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Synergistic emission reduction benefits of coal-fired power plants in the Yangtze River Delta region

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Abstract

Coal-fired power generation is the main source of electricity in the Yangtze River Delta region, and the process of coal combustion for power generation generates a large amount of air pollutants and CO_2. To improve the environment, the government has set strict emission standards and control measures, so it is important to study the characteristics, change trends and synergistic emission reduction effects of air pollutants and CO_2 emissions from coal-fired power plants. Using 2017 as the base year, three scenarios, baseline, policy and stringent, were set based on scenario analysis to quantify the emissions in 2025 and 2030, and analyze the emission reduction and synergistic emission reduction effects of coal-fired power plants under different scenarios. The results show that the emission reduction rates of air pollutants and CO_2 under the baseline scenario are 17.2%~69.4% and 21.8%~71.2% in 2025 and 2030, respectively, compared with the baseline scenario, and the reduction rates of SO_2, NOx, PM, PM_{10} and Cl^- are higher than those of other air pollutants under the policy scenario due to the upgrading of pollutant emission control measures. and CO_2 emission reduction rates are 17.2% and 21.8%, respectively, and CO2 emission reduction is mainly due to energy structure adjustment and reduction of coal consumption; the environmental loss costs in 2025 under the baseline, policy and Stricter scenarios are 216956.5, 169611.6 and 158161.4 million USD, respectively, and in 2030, the environmental loss costs are 216746.5, 16,622.9 and 137,146.7 million USD respectively in 2030, and the damage to the environment is further reduced under the policy and stringency scenarios; the coefficient of synergistic emission reduction effect S is greater than 0 under both the policy and stringency scenarios, and the synergistic emission reduction effect of air pollutants and CO_2 is realized.

Keywords: *Yangtze River Delta Region, Coal-fired power plants, Collaborative Emission Reduction, Scenario Simulation.*

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I. INTRODUCTION

In recent years, with the rapid economic development of China, the demand for electricity has increased dramatically, and in China, coal-fired power generation is still the most dominant form of power generation with high coal consumption, and coal-fired power plants are also facing a sharp increase in air pollution and CO_2 emissions[1] [2], and in order to control air pollutants and CO_2 emissions from coal-fired power plants, achieve carbon peaking and carbon neutrality, the government has introduced a series of policies to control coal-fired power plants to control pollutant emissions, retrofit coal-fired power plants with ultra-low emissions, conduct coal reduction, and vigorously develop new energy sources, such as hydroelectric and photovoltaic power generation[3]. As one of the most economically developed regions in China, the Yangtze River Delta region has huge coal consumption and high pollutant emissions from coal-fired power plants, and air pollution and CO_2 are more serious due to emissions from coal-fired power plants, and the pollutant emissions also affect human health and the environment [4].

A Co-benefits refer to the fact that for coal combustion emissions of air pollutants and CO_2, many emission control measures for air pollutants can reduce CO_2 emissions and many emission control measures for CO_2 can reduce emissions of air pollutants[5]. At present, synergistic emission reduction regarding air pollutants and CO_2 has been proven to exist. The ADILA study analyzed the synergies and synergistic benefits of using electric private cars, cabs and buses to reduce CO_2 and air pollutant emissions in Shanghai[6]. WANG proposes a multidisciplinary approach to discuss the synergistic benefits of carbon reduction from coal-fired power plants in China[7]. SHI evaluated the impact of energy and CO_2 emissions due to clean air actions from 2013 to 2020, and the study proved that clean air measures in China generate significant CO_2 co-benefits[8]. However, most studies on co-benefits have focused on the level of pollutant emissions, and fewer studies have considered the cost of environmental losses due to emissions of air pollutants and CO_2.

In this study, the 2017 pollutant emission inventory of coal-fired power plants in the Yangtze River Delta (YRD) region was compiled, and three scenarios of baseline scenario, policy and stringency were set up to estimate the pollutant emissions under different emission scenarios and explore the synergistic emission reduction benefits in the YRD region.

II. RESULT AND DISCUSSION

2.1 Calculation of emission inventories

2.1.1 Air pollutant emissions

Emissions from coal-fired power plants are treated according to the point source, based on the emission factor method, which calculates emissions from each coal-fired power plant based on coal consumption, with the following formula Components selection[9], as shown in equation (1):

$$E = A \times EF \times (1-\eta)(1)$$

Where *A* is the coal consumption of each coal-fired power plant, *EF* is the pollutant generation factor, and η is the pollutant removal efficiency of the pollutant control measures.

2.1.2 Greenhouse gas emissions

CO_2 emission inventories were estimated using the area-based approach defined by the World Resources Institute and the World Business Council for Sustainable Development[10, 11], as shown in equation (2), The emission inventory of N_2O was calculated based on the provincial guidelines for greenhouse gas preparation[12], as shown in Equation 3.

$$E_{CO_2} = \sum_i \sum_j FC_{ij} \times NCV_i \times CC_i \times OE_{ij} \ (2)$$

where E_{CO2} is the CO_2 emissions, FC_{ij} refers to the coal consumption (tons) for fuel type *i* and zone *j*, *NCV* is the net calorific value (GJ • t^{-1} $10^6 m^{-3}$), CC_i is the emissions per unit of net calorific value produced by the fuel (tCO_2 • TJ^{-1}), and OE_{ij} is the oxidation rate (%) during fossil fuel combustion.

$$E_{N_2O} = AD \times EF(3)$$

where *AD* is the amount of fossil fuel burned (TJ) and *EF* is the emission factor of N_2O (kg N_2O/TJ).

1.2 Scenario design

Based on the collected data, 2017 was selected as the base year to predict the emissions of air pollutants and CO_2 from coal-fired power plants in 2025 and 2030 under different scenarios to study the synergistic emission reduction effects, and three scenarios, baseline, policy and stringent, were designed based on the scenario analysis method.

Table 1: Parameter Setting.

Scenario	Scenario Description	Parameter Setting
Baseline scenario	No emission reduction policy measures are adopted by 2030, setting the demand for coal-fired power generation to increase with the development of society and coal consumption to develop with the current trend.	Energy structure: energy structure remains unchanged from 2015. Pollutant emission control measures: pollutant emission control measures for coal-fired power plants remain the same as in 2017.
Policy Scenarios	Based on the requirements of the 13th Five-Year Plan, 14th Five-Year Plan and the Carbon Peak Action Plan by 2030 in the Yangtze River Delta region, optimize the energy structure, accelerate coal reduction, eliminate backward production capacity, and carry out energy-saving upgrading of units; develop new energy wind and solar power generation.	Energy structure: the average annual reduction rate of coal consumption from 2020 to 2030 is 1.02%. Pollutant emission control measures: the application rate of pollutant emission control measures is 100%.
Stricter scenarios	On the basis of the policy scenario, further optimize the energy structure, increase the proportion of new energy generation and reduce coal consumption.	Energy structure: 2.26% average annual reduction rate of coal consumption from 2020 to 2030.

1.3 Environmental damage costs of air pollutants and CO_2 emissions from coal-fired power plants

In studies on the life cycle of coal-fired power plants for coal-fired power generation, the shadow price method can be used to determine the external environmental costs resulting from the environmental impacts of air pollution. The shadow price method refers to the redesign of an alternative to the original environmental state after the original environmental state has been destroyed, and the economy and society develop in the alternative state, consistent with the original state, and the design cost of the alternative is the environmental cost. The unit emission prices of external environmental costs of air pollutants and CO_2 emitted from coal-fired power plants were obtained by reviewing relevant literature to quantify the cost of environmental losses due to pollutant emissions[13, 14], and the unit costs of environmental losses are shown in Table 2**.**

Table 2: WTP values of atmospheric pollutants and CO_2 and environmental loss costs.

Contaminants	Environmental damage cost/($/kg)
CO_2	0.19×10^{-2}
CO	0.018
CH_4	0.049
N_2O	0.91
SO_2	0.44
PM	0.18
NOx	0.033

1.4 Assessment method and parameter selection for the control effect of collaborative emission reduction

The synergistic control cross-elasticity analysis was used to assess the synergistic emission reduction effect based on the ratio of the rate of change of CO_2 emissions to the rate of change of air pollutant emissions, S, using Equation (4)[15, 16].

$$S = \frac{\Delta E_{co_2}/E_{co_2}}{\Delta Ep/Ep} \quad (4)$$

where S is the coefficient of synergistic emission reduction effect; ΔE_{CO2} is the emission reduction of CO_2, E_{CO2} is the emission of CO_2, ΔE_P is the emission reduction of CO_2, and E_P is the emission of air pollutants. When S is greater than zero, there is a synergistic emission reduction effect.

III. RESULT AND DISCUSSION

3.1 Pollutant emission analysis.

In 2017, the emissions of CO_2 from coal-fired power plants in the Yangtze River Delta region were 845,727,700 t, SO_2, NOx, CO, PM, and PM_{10} were 247.01, 391.51, 1423.90, 434.52, and 155.61 kt, respectively, and CH_4, N2O, HCl, and Cl^- were 12890.09, 12,576.95, 5223.86, and 2893.63 t, respectively. 12576.95, 5223.86 and 2893.63 t. Under the baseline scenario, the emission control devices of pollutants do not change compared with 2017. in 2025, the emissions of CO_2 from coal-fired power plants in the Yangtze River Delta region are 93856.92 million tons, and the emissions of SO_2, NOx, CO, PM, and PM_{10} are 261.61, 431.28, 1588.36, 482.56, 171.43kt, and 14305.13, 13951.27, 5665.72 and 3177.61t for CH4, N2O, HCl and Cl^- respectively. 2030 CO_2 emissions from coal-fired power plants in the Yangtze River Delta region will be 937.688 million tons, SO_2, NOx, CO, PM PM_{10} emissions are 261.42, 430.75, 1586.58, 482.73, 171.50kt, and CH_4, N_2O, HCl and Cl^- emissions are 14290.49, 13943.33, 5662.32 and 3178.86t, respectively. compared with 2017, the emissions of CO_2 in 2025 are higher by 11% and shows a decreasing trend from 2025 to 2030, with a decrease of 10.9% in 2030 compared to 2017 and a decrease of 0.1% compared to 2025. The trend for other pollutants is roughly the same as that for CO_2, which is the same as the change in coal consumption in the YRD, peaking in 2025 and then beginning to decline.

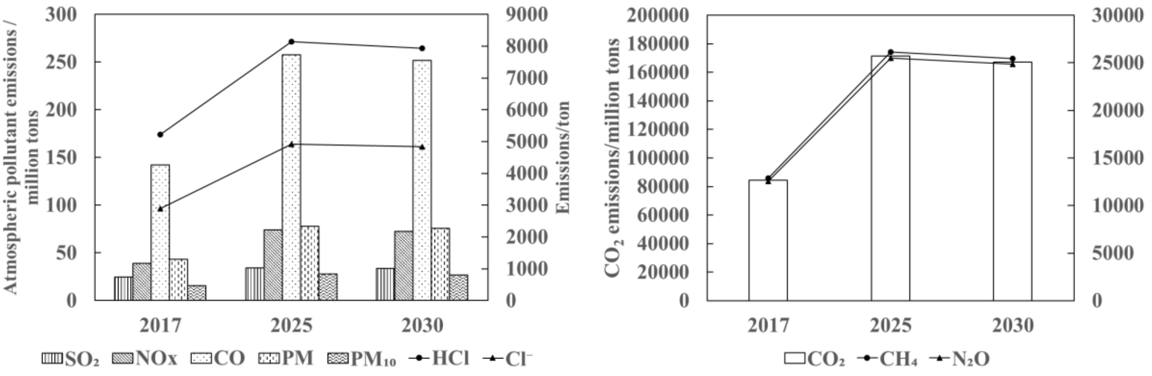

Figure 1: Air pollutants and CO_2 emissions from coal-fired power plants in 2017

3.2 Analysis of Emission Reductions under Policy and Stricter Scenarios.

The emissions of pollutants are significantly reduced under the policy and stringency scenarios due to the reduction of coal consumption in coal-fired power plants and the retrofitting of pollutant emission control devices with ultra-low emissions, and the emissions of air pollutants and CO_2 under different scenarios are collated in Table 3. Compared with the baseline scenario, the emissions of CO_2, SO_2, NOx, CO, PM, PM_{10}, CH_4, N_2O, HCl, and Cl^- are reduced by 17.2%, 69.4%, 27.6%, 37.9%, 13.8%, 17.2%, 17.2%, 56.1%, and 45.1%, respectively, in 2025 under the policy scenario, and in 2030, CO_2, SO_2, NOx, CO, PM, PM_{10}, CH_4, N_2O, HCl and Cl^- emissions in 2030 by 21.8%, 71.2%, 31.9%, 41.3%, 23.3%, 43.5%, 21.8%, 21.8%, 59.8% and 47.7% respectively; compared to the policy scenario, the Stricter scenario in 2025 for CO_2, SO_2, NOx, CO, PM, PM_{10}, CH_4, N_2O, HCl, and Cl^- emissions are further reduced by 6.8% in 2025 and by 14.3% in 2030 for CO_2, SO_2, NOx, CO, PM, PM_{10}, CH_4, N_2O, HCl, and Cl^- emissions compared to the policy scenario.

Table 3: Emissions in different scenarios(t).

Pollutants	**Baseline2025**	**Baseline2030**	**Policy2025**	**Policy2030**	**Stricter2025**	**Stricter2030**
SO_2	261608	261415	79994	75225	74593	64471
NOx	431278	430748	312234	293491	291155	251534
CO	1588360	1586579	986522	931739	919923	798541
PM	482563	482734	295957	273453	275977	234361
PM_{10}	171429	171496	105094	96813	97999	82973
CH_4	14305	14290	11838	11181	11039	9582
CO_2	938569218	937608781	776716365	733584250	724281244	628714009
N_2O	13958	13943	11551	10909	10771	9350
HCl	5666	5662	2485	2277	2317	1951
Cl^-	3178	3179	1743	1662	1625	1424

3.3 Cost of environmental damage from coal-fired power plant emissions.

In 2017, the total cost of environmental losses due to emissions of pollutants from coal-fired power plants in the Yangtze River Delta region was $196,068.67 million.$CO_2$, SO_2, CH_4, NOx, PM, and N_2O contributed 82%, 5%, 0.03%, 7%, 4%, and 1%, respectively, with CO_2 emissions causing the highest cost of environmental losses and the greatest environmental impact. With the implementation of the policy for coal-fired power plants, CO_2 and other pollutants are reduced synergistically, and the composition of the environmental loss costs under different scenarios is shown in Figure 2. Under the policy scenario, the total cost of environmental losses from coal-fired power plant emissions in 2025 is reduced by $473,449,000 compared to the baseline scenario, with CO_2 and other pollutants accounting for 68.3% and 31.7% of the reduction in environmental losses, respectively. The reduction in environmental loss costs for pollutants emitted from coal-fired power plants in 2030 is reduced by 19.8%, CO_2 emissions by 26.1%, and other pollutants by 8.2% in the policy scenario compared to 2025. The total environmental loss costs of pollutant emissions from coal-fired power plants in 2025 and 2030 for the Severe scenario are reduced by 6.8% and 16.3%, respectively, compared to the Policy scenario, with the same changes in emissions of CO_2 and other pollutants.

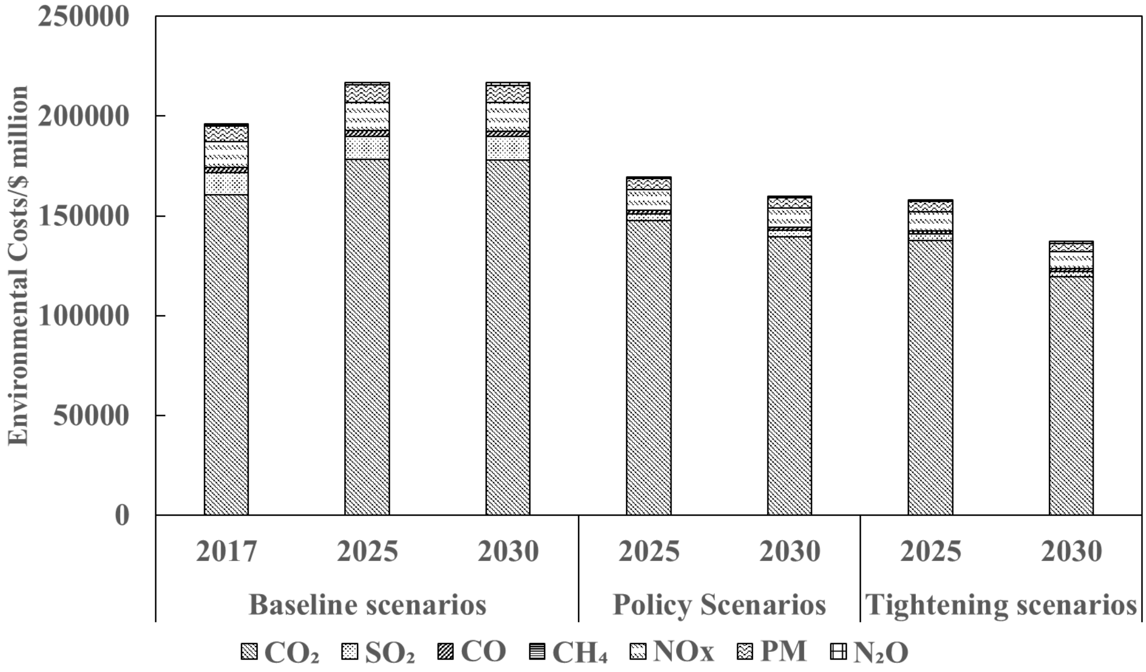

Fig.2: Cost of environmental loss under different scenarios.

3.4 Cost of environmental damage from coal-fired power plant emissions.

With the designation of the 14th Five-Year Plan and the Carbon Neutral Plan for Carbon Dumping related to coal-fired power plants in the Yangtze River Delta region, the energy mix is adjusted to assess the synergistic emission reduction effects of CO_2 and other pollutants under the policy and stringency scenarios.

The synergistic emission reduction factors for different scenarios are shown in Table 4. In the Yangtze River Delta region, the synergistic emission reduction effect coefficients S for SO_2, NOx, CO, PM_{10}, CH_4, N_2O, HCl and Cl^- under the policy scenarios in 2025 and 2030 are all greater than zero, indicating that coal-fired power plants in the Yangtze River Delta region achieve synergistic emission reductions of CO_2 and other pollutants with synergistic emission reduction effects under the relevant policy interventions. For CH4 and N_2O, the S value is equal to 1. For the same emission reduction effect that CO_2 and CH_4 and N_2O have, the S values of other pollutants are greater than 0 and less than 1, indicating that the emission reduction effect on pollutants is higher than that of CO_2 under the policy scenario. For the Stricter scenario, the coefficient of synergistic emission reduction effect is lower than 0 for both air pollutant and CO_2 emissions from coal-fired power plants due to further reduction of coal consumption and further upgrading of pollutant emission control devices.

Table 4: The synergistic emission reduction factors for different scenarios.

	Policy Scenarios	**Policy Scenarios**	**Stricter scenarios**	**Stricter scenarios**
	2025	2030	2025	2030
S_{SO_2}	0.25	0.31	0.32	0.44
S_{NOx}	0.62	0.68	0.70	0.79
S_{CO}	0.46	0.53	0.54	0.66
S_{PM}	0.45	0.50	0.53	0.64
$S_{PM_{10}}$	0.45	0.50	0.53	0.64
S_{CH_4}	1	1	1	1
S_{N_2O}	1	1	1	1
S_{HCl}	0.31	0.36	0.39	0.47
S_{Cl^-}	0.38	0.46	0.50	0.60

IV. CONCLUSION

(1) From the baseline scenario, CO_2 emissions in the Yangtze River Delta region were 845,727,700 tons in 2017, rising by 10.9% and 10.8% in 2025 and 2030, respectively, compared to 2017, and overall, other pollutants also follow the change in coal consumption, peaking in 2025 and then declining thereafter.

(2) From the changes of different scenarios, under the policy scenario, the emission of both air pollutants and CO_2 decreases compared with the baseline scenario, and the emission reduction of CO_2 in 2025 and 2030 is 161.85 million tons and 204.02 million tons, respectively. Under the Stricter scenario, the emission of air pollutants and CO_2 further decreases, and the emission reduction of CO_2 in 2025 and 2030 is 214.29 million tons and 308.89 million tons, respectively, compared with the baseline scenario, and coal-fired power plants in the Yangtze River Delta achieve significant emission reduction.

(3) In terms of environmental loss costs, the total environmental loss costs of coal-fired power plants due to pollutant emissions are reduced by 21.8% and 26.2% in 2025 and 2030, respectively, under the policy scenario compared with the baseline scenario, and further reduced under the Stricter scenario; therefore, in order to control environmental loss costs, coal consumption should be further controlled after 2025 to reduce coal-fired CO_2 and other pollutants and emissions from power plants.

(4) In terms of the synergistic emission reduction effect, the coefficients of the synergistic emission reduction effect under both the policy scenario and the stricter scenario are greater than 0. With the implementation of the policy, the air pollutants and CO_2 generated by the pollutants emitted from coal-fired power plants are further reduced, and the synergistic emission reduction of air pollutants and CO_2 is achieved.

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