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SO_2 emission cap planning for Chengdu-Chongqing economic zone

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Abstract

The SO_2 emission sources of the Chengdu-Chongqing economic zone were divided into 556 emissions units according to four different categories, which are city, industry, point sources, and area sources. The CALPUFF model was used to calculate the contribution of each unit, and consequently obtain an influence-transferring matrix. To ensure that the SO_2 concentrations of 46 cities and counties in the Chengdu-Chongqing economic zone meet air quality standards, an emission optimization model was developed to calculate optimal emissions of each emission unit under different development scenarios. The result showed the optimal emissions of SO_2 by different provinces and industries. To achieve the target of restricting and optimizing development, corresponding planning programs were developed for every district.

Key words: Chengdu-Chongqing economic zone; SO_2; emission cap planning; optimal distribution.

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Introduction

The Chengdu-Chongqing economic zone is a strategic region of economic development in China, and has been considered to be one of the key development zones at the national level in the "Planning of the National Primary Functional Area (Draft)". This area is also one of the regions with heavy air and acid rain pollution. According to environmental monitoring data from 2008, the annual average SO_2 concentrations of nearly 25% of the cities and counties in this area exceed Grade II of the Air Quality Standards; this shows that the acid rain pollution of the Chengdu-Chongqing economic zone is very serious. For all the 46 cities and counties of this area, nearly 78% have an annual average precipitation pH lower than 5.6; and the frequency of acid rain in nearly 25% of the cities and counties is more than 80%, and exhibits an obvious sulfuric nature (OTPC, 2008).

In this study, to determine the SO_2 emission cap of the Chengdu-Chongqing economic zone, we divided the emission control unit into sub-categories by city, industry, point sources and area sources to calculate the emission cap control optimal allocation. Based on the results, we specify a development plan for different districts, which can provide a scientific basis for the designation and adjustment of a future sustainable development strategy for this area (Li et al., 2005; Chai et al., 2006).

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1 Data sources and methods

1.1 Study area

The Chengdu-Chongqing economic zone is a comprehensive economic area in the southwest of China, with Chengdu and Chongqing in the center. It covers 15 cities of Sichuan Province and 31 counties of Chongqing, and the total area is about 206×10^3 km^2, with a population of approximately 98.4×10^6 inhabitants.

1.2 Data sources

In this study, the base year is 2007. To meet the needs of the model simulation, NCEP re-analysis data, meteorological elements data, daily data (8:00 and 20:00), and data from point sources and area sources based on environmental statistics and annual SO_2 concentration of every county were collected and summarized.

1.3 Methods

1.3.1 Technical process

The technical process of this study is shown in Fig. 1. The regional SO_2 emission optimization model adopted in this study consists of three sections: planning variables, planning objectives, and constraints. The planning variable can be defined as the emissions of air pollutants of each emission unit; the planning objective is to make the total emissions of air pollutants of region-wide units stay within a maximum value; the constraints include the standard limits under the Air Quality Standard, as well as the constraints of regional development and control.

To obtain the mutual influence among cities and coun-

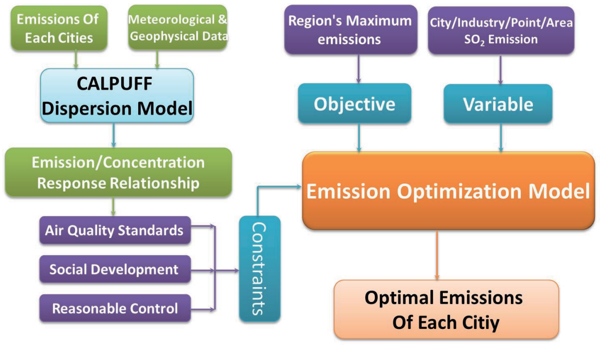

Fig. 1 Technical process.

ties, an appropriate atmospheric dispersion model is needed to build a response relationship between SO_2 emissions of different sources and the concentrations of air quality atmosphere control units. The CALPUFF regional atmospheric dispersion model was used in this study (Scire et al., 2000). The air quality constraint for each unit is set so that the air quality concentration meets the air quality standard.

Through solving the emission optimization model, it is possible to achieve optimal allocation of allowed emissions of SO_2 for every emission source in the different cities and counties. Further, the solution can obtain the maximum SO_2 emissions on the basis of the current emission space structure, and derive the minimum regional reductions indirectly. Therefore, this effort can provide references to set the regional SO_2 emission target.

1.3.2 Emission optimization model

The basic structure of the emission optimization model can be shown as follows (CTTM, 1990; Zhang and Niu, 2005; Yuan et al., 2007):

$$\text{Objective function: } \max F(Q) = \sum_{i=1}^{N} Q_i \tag{1}$$

$$\text{Constraints I: } \sum_{i=1}^{N} a_{ij} Q_i \leq D_j \qquad j = 1, 2, ..., L \tag{2}$$

$$\text{Constraints II: } Q_i \geq (1 - k_i) Q_{0i} \qquad i = 1, 2, ..., N \tag{3}$$

$$\text{Constraints III: } Q_i \leq m_i Q_{0i} \qquad i = 1, 2, ..., N \tag{4}$$

where, Q_i is the SO_2 emissions of unit i; N is number of emission sources of SO_2; $\max F(Q)$ is the objective function of SO_2 emission control; a_{ij} is the influence-transferring function, which is the contribution of SO_2 emissions of emission control unit i to the SO_2 concentration of unit j; D_j is the control target of SO_2 concentration of unit j, $j = 1, 2, \ldots, L$; Q_{0i} is the SO_2 emissions of the base year; k_i is the maximum reduction rate of unit i relative to the SO_2 emissions of the base year; m_i is the maximum emission rate relative to the SO_2 emissions of the base year.

In this study, the objective target of the model was to obtain the maximum SO_2 emissions of the cities and counties of the Chengdu-Chongqing economic zone, to guarantee the needs of social and economic development.

The key step of building the emission optimization model was calculating the influence transferring-function a_{ij}, which was then used in constraint I. It can be defined as the contribution of the SO_2 emissions of unit i to the SO_2 concentration of unit j. The calculation process can be described in the following way: using the CALPUFF model to calculate the concentration contribution of the SO_2 emissions of each source to the control unit, a transportation/receiving matrix $\{a_{ij}\}$ can be obtained. The ratio between the contribution a_{ij} to emissions Q_{ij} is defined as the influence coefficient of the SO_2 emissions of unit i to unit j.

Constraint I is the constraint of the air quality target for every control unit; Constraint II is the constraint of the minimum reduction, whose purpose is to avoid reductions that are too large for certain emission sources, to ensure the needs of regional development; Constraint III is the constraint of maximum emissions, which serves to avoid emissions becoming too large, and for emission units with smaller influence coefficients, the emission constraint can be enlarged to achieve economic optimization.

1.3.3 Division of emission units

Table 1 shows the statistics of emission units from different sources and cities. The emission sources are divided into point and area sources. Point sources include five industries, which are coal-fired power plants, chemical industry, metallurgy industry, building materials industry, and other industries; and area sources contains five categories, which are chemical industry, metallurgy industry, building materials industry, residential and other area sources. Because the SO_2 emissions of separate coal-fired power plant sources and area sources are relatively large, each coal-fired power plant and area source of every city is treated as a separate emission unit. However, the industries other than coal-fired power plants are treated as a separate unit belonging to the city, because of the relatively small emissions. In this study, we divide the study area into 556 emission units.

1.3.4 Setting of constraints

For SO_2 emission control, the objective function is to solve the maximum SO_2 emissions for the whole region, by treating the objective emissions of the 556 sources as variables.

Constraint I can be built under the condition that the product of the relative influence coefficient and objective

Table 1 Statistics of the number of emission units by different sources and cities

	Category	Number of control units	SO_2 emissions in 2007 (ton)
Point sources	Coal-fired power plants	104	746223
	Chemical industry	24	84635
	Metallurgy industry	19	92175
	Building materials Industry	26	79603
	Other industry	23	101446
Area sources	Chemical industry	72	22683
	Metallurgy industry	72	8541
	Building materials Industry	72	132994
	Residential sources	72	123032
	Other sources	72	244202
Total		556	1635533

emissions of each unit is lower than their air quality target (D_j). By comparing the monitoring values of every unit, the background concentration is obtained. The control target can be obtained by using Grade II of the air quality standard and subtracting the background concentration. Accordingly, Constraint I can be calculated.

Constraint II is built from the maximum reduction k_i. To avoid an outcome where all the emission sources of some cities would be eliminated, reserved parameters need to be set for different sources. The assumptions are: the maintenance of coal-fired power plants refers to the regional reduction plan of 2015; the residential area source should maintain 50%, and the emissions of planned coal-fired power plants, chemical, metallurgy, building materials, and other industries should maintain at least 10%.

Constraint III sets the upper limits for each unit. In general, this can set an overall upper limit, and there also can be different limits for different units. The assumptions of Constraint III are: according to the planning vision that the annual growth rate of GDP (Gross Domestic Product) is 10%, besides the residential area sources and current coal-fired power plants, the emissions of other units are permitted to exceed their 2007 level by 10%. In addition, according to the planning of industrial parks, the emission sources included in the planning are allowed to appropriately increase.

2 Results and discussion

2.1 Emission optimization allocation

By using the emission optimization model under the above constraints, SO_2 emissions after optimization, reductions and reduction rate of emissions relative to 2007 are shown in Table 2, in which a negative value represents reduction, and a positive value represents an increase.

The total SO_2 emissions in 2007 was 1.64×10^6 tons. To ensure that all the units reach the air quality standard, the SO_2 emissions after optimization is about 1.30×10^6 tons, and the reduction is 0.34×10^6 tons, with a reduction rate of 20.80%; reduction from coal-fired power plants is about 0.26×10^6 tons, with a reduction rate of 34.20%; emissions for chemical and metallurgy industry after optimization have a slight increase compared to that of 2007, with a separate growth rate of nearly 8.00%. From the geographical point of view, the optimized SO_2 emissions for Chongqing is about 0.52×10^6 tons, which is 0.21×10^6 tons less than the emissions of 2007, and the reduction rate is 28.40%; the optimized emissions of Sichuan is about 0.77×10^6 tons, which is 13.30×10^6 tons less than the emissions of 2007, and the reduction rate is 14.70%.

Because the distribution of emission sources in Chongqing is irregular, more than half of the current SO_2 emission sources are centralized in the downtown and surrounding areas, which causes the concentration in these areas to be much higher than that of other areas. Therefore, to make the SO_2 concentrations reach the standards, the emissions of these areas should be reduced greatly.

Comparison of the emission proportions of different SO_2 emission sources before and after the optimization is shown in Fig. 2. After optimization, the proportion of coal-fired power plants decreases from 46% to 38%, the proportion of the residential area source remains unchanged, and those of building materials, chemical, metallurgy, and other industries increase separately.

2.2 Environmental effect of optimization allocation

A comparison of the annual average SO_2 concentration of each area in the Chengdu-Chongqing economic zone before/after the optimization is shown in Fig. 3. Reductions in SO_2 concentration of the downtown and surrounding areas are relatively high. The annual average SO_2 concentrations of cities in Sichuan decline. However, because the emissions of some areas are allowed to increase, the annual average concentrations of the Dazu District of Chongqing and Luzhou City of Sichuan increase. From the view of reduction, the unit with maximum reduction is the Dadukou District, with a reduction of 36.46 μg/m^3; the next is the Jiulongpo District, with a reduction of 35.13 μg/m^3. The average SO_2 concentration of 46 units after optimization is about 26.00 μg/m^3, compared to the average value of 34.83 μg/m^3 before optimization, and the average reduction rate is about 22.57%.

3 Discussion and conclusions

During the optimization, because industries of some areas have a relatively large influence on other areas, it

Table 2 SO_2 emissions and reduction of different sources after optimization (unit: ton)

		PP	CI	MI	BMI	OI	RA	Total
Chongqing section	Optimized	181947	59368	29786	90760	74222	86685	522767
	Original	312216	55844	27765	113848	107299	112975	729946
	Reduction	–130269	3524	2021	–23088	–33077	–26290	–207179
	Reduction rate	–41.70%	6.30%	7.30%	–20.30%	–30.80%	–23.30%	–28.40%
Sichuan section	Optimized	309290	57411	79124	108455	113409	104538	772227
	Original	434007	51474	75814	98748	114317	131227	905587
	Reduction	–124717	5937	3310	9707	–907	–26689	–133360
	Reduction rate	–28.70%	11.50%	4.40%	9.80%	–0.80%	–20.30%	–14.70%
Total area	Optimized	491237	116779	108910	199215	187631	191223	1294994
	Original	746223	107318	103579	212596	221616	244202	1635533
	Reduction	–254986	9461	5331	–13381	–33985	–52979	–340539
	Reduction rate	–34.20%	8.80%	5.10%	–6.30%	–15.30%	–21.70%	–20.80%

PP: coal-fired power plants; CI: chemical industry; MI: metallurgy industry; BMI: building materials industry; OI: other industry; RA: residential area source.

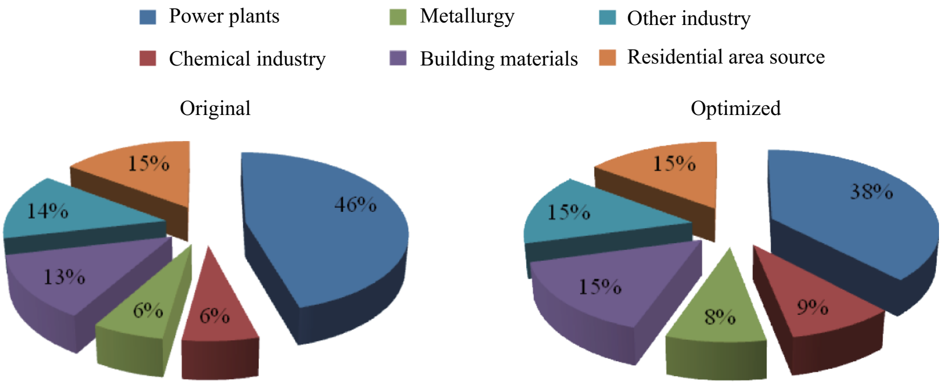

Fig. 2 Comparison of emission proportions of different SO_2 emission sources before and after optimization.

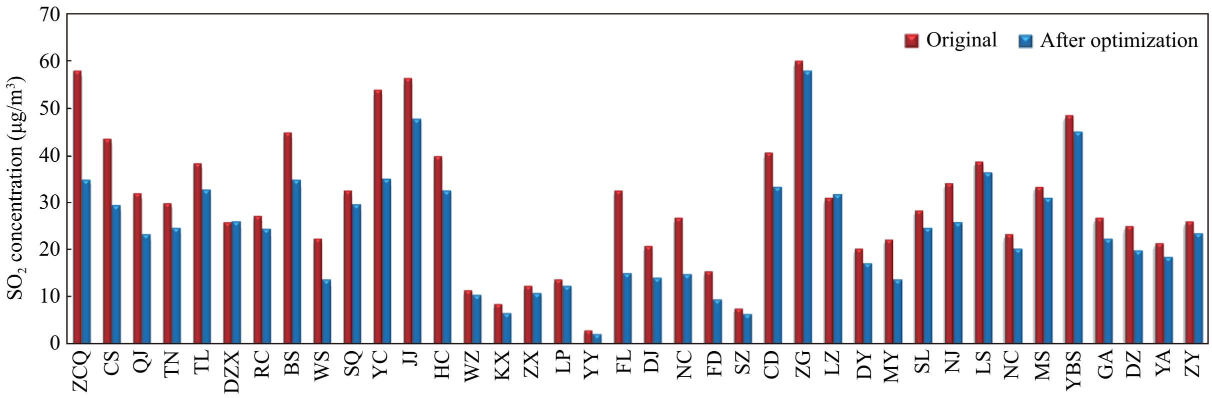

Fig. 3 Comparison of annual average SO_2 concentration of each area in the Chengdu-Chongqing economic zone before/after the optimization.

is necessary to undertake emission reduction projects, technology updating, structure optimization, promotion of large-scale and restriction of small-scale facilities, and so on to achieve emission control. Otherwise, the future development of these areas will be constrained. The industries and areas with constraint factors are shown as follows.

Coal-fired power plants: the downtown, Jiangjin, Qijiang, Nanchuan, and Wansheng District of Chongqing; Yibin, and Luzhou City of Sichuan.

Chemical industry: Yubei, Shapingba, Dadukou, Nanan, Banan, Wansheng, Fuling, and Nanchuan District of Chongqing; Deyang City of Sichuan.

Metallurgy industry: Dadukou, Jiulongpo, Banan, Nanan, Qijiang, Nanchuan, and Wansheng District of Chongqing; Deyang, and Mianyang City of Sichuan.

Building materials industry: the downtown, Banan, Fuling, Nanan, Wansheng, Changshou, Nanchuan, Dianjiang, and Fengdu District of Chongqing; Deyang City of Sichuan.

According to the results of allocation optimization, the geographic areas which should focus on SO_2 emission reduction on the basis of 2007 levels and plan to optimize development are: the downtown, Qijiang, Wansheng, Jiangjin, Fuling, and Nanchuan District of Chongqing, and Chengdu, Neijiang, Yibin, Guangan, and Dazhou City of Sichuan. In these areas, because of limited environmental capacity, efforts should persist toward environmental priority strategies, developing high-tech enterprises, optimizing industry structure, and promoting the upgrading of industries and products. At the same time, accomplishing the air pollutants emission reduction target, achieving increased production and pollution reduction should be the urgent objectives of these areas. Especially for areas planning the construction of coal-fired power plants, it will be necessary to reduce the current emissions effectively, and free the environmental capacity by adjusting the industry structure.

In addition, for some areas, the planning result shows that appropriate increased emissions are permitted, such as Changshou, Liangping, and Shizhu District of Chongqing, and Luzhou, Nanchong, and Meishan City of Sichuan. The result needs to be implemented to guide the development in these areas, accelerate the infrastructure construction, and make use of the environmental capacity scientifically and rationally. Although there is some remaining environmental capacity, it is still necessary to control the emission of air pollutants strictly to maintain the good air quality in these areas.

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