Japan-China Comparative Analysis on Measures against Sulfur Dioxides Pollution

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Introduction

Many of environmental issues today are closely related to the economic growth and energy consumption. Air pollution is the most typical example. Energy is requisite for economy growth and improvement of living standards. Such energy requirements, if covered with fossil fuels, would result in the generation of air pollutants, like sulfur dioxide (SO_2). Such pollutants, if discharged into the atmosphere without properly removed, would cause air pollution. Namely, we can find a chain relation among "(1) the maintenance of economic development and improvement of living standards --- (2) the increase in energy consumption --- (3) the increase in air pollutants generation --- (4) the increase in air pollutants emissions --- (5) the aggravation of air pollution."

Actually, Japan had suffered serious air pollution problems during her high economic growth period from the second half of the 1950s to the first oil crisis. It's evidence is the fact that the majority of more than 100,000 patients officially identified as victims of pollution are sufferers of air pollution (Ueda, 1996). China on its part has been threatened by serious air pollution since the late 1970s, when the country thrust into a high economic growth period. The World Bank (1997/9) estimated that the outdoor and indoor air pollution caused 178,000 and 111,000 premature deaths in urban China in 1995, respectively. Thus, yesterday's Japan and today's China alike confirm the presence of such a chain relation.

However, except the (4) --- (5) sequence, the chain relation of "(1) --- (2) --- (3) --- (4)" is not so strong as hardly severed. Increased energy efficiency could realize economic development and higher living standards without increasing in energy consumption, and thus weaken the (1) --- (2) sequence. If less-polluting energy sources cover greater energy use, the generation of pollutants could be curbed, which lessens the (2) --- (3) sequence. Moreover, even when pollutants generate in a large quantity, actual emissions into the atmosphere could be lowered if the generating pollutants are properly removed, which relaxes the (3) --- (4) sequence as well.

In Japan, real GDP in 1996 swelled 3.5 times over 1967 records when the Environment Law (or "Basic Anti-Pollution Law") was enacted, but primary and fossil energy consumption increased only 2.8 times and 2.4 times, respectively. SO_2 generation grew modestly by 1.5 times, and SO_2 emissions even decreased by 0.17 times. These put primary energy elasticity of GDP at 0.83 (3.62/4.37), fossil energy elasticity at 0.70 (3.05/4.37), SO_2 generation elasticity at 0.32 (1.42/4.37), and SO_2 emissions elasticity at -1.34 (-5.84/4.37). As a result, SO_2 concentrations shrank from 0.169 mg/m^3 (0.059 ppm) in 1967 to 0.026 mg/m^3 (0.009 ppm) in 1996, which remarkably improved air quality. This fact demonstrates that the chain-reaction relation of "(1) --- (2) --- (3) --- (4)" can be mitigated to considerable extent.

On air pollution, Japan has both a lesson of failure and an experience of success. How come the Japanese invited air pollution problems and why they could solve them? What kind of comprehensive measures China should take against worsening air pollution? The purpose of this paper is to grope for some answers to these questions by carrying out a Japan-China comparative analysis.

Air pollutants are various and include total suspended particulate matters, soot, sulfur dioxides and nitrogen oxides, etc. In this paper, however, we focus on air pollution problems related to sulfur dioxides (SO_2) emissions. There are two reasons. One is that SO_2 pollution is not only what Japan solved most successfully in the battle against environmental pollution, but also what threatens today's China so seriously that should require no-wait measures most. The other is, while to solve environmental problems, like SOx pollution, involves comprehensive policy measures centering on environment, energy and economic development, the Chinese environmental protection system lacks such measures.

In this paper, we describe our factor analysis model on SO_2 emissions in Section 1, and the data in

Section 2. Section 3 presents our analysis results. Finally, we make a Japan-China comparative analysis and consider viable suggestions for China in Sections 4.

1. Factor Analysis Model on Sulfur Dioxide Emissions

In macro terms, SO_2 emissions can be hierarchically broken down into 5 factors as illustrated in Fig. 1-1.

Sulfur dioxide emissions (ESO_2) depend on a generated amount of sulfur dioxide (PSO_2) and a rate of total desulfurization (α). α can be obtained by subtracting the portion of generated SO_2 that could not be desulfurized (ESO_2/PSO_2) from 1 ($1 - ESO_2/PSO_2$). A larger PSO_2, or a smaller α, leads to a larger ESO_2.

$ESO_2 = PSO_2 \cdot (1 - \alpha)$

$= PSO_2 \cdot (ESO_2/PSO_2)$ (1)

$\Delta ESO_2/\Delta PSO_2 > 0, \Delta ESO_2/\Delta \alpha < 0,$

or, $\Delta ESO_2/\Delta (ESO_2/PSO_2) > 0$

A total desulfurization rate (α) depends on product desulfurization at the primary energy processing stage, and flue gas desulfurization at the energy consumption stage. Economic development level, technology policy and environmental policy, among others, also affect these factors.

A generated amount of sulfur dioxide (PSO_2) depends on fossil energy consumption (CRN) as primary energy and total sulfur content (PSO_2/CRN). A larger CRN, and a higher (PSO_2/CRN), lead to a larger PSO_2.

$PSO_2 = CRN \cdot (PSO_2/CRN)$ (2)

$\Delta PSO_2/ \Delta CRN > 0, \Delta PSO_2/\Delta (PSO_2/CRN) > 0$

Total sulfur content varies depending on different sulfur contents of different fossil fuels and consumption mix. In general, coal is sulfur-richer than oil and natural gas. Sulfur content differs among producing areas as well. Taking coals as an example, those produced in southern China are sulfur-richer than those in northern China. In case of crude oil, those produced in Middle Eastern are sulfur-richer than their Chinese counterparts, generally. Even among the Chinese oilfields, Daqing is less sulfur-laden than Shengli. Given these differences in sulfur content, which fossil fuel should be in use strongly depends on what policies are taken on environment, energy supply & demand, energy security, etc, but the outcome affects the total sulfur content.

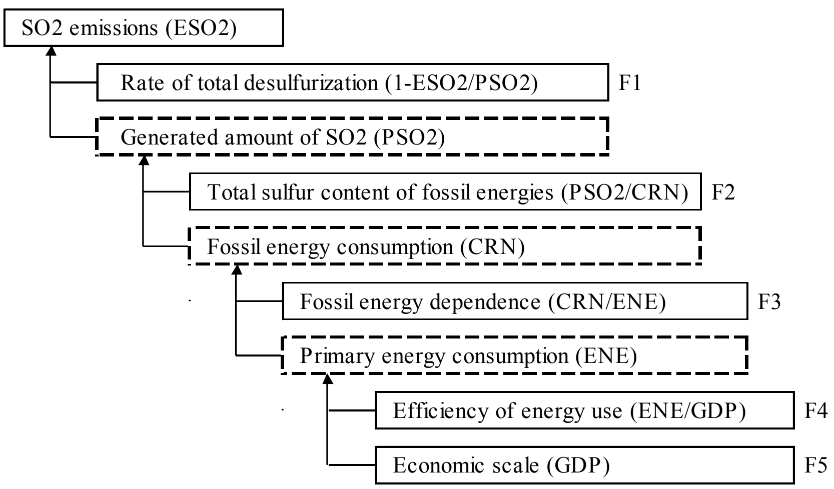
Fossil energy consumption (CRN) depends on primary energy consumption (ENE) and fossil energy dependence (CRN/ENE). A larger ENE, or a higher (CRN/ENE), leads to a larger CRN.

$CRN = ENE \cdot (CRN/ENE)$ (3)

$\Delta CRN/\Delta ENE > 0, \Delta CRN/\Delta (CRN/ENE) > 0$

Fossil energy dependence (CRN/ENE) varies depending on a primary energy consumption mix. Energy sources can roughly be divided into two groups: fossil energy and non-fossil energy (hydro and other renewable energy, plus nuclear energy). Non-fossil energy sources have both demerits and merits. The former includes massive initial investments (hydro, nuclear), long construction period (hydro, nuclear), vulnerability to natural conditions (all but nuclear), indistinct economies of scale (all but hydro and nuclear). The latter includes that they are clean energy sources benign to the environment, and indigenous renewable resources contributing to the security. Fossil energy sources on their part have demerits and merits as well. One of their problems is that, because they are not so clean as non-fossil sources, environmental problems are inherent to them. Limited resource availability poses another demerit, because it can induce stable-supply and security problems. On the other hand, their merits include that they are free from all the problems inherent to non-

Fig. 1-1 Hierarchical Structure of Determinants of SO2 Emissions



fossil energy sources, and that they can be supplied in large quantities in a short period. Which energy should be in use to what extent strongly reflects relevant policies under way on energy supply and demand, security, and environment, among others. The outcome affects (CRN/ENE).

Primary energy consumption (ENE) depends on energy intensity of GDP (ENE/GDP) and the economic scale (GDP). A higher ENE/GDP, or a larger GDP, leads to a larger ENE.

$$ENE = GDP \cdot (ENE/GDP) \quad (4)$$

$$\Delta ENE / \Delta GDP > 0, \Delta ENE / \Delta (ENE/GDP) > 0$$

Energy intensity of GDP depends on various factors, including energy mix, energy utilization technologies, energy prices, economic structure, import/export structure and life style, etc. These factors on their part reflect a wide variety of elements ranging from energy policy to technology policy, economic development strategy and policy, and public consciousness.

The economic scale (GDP) not only reflects the economic system, development strategy, policies and so on, but also depends on energy supply and demand as well as environmental conditions. Shortage of energy, ecological destruction and environmental pollution, if under way, should induce a slowdown in economic development. Here, however, GDP is treated as an exogenous variable.

By aggregating the equations of (1) --- (4), we can obtain a decision equation of SO_2 emissions at macro level.

$$ESO_2 = (ESO_2/PSO_2) \cdot (PSO_2/CRN) \cdot (CRN/ENE) \cdot (ENE/GDP) \cdot GDP \quad (5)$$

ESO_2: Emissions of sulfur dioxide
PSO_2: Total content of sulfur dioxide
CRN: Fossil energy consumption as primary energy
ENE: Primary energy consumption
GDP: Gross domestic product in real terms
ESO_2/PSO_2: Rate of total sulfur emissions (1 - total desulfurization rate)
PSO_2/CRN: Rate of total sulfur content
CRN/ENE: Dependence on fossil energies
ENE/GDP: primary energy intensity of GDP

Differentiating Equation (5), we obtained the factor analysis equation on the change in SO_2 emissions.

$$\Delta ESO_2 = \Delta (ESO_2/PSO_2) \cdot (PSO_2/CRN) \cdot CRN/ENE) \cdot ((ENE/GDP) \cdot GDP$$
$$+ (ESO_2/PSO_2) \cdot \Delta (PSO_2/CRN) \cdot (CRN/ENE) \cdot (ENE/GDP) \cdot GDP$$
$$+ (ESO_2/PSO_2) \cdot (PSO_2/CRN) \cdot \Delta (CRN/ENE) \cdot (ENE/GDP) \cdot GDP$$
$$+ (ESO_2/PSO_2) \cdot (PSO_2/CRN) \cdot (CRN/ENE) \cdot \Delta (ENE/GDP) \cdot GDP$$
$$+ (ESO_2/PSO_2) \cdot (PSO_2/CRN) \cdot (CRN/ENE) \cdot (ENE/GDP) \cdot \Delta GDP$$
$$+ \text{Crossing items}$$
$$= [ESO_2/(ESO_2/PSO_2)] \cdot \Delta (ESO_2/PSO_2) \text{ --- F1: Factor of total desulfurization}$$
$$+ [ESO_2/(PSO_2/CRN)] \cdot \Delta (PSO_2/CRN) \text{ --- F2: Factor of low-sulfur fossil fuels}$$
$$+ [ESO_2/(CRN/ENE)] \cdot \Delta (CRN/ENE) \text{ --- F3: Factor of less dependence on fossil fuels}$$
$$+ [ESO_2/(ENE/GDP)] \cdot \Delta (ENE/GDP) \text{ --- F4: Factor of energy conservation}$$
$$+ [ESO_2/GDP] \cdot \Delta GDP \text{ --- F5: Factor of economic growth}$$
$$+ \text{Crossing items} \quad (6)$$

Here, Δ is the change between the current period (t) and the previous period (t-1). For example, this can be expressed as follows; $\Delta ESO_2 = [ESO_2(t) - ESO_2(t-1)]$. Also, put in the [·] mark can be either one of the values for the current period, the previous period, or an average value of the two periods (see Kurasawa, 1988). Here, an average of the two periods is put for its approximate accuracy. For example, we put as follows;

$$[ESO_2/(ENE/GDP)]=[[(ESO_2(t)+ESO_2(t-1))/2]/[(ENE(t)/GDP(t)+ENE(t-1)/GDP(t-1))/2]]$$

2. Data

Japan and China have been measuring atmospheric SO_2 concentrations periodically since 1965 and 1981, respectively, and publishing resultant data. In Japan, SO_2 concentrations began sharply dropping after a peak of 0.169 mg/m^3 (0.059 ppm) was recorded in 1967 in annual average terms (continuously measured at 15 stations), and have remained constant below 0.03 mg/m^3 (0.010 ppm) from 1986 onward (Table 2-1). In China, annual average concentrations in urban areas reached a peak of 0.117 mg/m^3 (0.041 ppm) in 1987, then moderately went down to 0.066 mg/m^3 (0.023 ppm) in 1997 (Table 2-2). Comparing annual average concentrations in 1996, the Chinese figure, 0.079 mg/m^3 (0.028 ppm), is 2.3 times larger than Japan's 0.026 mg/m^3 (0.009 ppm). SO_2 pollution, rapidly cleaned up in Japan, is still getting worse in China.

It is SO_2 emissions (ESO_2) that have a direct impact on SO_2 concentrations. Regretfully, except a few specific years, neither Japan nor China has conducted annual surveys on total emissions. Here, we estimated the emissions of each country as follows.

The data on Japan's SO_2 emissions in 1970, 1975 and 1989 were taken from those released by OECD (1994/8) and the Air Quality Division of the Air Quality Conservation Bureau, the Environment Agency (1994/1). We estimated the emissions in 1960-69, 1971-74 and 1976-88 in reference to the Ad Hoc Com-

Table 2-1 SO2-related Indicators: Japan

	SO_2 emissions	Real GDP	Energy consumption	Fossil fuel consumption	SO_2 generation	Energy intensity of GDP	Share of fossil fuels	Total SO_2 content of fossil energy	Rate of SO_2 emissions	Intensity of SO_2 emissions of GDP	Intensity of SO_2 generation of GDP	Atmospheric SO_2 concentrations	
	(ESO2)	(GDP)	(ENE)	(CRN)	(PSO2)	(ENE/GDP)	(CRN/ENE)	(PSO2/CRN)	(ESO2/PSO2)	(ESO2/GDP)	(PSO2/GDP)		
	1,000t	billion JPN yen	1,000TOE	1,000TOE	1,000t	TOE/mill. JPN yen	%	%	%	kg/mill. JPN yen	kg/mill. JPN yen	PPM	mg/m^3
1960	2,800	73,126	82,295	77,266	3,208	1.13	93.89	4.15	87.27	38.29	43.88		
1961	3,140	81,766	93,296	87,447	3,557	1.14	93.73	4.07	88.27	38.40	43.51		
1962	3,440	88,056	99,324	93,958	3,841	1.13	94.60	4.09	89.56	39.07	43.62		
1963	3,940	96,924	113,720	107,788	4,342	1.17	94.78	4.03	90.74	40.65	44.80		
1964	4,430	106,565	126,396	120,482	4,845	1.19	95.32	4.02	91.44	41.57	45.46		
1965	4,880	113,362	136,932	130,390	5,280	1.21	95.22	4.05	92.42	43.05	46.58	0.057	0.163
1966	5,010	125,882	153,885	146,905	5,815	1.22	95.46	3.96	86.16	39.80	46.19	0.057	0.163
1967	5,015	139,780	179,407	173,355	6,616	1.28	96.63	3.82	75.80	35.88	47.33	0.059	0.169
1968	5,000	157,059	201,070	194,492	7,112	1.28	96.73	3.66	70.30	31.84	45.28	0.055	0.157
1969	4,990	175,940	232,853	226,087	7,859	1.32	97.09	3.48	63.50	28.36	44.67	0.050	0.143
1970	4,978	190,448	257,776	250,093	8,078	1.35	97.02	3.23	61.63	26.14	42.41	0.043	0.123
1971	4,900	200,052	269,568	260,241	8,103	1.35	96.54	3.11	60.47	24.49	40.51	0.037	0.106
1972	4,700	218,215	288,186	278,392	8,175	1.32	96.60	2.94	57.49	21.54	37.46	0.031	0.089
1973	4,010	229,326	323,617	315,113	8,703	1.41	97.37	2.76	46.08	17.49	37.95	0.030	0.086
1974	3,450	228,243	325,036	312,706	8,698	1.42	96.21	2.78	39.66	15.12	38.11	0.024	0.069
1975	2,590	237,330	308,240	294,433	8,070	1.30	95.52	2.74	32.10	10.91	34.00	0.021	0.060
1976	2,100	246,262	327,223	310,980	8,426	1.33	95.04	2.71	24.92	8.53	34.22	0.020	0.057
1977	1,700	257,412	332,883	318,098	8,615	1.29	95.56	2.71	19.73	6.60	33.47	0.018	0.051
1978	1,500	271,349	339,993	317,997	8,785	1.25	93.53	2.76	17.08	5.53	32.37	0.017	0.049
1979	1,450	285,321	354,614	328,551	9,135	1.24	92.65	2.78	15.87	5.08	32.02	0.016	0.046
1980	1,500	292,737	346,491	316,601	8,712	1.18	91.37	2.75	17.22	5.12	29.76	0.016	0.046
1981	1,400	301,489	337,593	306,402	8,218	1.12	90.76	2.68	17.04	4.64	27.26	0.014	0.040
1982	1,300	310,826	334,995	300,189	7,964	1.08	89.61	2.65	16.32	4.18	25.62	0.013	0.037
1983	1,100	318,690	335,355	297,082	7,852	1.05	88.59	2.64	14.01	3.45	24.64	0.012	0.034
1984	1,050	331,754	360,696	318,381	8,232	1.09	88.27	2.59	12.75	3.16	24.81	0.012	0.034
1985	1,030	345,446	361,530	311,531	7,417	1.05	86.17	2.38	13.89	2.98	21.47	0.011	0.031
1986	920	356,286	365,824	313,822	7,477	1.03	85.78	2.38	12.30	2.58	20.99	0.010	0.029
1987	906	373,233	370,041	313,466	7,789	0.99	84.71	2.48	11.63	2.43	20.87	0.010	0.029
1988	891	395,532	395,280	339,786	8,190	1.00	85.96	2.41	10.88	2.25	20.71	0.010	0.029
1989	876	413,120	410,436	353,704	8,458	0.99	86.18	2.39	10.36	2.12	20.47	0.011	0.031
1990	876	436,044	432,080	370,190	8,457	0.99	85.68	2.28	10.36	2.01	19.40	0.010	0.029
1991	876	448,903	441,713	376,175	8,411	0.98	85.16	2.24	10.42	1.95	18.74	0.011	0.031
1992	876	450,606	449,925	383,106	8,772	1.00	85.15	2.29	9.99	1.94	19.47	0.009	0.026
1993	876	452,758	454,197	379,490	8,955	1.00	83.55	2.36	9.78	1.93	19.78	0.008	0.023
1994	876	455,690	476,251	398,435	9,316	1.05	83.66	2.34	9.40	1.92	20.44	0.008	0.023
1995	876	468,446	490,063	404,179	9,657	1.05	82.47	2.39	9.07	1.87	20.61	0.008	0.023
1996	876	483,295	503,308	414,226	9,948	1.04	82.30	2.40	8.81	1.81	20.58	0.009	0.026
<Annual average growth: %>													
1960-67	8.67	8.07	9.35	9.61	8.87	1.19	0.24	-0.68	-0.18	0.55	0.74	-	-
1967-73	-3.64	10.51	13.19	13.56	6.95	2.42	0.33	-5.82	-9.91	-12.81	-3.22	-10.15	-10.15
1973-96	-6.40	3.29	1.94	1.20	0.58	-1.31	-0.73	-0.61	-6.94	-9.39	-2.62	-5.10	-5.10
1967-96	-5.84	4.37	3.62	3.05	1.42	-0.72	-0.55	-1.58	-7.15	-9.78	-2.83	-6.28	-6.28
<GDP elasticity = annual average growth of X/annual average GDP growth>													
1960-67	1.07	1.00	1.16	1.19	1.10								
1967-73	-0.35	1.00	1.25	1.29	0.66								
1973-96	-1.94	1.00	0.59	0.36	0.18								
1967-96	-1.34	1.00	0.83	0.70	0.32								

(Notes)

1. ESO2 figures for 1970, 1975 and 1989 taken from those released by OECD (1994/8) and the Air Quality Division of the Air Quality Conservation Bureau, the Environment Agency (1994/1). The figures for 1960-69, 1971-74 and 1976-88 were estimated in reference to the Ad Hoc Committee on Air Pollution Experience of Japan (1997/6), the National Institute of Science and Technology Policy, the Science and Technology Agency (1992/6), and the stationary-source pollution surveys by the Environment Agency. The figures for the period from 1990 onward were assumed to stay constant at 1989 levels based on the Ad Hoc Committee's views (1997/6).
2. The figures for real GDP are in 1990 prices and taken from "Energy and Economy Statistical Handbook, each year's edition" available from the Energy Data and Modeling Center, IEEJ.
3. The figures for ENE and CRN were taken from the IEA statistics.
4. PSO2 figures were calculated by multiplying primary energy consumption of each fossil fuel by its sulfur content. Sulfur content of natural gas was assumed at 0.046%/TOE in reference to the National Institute of Science and Technology Policy, the Science and Technology Agency. Sulfur contents of oil were taken from "Idemitsu Data Book on Petroleum," each year's edition. Sulfur contents of coal were estimated by dividing into indigenous and imported coals and based on "Coal Note," each year's edition.
5. The figures for SO_2 concentrations are in annual average terms at fixed spots for continuous measurement, taken from "White Paper on Environment," each year's edition, the Environment Agency.
6. 1 ppm = 2.860 mg/m^3
7. Among the measures, TOE stands for tons oil equivalent (1 kg = 10,000 kcal). kg stands for kilogram.

Table 2-2 SO2-related Indicators: China

	SO_2 emissions	Real GDP	Energy consumption	Fossil fuel consumption	SO_2 generation	Energy intensity of GDP	Share of fossil fuels	Total SO_2 content of fossil energy	Rate of SO_2 emissions	Intensity of SO_2 emissions of GDP	Intensity of SO_2 generation of GDP	Atmospheric SO_2 concentrations	
	(ESO2)	(GDP)	(ENE)	(CRN)	(PSO2)	(ENE/GDP)	(CRN/ENE)	(PSO2/CRN)	(ESO2/PSO2)	(ESO2/GDP)	(PSO2/GDP)		
	1,000t	billion CHN yen	1,000TOE	1,000TOE	1,000t	TOE/mill. CHN yen	%	%	%	kg/mill. CHN yen	kg/mill. CHN\	PPM	mg/m^3
1971	6,798	800	235,994	233,414	9,012	295.10	98.91	3.86	75.43	8,500.58	11,269.44		
1972	7,136	830	252,184	249,260	9,461	303.80	98.84	3.80	75.43	8,597.01	11,397.30		
1973	7,287	896	263,659	260,391	9,661	294.37	98.76	3.71	75.43	8,136.06	10,786.22		
1974	7,259	916	271,314	267,616	9,624	296.10	98.64	3.60	75.43	7,922.28	10,502.79		
1975	8,466	996	313,484	309,614	11,224	314.74	98.77	3.63	75.43	8,500.31	11,269.18		
1976	8,556	980	327,134	323,213	11,343	333.79	98.80	3.51	75.43	8,730.07	11,573.77		
1977	9,758	1,055	368,821	364,727	12,937	349.74	98.89	3.55	75.43	9,253.64	12,267.89		
1978	10,952	1,178	411,213	407,378	14,520	349.10	99.07	3.56	75.43	9,297.75	12,326.37		
1979	11,207	1,267	418,514	414,205	14,858	330.20	98.97	3.59	75.43	8,842.19	11,722.36		
1980	11,084	1,366	413,176	408,170	14,695	302.40	98.79	3.60	75.43	8,112.37	10,754.80		
1981	11,044	1,437	407,211	401,548	14,641	283.30	98.61	3.65	75.43	7,683.45	10,186.17	0.040	0.115
1982	11,612	1,568	423,257	416,831	15,395	269.91	98.48	3.69	75.43	7,404.88	9,816.92	0.040	0.115
1983	12,270	1,739	445,134	437,670	16,266	255.96	98.32	3.72	75.43	7,055.21	9,353.34	0.033	0.094
1984	13,459	2,003	481,709	474,179	17,843	240.44	98.44	3.76	75.43	6,717.82	8,906.03	0.032	0.092
1985	14,507	2,274	516,998	508,962	19,232	227.36	98.45	3.78	75.43	6,379.74	8,457.85	0.037	0.105
1986	15,375	2,474	547,946	539,716	20,384	221.48	98.50	3.78	75.43	6,214.73	8,239.05	0.037	0.106
1987	16,401	2,761	583,804	575,095	21,743	211.45	98.51	3.78	75.43	5,940.20	7,875.11	0.041	0.117
1988	17,425	3,073	620,560	611,047	23,100	201.94	98.47	3.78	75.43	5,670.25	7,517.23	0.033	0.094
1989	18,100	3,199	645,635	635,305	23,996	201.83	98.40	3.78	75.43	5,658.21	7,501.29	0.037	0.105
1990	18,456	3,321	655,805	644,748	24,467	197.50	98.31	3.79	75.43	5,558.01	7,368.43	0.034	0.098
1991	19,072	3,626	680,765	669,762	25,285	187.74	98.38	3.78	75.43	5,259.89	6,973.21	0.031	0.090
1992	19,431	4,141	699,055	687,524	25,760	168.82	98.35	3.75	75.43	4,692.43	6,220.91	0.034	0.096
1993	20,480	4,700	745,308	731,374	27,152	158.58	98.13	3.71	75.43	4,357.60	5,777.01	0.034	0.098
1994	22,049	5,292	795,146	777,229	29,231	150.25	97.75	3.76	75.43	4,166.37	5,523.49	0.030	0.086
1995	23,700	5,848	852,556	833,286	31,420	145.79	97.74	3.77	75.43	4,052.75	5,372.87	0.028	0.081
1996	24,579	6,409	890,718	871,125	32,585	138.97	97.80	3.74	75.43	3,834.92	5,084.08	0.028	0.079
<Annual average growth: %>													
1971-79	6.45	5.93	7.42	7.43	6.45	1.41	0.01	-0.92	0.00	0.49	0.49	-	-
1979-89	4.91	9.70	4.43	4.37	4.91	-4.80	-0.06	0.52	0.00	-4.37	-4.37	-	-
1989-96	4.47	10.44	4.70	4.61	4.47	-5.19	-0.09	-0.14	0.00	-5.40	-5.41	-3.98	-3.98
1979-96	4.73	10.00	4.54	4.47	4.73	-4.96	-0.07	0.25	0.00	-4.80	-4.80	-	-
<GDPelasticity=annualaveragegrowthofX/annualaverageGDPgrowth>													
1971-79	1.09	1.00	1.25	1.25	1.09								
1979-89	0.51	1.00	0.46	0.45	0.51								
1989-96	0.43	1.00	0.45	0.44	0.43								
1979-96	0.47	1.00	0.45	0.45	0.47								

(Notes)

1. As for ESO2, the figure for 1995 was taken from the "China Environment Yearbook, 1996." ESO2 figures for the rest of the years were calculated by fixing the ratio of each year's sulfur content to 1995 records, then multiplying the ratio by each year's sulfur content. The emissions are overestimated for the years when the total desulfurization rate was higher than in 1995, and underestimated for the years with a lower desulfurization rate than in 1995.
2. Real GDP is in 1995 prices and was calculated based on "Statistical Yearbook of China, 1998."
3. The figures for ENE and CRN were taken from the IEA statistics.
4. PSO2 figures were calculated by multiplying primary energy consumption of each fossil fuel by its sulfur content. Sulfur content of natural gas was assumed at 0.046%/TOE in reference to the National Institute of Science and Technology Policy, the Science and Technology Agency. Sulfur contents of oil were assumed at 0.3% for indigenous oil, and at 1.0% for imported oil. Sulfur content of coal was put at 1.15% per ton of raw coal.
5. The figures for SO2 concentrations are in annual average terms at all measuring stations, taken from "China Environment Yearbook" each year's edition.
6. 1 PPM = 2.860 mg/m^3
7. Among the measures, TOE stands for tons oil equivalent (1 kg = 10,000 kcal). kg stands for kilogram.

mittee on Air Pollution Experience of Japan (1997/6), the National Institute of Science and Technology Policy, the Science and Technology Agency (1992/6), and the pollution-attributable-to-stationary-sources surveys by the Environment Agency. For the period from 1990 onward, we assumed the emissions have stayed constant at 1989 levels based on the Ad Hoc Committee's views (1997/6). In regard to China, the data on its 1995 emissions were taken from the "China Environment Yearbook, 1996." For the rest of the years subject to our analysis, we calculated the emissions by first assuming the emission rate of each year is constant to 1995 records, then multiplying the ratio by each year's sulfur content. The data on the emissions so estimated can be questioned for their accuracy. Yet, on a belief that the data are almost reliable to reflect general trends of emissions, we take the liberty of advancing our analysis forward.

In Japan SO_2 emissions, having once grown from the 3-million-ton level in the early 1960s to the 5-million-ton mark in the second half of the same decade, started sharply shrinking with the enactment of the Environment Law in 1967 as a turning point. From the mid-1980s onward, Japan's SO_2 emissions have stayed below a million tons. On the other hand, in China, SO_2 emissions have kept growing from 7 million tons in the early 1970s to the 24-million-ton level by the mid-1990s.

What calls for attention is the relation between the emissions and concentrations? In Japan, the two are changing toward an identical direction. Namely, decreasing emissions send the concentrations also down. In China, however, the two are running toward reverse directions from each other. Why the concentrations get lower when the emissions keep growing? There are various causes, but two of them are particularly important. One is that, though dropping in urban areas where the concentrations are measured; the strong likelihood is those mounting emissions continue in the rest, typically rural areas. For example, urban-based mining and manufacturing enterprises run by larger entities emitted 13.96 million tons in 1995, virtually flat at 13.96 million tons they produced in 1989. On the contrary, rural-based Township and Villages mining and manufacturing enterprises emitted 5.49 million tons in 1995, sharply up by 1.53 times over 3.60 million tons in 1989 (Li, 1999). The other is that, unlike the Japanese data collected continuously at certain measuring spots, the Chinese ones involve all measurements across the country. It means the data can not necessarily reflect properly comparable changes in the concentrations. For example, the Chinese measuring spots, having numbered 63 cities in 1989, increased to 90 cities by 1996.

The data on SO_2 content (PSO_2) were calculated by multiplying primary consumption (CRN) of coal, oil, or natural gas by sulfur content of each energy. The data on primary consumption were taken from the IEA statistics. The Japanese data on sulfur contents of coal and oil were collected by year, and by dividing these fossil fuels into indigenous and imported ones. As for the Chinese data, we assumed sulfur contents of coal at 1.15% per ton of raw coal, indigenous crude oil at 0.3% per TOE (ton of oil equivalent), and imported crude oil at 1.0%. As for natural gas, its sulfur content, applied to both Japan and China, was put at 0.046% per TOE in reference to the National Institute of Science and Technology Policy (1992/4).

The data on primary energy consumption (ENE) were taken from the IEA statistics just like the data on CRN. The data on GDP were taken from respective governments' statistics. The secondary data necessary for the factor analysis (ESO_2/PSO_2, PSO_2/CRN, CRN/ENE, ENE/GDP) were calculated from the primary data mentioned above. Data sets for Japan and China are shown in Table 2-1 &2 respectively.

3. Results and Discussion

3-1 Japan

Table 3-1 shows our analysis results on Japan. We confirmed following points.

(1) Desulfurization began contributing to reducing SO_2 emissions since around the mid-1960s and low-sulfur fuels did since the early 1960s. On desulfurization efforts, the capacity of heavy-oil desulfurizers installed at oil refineries increased from 509,000 BPSD in 1971 to 1,468,000 BPSD in 1998. As a result, an average sulfur content of heavy oil dropped from 2.6% in the pre-1966 days to 1.93% in 1970, 1.43% in 1973, and further to 1.05% in 1993 ("Yearbook of Resources and Energy, 1995/96 edition"). Flue gas desulfurizers (FGDs) introduced at energy-consuming stage increased from 102 units in 1970 to 2,249 units by 1995, with their combined capacity growing from 5.40 million km^3/h to 215.50 million km^3/h (Fig. 3-1). On the other hand, given the greater use of low-sulfur fuels, sulfur content of crude oil lowered from 2.03% in 1960 to 1.35% in 1996, and that of coal did from 1.06% to 0.60% over the same period (Table 3-2). Introduction of relevant laws to air quality protection is considered having significantly encouraged SO_2 control measures.

(2) The factors of less fossil fuel dependence and energy conservation alike began contributing to SO_2 reductions after the first oil crisis (1973). The efforts to become less dependent on fossil fuels have centered on the promotion of nuclear power development. Nuclear power, first introduced in 1966, increased its share in primary energy from 0.8% at the time of the first oil crisis to 5.2% at the second oil crisis (1979), and further to 15.6% in 1996. Energy conservation efforts have unfolded in the whole processes from energy production and transformation to final consumption, which sent energy intensity of GDP down from 1.41 in 1973 to 1.04 in 1996 (Table 2-1). Manu-

facturing achieved particularly remarkable progress in energy conservation, with energy use per production index shrinking from 100 in 1973 to 58.1 by 1996 ("Energy and Economy Statistical Handbook, 1999 edition"). The soaring energy prices, particularly oil, prompted the moves toward energy shifts and conservation, and thus helped the SO_2 reductions.

(3) The economic growth has consistently acted as a contributor to increasing SO_2 emissions.

As described above, air pollution kept worsening in Japan until the relevant laws to air quality protection were enacted, because few environmental measures had been in practice. Later, particularly after the first oil crisis, air pollution problems have been solved one after another thanks largely to comprehensive environmental measures, which centered on desulfurization efforts and included energy-related policies. Ranking of contributors to SO_2 reductions after the first oil crisis is put as follows: Desulfurization > energy conservation > less fossil fuel dependence > low-sulfur fuels.

3-2 China

Table 3-3 shows the analysis results on China. Following points were confirmed.

Table 3-1 Factor Analysis Results of Japan's SO2 Emissions

	Change in SO_2 emissions 1,000t	F1: Desulfurization	F2: Low-sulfur fuels	F3: Less fossil-dependence	F4: Energy conservation	F5: Economic growth	Factors total (F1 - F5)	Crossing items (Residual)
1960	-	-	-	-	-	-	-	-
1961	340	33.85	-61.10	-5.01	40.94	331.35	340.03	-0.03
1962	300	47.66	16.28	30.28	-37.84	243.72	300.10	-0.10
1963	500	48.43	-54.37	7.26	145.34	353.82	500.48	-0.48
1964	490	32.05	-7.42	23.66	45.41	396.56	490.26	-0.26
1965	450	49.83	32.63	-4.82	84.90	287.71	450.26	-0.26
1966	130	-346.66	-112.91	12.54	59.14	517.57	129.68	0.32
1967	5	-641.53	-182.42	60.67	244.21	524.44	5.37	-0.37
1968	-15	-376.97	-213.93	5.27	-12.80	582.97	-15.45	0.45
1969	-10	-507.89	-253.51	18.85	165.98	566.44	-10.13	0.13
1970	-12	-149.12	-365.66	-3.84	111.88	394.70	-12.04	0.04
1971	-78	-93.47	-180.95	-24.47	-22.07	242.94	-78.03	0.03
1972	-200	-242.45	-281.08	3.06	-96.55	416.87	-200.16	0.16
1973	-690	-959.96	-267.08	34.61	288.58	216.25	-687.60	-2.40
1974	-560	-558.10	26.69	-44.92	33.99	-17.67	-560.01	0.01
1975	-860	-636.97	-44.70	-21.61	-277.94	117.89	-863.32	3.32
1976	-490	-590.05	-26.81	-11.93	53.50	86.63	-488.66	-1.34
1977	-400	-441.45	-1.04	10.42	-51.55	84.12	-399.50	-0.50
1978	-200	-231.14	31.79	-34.32	-50.55	84.35	-199.87	-0.13
1979	-50	-107.67	9.56	-13.95	-11.95	74.04	-49.97	-0.03
1980	50	119.95	-15.37	-20.47	-72.02	37.85	49.95	0.05
1981	-100	-15.43	-37.13	-9.76	-80.42	42.71	-100.02	0.02
1982	-100	-57.70	-14.69	-17.23	-51.59	41.17	-100.03	0.03
1983	-200	-183.10	-4.52	-13.77	-28.69	29.98	-200.11	0.11
1984	-50	-100.75	-23.62	-3.88	35.12	43.18	-49.94	-0.06
1985	-20	88.42	-85.81	-25.02	-39.65	42.06	-20.00	0.00
1986	-110	-117.82	0.71	-4.37	-18.61	30.12	-109.98	-0.02
1987	-14	-51.34	38.38	-11.50	-31.96	42.42	-14.00	0.00
1988	-15	-60.11	-27.30	13.16	7.15	52.12	-14.99	-0.01
1989	-15	-43.45	-7.01	2.23	-5.20	38.43	-15.00	0.00
1990	0	0.10	-40.00	-5.11	-2.29	47.30	0.00	0.00
1991	0	4.83	-18.88	-5.27	-6.14	25.46	0.00	0.00
1992	0	-36.78	20.80	-0.14	12.82	3.32	0.00	0.00
1993	0	-18.11	26.42	-16.59	4.11	4.17	0.00	0.00
1994	0	-34.61	-8.06	1.14	35.87	5.66	0.00	0.00
1995	0	-31.49	18.95	-12.51	0.86	24.18	0.00	0.00
1996	0	-26.04	4.53	-1.85	-3.98	27.33	0.00	0.00
1961-66	2,210	-134.84	-186.88	63.90	337.90	2,130.72	2,210.80	-0.80
1967-73	-1,000	-2971.39	-1,744.62	94.15	679.22	2,944.62	-998.03	-1.97
1974-96	-3,134	-3128.82	-177.10	-247.23	-549.13	966.82	-3,135.46	1.46

(Note) Calculated from the data in Table 2-1.

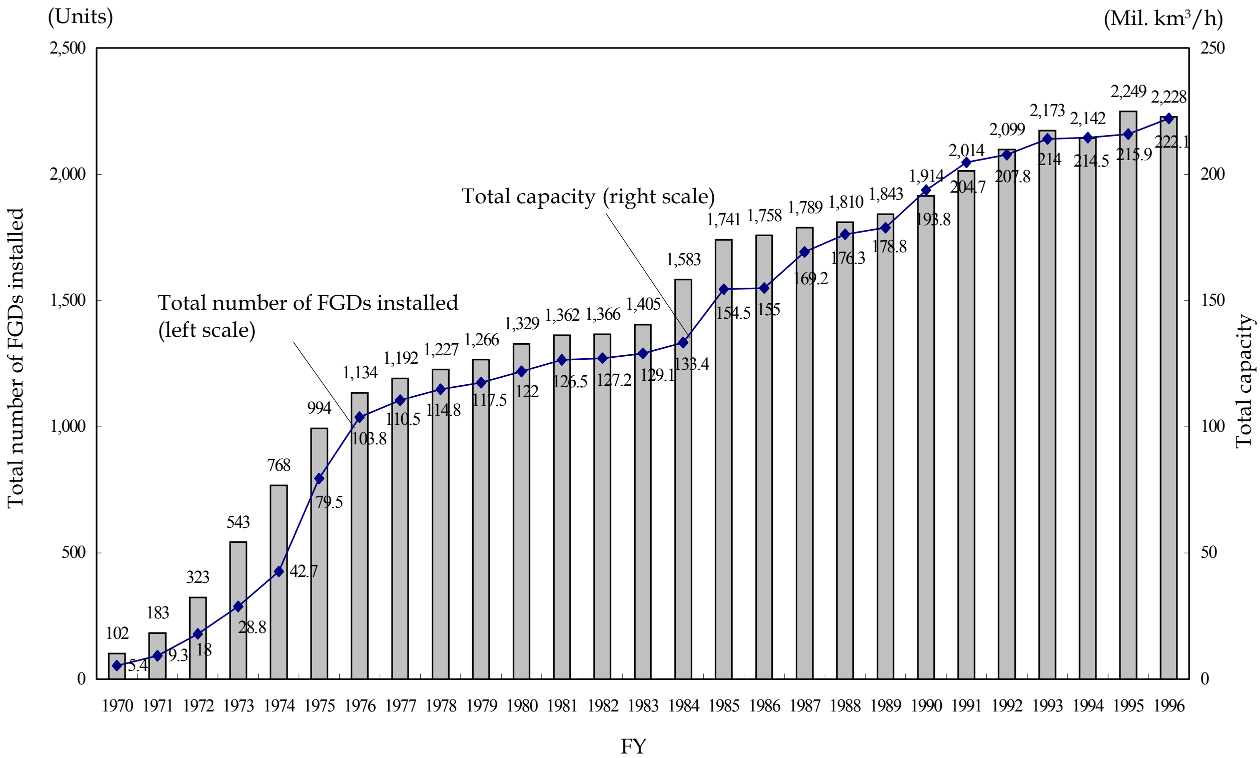
(1) The greater use of low-sulfur fossil fuels contributed to SO_2 reductions in the first half of the 1970s and during the 1990s. Less fossil fuel dependence also contributed to SO_2 reductions in the 1990s, and energy conservation did from the late 1970s onward. The greater use of low-sulfur fuels in the 1970s was attributable to oil and natural gas output increases that bolstered the policy to reduce coal dependence. The similar trend in the 1990s reflected consumers' spontaneous shifts from coal as a result of sharply growing oil demand. The factor of low-sulfur fuels contributed little during the 1980s, because China unrolled oil-to-coal shifts for domestic use in order to expand its oil exports as a hard-currency earner. Meanwhile, China became less dependent on fossil fuels in the 1990s, which mainly reflected stepped-up hydro and nuclear development in an effort to solve electricity shortage (Table 3-4). Energy conservation owed to technological advance resulting from reforms and opening, shifts in the economic structure, rising energy prices, greater imports of energy-intensive consumer goods, etc. (see Li, 1999, for instance). All of these effects are related to energy. In other words, we could not confirm any obvious effects of the enactment of the Environment Law (1979) and its amendment (1989).
(2) No effect of desulfurization was confirmed. This outcome can be best explained by our assumption that the desulfurization rate would be constant. Yet, given that the coal processing rate still remains at around 20%, and that FGD-equipped fossil-fired power plants amounted to a mere 1,145 MW (Wang, Shen, 1999) with their operating rate remaining low, among others, the outcome can be counted as reflecting the realities in China almost well.
(3) The economic growth acts consistently as a contributor to increasing SO_2 emissions.

As described above, in China, SO_2 emissions grew sharply by 1.45%/year, with GDP elasticity standing at 1.09, until 1979 when the Environment Law was enacted. It was because few environmental measures have been in practice. On the other hand, since 1979, the growth of SO_2 emissions has turned up to 4.73%/year, but GDP elasticity down to 0.47. The principal cause of the declines was improved efficiency. Ranking of contributors to SO_2 reductions is as follows: Energy conservation > low-sulfur fossil fuels > less fossil fuel dependence

3-3 Japan-China comparison

The analysis results-based comparison between Japan and China is summarized in Table 3-5. We can read out following characteristics.

Fig. 3-1 Flue Gas Desulfurizers Installed in Japan by Fiscal Year



(Note) Up to 1982, the figures are as of January 1, each fiscal year. From FY1983 onward, the figures are as of March 31, each fiscal year.
(Source) Environment Agency, "White Paper on Environment," 1998 edition.

Table 3-2 Japan's Primary Energy Mix and Sulfur Content

	Primary energy demand (1000TOE)								Sulfur content of primary energy (% per specific unit)			
	Coal	Oil	Natural gas	Fossil total	Hydro	Nuclear	Non-fossil total	Primary energy total	Oil	Domestic coal	Imported coal	Coal average
1960	47,515	29,108	643	77,266	5,031	0	5,029	82,295	2.03	1.12	0.72	1.06
1961	49,296	37,156	995	87,447	5,848	0	5,849	93,296	1.96	1.12	0.69	1.06
1962	47,470	45,228	1,260	93,958	5,366	0	5,366	99,324	2.01	1.12	0.69	1.06
1963	48,786	57,297	1,705	107,788	5,931	0	5,932	113,720	2.02	1.12	0.69	1.03
1964	50,007	68,620	1,855	120,482	5,914	0	5,914	126,396	2.02	1.12	0.68	1.03
1965	49,197	79,394	1,799	130,390	6,540	0	6,542	136,932	2.04	1.12	0.67	1.03
1966	52,510	92,514	1,881	146,905	6,824	156	6,980	153,885	1.99	1.12	0.67	1.01
1967	57,760	113,608	1,987	173,355	5,895	156	6,052	179,407	1.93	1.12	0.69	0.96
1968	59,553	132,810	2,129	194,492	6,317	261	6,578	201,070	1.82	1.12	0.70	0.95
1969	63,749	159,770	2,568	226,087	6,480	287	6,766	232,853	1.72	1.12	0.71	0.92
1970	61,618	185,426	3,049	250,093	6,484	1,199	7,683	257,776	1.57	1.12	0.72	0.90
1971	56,041	200,886	3,314	260,241	7,241	2,085	9,327	269,568	1.53	1.12	0.67	0.86
1972	54,742	220,206	3,444	278,392	7,319	2,476	9,794	288,186	1.44	1.12	0.65	0.82
1973	57,862	252,178	5,073	315,113	5,743	2,530	8,504	323,617	1.35	1.12	0.65	0.80
1974	61,516	244,469	6,721	312,706	7,110	5,134	12,330	325,036	1.37	1.12	0.68	0.79
1975	57,091	229,625	7,717	294,433	7,173	6,548	13,807	308,240	1.36	1.12	0.66	0.77
1976	56,498	245,412	9,070	310,980	7,189	8,881	16,243	327,223	1.35	1.12	0.64	0.76
1977	53,228	253,755	11,115	318,098	6,275	8,251	14,785	332,883	1.36	1.12	0.63	0.76
1978	46,576	255,754	15,667	317,997	6,024	15,457	21,996	339,993	1.42	1.13	0.62	0.74
1979	51,217	258,720	18,614	328,551	6,944	18,345	26,063	354,614	1.44	1.13	0.64	0.74
1980	59,556	235,649	21,396	316,601	7,593	21,524	29,890	346,491	1.43	1.13	0.66	0.75
1981	65,069	219,307	22,026	306,402	7,533	22,886	31,191	337,593	1.38	1.12	0.68	0.75
1982	64,303	213,153	22,733	300,189	7,018	26,694	34,806	334,995	1.37	1.11	0.67	0.74
1983	61,768	211,376	23,938	297,082	7,247	29,785	38,273	335,355	1.38	1.10	0.65	0.73
1984	69,576	216,284	32,521	318,381	6,159	34,990	42,315	360,696	1.38	1.10	0.64	0.71
1985	72,977	203,563	34,991	311,531	7,127	41,587	49,999	361,530	1.25	1.09	0.63	0.69
1986	69,000	209,327	35,495	313,822	6,950	43,861	52,002	365,824	1.26	1.07	0.62	0.68
1987	66,841	210,493	36,132	313,466	6,432	48,931	56,575	370,041	1.35	1.07	0.61	0.66
1988	73,637	228,596	37,553	339,786	7,765	46,560	55,494	395,280	1.30	1.02	0.61	0.65
1989	73,246	239,845	40,613	353,704	7,890	47,657	56,732	410,436	1.30	0.97	0.60	0.63
1990	74,002	252,925	43,263	370,190	7,680	52,713	61,890	432,080	1.23	0.92	0.60	0.62
1991	76,589	253,076	46,510	376,175	8,384	55,629	65,538	441,713	1.20	0.87	0.61	0.62
1992	75,229	260,613	47,264	383,106	7,099	58,183	66,819	449,925	1.24	0.82	0.61	0.62
1993	76,829	254,880	47,781	379,490	8,221	64,958	74,707	454,197	1.30	0.77	0.61	0.61
1994	78,755	268,513	51,167	398,435	5,785	70,136	77,816	476,251	1.29	0.72	0.60	0.61
1995	82,592	269,569	52,018	404,179	7,062	75,903	85,884	490,063	1.33	0.67	0.61	0.61
1996	84,643	273,527	56,056	414,226	6,925	78,755	89,082	503,308	1.35	0.62	0.60	0.60

	Share in primary energy demand (%)								Share in primary energy demand (%)			
	Coal	Oil	Natural gas	Fossil total	Hydro	Nuclear	Non-fossil total	Primary energy total	Coal	Oil	Natural gas	Fossil total
1960	57.7	35.4	0.8	93.9	6.1	0.0	6.1	100.0	61.5	37.7	0.8	100.0
1961	52.8	39.8	1.1	93.7	6.3	0.0	6.3	100.0	56.4	42.5	1.1	100.0
1962	47.8	45.5	1.3	94.6	5.4	0.0	5.4	100.0	50.5	48.1	1.3	100.0
1963	42.9	50.4	1.5	94.8	5.2	0.0	5.2	100.0	45.3	53.2	1.6	100.0
1964	39.6	54.3	1.5	95.3	4.7	0.0	4.7	100.0	41.5	57.0	1.5	100.0
1965	35.9	58.0	1.3	95.2	4.8	0.0	4.8	100.0	37.7	60.9	1.4	100.0
1966	34.1	60.1	1.2	95.5	4.4	0.1	4.5	100.0	35.7	63.0	1.3	100.0
1967	32.2	63.3	1.1	96.6	3.3	0.1	3.4	100.0	33.3	65.5	1.1	100.0
1968	29.6	66.1	1.1	96.7	3.1	0.1	3.3	100.0	30.6	68.3	1.1	100.0
1969	27.4	68.6	1.1	97.1	2.8	0.1	2.9	100.0	28.2	70.7	1.1	100.0
1970	23.9	71.9	1.2	97.0	2.5	0.5	3.0	100.0	24.6	74.1	1.2	100.0
1971	20.8	74.5	1.2	96.5	2.7	0.8	3.5	100.0	21.5	77.2	1.3	100.0
1972	19.0	76.4	1.2	96.6	2.5	0.9	3.4	100.0	19.7	79.1	1.2	100.0
1973	17.9	77.9	1.6	97.4	1.8	0.8	2.6	100.0	18.4	80.0	1.6	100.0
1974	18.9	75.2	2.1	96.2	2.2	1.6	3.8	100.0	19.7	78.2	2.1	100.0
1975	18.5	74.5	2.5	95.5	2.3	2.1	4.5	100.0	19.4	78.0	2.6	100.0
1976	17.3	75.0	2.8	95.0	2.2	2.7	5.0	100.0	18.2	78.9	2.9	100.0
1977	16.0	76.2	3.3	95.6	1.9	2.5	4.4	100.0	16.7	79.8	3.5	100.0
1978	13.7	75.2	4.6	93.5	1.8	4.5	6.5	100.0	14.6	80.4	4.9	100.0
1979	14.4	73.0	5.2	92.7	2.0	5.2	7.3	100.0	15.6	78.7	5.7	100.0
1980	17.2	68.0	6.2	91.4	2.2	6.2	8.6	100.0	18.8	74.4	6.8	100.0
1981	19.3	65.0	6.5	90.8	2.2	6.8	9.2	100.0	21.2	71.6	7.2	100.0
1982	19.2	63.6	6.8	89.6	2.1	8.0	10.4	100.0	21.4	71.0	7.6	100.0
1983	18.4	63.0	7.1	88.6	2.2	8.9	11.4	100.0	20.8	71.2	8.1	100.0
1984	19.3	60.0	9.0	88.3	1.7	9.7	11.7	100.0	21.9	67.9	10.2	100.0
1985	20.2	56.3	9.7	86.2	2.0	11.5	13.8	100.0	23.4	65.3	11.2	100.0
1986	18.9	57.2	9.7	85.8	1.9	12.0	14.2	100.0	22.0	66.7	11.3	100.0
1987	18.1	56.9	9.8	84.7	1.7	13.2	15.3	100.0	21.3	67.2	11.5	100.0
1988	18.6	57.8	9.5	86.0	2.0	11.8	14.0	100.0	21.7	67.3	11.1	100.0
1989	17.8	58.4	9.9	86.2	1.9	11.6	13.8	100.0	20.7	67.8	11.5	100.0
1990	17.1	58.5	10.0	85.7	1.8	12.2	14.3	100.0	20.0	68.3	11.7	100.0
1991	17.3	57.3	10.5	85.2	1.9	12.6	14.8	100.0	20.4	67.3	12.4	100.0
1992	16.7	57.9	10.5	85.1	1.6	12.9	14.9	100.0	19.6	68.0	12.3	100.0
1993	16.9	56.1	10.5	83.6	1.8	14.3	16.4	100.0	20.2	67.2	12.6	100.0
1994	16.5	56.4	10.7	83.7	1.2	14.7	16.3	100.0	19.8	67.4	12.8	100.0
1995	16.9	55.0	10.6	82.5	1.4	15.5	17.5	100.0	20.4	66.7	12.9	100.0
1996	16.8	54.3	11.1	82.3	1.4	15.6	17.7	100.0	20.4	66.0	13.5	100.0

(Notes)

1. Energy figures were calculated from the IEA, "Energy Statistics and Balances of OECD Countries, 1960-96," magnetic tape, 1998.
2. Sulfur contents were calculated from "Idemitsu Data Book on Petroleum" for oil, and from "Coal Note" for imported coal. Those of domestic coal were assumed in reference to relevant materials.

(1) Desulfurization acts consistently as the greatest contributor to SO_2 reductions in Japan, but its particular effect cannot be confirmed in China. Desulfurization efforts, mainly consisting of product desulfurization and flue gas desulfurization, form the core of Japan's SOx control measures, but their introduction has advanced little in China. Potentials of SO_2 reduction through desulfurization efforts are greater in China than in Japan.
(2) Low-sulfur fuels contributed to SO_2 reductions consistently in Japan, and during the 1970s and the 1990s in China. Shifts to non-fossil energies began contributing to SO_2 reductions after the first oil crisis in Japan, and since entering the 1990s in China. But, as of 1995, China's primary energy consumption mix consists of "coal 76.2% > oil 19.5% > natural gas 2.1% > hydro 1.8% > nuclear 0.4%," compared with that of Japan composed of "oil 54.3% > coal 16.8% > nuclear 15.6% > natural gas 11.1% > hydro 1.4%" (Tables 3-3 & 3-4). This means China has larger SO_2 reduction potentials than Japan if its energy mix is properly adjusted.
(3) Energy conservation has been a contributor to reducing SO_2 after the first oil crisis in Japan, and since around the late 1970s in China. But, the degree of contribution varied greatly between the two countries. This factor, ranking the second or third place in Japan, is the top contributor in China. However, it does not mean China is more energy efficient than Japan. The 1994 records show that China's energy efficiency remained at 60% of Japan's in terms of purchasing power parity equivalent GDP, and at 60-80% of Japan's on a material basis. Thus, energy conservation promises China greater SO_2 reduction potentials than Japan.

As discussed so far, in Japan, all factors but the economic growth, particularly desulfurization, have functioned as contributors to reducing SO_2 after the first oil crisis. As a result, Japan was able to cut SO_2 emissions effectively. On the contrary, in China, desulfurization little functioned as an emission cutter and the remaining factors contributed less than in Japan. On top of these, China's economic growth, much

Table 3-3 Factor Analysis Results of China's SO2 Emissions

	Change in SO_2 emissions 1,000t	F1: Desulfurization	F2: Low-sulfur fuels	F3: Less fossil-dependence	F4: Energy conservation	F5: Economic growth	Factors total (F1 - F5)	Crossing items (Residual)
1971	-	-	-	-	-	-	-	-
1972	338.30	0.00	-119.25	-4.67	202.51	259.74	338.33	-0.03
1973	150.93	-0.01	-164.12	-5.84	-227.44	548.10	150.70	0.23
1974	-28.28	0.01	-227.34	-9.10	42.80	165.38	-28.27	-0.01
1975	1,207.28	-0.05	63.57	10.23	479.82	655.57	1,209.13	-1.85
1976	89.77	0.01	-276.07	3.08	499.86	-137.23	89.65	0.12
1977	1,202.35	0.00	97.52	8.24	427.52	670.43	1,203.70	-1.35
1978	1,193.67	-0.01	49.81	18.53	-19.09	1,144.59	1,193.83	-0.16
1979	254.94	0.06	70.73	-10.83	-616.42	811.20	254.75	0.19
1980	-122.95	0.00	40.63	-20.52	-979.62	836.79	-122.71	-0.24
1981	-40.13	0.00	140.84	-20.08	-721.52	560.76	-40.00	-0.13
1982	568.15	-0.06	145.21	-14.68	-548.70	985.98	567.75	0.40
1983	657.53	0.01	75.15	-19.22	-633.41	1,234.21	656.74	0.79
1984	1,189.10	0.02	159.24	14.87	-804.26	1,817.30	1,187.18	1.92
1985	1,048.15	-0.02	58.85	1.24	-781.88	1,768.29	1,046.48	1.67
1986	868.41	0.06	-7.99	7.94	-391.53	1,259.44	867.93	0.48
1987	1,025.53	-0.02	17.12	1.67	-736.45	1,741.95	1,024.27	1.26
1988	1,023.72	-0.02	-1.49	-7.10	-777.86	1,808.92	1,022.44	1.28
1989	675.90	-0.03	-15.51	-12.09	-10.11	713.62	675.89	0.01
1990	355.10	0.05	85.36	-15.96	-396.01	681.61	355.05	0.05
1991	616.91	-0.03	-97.20	13.28	-950.33	1,650.38	616.10	0.81
1992	358.50	-0.02	-145.38	-6.51	-2,043.95	2,552.54	356.69	1.81
1993	1,049.52	0.06	-184.11	-44.70	-1,248.10	2,523.66	1,046.80	2.72
1994	1,568.51	-0.06	276.16	-83.33	-1,146.83	2,520.59	1,566.54	1.97
1995	1,650.74	0.03	58.42	-1.64	-689.18	2,281.98	1,649.61	1.13
1996	879.06	0.00	-192.83	14.97	-1,155.54	2,211.23	877.83	1.23
1972-78	4,154.02	-0.06	-575.89	20.47	1,405.97	3,306.57	4,157.07	-3.05
1979-88	6,472.45	0.03	698.29	-66.71	-6,991.63	12,824.86	6,464.84	7.61
1989-96	7,154.24	0.01	-215.09	-135.97	-7,640.05	15,135.61	7,144.50	9.74

(Note) Calculated from the data in Table 2-2.

Table 3-4China's Primary Energy Mix and Sulfur Content

	Primary energy demand (1000TOE)								Sulfur content of primary energy (% per specific unit)			
	Coal	Oil	Natural gas	Fossil total	Hydro	Nuclear	Non-fossil total	Primary energy total	Coal	Domestic oil	Imported oil	Oil average
1971	190,409	39,873	3,132	233,414	2,580	0	2,580	235,994	1.15	0.30		0.300
1972	199,276	45,929	4,054	249,260	2,924	0	2,924	252,184	1.15	0.30		0.300
1973	202,642	52,741	5,008	260,391	3,268	0	3,268	263,659	1.15	0.30		0.300
1974	200,667	60,644	6,305	267,616	3,698	0	3,698	271,314	1.15	0.30		0.300
1975	234,419	67,783	7,412	309,614	3,870	0	3,870	313,484	1.15	0.30		0.300
1976	235,391	79,363	8,458	323,213	3,922	0	3,922	327,134	1.15	0.30		0.300
1977	269,073	85,505	10,149	364,727	4,094	0	4,094	368,821	1.15	0.30		0.300
1978	302,284	93,614	11,479	407,378	3,836	0	3,836	411,213	1.15	0.30		0.300
1979	309,732	92,342	12,131	414,205	4,309	0	4,309	418,514	1.15	0.30		0.300
1980	306,557	89,654	11,960	408,170	5,006	0	5,006	413,176	1.15	0.30		0.300
1981	306,175	84,696	10,678	401,548	5,637	0	5,663	407,211	1.15	0.30		0.300
1982	322,689	84,143	9,999	416,831	6,398	0	6,427	423,257	1.15	0.30		0.300
1983	341,364	86,072	10,234	437,670	7,427	0	7,464	445,134	1.15	0.30		0.300
1984	375,311	88,292	10,577	474,179	7,463	0	7,529	481,709	1.15	0.30		0.300
1985	404,841	93,290	10,831	508,962	7,944	0	8,036	516,998	1.15	0.30		0.300
1986	429,034	99,155	11,526	539,716	8,130	0	8,230	547,946	1.15	0.30		0.300
1987	457,721	105,739	11,635	575,095	8,601	0	8,708	583,804	1.15	0.30		0.300
1988	486,268	112,833	11,945	611,047	9,387	0	9,513	620,560	1.15	0.30		0.300
1989	505,054	117,647	12,603	635,305	10,182	0	10,330	645,635	1.15	0.30		0.300
1990	515,414	116,534	12,800	644,748	10,898	0	11,056	655,805	1.15	0.30		0.300
1991	532,131	124,187	13,445	669,762	10,758	0	11,003	680,765	1.15	0.30		0.300
1992	541,355	132,545	13,625	687,524	11,286	0	11,531	699,055	1.15	0.30		0.300
1993	569,114	146,653	15,608	731,374	13,139	418	13,934	745,308	1.15	0.30	1.00	0.307
1994	614,745	146,138	16,346	777,229	14,470	3,624	17,918	795,146	1.15	0.30	1.00	0.300
1995	658,142	158,436	16,707	833,286	16,390	3,344	19,271	852,556	1.15	0.30	1.00	0.337
1996	678,978	173,422	18,724	871,125	16,165	3,737	19,593	890,718	1.15	0.30	1.00	0.365

	Share in primary energy demand (%)								Share in primary energy demand (%)			
	Coal	Oil	Natural gas	Fossil total	Hydro	Nuclear	Non-fossil total	Primary energy total	Coal	Oil	Natural gas	Fossil total
1971	80.7	16.9	1.3	98.9	1.1	0.0	1.1	100.0	81.6	17.1	1.3	100.0
1972	79.0	18.2	1.6	98.8	1.2	0.0	1.2	100.0	79.9	18.4	1.6	100.0
1973	76.9	20.0	1.9	98.8	1.2	0.0	1.2	100.0	77.8	20.3	1.9	100.0
1974	74.0	22.4	2.3	98.6	1.4	0.0	1.4	100.0	75.0	22.7	2.4	100.0
1975	74.8	21.6	2.4	98.8	1.2	0.0	1.2	100.0	75.7	21.9	2.4	100.0
1976	72.0	24.3	2.6	98.8	1.2	0.0	1.2	100.0	72.8	24.6	2.6	100.0
1977	73.0	23.2	2.8	98.9	1.1	0.0	1.1	100.0	73.8	23.4	2.8	100.0
1978	73.5	22.8	2.8	99.1	0.9	0.0	0.9	100.0	74.2	23.0	2.8	100.0
1979	74.0	22.1	2.9	99.0	1.0	0.0	1.0	100.0	74.8	22.3	2.9	100.0
1980	74.2	21.7	2.9	98.8	1.2	0.0	1.2	100.0	75.1	22.0	2.9	100.0
1981	75.2	20.8	2.6	98.6	1.4	0.0	1.4	100.0	76.2	21.1	2.7	100.0
1982	76.2	19.9	2.4	98.5	1.5	0.0	1.5	100.0	77.4	20.2	2.4	100.0
1983	76.7	19.3	2.3	98.3	1.7	0.0	1.7	100.0	78.0	19.7	2.3	100.0
1984	77.9	18.3	2.2	98.4	1.5	0.0	1.6	100.0	79.1	18.6	2.2	100.0
1985	78.3	18.0	2.1	98.4	1.5	0.0	1.6	100.0	79.5	18.3	2.1	100.0
1986	78.3	18.1	2.1	98.5	1.5	0.0	1.5	100.0	79.5	18.4	2.1	100.0
1987	78.4	18.1	2.0	98.5	1.5	0.0	1.5	100.0	79.6	18.4	2.0	100.0
1988	78.4	18.2	1.9	98.5	1.5	0.0	1.5	100.0	79.6	18.5	2.0	100.0
1989	78.2	18.2	2.0	98.4	1.6	0.0	1.6	100.0	79.5	18.5	2.0	100.0
1990	78.6	17.8	2.0	98.3	1.7	0.0	1.7	100.0	79.9	18.1	2.0	100.0
1991	78.2	18.2	2.0	98.4	1.6	0.0	1.6	100.0	79.5	18.5	2.0	100.0
1992	77.4	19.0	1.9	98.4	1.6	0.0	1.6	100.0	78.7	19.3	2.0	100.0
1993	76.4	19.7	2.1	98.1	1.8	0.1	1.9	100.0	77.8	20.1	2.1	100.0
1994	77.3	18.4	2.1	97.7	1.8	0.5	2.3	100.0	79.1	18.8	2.1	100.0
1995	77.2	18.6	2.0	97.7	1.9	0.4	2.3	100.0	79.0	19.0	2.0	100.0
1996	76.2	19.5	2.1	97.8	1.8	0.4	2.2	100.0	77.9	19.9	2.1	100.0

(Notes)
1. Energy figures were calculated from the IEA, "Energy Statistics and Balances of OECD Countries, 1960-96," magnetic tape, 1998.
2. Sulfur contents are on a reserve basis for coal, in terms of 1995 average for domestic crude oil, and estimated for imported crude oil.

Table 3-5 Contributors to SO2 Reductions in Japan and China

	Period	Contributors ranking	Laws, measures & other key moves (year)
Japan	1960-66	(1) Low-sulfur (2) Desulfurization	Air Pollution Control Law (APCL) enacted (`62); designated area system & concentration standards introduced, and Advisory Committee for Energy (ACE) formed (`65); nuclear & LNG introduction underscored, and 1st commercial nuclear power plant commissioned (`66)
	1967-73	(1) Desulfurization (2) Low-sulfur	Pollution Control Law enacted (`67) & amended (`70); APCL amended (`68 & `70); k-value total volume control introduced and tightened (8 times by `76); Low Sulfur Issues Working Group set within ACE (`69); Environment Agency established (`71); 1st oil crisis (`73)
	1974-96	(1) Desulfurization (2) Conservation (3) Less-fossil dependence (4) Low sulfur	APCL amended (`74); total volume control introduced (designated areas increased from 11 to 24 by `76); three power development-related laws enacted (`74); Oil Alternative Energy Law enacted (`80); Environment Basic Law enacted (`92); Energy Conservation Law amended (`98)
China	1971-78	(1) Low sulfur	1st National Conference on Environmental Protection (NCEP) held (`73); emissions standards for three industrial wastes introduced (`73); concentration standards.
	1979-88	(1) Conservation (2) Less-fossil dependence	Environment Law (tentative) enacted (`79); air quality standards set (`82); Environmental Protection Bureau (EPB) formed (`82); 2nd NCEP held (`83-`84); Air Quality Law (AQL) enacted (`87); EPB reorganized (`88)
	1989-96	(1) Conservation (2) Low-sulfur (3) Less-fossil dependence	3rd NCEP held(`89); detailed rules for AQL implementation set (`91); experimental dues collection from SO2 polluters initiated (`92); 1st nuclear power plant commissioned (`94); AQL amended without referring to total volume control (`95); 4th NCEP held and environmental protection plans for 2000 & 2010 made (`96); total volume control introduced, and designated areas for SOx & acid rain control introduced (`97); Energy Conservation Law enacted (`97)

Table 3-6 China-Japan-U.S. Tripartite Comparison in Energy Use

		China	Japan	US	China/Japan	China/US
Primary energy consumption (Mtoe)		795	477	1,977	166.7%	40.2%
Population (mil. persons)		1,199	124	261	966.9%	459.4%
Nominal GDP in terms of exchange rate (bill. US$)		553	4,617	6,625	12.0%	8.3%
Nominal GDP in terms of purchasing power parity (bill. PPP$)		2,979	2,807	6,625	106.1%	45.0%
Per capital consumption (toe/capital)		0.66	3.85	7.57	17.1%	8.7%
Per capital nominal GDP ($/capital):	In exchange rate terms	461	37,234	25,383	1.2%	1.8%
	In purchasing power parity terms	2,485	22,637	25,383	11.0%	9.8%
Nominal GDP output ($/toe):	In exchange rate terms	696	9,679	3,351	7.2%	20.8%
	In purchasing power parity terms	3,747	5,885	3,351	63.7%	111.8%
Exchange rate memos:		(CHN yen/$)	(yen/$)	($/$)	(yen/CHN yen)	($/CHN yen)
	Exchange rate	8.619	102.2	1	11.86	0.116
	Purchasing power parity	1.600	168.1	1	105.06	0.625

(Note) 1995 values were employed for purchasing power parity.
(Source) Zhi Dong Li, "Environmental Protection System of China" (1994/4)

Table 3-7 International Comparison of Energy Intensity of Material Production (1994)

	Energy intensity		China/abroad	
	China	Advanced levels abroad	Intensity ratio	Efficiency ratio
(1) Electricity use in coal production (kWh/t)	31.19	17.65 (US`92)	176.7%	56.6%
(2) Fuel use in fossil-fired power supply (gce/kWh)	414	332 (Japan`93)	124.7%	80.2%
(3) Energy use in steel production (kgce/t)	973	656 (Japan)	148.3%	67.4%
(4) Energy use in oil refining (kgce/t)	20.93	21.57 (Japan)	97.0%	103.1%
(5) Energy use in synthetic ammonia production (kgce/t)	1284	970 (US)	132.4%	75.5%
(6) Energy use in cement production (kgec/t)	193	117.3 (Japan)	164.5%	60.7%

(Notes) (1) China's figure is intensity in raw coal production at state-owned priority mines. (2) China's figure shows intensity at fossil-fired power plants of 6 MW or larger, while Japan's at electric utilities' plants. (3) China's figure is intensity recorded by priority firms. (4) The figure gained with the calculation method currently in use in China. (5) Large equipment designed to produce ammonia from natural gas. (6) China's figure is electricity use by large- and medium-sized firms in 1993.
(Source) Quoted from Zhi Dong Li, "Environmental Protection System of China" (1994/4), though the original texts are "A Study Report on Energy in China" written by Qing Yi Wang and "A Report on Energy Development in China 1997" edited by Chang Le Yan (1997/6).

higher than Japan's, made by far greater contribution to increasing SO_2 than the combined effect of SO_2-reducing factors. As a result, China was unable to reduce SO_2 emissions effectively.

4. Suggestions to China

How come Japan was more successful than China in solving SOx pollution? In other words, why SOx-reducing factors do not function in China so well as in Japan?

On the success of Japan, "Japan's Experience of Air Pollution" (The Ad Hoc Committee on Air Pollution Experience of Japan, 1997) puts that, Japan's success in the years to 1973 was attributable to the united efforts at public and private levels. The former included "the government's regulations and its guidance given to industry on the security of low-sulfur crude oil and well-planned introduction of heavy-oil desulfurizers, while the latter did technological development on flue gas desulfurizers, etc. and investments on pollution abatement. On the success from 1974 onward, the committee stated that, in addition to conventional measures, "rising energy prices in the post-oil crisis days encourage conservation efforts, and industrial structural shifts have accelerated from heavy chemical industries to machinery assembling, information, etc. These consequently contributed to reducing air pollution attributable to the industrial sector" (pp11-12). The committee's statement continued: "Behind the success, there were strenuous efforts made by various entities, on trial and error, while facing a dilemma between the pursuit of economic affluence and profits and the protection of sound environment. They included concerted actions by residents often led by those who were affected and pioneering commitments by municipal governments to protecting community people's health. Though belated a little, they were followed by the national government's moves to install effective systems to mitigate pollution, and corporate efforts to develop and introduce pollution abatement technologies" (p54). In specific terms: (1) Residents unfolded anti-pollution movements, which spurred pollution abatement efforts among local public organizations, the national government and private firms. (2) Some municipal governments were quicker than the national government in taking actions. They introduced the bylaws for environmental protection that reflected local conditions best, while responsible for environmental administration entrusted by the national government. (3) The national government established a comprehensive pollution control system, then introduced specific conditions that help effective implementation of comprehensive measures through administrative guidance, subsidies and so on. (4) Private firms committed to environmental measures, centering on environmental investments and technology development (pp54 - 77). In short, the key to the Japanese success is that different entities endeavored to fulfill their own roles society-wide.

The principal objective of this paper is to analyze a comprehensive policy on environment. In the following sections, therefore, we focus on the role of the national government as the entity responsible for policy-making. By reviewing environmental policies that the Japanese and Chinese governments are taking in their effort to mitigate SOx pollution, we try to produce some viable suggestions for China. While a comprehensive environmental policy contains manifold policy measures, we pick out only those on environmental regulation and energy-environment.

4-1 Policy on environmental regulation

Environmental regulations designed to lower atmospheric SO_2 concentrations include environmental standards, effluent concentration standards and emission standards applicable to a single source, total volume control applicable to total emissions in a given area, fuel-use regulations, mandatory introduction of desulfurizers and so on. The environmental standards show specific targets to be met, while the others provide the rules to help achieve the targets. The target-posting regulation is essential and unshakable, while the remaining measures-providing regulations have options. Air quality can deteriorate in either case where a single source produces SOx of low concentrations in large quantities, or where, though each in limited quantities, there are many SOx sources. This means that a quantitative regulation is more effective than regulating concentrations, and that a combined use of single-source emission standards and total volume control is most desirable. A quantitative regulation, if successfully introduced, could eliminate the need for a fuel-use regulation or mandatory introduction of desulfurizers. Because, in order to meet the quantitative regulation, individual sources have no choices but to take voluntarily some action, like energy conservation, energy switching, desulfurization, or a combination of these. Conversely, without a quantitative regulation, the mandatory introduction of desulfurizers could not work well. Not only few incentives for emissions reductions would function, but also the desulfurizers, even if introduced as many as regulated, could not necessarily warrant emissions reductions. In this sense, in preparing an environmental policy system to regulate SOx emissions, it is recommended to build the policy system on a quantitative regulation as its core.

In Japan, the concentration standards for designated areas were first introduced in 1962 under the "Law on the Regulation of Soot and Other Emissions." In 1968, when the "Air Pollution Control Law" was enacted, the concentration standards were replaced with the newly introduced emissions standards (so-called K-value standards). Later, the emissions standards were implemented nationwide under the Air Pollution Control Law as amended in 1970. In 1974, it was amended again, under which total volume control was applied to designated areas. By 1976, the emissions standards were tightened eight times, while the areas subject to total volume control were designated three times, with their numbers increased from initial 11 to 24 areas. SO_2 standards were set first in 1969, then strengthened in 1973. Among others, the fuel use regulation was introduced in 1971, and tightened in the following year.

On the other hand, China introduced emissions standards for "three industrial wastes (gaseous, liquid and solid)□@" in 1973, and enacted the Environmental Protection Law (tentative) in 1979 and the Air Pollution Control and Rehabilitation Law in 1987. These laws were amended in 1989 and 1995, respectively. Yet, the amended laws introduced only the concentration standards applicable to single sources, and did not call for a switchover from the concentration to emissions standards. Total volume control in a designated area (synonymous with applying emissions standards to all sources in the designated area) was introduced under the "9th five-year plan for the state environmental protection and long-range targets for 2010" prepared in 1996, and enforced in 1998. Air quality standards were set in 1982 and revised in 1996, though the revision did not cover SO_2. Within existing legal framework, no provisions directly require mandatory introduction of desulfurizers, but a general rule calls for the "three simultaneity" system (which demands every construction project to design, construct and operate pollution control facilities simultaneously with the main construction works). The "three simultaneity" system appears applicable to desulfurizers. That is, China has already required mandatory introduction, though indirectly.

Comparing Japan and China in SOx control measures, the two countries apparently have different policy systems from each other. Japan's system centers on emission standards, total volume control and fuel use regulations, while China depends largely on concentration standards and desulfurizers, with no quantitative and fuel regulations laid out. The absence of quantitative regulation is a defect of the Chinese environmental policy system. Despite the virtually mandatory requirement for desulfurizer introduction, desulfurization contributes little to SO_2 reductions in China. At least two reasons can be cited for the poor outcome. One is that the concentration standards could be met without desulfurizers. The other is few observed the indirectly mandatory requirement for desulfurizer introduction. Given the not-yet-attained SO_2 standards and the delays in FGD introduction and product desulfurization, the second reason can be blamed more for the present situations in China.

4-2 Energy-environment policy

Energy-environment policies effective in SOx reductions consist of those to encourage the greater use of lower-sulfur fossil fuels, the replacement of fossil energies with non-fossil ones, and energy conservation.

In Japan, a cabinet meeting approved SOx standards in February 1969. Three months later, the Advisory Committee for Energy, MITI, formed a working committee on how to spur the greater use of low-sulfur fuels. To encourage switching to non-fossil energies, Japan enacted in 1974, a year after the first oil crisis, three laws to prompt power development, particularly nuclear power generation. (They are: the Law for the Infrastructure Construction in the Vicinity of Power Stations, the Law for the Promotion of Power Source Development and the Law for Special Accounts for Power Source Development.) Then, the Law for the Promotion of Development and Introduction of Alternative Energies to Oil was enacted in 1980. In an attempt to stimulate energy conservation efforts, the Law on the Rationalization of Energy Use was introduced in 1979. It was in 1993 when two conservation-related laws were enforced, the Law for Upgrading Energy Supply and Demand Structure and the Law for Supporting Energy Conservation and Recycling, the latter amended in 1998 for tightening its provisions. Meanwhile, the two petroleum-related laws, the Law for the Establishment of Optimal Oil Supply and Demand Structure and the Provisional Law for the Stabilization of National Life, both enacted in December 1973 as emergency policy measures to overcome the first oil crisis, facilitated energy conservation moves.

China on its part has promoted energy conservation by enacting the Extraordinary Bylaws on Energy Conservation Management in 1986 and the Energy Conservation Law in 1997. Yet, China remains very lukewarm on the policies to promote the greater use of low-sulfur fossil fuels and/or switching to non-fossil energies. For example, the Air Pollution Control Law (1995) and the Coal Law (1996), both as amended, contain the provisions to limit the production and use of high-sulfur coals just in a vague language. Likewise, the 9th five-year plan and the long-range targets for 2010 prepared in 1996 called for "stepping up oil and gas exploration/development and challenging new energy development, while placing electricity in the center and coal as the foundation," thus hammering out a strategy that sounded like energy diversification. However, there were no straightforward wordings on reducing coal use, a crucial issue to solving environmental problems.

It is a defect of the Chinese energy-environment policy that the government fails to declare a clear-cut stance toward structural shifts in energy (to low-sulfur fossil energies and to non-fossil energies).

Conclusion

To be successful in keeping a strong economic growth and reducing SOx emissions simultaneously, all of the factors, including desulfurization, greater use of low-sulfur fuels, switching to non-fossil energies and energy conservation, must function well as contributors to SOx reductions. To that end, to establish a sound, comprehensive policy system on environment is requisite. While stepping up energy conservation measures, it will be top priorities for China to replace existing concentration standards with emissions standards, expand the designated areas subject to total volume control, take policy measures effective in reducing coal dependence, and prompt shifts to non-fossil energies.

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