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Evaluation of ambient air quality in Guangzhou, China

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Abstract

On the basis of the reported air quality index (API) and air pollutant monitoring data provided by the Guangzhou Environment Monitoring Stations over the last twenty-five years, the characteristics of air quality, prominent pollutants, and variation of the average annual concentrations of SO_2, NO_2, total suspended particulate (TSP), fine particulates (PM_{10}), CO and dustfall in Guangzhou City were analyzed. Results showed that TSP was the prominent pollutant in the ambient air environment of Guangzhou City. Of the prominent pollutants, TSP accounted for nearly 62%, SO_2 12.3%, and NO_x 6.4%, respectively. The average API of Guangzhou over 6 years was higher than that of Beijing, Tianjin, Nanjing, Hangzhou, Suzhou and Shanghai, and lower than that of Shenzhen, Zhuhai and Shantou. Concentrations of air pollutants have shown a downward trend in recent years, but they are generally worse than ambient air quality standards for USA, Hong Kong and EU. SO_2 and NO_x pollution were still serious, impling that waste gas pollution from all kinds of vehicles had become a significant problem for environmental protection in Guangzhou. The possible causes of worsening air quality were also discussed in this paper.

Key words: air pollution index (API); total suspended particulates (TSP); atmospheric quality; Guangzhou

Introduction

Guangdong Province in China is in short of energy resources. Energy resource per capita is only 5% of the average of the country. At the same time, Guangdong is a large province in Mainland China with a strong economy and high energy consumption. Its total energy consumption in 2004 was 0.15 billion tce (tons of standard coal equivalent), 15.2% higher in the previous year. The growth rate of energy consumption exceeded that of GDP, resulting in decreasing efficiency of energy use. Research has shown that, if the demand for energy continues to increase at the same rate, energy consumption in Guangdong Province will exceed 0.30 billion tce by the year 2010 (Nie *et al*., 2001). The dominance of coal as an energy source leads to serious environmental pollution problems. Urban atmospheric pollution and acid rain are more severe than ever before. As a result of worsening ambient air quality, concern about the exposure of citizens to various air pollutants has increased in recent years (Kristin and Pan, 2004; Wang *et al*., 2003; Ye *et al*., 2000; Passali *et al*., 1999; Gurjar *et al*., 1996). Guangdong has become one of the regions in Mainland China, where control of air pollution is vital.

Guangzhou (latitude 22°26′–23°56′N and longitude 112°57′–114°13′E), capital of Guangdong Province, is located in southeast of Guangdong Province, northerly margin of the Pearl River Delta area (PRD). In the process of rapid urbanization and development of society and economy, Guangzhou, just like other metropolitan cities in the world, is facing more pressure for environmental protection and the restoration of environmental damage. Several investigations have been conducted to study the urban environment and atmospheric pollutants in Guangzhou City (Chen, 2005; Huang *et al*., 2005; Zhao *et al*., 2004; Zhou *et al*., 2005; Weng and Yang, 2004; Chan *et al*., 2002; Xu and Yang, 1998; Qin and Chan, 1993; Qin and Kot, 1993). However, previous studies addressing ambient air quality have often either been limited to single factor, or have been case studies which do not take account of the air quality in other mega cities. In addition, the use of air pollution index (API) values, based on the ambient concentrations of all pollutants, is better suited to assess air quality than the EPA's pollutant standards index (PSI) (Khanna, 2000). Thus, for this investigation, API was used to evaluate ambient air quality in Guangzhou.

API, a referential parameter describing air pollution level with respect to its effects on the human health, was employed to provide overviews of air quality in Guangzhou. API data for Guangzhou was first reported

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to the public in 2000. The State Environmental Protection Agency of China selected the air pollutants sulphur dioxide (SO_2), nitrogen oxides (NO_x), and total suspended particulates (TSP) for API reporting and forecasting. The air pollutants were changed to SO_2, and nitrogen dioxide (NO_2), respirable particulate matter (PM_{10}) so as to meet a significant increase in the health concern about PM_{10} after 2001. In order to well evaluate ambient air quality in Guangzhou, concentrations of carbon monoxide (CO) and dustfall were also monitored and reported. Monitoring data can be found at the official web site: http://www.zhb.gov.cn/ or http://www.gzepb.gov.cn/.

Prominent pollutant and variation of pollutants between 2000 and 2005, and concentrations of SO_2, NO_x, TSP, PM_{10}, CO and dustfall between 1984 and 2005 were studied in this article. This research was conducted to reveal prominent pollutant and annual and seasonal variation of ambient air pollutants in Guangzhou City. These results are useful to the Guangzhou authority for reviewing air quality management and for establishing an environmental-friendly and resource-saving culture in Guangzhou.

1 Data acquisition

The API data between 2000 and 2005 were obtained from State Environmental Protection Administration and Guangzhou Environment Monitoring Stations. The API data, to a scale of 0 to 500, is converted arithmetic average of daily concentrations of the three pollutants measured at an optimized and ratified network of nine monitoring stations in Guangzhou. The detailed calculation methods and steps of API for a certain day can be found at the official web site: http://www.sepa.gov.cn. The API data and limits for air pollutant concentrations are shown in Table 1.

The concentration data of mentioned pollutants between 1981 and 2005 are obtained from Guangzhou Environmental Protection Administration. It also can be found at the official web site: http://www.gzepb.gov.cn/ or http://www.sdinfo.net.cn/. Rainfall data during 2000 and 2005 is obtained from Guangzhou Meteorological Bureau, China.

2 Evaluation of ambient air quality in Guangzhou City

2.1 Variation of APIs

According to Ambient Air Quality Standard of China (1996), API value is divided into 5 classes based on the statistical value of prominent pollutants in ambient air. The days, which corresponded to each class, are shown in Table 2.

It can be seen that, air quality was “good” or “moderate” in more than 89.5% of the statistical days over 6 years. Other 10.3% and 0.2% days were light pollution and middling pollution, respectively, during which concentrations of ambient air pollutants exceeded the health-protected guidelines stated in the Chinese national air quality standard.

Compared to other mega cities in Mainland China, the mean value of API (70) in Guangzhou over 6 years was lower than that in Beijing (BJ), Tianjin (TJ), Nanjing (NJ), Hangzhou (HZ), Suzhou (SUZ) and Shanghai (SH), and higher than that of Ningbo (NB), Wenzhou (WZ), Shenzhen (SZ), Zhuhai (ZH) and Shantou (ST). Results revealed that ambient air quality in Guangzhou was apparently better than in northern cities Beijing, Tianjin and some southern cities, but was the worse than in any other city in PRD region (Table 3).

Monthly variation of APIs in mega-cities of Mainland China during the period 2000–2005 is shown in Fig.1. Guangzhou, Shanghai, Beijing and Chongqing are typical mega cities, representing South China costal zones, East China costal zones and northern inland cities, respectively. Monthly variation of APIs in other major cities showed a similar trend. Average APIs of Shanghai and Guangzhou were generally lower (varying from 59–89) than average APIs of northern inland cities Beijing and Chongqing,

Table 1 API value and limits for pollutant concentrations

API value	Pollutant concentrations (mg/m^3)					
	SO_2 (daily average)	NO_2 (daily average)	PM_{10} (daily average)	TSP (daily average)	CO (hourly average)	O_3 (hourly average)
50	0.050	0.080	0.050	0.120	5	0.120
100	0.150	0.120	0.150	0.300	10	0.200
200	0.250	0.280	0.350	0.500	60	0.400
300	1.600	0.565	0.420	0.625	90	0.800
400	2.100	0.750	0.500	0.875	120	1.000
500	2.620	0.940	0.600	1.000	150	1.200

Table 2 Air quality classes in Guangzhou, 2000–2005

API value	Pollution classes	2000		2001		2002		2003		2004		2005		Total	
		Days	%	Days	%	Days	%	Days	%	Days	%	Days	%	Days	%
0–50	Good	61	16.7	89	24.4	75	20.5	61	16.7	38	10.4	77	21.2	401	18.3
51–100	Moderate	268	73.2	264	72.3	255	69.9	254	69.6	266	72.7	253	69.7	1560	71.2
101–200	Unhealthy	31	8.5	12	3.3	31	8.5	39	10.7	60	16.4	29	8.0	202	9.3
201–300	Very unhealthy	6	1.6			4	1.1	6	1.6	2	0.5	4	1.1	22	1.0
>300	Hazardous							5	1.4					5	0.2

Table 3 APIs in main mega cities in Mainland China

Year	BJ	TJ	NJ	HZ	SUZ	SH	GZ	NB	WZ	SZ	ST	ZH
2000	130	132	79	78	68	69	68	71	63	49	55	48
2001	112	112	96	86	75	76	63	49	62	54	52	48
2002	112	98	93	89	87	79	67	55	62	52	41	43
2003	97	93	83	87	84	72	75	62	61	58	46	44
2004	102	83	80	83	81	74	78	63	58	64	52	43
2005	94	79	87	76	74	67	66	64	60	49	48	34
Mean	107	100	87	83	78	73	70	61	61	54	49	43

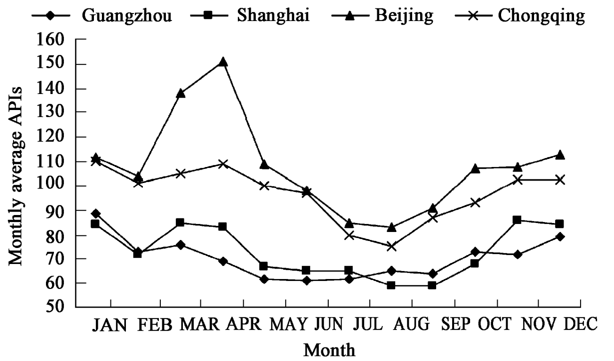

Fig. 1 Monthly variation of APIs in cities of Mainland China, 2000–2005.

which varied from 75–151. It suggested that these typical cities were polluted at different levels due to local factors such as economic development and meteorological conditions. Guangzhou has a typical subtropical climate, which is influenced more by the East Asian Monsoon than by the Indian monsoon circulation. 89.4% of the rainfall occurs between April and September with the highest rainfall in spring. Between April and September, ambient air pollutants are dispersed and diluted by frequent rainfall, landing typhoons, and strong updrafts and downdrafts. Thus, concentrations of air pollutants in the spring's plum rain period were lower than in other months. It can also be seen that concentrations of ambient air pollutants were generally lower in Guangzhou city than in northern cities, such as Beijing and Tianjin.

2.2 Annual variation of prominent pollutants

Fig.2 shows the days of prominent pollutants during the period of 2000–2005.

Prominent pollutant is not reported to the public and labeled as "Nothing" if API value is below 50. The results showed that, TSP as prominent pollutant accounted for 62% of statistical days, nothing 19.3%, SO_2 12.3% and NO_2 6.4%, respectively. Annual mean concentrations of ambient air prominent pollutants in Guangzhou City are shown in Fig.3. Although annual mean concentrations showed a downward trend after 1995, TSP remained the prominent pollutant in ambient air in Guangzhou City. Annual mean concentrations of TSP over 6 years were higher than Chinese air quality secondary standard limits (0.20 mg/m^3) and limits for Hong Kong (80 μg/m^3; http://www.epd.gov.hk/), and higher than Chinese air quality tertiary standard limits (0.30 mg/m^3) during 1994–1995. Annual mean concentrations of PM_{10} were lower than limits for secondary standards (100 μg/m^3), but higher than limits for Hong Kong (55 μg/m^3), USEPA National Ambient Air Quality Standards (50 μg/m^3; http://www.epa.gov/air/criteria.html) and for European Commission Ambient Air Quality Standards (30 μg/m^3).

Annual mean concentrations of SO_2 fluctuated above and below the limit of 0.06 mg/m^3 established by Chinese air quality secondary standards, but seriously exceeded the limit value in 1989. Annual mean concentrations of NO_x were also higher than the limit value for Chinese ambient air quality secondary standard (0.05 mg/m^3) during the studied period and exceeded the tertiary standard limit (0.10 mg/m^3) during 1986 and 2000.

A comparative study of the concentrations of ambient air pollutants over the last decade in the international harbor cities Guangzhou (GZ), Shanghai (SH) and Hong Kong (HK), is shown in Table 4.

It can be seen that, annual mean concentrations of SO_2 in Guangzhou over the last decade were higher than those in Hong Kong or in Shanghai. It was therefore, concluded that SO_2 and NO_x pollution in ambient air of Guangzhou City was still serious, implying that waste gas pollution

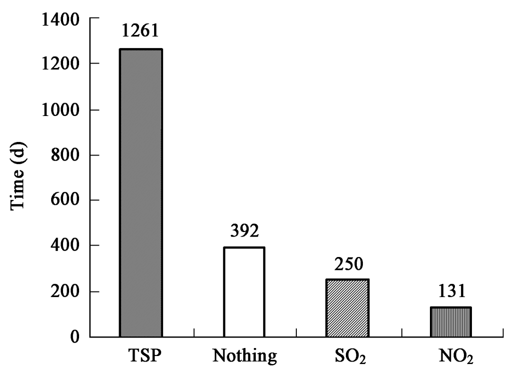

Fig. 2 Total days of prominent pollutants appearing in Guangzhou.

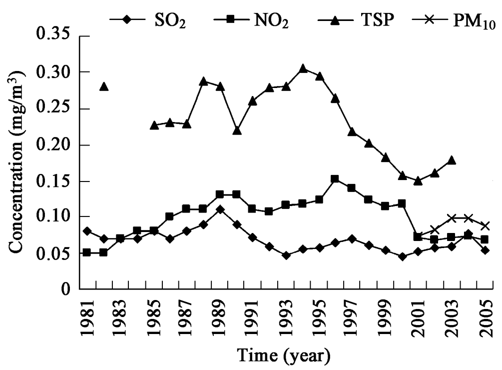

Fig. 3 Annual concentration variation of SO_2, NO_2, TSP and PM_{10} in Guangzhou, 1981–2005.

Table 4 Comparison of concentrations of ambient air pollutants in Hong Kong (HK), Guangzhou (GZ) and Shanghai (SH)

Year	SO_2			NO_x			PM_{10}			TSP		
	HK	GZ	SH	HK	GZ	SH	HK	GZ	SH	HK	GZ	SH
1996	19.5	65	32	127.6	151	54	56.7	–	–	56.7	265	229
1997	17.2	70	32	143.6	139	59	57.9	–	–	57.9	217	213
1998	14.2	61	25	180.4	124	58	59.1	–	–	59.1	202	189
1999	20.1	54	20	181.7	114	59	58.9	–	–	58.9	182	175
2000	18.0	45	22	179.4	118	56	54.1	–	–	54.1	158	155
2001	16.9	51	24	186.5	71	44	57.4	73	100	57.4	150	–
2002	17.4	58	35	180.5	68	58	51.7	82	108	51.7	161	–
2003	17.2	59	43	175	72	57	58.8	99	97	58.8	178	–
2004	24.5	77	–	165.0	73	–	64.9	99	–	64.9	–	–
2005	21.6	53	–	166.5	68	–	59.2	88	–	59.2	–	–
AC	18.7	59.3	29.1	152.9	99.8	55.6	57.9	88.2	102	82.9	189.1	192.2

All units are micrograms per cubic meter; the symbol "–" means unfounded or unmonitored data in given year, and AC means average concentration; data are from Environmental Protection Department of Hong Kong, Guangzhou and Shanghai, which can also be found at the official web site, respectively.

produced by all kinds of vehicles had become a significant problem for environmental protection in Guangzhou.

Variations in average concentrations of CO and dustfall are shown in Fig.4. Daily mean concentrations of CO have declined over most of the last twenty years, and are much lower than the Chinese air quality primary standards limit of 4.0 mg/m^3. Monthly mean concentrations of dustfall from 1985 to 1999 were higher than the standard (8 t/km^2·month) recommended by Guangdong Province, but have shown a downward trend since 2000.

2.3 Monthly variation of air prominent pollutants

Monthly variation of ambient air pollutant in Guangzhou City during 2000 and 2005 is shown in Fig.5. The prominent pollutant in ambient air in Guangzhou City was TSP over the whole year. Pollution from NO_2 (January and December) and SO_2 (June, July and August) was also serious.

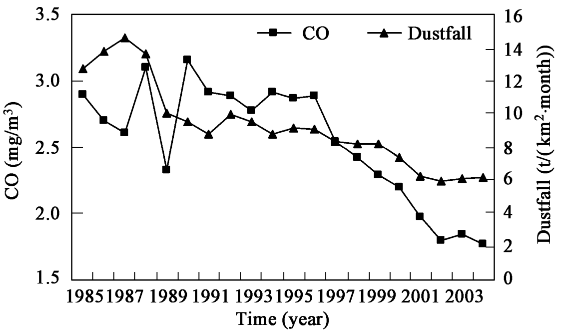

Fig. 4 Annual concentration variation of CO and dustfall in Guangzhou.

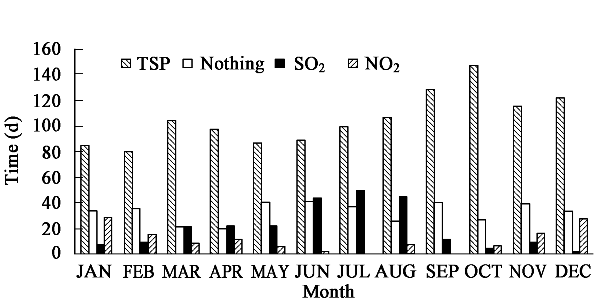

Fig. 5 Monthly variation of prominent pollutants of ambient air environment in Guangzhou.

2.4 Monthly variation of APIs

Based on a database of daily APIs during 2000 and 2005, arithmetic means of monthly APIs in Guangzhou City are shown in Fig.6. Monthly variation of APIs during 2000–2005, was 50 to 135 in Guangzhou City. Annual mean APIs varied from 61 to 89. Monthly mean APIs were below Chinese air quality secondary standards from 2000 to 2005, except in January 2000 (135) and January 2003 (106). It can be seen from Fig.6 that, monthly mean APIs were relatively lower during April and September, but higher in other months, especially in January and December. Monthly mean APIs were partly influenced by the large scale weather background of monsoon circulation and rainfall in Guangzhou City. Guangzhou has a typical south subtropical marine climate, with seasonal variation of wind directions and rainfall. Owing to the influence of monsoon circulation, wind direction has seasonal characteristics, i.e. southeasterly wind in summer and autumn, and northerly wind in winter and spring. Wet deposition occurs frequently from clean and humid southeasterly shoreward wind from the oceans (South China Sea and Tropical Pacific). In contrast, northerly winds bring drier polluted air from Mainland China in spring and winter. Thus, ambient air pollutants are diluted and diffused in summer and autumn.

Based on daily rainfall data from 2000 to 2005 in Guangzhou, it can be seen that, 89.4% of the rainfall occurs during April and September (Fig.7). More rainfall occurs

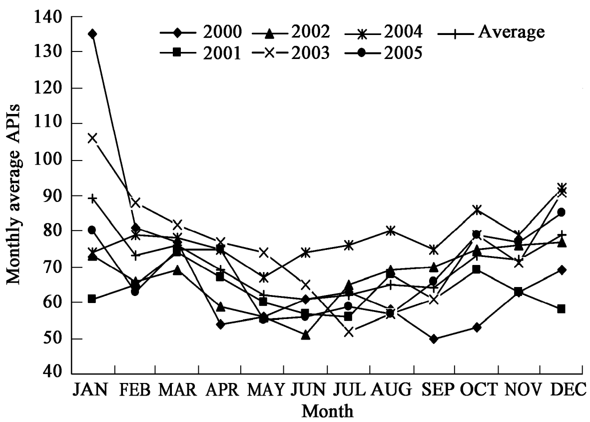

Fig. 6 Monthly variation of APIs in Guangzhou, 2000–2005.

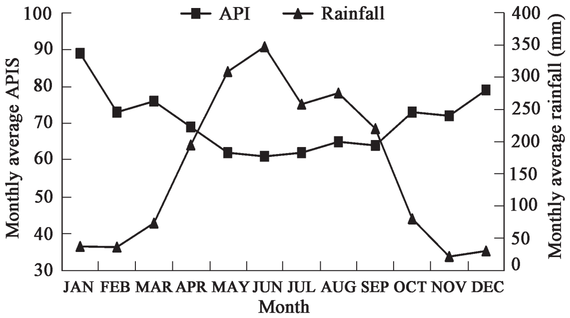

Fig. 7 Monthly average APIs and rainfall in Guangzhou, 2000–2005.

in the rainy season than in other months, with December and January being the driest months. Due to effective removal air pollutants by rainfall, monthly mean APIs from April to September were the lowest and varied little in the rainy season.

Monthly mean of APIs was negatively correlated with monthly mean temperature and monthly rainfall in Guangzhou City during 2000–2005, with a correlation coefficient of –0.7995 and –0.7147, respectively.

3 Results and discussion

Results showed that, due to sustained efforts to improve the city's ambient air quality, air quality in Guangzhou reached the Chinese ambient air quality secondary standard during 2000–2005. TSP was the prominent pollutant in more than 60% of statistic days in the ambient air environment of Guangzhou City. It is concluded that concentrations of TSP, NO_2, SO_2, CO and dustfall decreased with the increasing efforts, especially those of CO and dustfall. However, air pollution from SO_2 and NO_x were still serious, which implied that waste gas pollution produced by all kinds of vehicles had become a significant problem for environmental protection in Guangzhou. Daily mean APIs were lower during April and September than in other months, and higher in January and December, which implied that the value of API was related to weather background, monsoon circulation and rainfall in Guangzhou City.

In order to maintain sustainable and coordinated development, Guangzhou authorities haven taken a series of appropriate measures and have made great progress in controlling ambient air pollution. The greenbelt area per person and the greenbelt vegetation cover have steadily increased; urban traffic congestion and air pollution have been considerably improved in the last twenty years. For its improvement of infrastructure construction and renovation of the environment, Guangzhou received the "China Human Settlements Environment Award for Practices" by the Chinese Ministry of Construction in 2001 and, has been endorsed as an "International Garden City" by the United Nations Environment Programme in 2001. Guangzhou also won the "Dubai International Award for Best Practices to Improve the Living Environment" in 2002.

However, in the process of rapid urbanization and rapid development of society and economy, Guangzhou, just like most of the developing countries and metropolitan cities in the world, is facing more and more pressure to protect the urban atmospheric environment. SO_2 emission from factories burning coal and the total volume of industrial waste gas emissions have exceeded 1.811×10^5 t and 2.618×10^{11} m^3, 1.3% and 43.4% higher in 2005 than in 2004, respectively (Guangzhou Bureau of Statistics, 2005, http://www.gzstats.gov.cn/). In fact, air environmental pollution has to some extent restricted sustainable development and damaged citizen health.

There are several possible causes of the worsening of ambient air quality in Guangzhou City. (1) Because of rapid development of the economy, there has been a shortage of electric power in recent years, and total emissions of waste from industrial coal utilization and oil have greatly increased. According to the reported statistic evidence, industrial coal and industrial oil utilization exceeded 1.7 million tons and 1.272 million tons in 2004, which are 11.75% and 19.72% higher than in 2003, respectively. It has been reported that 70% of soot, 90% of SO_2, 67% of NO_x and 70% of CO_2 emissions were related to burning coal. As a result, the emission of SO_2 to ambient air in Guangzhou City increased quickly, and ranked the city 13th out of 113 main cities in Mainland China (State Environmental Protection Administration of China, 2004, http://www.sepa.gov.cn/). (2) To reduce production costs, high sulphur coal and petroleum are used by many enterprises and manufactories in Mainland China, and desulphuration is operated ineffectively. Without further control measures, total emissions of atmospheric pollutants will rise consistently with the rapid socioeconomic development and increased energy consumption of Guangzhou. (3) Guangdong Province has encountered severe drought in the last 50 years. Total annual rainfall is less than the usual annual quantity. Landing typhoons, and strong updrafts and downdrafts in the ambient air of Guangzhou are lacking, so air pollutants cannot be easily diffused and diluted. (6) Ambient air pollution in Guangzhou City is influenced by interactions with circumjacent cities in PRD region (Wang *et al*., 2005). Emissions of urban atmospheric pollutants from different cities in this area and transmission to each other are the main reasons for air pollution problems in the PRD region.

It has been promised that the total emission volume of SO_2 in Guangdong Province will be reduced by 70% by the year 2010. It is, therefore, imperative to optimize energy consumption constructure, utilize clean fuels and renewable energy, increase the vegetation cover and improve ecological service functions of vegetation, and implement an integrated environmental plan within the PRD region in near future. In order to greatly improve the quality of the air environment and to carry out international agreements to mitigate climate change, rigorous and forceful measures should be adopted and the total emission volume of pollutants must be controlled, the sustainable develop economic mechanism will be built to optimize the energy structural imbalance in the term of Eleventh Five-Year National Planning.

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