’s Republic of China. The 14th FYP for Economic and Social Development of Jiangsu Province. Available online: http://fzggw.jiangsu.gov.cn/art/2021/3/1/art_284_9683575 (accessed on 3 October 2021).

51. National Development and Reform Commission (NDRC) of People’s Republic of China. The 14th FYP for Economic and Social Development of Zhejiang Province. Available online: https://www.ndrc.gov.cn/fggz/fzzlgh/dffzgh/202104/t20210408_1271915_ext (accessed on 3 October 2021).

52. Liu, M.; Huang, X.; Song, Y.; Tang, J.; Cao, J.; Zhang, X.; Zhang, Q.; Wang, S.; Xu, T.; Kang, L.; et al. Ammonia emission control in China would mitigate haze pollution and nitrogen deposition, but worsen acid rain. Proc. Natl. Acad. Sci. USA 2019, 16, 7760–7765. [CrossRef] [PubMed]

53. Chinese Standard. Available online: https://www.chinesestandard.net/ (accessed on 28 November 2021).

54. Simon, H.; Reff, A.; Wells, B.; Xing, J.; Frank, N. Ozone Trends Across the United States over a Period of Decreasing NOx and VOC Emissions. Environ. Sci. Technol. 2015, 49, 186–195. [CrossRef] [PubMed]