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An Enhanced Environmental Air Pollutant Capacity Calculation Method Considering Air Fluidity

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***Abstract*—The environmental capacity of air pollutants in the region is an important basis for the Government to scientifically formulate the environmental protection policy of the atmosphere. The known SO2, NOx, and primary PM2.5 environmental capacity of the regions has obvious bias compared to real air quality, because the evaluation method used only considered the local air purification capability and neglected the air fluidity. Thus, this paper proposes a method to improve the environmental capacity by using the air cross-border conveying matrix. As influence of the transboundary transmission of atmospheric pollutants is fully taken into account, the obtained environmental capacity is closer to practical situations.**

Keywords—environmental capacity; air fluidity; air pollution; optimization issues

I. Introduction

In the 2017, 338 cities and above in the country, 239 urban environmental air quality exceeded the standard, accounting for 70.7% [1]. The quality of atmospheric environment has become the focus of public attention, and improving air quality has been proposed as China's national policy on environmental protection.

World Health Organization Air quality Standards and transition targets (annual average concentration, ug/m^3) are as follows [1].

- Air quality Guide: PM2.5<10, PM10<20, below this standard, there is no evidence that an increase in cardiopulmonary and lung cancer mortality is associated with prolonged exposure to PM2.5.
- The transition target-1:PM2.5<35, PM10<70 that this standard increases the risk of long-term mortality by 15% compared to the final guide.
- The transition target-2:PM2.5<25, PM10<50 that this standard reduces the risk of premature death by an average of about 6% compared to the transition target-1.
- The transition target-3:PM2.5<15, PM10<30 that this standard reduces the risk of premature death by an average of about 6% compared to the transition target-2.

The Chinese government is committed to making sure that urban air quality should be up to standard in 2030 (PM2.5 control within 35 micrograms per cubic meters) [2], that is, the World Health Organization transition target-1 level. The ministry of environmental protection calculates the SO2, NOx, and primary PM2.5 environmental capacity of the regions under the PM2.5 of the World Health Organization transition Target-1, as shown in Table I [3]. The capacity of atmospheric environment emphasizes that under the premise of normal structure and function of atmospheric environment system, human social and economic activities that atmospheric environmental systems can withstand. The capacity of atmospheric environment is an important means to analyze and evaluate the quality of atmospheric environment, and it is an important foundation for effectively controlling atmospheric environmental pollution and improving environmental quality. It can provide an important basis for coordinating and planning the layout of regional socio-economic development.

Because of air fluidity, cross-border air pollution in an area has a great impact on local air quality, so this paper studies the regional environmental capacity considering the influence of the transboundary transmission of atmospheric pollutants [4-5]. Considering that the regional environmental capacity of atmospheric pollutants cross-border transmission is closer to the actual situation, it can better guide the actual emission reduction work to carry out.

TABLE I. ENVIRONMENTAL CAPACITY (MILLION TONS) OF THE REGIONS UNDER THE PM2.5 OF THE WORLD HEALTH ORGANIZATION TRANSITION TARGET-1

Region	SO_2	NOx	primary PM2.5
Beijing	4.11	6.79	2.79
Tianjin	8.68	10.7	3.57
Hebei	48.58	51.19	23.19
Shanxi	85.37	66.08	34.78
Inner mongolia	130.96	118.77	42.67
Liaoning	72.81	59.05	29.12
Jilin	32.53	42.98	21.81
Heilongjiang	39.19	55.01	24.34
Shanghai	14.4	22.78	5.4
Jiangsu	52.38	63.37	24.57
Zhejiang	39.74	45.36	14.15
Anhui	20.78	30.71	16.8
Fujian	39.05	43.71	18.73
Jiangxi	41.86	39	16.1
Shandong	70.92	57.17	33.85

Henan	47.39	44.27	21.92
Hubei	31.37	24.21	21.67
Hunan	34.09	25.59	18.03
Guangdong	68.95	105.72	37.21
Guangxi	50.5	38.4	41.15
Hainan	3.11	8.03	3.18
Chongqing	35.07	20.78	14.32
Sichuan	37.9	23.88	27.72
Guizhou	63.81	23.2	19.04
Yunnan	65.47	46.52	31.76
Tibet	0.42	3.83	0.57
Shaanxi	60.43	47.06	21.5
Gansu	52.06	35.24	18.51
Qinghai	14.37	9.89	5.98
Ningxia	34.61	35.85	6.85
Xinjiang	62.33	53.33	17.75
Total	1363.26	1258.48	619.04

II. Related Work

A. Environmental Capacity

According to the definition, environmental capacity refers to the maximum load value of pollutants that can be accommodated in an environment under the premise of ensuring the survival and development of human beings from harm and the destruction of natural ecological balance [6]. The natural ability to eliminate contaminants in specific environments, such as natural areas and cities, is limited. The size of its capacity is related to the characteristics of each environmental element, the size of the ambient space, and the chemical and physical properties of the pollutant itself. Generally speaking, the greater the ambient space, the greater the environmental purification capacity of pollutants, the greater the environmental capacity. For a pollutant, the more unstable their physical and chemical properties are, the greater the capacity of the environment for it.

B. Air Cross-Boundary Transport Characteristics

Air pollutant emissions affect not only air quality in the local area, but also some emissions through long-distance atmospheric transport to downstream areas. Air pollution is transmitted between different cities, regions and even beyond, due to the action of gas masses, airflow and wind. July 8, 2016, Environmental Planning Institute of the Ministry of Environmental Protection released the 2015 National PM2.5 Transport matrix, in addition to Xinjiang does not exist PM2.5 cross-provincial transport, other provinces have a certain proportion of transmission. Cross-provincial transmission matrix shows that PM2.5 pollution presents typical regional characteristics. There are significant cross-regional transport laws, as shown in the table II.

III. Environmental Capacity Correction Considering the Flow of Air Pollutants in the Region

According to Tables I and II, the revised environmental capacity to consider the flow of air pollutants in the area is calculated as follow. The $x_{i,j}$ is the revised area i emissions of type j air pollutants, $y_{i,j}$ is the original area i emissions of type j air pollutants, $xlb_{i,j}$ is the lower limit of area i emissions of type j air pollutants, $xub_{i,j}$ is the upper limit of area i emissions of type j air pollutants. i represents 31 regions of the country ($1 \leqslant i \leqslant 31$), and j represents SO_2, NOx and primary PM2.5 of three air pollutants ($1 \leqslant j \leqslant 3$). The environmental capacity variables are shown in the Table III.

TABLE II. AIR CROSS-BORDER CONVEYING MATRIX (%)

Region	BJ	TJ	HB	SX	NM	LN	JL	HLJ	SH	JS	ZJ	AH	FJ	JX	SD	HN	HB	HN	GD	GX	HN	CQ	SC	GZ	YN	XZ	SX	GS	QH	NX	XJ
Beijing	**66**	4	18	2	2	0	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tianjin	5	**56**	20	1	1	0	0	0	0	1	0	1	0	0	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hebei	5	6	**62**	5	3	1	0	0	0	1	0	1	0	0	11	6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Shanxi	0	0	4	**69**	5	0	0	0	0	0	0	0	0	0	1	13	1	0	0	0	0	0	0	0	0	0	5	1	0	1	0
Inner mo -ngolia	0	0	3	4	**79**	3	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	1	0	3	0
Liaoning	1	1	5	1	7	**68**	3	2	0	2	0	1	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jilin	0	0	3	1	8	21	**52**	8	0	1	0	1	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heilongj iang	0	0	1	0	5	5	8	**80**	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shanghai	0	0	2	1	1	1	0	0	**47**	27	11	4	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jiangsu	0	1	3	2	1	1	0	0	2	**50**	5	19	0	0	11	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zhejiang	0	0	3	2	1	1	0	0	4	17	**52**	8	1	1	6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anhui	0	0	4	2	1	1	0	0	1	9	2	**59**	0	2	8	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fujian	0	0	2	1	1	1	0	0	1	6	10	5	**60**	3	4	2	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Jiangxi	0	0	2	2	1	0	0	0	0	4	3	10	1	**55**	4	4	7	5	1	0	0	0	0	0	0	0	1	0	0	0	0
Shandon g	1	2	12	2	1	1	0	0	0	6	1	5	0	0	**60**	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Henan	0	0	9	8	1	0	0	0	0	1	0	3	0	0	5	**65**	5	1	0	0	0	0	0	0	0	0	2	0	0	0	0
Hubei	0	0	3	3	1	0	0	0	0	2	1	6	0	4	3	10	**60**	5	0	0	0	1	0	0	0	0	1	0	0	0	0
Hunan	0	0	2	2	1	0	0	0	0	1	0	3	0	5	2	6	11	**63**	1	1	0	0	0	1	0	0	1	0	0	0	0
Guangdo ng	0	0	1	1	0	0	0	0	0	2	2	4	5	6	3	2	2	3	**68**	1	0	0	0	0	0	0	0	0	0	0	0
Guangxi	0	0	1	1	1	0	0	0	0	1	1	3	1	3	2	4	5	12	8	**54**	0	0	0	2	0	0	1	0	0	0	0
Hainan	0	0	2	2	1	1	0	0	0	3	3	5	4	5	3	3	7	9	20	4	**28**	0	0	0	0	0	1	0	0	0	0
Chongqi ng	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	**70**	13	10	1	0	1	0	0	0	0
Sichuan	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	14	**74**	5	1	0	1	1	0	0	0
Guizhou	0	0	1	1	0	0	0	0	0	0	0	1	0	1	1	2	3	5	0	3	0	4	8	**63**	6	0	1	0	0	0	0
Yunnan	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	3	0	3	9	13	**65**	0	1	0	0	0	0
Tibet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**99**	0	0	0	0	0
Shaanxi	0	0	1	4	3	0	0	0	0	0	0	0	0	0	1	5	4	1	0	0	0	2	4	1	0	0	**69**	3	0	2	0
Gansu	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	3	8	1	0	0	9	**67**	4	4	0
Qinghai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	**88**	0	0
Ningxia	0	0	0	1	11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	3	1	0	0	3	13	1	**65**	0
Xinjiang	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**100**

Source: Environmental Planning Institute, Ministry of Environmental Protection

TABLE III. ENVIRONMENTAL CAPACITY VARIABLE DESCRIPTION

Region	revised SO_2 capacity	revised NOx capacity	revised Smoke (powder) dust capacity	Original SO_2 capacity	Original NOx capacity	Original Smoke (powder) dust capacity	lower limit of SO_2 capacity	lower limit of NOx capacity	lower limit of Smoke (powder) dust capacity	upper limit of SO_2 capacity	upper limit of NOx capacity	upper limit of Smoke (powder) dust capacity
Beijing	$x_{1,1}$	$x_{1,2}$	$x_{1,3}$	$y_{1,1}$	$y_{1,2}$	$y_{1,3}$	$xlb_{1,1}$	$xlb_{1,2}$	$xlb_{1,3}$	$xub_{1,1}$	$xub_{1,2}$	$xub_{1,3}$
Tianjin	$x_{2,1}$	$x_{2,2}$	$x_{2,3}$	$y_{2,1}$	$y_{2,2}$	$y_{2,3}$	$xlb_{2,1}$	$xlb_{2,2}$	$xlb_{2,3}$	$xub_{2,1}$	$xub_{2,2}$	$xub_{2,3}$
Hebei	$x_{3,1}$	$x_{3,2}$	$x_{3,3}$	$y_{3,1}$	$y_{3,2}$	$y_{3,3}$	$xlb_{3,1}$	$xlb_{3,2}$	$xlb_{3,3}$	$xub_{3,1}$	$xub_{3,2}$	$xub_{3,3}$
…	…	…	…	…	…	…	…	…	…	…	…	…
Ningxia	$x_{30,1}$	$x_{30,2}$	$x_{30,3}$	$y_{30,1}$	$y_{30,2}$	$y_{30,3}$	$xlb_{30,1}$	$xlb_{30,2}$	$xlb_{30,3}$	$xub_{30,1}$	$xub_{30,2}$	$xub_{30,3}$
Xinjiang	$x_{31,1}$	$x_{31,2}$	$x_{31,3}$	$y_{31,1}$	$y_{31,2}$	$y_{31,3}$	$xlb_{31,1}$	$xlb_{31,2}$	$xlb_{31,3}$	$xub_{31,1}$	$xub_{31,2}$	$xub_{31,3}$

It should be explained that in Table III, the relationship between smoke (powder) dust and primary PM2.5 is estimated to be 0.64~0.66, and the following analysis will analyze the amount of smoke (powder) dust discharge, the primary PM2.5 discharge is equal to 0.65 times the amount of smoke (powder) dust discharge.

A. *Optimization Problem Modeling*

The above problems can be transformed into the maximum emission of pollutants in various regions under the premise that the pollutants in each region are less than the environmental capacity after the air circulation is considered.

The parameter (such as 0.66, 0.05, 005, 0.01, 0.01) in the line of $y_{1,1}$, $y_{1,2}$ and $y_{1,3}$ in formula (1) corresponds to the first column parameter of Table II, the parameter in the line of $y_{2,1}$, $y_{2,2}$ and $y_{2,3}$ corresponds to the second column parameter, and so on.

(1) Solving revised SO_2 environmental capacity

$$\begin{aligned}
&\max_{x_{i,1}}\left(\sum_{i=1}^{i=31} x_{i,1}\right)\\
&s.t.\, x_{1,1}\times 0.66 + x_{2,1}\times 0.05 + x_{3,1}\times 0.05 + x_{6,1}\times 0.01 + x_{15,1}\times 0.01 \le y_{1,1}\\
&\quad x_{1,1}\times 0.04 + x_{2,1}\times 0.56 + x_{3,1}\times 0.06 + x_{6,1}\times 0.01 + x_{10,1}\times 0.01 + x_{15,1}\times 0.02 \le y_{2,1}\\
&\quad \vdots\\
&\quad x_{4,1}\times 0.01 + x_{5,1}\times 0.03 + x_{27,1}\times 0.02 + x_{28,1}\times 0.04 + x_{30,1}\times 0.65 \le y_{30,1}\\
&\quad x_{31,1}\times 1 \le y_{31,1}\\
&\quad xlb_{i,1} \le x_{i,1} \le xub_{i,1} \quad 1 \le i \le 31
\end{aligned} \tag{1}$$

(2) Solving revised NOx environmental capacity

$$\begin{aligned}
&\max_{x_{i,2}}\left(\sum_{i=1}^{i=31} x_{i,2}\right)\\
&s.t.\\
&\quad x_{1,2}\times 0.66 + x_{2,2}\times 0.05 + x_{3,2}\times 0.05 + x_{6,2}\times 0.01 + x_{15,2}\times 0.01 \le y_{1,2}\\
&\quad x_{1,2}\times 0.04 + x_{2,2}\times 0.56 + x_{3,2}\times 0.06 + x_{6,2}\times 0.01 + x_{10,2}\times 0.01 + x_{15,2}\times 0.02 \le y_{2,2}\\
&\quad \vdots\\
&\quad x_{4,2}\times 0.01 + x_{5,2}\times 0.03 + x_{27,2}\times 0.02 + x_{28,2}\times 0.04 + x_{30,2}\times 0.65 \le y_{30,2}\\
&\quad x_{31,2}\times 1 \le y_{31,2}\\
&\quad xlb_{i,2} \le x_{i,2} \le xub_{i,2} \quad 1 \le i \le 31
\end{aligned} \tag{2}$$

(3) Solving revised smoke (powder) dust environmental capacity

$$\begin{aligned}
&\max_{x_{i,3}}\left(\sum_{i=1}^{i=31} x_{i,3}\right)\\
&s.t.\\
&\quad x_{1,3}\times 0.66 + x_{2,3}\times 0.05 + x_{3,3}\times 0.05 + x_{6,3}\times 0.01 + x_{15,3}\times 0.01 \le y_{1,3}\\
&\quad x_{1,3}\times 0.04 + x_{2,3}\times 0.56 + x_{3,3}\times 0.06 + x_{6,3}\times 0.01 + x_{10,3}\times 0.01 + x_{15,3}\times 0.02 \le y_{2,3}\\
&\quad \vdots\\
&\quad x_{4,3}\times 0.01 + x_{5,3}\times 0.03 + x_{27,3}\times 0.02 + x_{28,3}\times 0.04 + x_{30,3}\times 0.65 \le y_{30,3}\\
&\quad x_{31,3}\times 1 \le y_{31,3}\\
&\quad xlb_{i,3} \le x_{i,3} \le xub_{i,3} \quad 1 \le i \le 31
\end{aligned} \tag{3}$$

B. *The Upper and Lower Bounds of Environmental Capacity*

If we do not set the upper and lower boundaries of environmental capacity, the optimization problems described above may result in some regional pollutant emissions of zero and other areas with significant pollutant emissions. This is not realistic, as the actual pollutant emission is unlikely to be zero. Therefore, it is necessary to study the upper bound of environmental capacity value.

Considering the background of energy conservation and emission reduction, future pollutant emissions must be a long-term downward trend. The upper bound of environmental capacity can take the actual emission values of each region in the previous year shown in Table IV. Considering the size of the emission reduction space in each region, the lower bound of environmental capacity can take the 30%~50% of the environmental capacity of each region in Table I.

TABLE IV. EMISSIONS OF AIR POLLUTANTS FROM EXHAUST GASES IN VARIOUS REGIONS 2016 (MILLION TONS)

Region	SO_2	NOx	Smoke (powder) dust
Beijing	3.32	9.61	3.45
Tianjin	7.06	14.47	7.81
Hebei	78.94	112.66	125.68
Shanxi	68.64	67.28	68.15
Inner mongolia	62.57	64.53	59.90
Liaoning	50.77	61.53	64.91
Jilin	18.81	30.07	21.87
Heilongjiang	33.82	53.97	44.71
Shanghai	7.42	16.63	7.95
Jiangsu	57.01	93.03	47.17
Zhejiang	26.84	38.04	18.23
Anhui	28.16	50.76	32.13
Fujian	18.93	26.18	23.79
Jiangxi	27.69	41.93	33.31
Shandong	113.45	122.94	87.38
Henan	41.36	80.83	42.89
Hubei	28.56	39.14	27.58
Hunan	34.68	42.06	26.21

Guangdong	35.37	84.27	28.17
Guangxi	20.11	30.29	26.19
Hainan	1.70	6.20	2.08
Chongqing	28.83	21.77	9.58
Sichuan	48.83	45.10	27.27
Guizhou	64.71	37.79	20.43
Yunnan	52.62	44.69	24.76
Tibet	0.54	5.52	1.65
Shaanxi	31.80	38.03	28.74
Gansu	27.20	25.80	18.03
Qinghai	11.37	9.42	14.86
Ningxia	23.69	19.78	20.12
Xinjiang	48.07	59.98	45.67
Total	1102.86	1394.31	1010.66

C. *Environmental Capacity After Correction of Air Pollutant Flow*

Using the data in Table I-IV, we take the lower environment capacity of 30% of the regional environmental capacity in Table I, and calculate the revised regional environmental capacity according to Section III as shown in Table V.

TABLE V. REVISED ENVIRONMENTAL CAPACITY (MILLION TONS)

Region	**SO_2**	**NOx**	**Smoke (powder) dust**
Beijing	1.23	4.76	1.91
Tianjin	7.06	11.19	2.74
Hebei	31.75	40.01	15.81
Shanxi	68.64	67.28	16.05
Inner mongolia	62.57	64.53	41.44
Liaoning	50.77	61.53	30.58
Jilin	18.81	30.07	21.87
Heilongjiang	33.82	53.97	26.96
Shanghai	7.42	16.63	7.95
Jiangsu	15.71	28.43	11.34
Zhejiang	11.92	38.04	16.25
Anhui	6.23	9.21	7.76
Fujian	18.93	26.18	23.79
Jiangxi	12.56	41.93	14.68
Shandong	84.81	47.03	29.51
Henan	25.02	19.16	10.12
Hubei	13.30	14.94	10.00
Hunan	34.68	20.58	16.43
Guangdong	35.37	84.27	28.17
Guangxi	20.11	30.29	26.19
Hainan	1.70	6.20	2.08
Chongqing	28.83	20.85	9.58
Sichuan	27.14	15.31	27.20
Guizhou	64.71	20.46	19.59
Yunnan	52.62	44.69	24.76
Tibet	0.42	3.87	0.58
Shaanxi	31.80	38.03	22.85
Gansu	27.20	25.80	18.03
Qinghai	11.37	9.42	5.90
Ningxia	23.69	19.78	6.57
Xinjiang	48.07	53.33	17.75
Total	878.27	967.79	514.43

As can be seen from Tables I and V, the environmental capacity of pollutant emissions in various regions is significantly reduced after air fluidity is taken into account. If these changes are not taken into account, it may be difficult to meet the Chinese government's goal of air compliance.

IV. CONCLUSION

This paper analyzes the shortcomings of the existing environmental capacity of pollutant (SO_2, NOx, and primary PM2.5) emissions in various regions, and puts forward the calculation method of environmental capacity improvement of pollutant emission in various regions considering air fluidity, then gives the calculation results in combination with the actual data. Comparing with the present results, it can be seen that the environmental capacity of pollutant emission in various regions is obviously reduced after considering air fluidity. The calculation results of this paper are helpful for the government to improve the policymaking.

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