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Efficient waste and pollution abatements for regions in Japan

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This paper computes efficient industrial waste and air pollutants abatements for 47 regions in Japan for the period 1992–2002. The variable-returns-to-scale (VRS) data envelopment analysis (DEA) with a single output (real GDP) and seven inputs (labor, real public capital stock, real private capital stock, industrial waste, sulfur oxide, nitrogen oxide, and soot and dust) is used to compute target wastes of each region for each year. The efficient abatement ratios of each region in each year are obtained by comparing the actual to the target amount of a pollutant. Our major findings are: (1) Most regions in Japan have significant room to reduce their pollution since there is a wide gap between efficient and inefficient regions; (2) For each air pollutant, approximately 25–33% of Japan's prefectures can reduce their output by more than 50% without harming regional GDP, and approximately one-third of prefectures can reduce industrial waste more than 30%; (3) Hokkaido is the least efficient region for all years studied and for all waste and pollutants, and target abatement ratios there drastically worsened in the last two sample years; (4) Tokyo, Saitama, Yamanashi, Shiga, Nara, and Tottori are efficient with respect to each type of industrial waste and pollution throughout the study period; (5) many regions in the bottom quartile with respect to real per capita income have significant room to reduce their waste and pollution output; and (6) many regions where energy-intensive industries dominate produce excessive amounts of waste and air pollution compared to other regions.

Keywords: data envelopment analysis; efficiency frontier; abatement targets; industrial waste; air pollution

Introduction

Economic activity often includes unintended by-products (pollution or waste) that affect human health and the environment. For sustainable development, production processes should be more efficient in their use of resources, labor, and capital, and should generate less pollution and waste. Japan is one country that faces serious waste problems. In 2005, industrial waste in Japan amounted to 422 million tons, and the amount recycled was 219 million tons. The volume of industrial waste has remained constant over the last several years, but the recycling rate has increased from 37.3% in 1995 to 51.3% in 2005. In the case of general waste, the amount produced in 2005 was 52 million tons, and the amount recycled was 10 million tons. The volume of general waste has been decreasing slightly since 2001, and the recycling rate increased from 9.9% in 1995 to 19.0% in 2005.

Establishing 'a sound material-cycle society' is an important issue in Japan. This concept was proposed by the Japanese Government in order to promote a recycling-based society and thereby pursue sustainable development. Although environmental policy has increased the recommended recycling rates, waste problems remain unsolved. In particular, illegal dumping and improper waste disposal are significant problems in Japan. In 2004, the remaining life of existing landfill sites for industrial waste was 7.2 years, and that for general waste was 13.2 years (MOE 2007a). Securing landfill sites is an urgent issue, especially for industrial waste. It is difficult to establish industrial waste disposal facilities due to public distrust created by improper disposal of such waste and the classical problem of not in my backyard (NIMBY). The shortage of disposal facilities contributes to illegal dumping and improper disposal, thereby creating a vicious circle. The 3R policy proposed by Japan's Ministry of the Environment (reduce generation of waste, *r*euse and recycle resources and products) should be implemented. It is especially important to reduce waste in the production process.

Levels of air pollution in Japan have improved in the past 30 years, except for a few areas in recent years. The country reduced sulfur oxide emissions by 82% and nitrogen oxide emissions by 22% in the 1970s and 1980s (OECD 2002, p. 23). In the 2000s, the achievement rate of the environmental quality standard (EQS) for SO_2 was approximately 99%, that of NO_2 was about 99%, and that of suspended particulate matter (SPM) ranged from 53% to 99% (MOE 2007b). Nevertheless, air pollution remains a challenge for Japan. Based on the recommendations of the Organisation for Economic Co-operation and Development (OECD) (2002), the Japanese Government should continuously reduce emissions of air pollutants from both mobile and stationary sources.

In recent years, chemical substances discharged into the environment and impacting human health have attracted widespread attention. For example, Kajihara et al. (2000) studied the aggregate cancer risk due to ambient benzene in Japan. They estimated the annual number of cancer deaths caused by benzene was 29.6 at 1997 levels. There has been more interest in chemical substances because of the associated health effects. In response to OECD recommendations in 1996, Japan established the Pollutant Release and Transfer

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Register (PRTR) system in 1999. By law, businesses must monitor the amounts of 354 chemical substances released into the air, water, and land or transferred to waste management facilities, and must submit reports to the government. The data have been published regularly since 2001. Toluene emitted from industry totaled 101,807 tons, xylene 43,920 tons, and dichloromethane 19,669 tons in 2006. These are the top three chemical substances in the PRTR every year.

To the best of our knowledge, the existing literature rarely incorporates all types of pollution and solid waste described above. Murakami and Matsuoka (2006) employed factor analysis to extract four governmental elements of capacity for urban air quality management using city-level panel data in Japan. These four elements are scientific knowledge, environmental policy resources, direct regulation, and financial assistance to polluting firms. They estimated the contribution of these elements to air quality. Kagawa et al. (2004) provided a multi-regional, input–output model for waste analysis that estimates intra- and inter-regional linkage effects of industrial wastes. They showed that household consumption in the Kanto and Kinki areas significantly affects industrial waste emissions and waste landfills in other regions, while the Chugoku and Shikoku areas produce waste-intensive goods and services for the other regions. Kondo and Nakamura (2005) developed a waste input–output linear programming model and studied two measures of eco-efficiency nationwide: the ratio of GDP to carbon dioxide emissions, and the ratio of GDP to landfill consumption by type of waste. They identified potential optimal waste management and recycling strategies and showed that neither of the two eco-efficiency measures is maximized in Japan.

Kajihara et al. (2000) estimated the number of excess cancer deaths due to benzene in Japan in 1997 in three regional categories: urban, suburban, and rural. Yamamoto and Nakai (2005) measured the recycling efficiency of Japan's municipal waste system in each region using the DEA technique, which is also used in the present paper. The DEA, was introduced by Charnes et al. (1978), and is a useful nonparametric method for evaluating the efficiency of decision-making units (DMU) such as firms, government agencies, hospitals, and schools. In their model, they the treat amount of recycled material as a desirable output and the amount of final disposal waste as an undesirable output. There are two differences between their model and that used here. First, we treat GDP as output and labor, capital, and other pollutants as inputs. Second, their model is an output-oriented DEA approach, whereas ours is an input-oriented approach.

Reducing pollution in the air, water, and soil, and reducing the production of solid waste benefit the environment and economy without reducing regional GDP. We indicate regional target ratios for efficient pollution and waste production that take into account Japan's own production frontier. We show that efficient abatements are possible using Japan's best available technology without harming economic performance. This paper analyzes target values of pollutants and waste for 47 regions in Japan using data envelopment analysis (DEA). Target amounts of pollutants and waste for each region in each year can be obtained from observed input and output in that year. They form the efficiency frontiers in each year, which represent best performance. The target emission abatement ratio in each region is derived from a total-factor framework. It indicates how much the region can reduce pollutants and waste without decreasing regional GDP.

Methods and data sources

Methodology of data envelopment analysis (DEA)

DEA is a mathematical programming method for assessing the comparative efficiencies of a DMU. In our study, a region is counted as a DMU. DEA is a non-parametric method that uses linear programming to construct a piecewise frontier over the data for efficiency measurement. DEA does not need to specify either the functional form of production or weighting factors for different inputs and outputs. Comprehensive reviews of the development of an efficiency measurement can be found in Lovell (1993). There are K inputs and M outputs for each of the N DMUs. The envelopment of the i-th DMU can be derived from the following linear programming problem:

$$\begin{aligned} & \mathrm{Min}_{\theta,\lambda} \quad \theta \\ \text{s.t.} \quad & -y_i + Y\lambda \geq 0, \\ & \theta x_i - X\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned} \tag{1}$$

where θ is a scalar representing the efficiency score for the i-th DMU, $N1$ is an $N \times 1$ vector of ones, λ is an $N \times 1$ vector of constants, y_i is an $M \times 1$ output vector of DMU i, Y is an $M \times N$ output matrix constituted by all output vectors of these N DMUs, x_i is a $K \times 1$ input vector of DMU i, and X is a $K \times N$ input matrix constituted by all input vectors of these N DMUs. The efficiency score will satisfy $0 \leq \theta \leq 1$, with a value of 1 indicating a point on the frontier and, hence, a technically efficient DMU (Coelli et al. 1998).

The above procedure constructs a piecewise linear approximation to the frontier by minimizing quantities of the K inputs required to meet the output levels of the i-th DMU. The weight λ serves to form a convex combination of observed inputs and outputs. It is an input-oriented measurement of efficiency. Equation (1) is known as the variable returns to scale (VRS) DEA model (Banker et al. 1984). This model calculates the pure technical efficiency (PTE) of each DMU. In order to control for the differences caused by the scales of each region, this study adopts the VRS DEA model. Although the DEA approach was originally intended for use in microeconomic environments to measure the performance of institutions such as schools and hospitals, it is also ideally suited to macroeconomic performance analysis.

In this study, we treat air emissions as proxies for the cost of environmental goods used for production (Oates and

Schwab 1988; López 1994; Smulders 1999; de Bruyn 2000), such as health problems caused, corrosion of industrial equipment due to polluted air, and other related social expenses. The existing literature computes efficient targets of pollution abatement ratios by constructing the efficiency frontier of regions in an economy. For example, Hu (2006) used three air emissions as inputs to compute efficient air pollution abatement ratios for regions in China. Hu and Lee (2008) found target waste abatement values for three forms of waste (air, solid, and water) for different regions in China. Hu (2006) and Hu and Lee (2008) constructed a total-factor pollution abatement ratio index to compute how far away a region's emissions are from the most efficient level. The higher the saving ratio, the lower the total-factor efficiency will be.

$$\text{Target emission abatement ratio}_{k(i,t)} = 1 - \text{Target emission}_{k(i,t)}/\text{Actual emission}_{k(i,t)} \quad (2)$$

for the *i*-th region and the *t*-th year for the *k*-th emission. As Equation (2) shows, the saving ratio represents how far away a region's three major types of energy are from their most efficient levels. The efficiency targets of energy-saving ratios for each region in each year are then obtained by dividing the target energy consumption by the actual energy consumption. The actual value is always larger than or equal to the target value, such that the saving ratio will always be between 0 and 1.

Data sources

Regional GDP is the sole output. Since the data on private and public capital stocks are unavailable, the data estimated in Fukao and Yue (2000) are extended. Our extension method of real public and private capital stocks is similar to that used by Honma and Hu (2008). Data on prefectural real GDP and labor (employed persons) are taken from the *Annual Report on Prefectural Accounts* published by the Cabinet Office (2006). All monetary values are adjusted to market prices for the calendar year 1995.

In Japan, wastes are classified into two categories: general (non-industrial) and industrial wastes. The latter is more appropriate for our research aim. The *Waste Disposal and Public Cleansing Law* defines 20 types of wastes produced by business activities. They are measured in the *Survey on Discharge and Disposal of Industrial Waste* (MOE 2007c). For waste and air pollution, earlier data before those published on the Web and in books were obtained directly from the Japanese Ministry of the Environment. Data on the amounts of three air pollutants – sulfur oxide, nitrogen oxides, and soot and dust – are from MOE (2007d); these pollutants are emitted from stationary sources such as factories, electric power plants, and incineration sites. They do not include mobile emission sources such as vehicles. Emissions from stationary sources have been investigated triennially in Japan since 1996, although they were previously investigated every year. Data on air pollutants in 1997, 1998, 2000, and 2001 are missing; as a result, our dataset includes the period from 1992 to 1996, 1999, and 2002. Summary statistics of these inputs and output are shown in Tables 1 and 2.

Table 1. Summary statistics of inputs and outputs.

	Mean	Standard deviation	Minimum	Maximum
Inputs				
Employed persons (no.)	1,376,126	1,468,477	315,916	8,782,396
Private capital stock (billion yen)	20,395	24,296	3,015	165,961
Public capital stock (billion yen)	14,748	12,800	3,771	82,142
Industrial waste (t)	8,508,470	7,301,079	1,365,929	40,200,391
Sulfur oxides (t)	13,501	13,348	696	98,097
Nitrogen oxides (t)	16,849	14,679	717	68,610
Soot and dust (t)	1,810	1,564	97	9,881
Output				
Real GDP(billion yen)	10,651	13,583	2,001	87,104

Note: Monetary values are in 1995 prices.

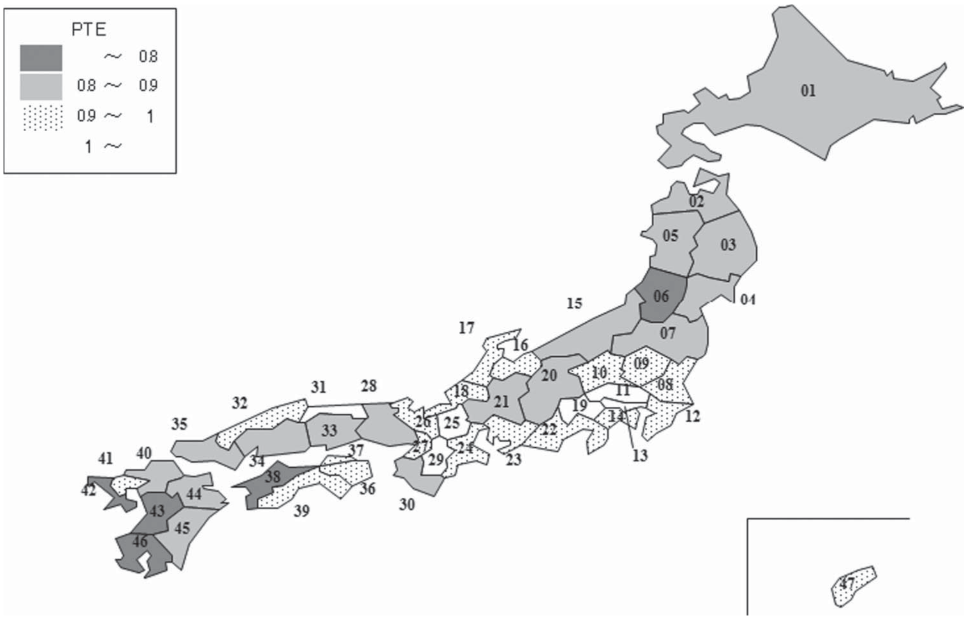
There are seven inputs and one output in our DEA model. The seven inputs are three production factors (private capital stock, public capital stock, labor) and four waste and pollution factors (industrial waste, sulfur oxide, nitrogen oxides, and soot and dust). These four waste and pollutant factors are treated as inputs because they are aggregated proxies that capture the cost of production. Pollution and wastes that degrade the environment exact a cost on society; therefore, the macroeconomic performance of each region is evaluated on the basis of the ability not only to maximize GDP but also to minimize pollution and waste. Summary statistics of these inputs and output are shown in Tables 1 and 2, respectively.

Empirical results

After DEA computation, the PTE scores for the administrative regions in Japan are given in Figure 1. Because data on atmospheric pollution emitted from fixed sources are lacking for certain years, our results are from 1992 to 1996, 1999, and 2002. The regional target abatement ratios of industrial waste, sulfur oxide, nitrogen oxides,

Table 2. Correlation coefficients between inputs and the output.

Inputs	Employed persons	Private capital stock	Public capital stock	Industrial waste	SOX	NOX	Soot and dust
Real GDP	0.994	0.985	0.890	0.764	0.068	0.183	0.191



Hokkaido area
- 01 Hokkaido

Tohoku area
- 02 Aomori
- 03 Iwate
- 04 Miyagi
- 05 Akita
- 06 Yamagata
- 07 Fukushima

Kanto area
- 08 Ibaraki
- 09 Tochigi
- 10 Gunma
- 11 Saitama
- 12 Chiba
- 13 Tokyo
- 14 Kanagawa

Chubu area
- 15 Niigata
- 16 Toyama
- 17 Ishikawa
- 18 Fukui
- 19 Yamanashi
- 20 Nagano
- 21 Gifu
- 22 Shizuoka
- 23 Aichi

Kinki area
- 24 Mie
- 25 Shiga
- 26 Kyoto
- 27 Osaka
- 28 Hyogo
- 29 Nara
- 30 Wakayama

Chugoku area
- 31 Tottori
- 32 Shimane
- 33 Okayama
- 34 Hiroshima
- 35 Yamaguchi

Shikoku area
- 36 Tokushima
- 37 Kagawa
- 38 Ehime
- 39 Kouchi

Kyushu area
- 40 Fukuoka
- 41 Saga
- 42 Nagasaki
- 43 Kumamoto
- 44 Oita
- 45 Miyazaki
- 46 Kagoshima
- 47 Okinawa

Figure 1. Geographic distribution of efficient and inefficient regions in Japan.
Note: Higher score on pure technical efficiency (PTE) means higher efficiency.

and soot and dust during the sample periods are shown in Tables 3–6. Six regions (Saitama (11), Tokyo (13), Yamanashi (19), Shiga (25), Nara (29), and Tottori (31)) have zero target abatement ratios for all years of the study and for all types of waste and pollutants. These regions operate on Japan's efficient frontier in each year, so they cannot improve their waste efficiency without reducing GDP.

Industrial waste

Table 3 and Figure 2 describe the average industrial waste produced abatement ratios in each region and area, respectively. There are 13 regions where the target abatement ratios for industrial waste production remained higher than 30% throughout the study period. In particular, Hokkaido (01), Iwate (03), Chiba (12), Hyogo (28), Miyazaki (45),

Table 3. Actual emissions and target abatement ratios of industrial waste for regions in Japan.

			1992		1993		1994		1995		1996		1999		2002	
ID	Region	Area	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (t)	Abatement ratio
01	Hokkaido	A	30,737,551	0.56	33,524,014	0.65	35,446,833	0.66	35,074,863	0.66	34,888,326	0.65	37,313,701	0.76	40,200,391	0.84
02	Aomori	B	4,629,991	0.23	4,264,412	0.15	4,261,874	0.14	4,208,111	0.52	4,413,986	0.53	4,501,257	0.59	4,950,322	0.65
03	Iwate	B	6,263,261	0.47	7,162,964	0.56	7,739,240	0.53	6,061,819	0.65	6,085,297	0.64	7,119,148	0.72	6,919,338	0.73
04	Miyagi	B	7,771,055	0.32	7,664,962	0.46	7,076,049	0.44	6,928,100	0.43	7,081,572	0.39	7,119,630	0.58	8,031,070	0.57
05	Akita	B	3,338,766	0.21	3,250,741	0.41	3,271,400	0.41	3,182,673	0.36	3,932,198	0.49	3,830,249	0.33	3,377,233	0.19
06	Yamagata	B	3,810,010	0.21	3,577,211	0.45	3,788,299	0.49	3,746,254	0.49	3,789,329	0.48	3,871,359	0.37	3,537,578	0.26
07	Fukushima	B	6,843,508	0.22	6,892,369	0.33	7,445,870	0.39	7,508,666	0.40	7,619,430	0.39	8,540,556	0.52	7,862,755	0.46
08	Ibaraki	C	12,172,378	0.39	11,523,567	0.44	11,410,089	0.42	11,093,159	0.41	11,612,894	0.42	11,288,740	0.59	10,656,520	0.59
09	Tochigi	C	8,065,788	0.41	6,911,945	0.42	6,726,179	0.45	6,378,010	0.42	6,679,542	**0.00**	7,359,734	0.42	7,443,443	0.43
10	Gunma	C	7,820,168	0.46	6,336,677	**0.00**	6,498,321	***0.00***	6,293,229	**0.00**	8,467,023	0.60	7,197,481	0.47	6,911,180	0.56
11	Saitama	C	15,467,150	**0.00**	13,019,399	**0.00**	12,640,636	**0.00**	12,273,992	**0.00**	12,545,880	**0.00**	12,913,544	**0.00**	12,585,196	**0.00**
12	Chiba	C	18,719,956	0.46	18,196,668	0.49	20,237,152	0.55	19,348,584	0.53	19,863,036	0.54	27,842,096	0.75	26,525,999	0.76
13	Tokyo	C	33,032,318	**0.00**	29,513,977	**0.00**	27,536,478	**0.00**	27,334,195	**0.00**	29,548,254	**0.00**	27,288,787	**0.00**	26,190,148	**0.00**
14	Kanagawa	C	21,439,265	**0.00**	25,676,015	0.52	22,911,411	0.46	22,758,419	**0.00**	23,480,180	**0.00**	23,600,654	0.51	16,353,511	0.33
15	Niigata	D	8,039,042	0.18	8,503,563	0.31	7,874,486	0.26	8,103,862	0.30	8,621,046	0.33	7,921,799	0.60	7,513,739	0.44
16	Toyama	D	4,061,894	0.11	5,283,810	0.36	5,903,100	0.45	6,003,268	0.47	6,045,910	0.46	4,823,955	0.33	4,678,024	0.35
17	Ishikawa	D	2,703,737	0.03	3,989,490	0.20	3,005,866	0.37	3,011,796	0.34	3,155,969	0.33	3,108,093	0.18	3,052,058	0.29
18	Fukui	D	2,351,923	**0.00**	1,489,463	**0.00**	1,877,257	**0.00**	2,865,972	0.08	3,041,204	0.05	2,982,700	0.14	2,975,738	0.14
19	Yamanashi	D	2,083,066	**0.00**	2,082,415	**0.00**	2,272,109	**0.00**	2,154,087	**0.00**	2,134,205	**0.00**	1,939,538	**0.00**	1,770,060	**0.00**
20	Nagano	D	6,392,178	0.31	4,870,963	0.38	5,168,164	0.35	5,254,078	0.29	5,454,294	0.30	5,148,415	0.41	4,751,730	0.30
21	Gifu	D	6,900,248	0.25	6,842,948	0.44	6,877,910	0.50	6,621,937	0.46	6,027,372	0.36	5,735,048	0.52	5,100,514	0.50
22	Shizuoka	D	13,039,379	0.34	11,021,199	0.30	11,534,549	0.50	11,145,275	0.38	10,589,989	0.31	11,379,521	0.31	11,348,102	0.33
23	Aichi	D	24,467,569	0.42	10,270,882	**0.00**	15,174,896	0.22	15,213,827	0.21	15,872,419	0.17	17,046,623	0.28	18,292,526	0.35
24	Mie	E	5,938,267	0.13	2,868,862	0.08	3,075,081	0.09	2,816,785	0.06	5,129,561	0.18	4,773,851	0.48	5,521,113	0.39
25	Shiga	E	4,305,645	**0.00**	3,726,252	**0.00**	3,492,788	**0.00**	3,383,938	**0.00**	3,522,403	**0.00**	3,857,510	**0.00**	3,515,937	**0.00**
26	Kyoto	E	5,955,011	0.15	7,036,627	0.39	7,382,779	0.46	6,547,150	0.43	6,789,389	0.43	5,922,633	0.37	6,292,072	0.45
27	Osaka	E	25,046,132	**0.00**	20,160,247	**0.00**	20,074,529	0.29	19,189,994	0.27	19,682,800	0.23	17,086,265	0.19	14,922,764	0.17
28	Hyogo	E	18,092,495	0.46	18,863,604	0.53	17,679,063	0.54	19,384,093	0.58	20,796,716	0.58	16,959,125	0.53	16,311,307	0.56
29	Nara	E	2,447,223	**0.00**	1,454,058	**0.00**	1,501,272	**0.00**	1,523,516	**0.00**	1,594,584	**0.00**	1,365,929	**0.00**	1,509,315	**0.00**
30	Wakayama	E	2,769,819	0.09	5,618,258	0.48	5,699,388	0.50	6,187,461	0.54	5,044,033	0.42	4,217,041	0.39	3,799,690	0.33
31	Tottori	F	1,903,293	**0.00**	2,442,057	**0.00**	2,509,719	**0.00**	2,542,354	**0.00**	2,594,692	**0.00**	1,876,444	**0.00**	2,052,912	**0.00**
32	Shimane	F	2,485,666	0.22	3,874,890	0.44	3,501,033	0.31	2,237,079	0.01	2,333,448	0.04	2,268,381	0.08	2,140,614	0.06
33	Okayama	F	7,637,232	0.34	10,819,728	0.60	10,976,451	0.63	10,977,901	0.64	11,258,757	0.64	7,985,259	0.45	8,208,583	0.52

34	Hiroshima	F	9,112,815	0.26	12,687,328	0.53	13,330,946	0.57	7,620,056	0.25	7,637,660	0.24	7,593,212	0.38	8,308,906	0.42
35	Yamaguchi	F	5,949,424	0.26	6,007,177	0.37	7,908,936	0.55	7,855,864	0.57	7,665,599	0.55	7,980,131	0.52	9,995,491	0.65
36	Tokushima	G	2,262,516	0.07	2,322,369	0.06	2,491,045	0.07	2,512,662	0.06	2,719,473	0.06	2,440,858	0.12	2,233,162	0.03
37	Kagawa	G	3,488,233	0.13	3,142,460	0.07	3,218,629	0.08	3,071,002	0.05	3,213,495	0.06	2,641,407	**0.00**	2,485,442	**0.00**
38	Ehime	G	5,392,241	0.31	9,427,223	0.68	9,353,202	0.70	9,771,540	0.72	10,092,006	0.73	11,401,330	0.72	11,353,771	0.73
39	Kouchi	G	1,755,618	**0.00**	1,981,816	0.01	1,938,295	**0.00**	1,910,388	**0.00**	2,079,109	**0.00**	1,747,161	0.03	1,681,979	**0.00**
40	Fukuoka	H	13,149,633	0.34	13,504,876	0.41	13,647,469	0.43	13,596,453	0.45	14,271,519	0.42	9,484,150	0.36	10,867,015	0.36
41	Saga	H	2,756,109	0.21	2,961,823	0.09	3,051,271	0.33	2,943,290	**0.00**	3,430,536	**0.00**	3,448,488	0.34	3,251,952	0.44
42	Nagasaki	H	4,146,452	0.22	3,593,753	0.34	3,763,213	0.40	3,738,275	0.42	3,797,916	0.42	4,862,818	0.53	4,808,542	0.48
43	Kumamoto	H	5,788,672	0.35	6,311,684	0.60	6,907,865	0.64	6,888,158	0.64	6,838,251	0.60	6,754,040	0.67	6,813,925	0.63
44	Oita	H	4,812,434	0.29	5,265,917	0.38	5,219,254	0.40	5,072,961	0.39	5,357,783	0.41	3,574,085	0.09	4,067,622	0.25
45	Miyazaki	H	6,046,949	0.54	6,451,221	0.54	7,048,976	0.63	6,910,842	0.64	6,983,800	0.67	7,390,011	0.68	8,012,979	0.68
46	Kagoshima	H	8,865,614	0.55	9,304,451	0.73	11,095,234	0.74	10,707,718	0.77	8,991,414	0.73	10,631,579	0.81	10,523,780	0.81
47	Okinawa	H	3,222,788	0.13	5,173,128	0.38	3,909,921	0.19	3,858,319	0.53	3,847,241	0.51	3,677,529	0.60	3,530,665	0.54

Notes: 1. Actual emissions are in tons.
2. Abatement ratios are percentages terms.
3. Notations of areas are as follows: A, Hokkaido; B, Tohoku; C, Kanto; D, Chubu; E, Kinki; F, Chugoku; G, Shikoku; H, Kyushu.

Table 4. Actual emissions and target abatement ratios of SOX for regions in Japan.

			1992		1993		1994		1995		1996		1999		2002	
ID	Region	Area	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio
01	Hokkaido	A	75,034	0.90	69,774	0.90	65,049	0.93	77,143	0.90	88,757	0.92	98,097	0.96	70,930	0.98
02	Aomori	B	9,506	0.44	7,457	0.48	8,423	0.41	8,586	0.80	7,737	0.79	6,749	0.80	8,671	0.91
03	Iwate	B	4,586	0.22	3,806	0.19	5,589	0.17	9,903	0.82	6,617	0.74	5,443	0.74	6,482	0.84
04	Miyagi	B	6,760	0.15	5,080	0.14	5,014	0.14	5,989	0.15	6,894	0.47	10,920	0.89	9,884	0.74
05	Akita	B	9,203	0.72	6,880	0.68	8,354	0.66	8,723	0.61	8,243	0.76	9,320	0.67	7,273	0.55
06	Yamagata	B	5,069	0.24	3,366	0.30	3,511	0.22	4,389	0.22	4,428.57	0.55	5,666	0.62	4,531	0.32
07	Fukushima	B	21,474	0.63	19,620	0.65	23,437	0.65	27,571	0.61	25,220	0.80	36,114	0.88	35,184	0.85
08	Ibaraki	C	44,066	0.82	35,480	0.81	47,109	0.85	41,497	0.76	36,234	0.84	30,434	0.92	30,981	0.96
09	Tochigi	C	7,726	0.10	5,251	0.05	5,786	0.04	7,791	0.03	7,417	**0.00**	5,374	0.22	9,172	0.44
10	Gunma	C	6,491	0.12	4,680	**0.00**	8,477	**0.00**	7,374	**0.00**	4,866	0.53	6,091	0.65	5,425	0.61
11	Saitama	C	7,726	**0.00**	6,806	0.00	4,231	**0.00**	7,191	**0.00**	7,877	**0.00**	8,974	**0.00**	4,940	**0.00**
12	Chiba	C	29,674	0.73	29,743	0.77	30,969	0.78	27,337	0.66	24,920	0.77	27,534	0.91	33,381	0.96
13	Tokyo	C	7,729	**0.00**	7,274	**0.00**	5,680	**0.00**	6,009	0.00	5,186	0.00	2,994	**0.00**	2,399	**0.00**
14	Kanagawa	C	9,749	**0.00**	6,031	0.36	9,386	0.58	5,363	**0.00**	5,989	0.00	6,429	0.51	5,591	0.65
15	Niigata	D	22,840	0.68	20,851	0.67	23,103	0.68	30,166	0.66	24,654	0.77	20,669	0.94	22,643	0.81
16	Toyama	D	10,826	0.34	9,689	0.37	9,554	0.20	10,271	0.15	12,234	0.68	7,294	0.39	7,284	0.45
17	Ishikawa	D	4,423	0.50	4,109	0.07	4,397	0.57	5,989	0.50	5,846	0.66	7,083	0.69	5,955	0.65
18	Fukui	D	6,931	**0.00**	5,240	**0.00**	5,760	**0.00**	6,191	0.30	5,537	0.49	5,943	0.54	6,397	0.56
19	Yamanashi	D	2,231	**0.00**	1,274	**0.00**	849	0.00	1,886	0.00	1,191	**0.00**	877	**0.00**	1,255	0.00
20	Nagano	D	6,660	0.63	3,683	0.63	4,631	0.54	8,643	0.53	7,066	0.66	6,174	0.76	4,963	0.55
21	Gifu	D	11,080	0.57	8,149	0.59	7,594	0.67	10,729	0.61	11,651	0.72	7,623	0.81	10,373	0.93
22	Shizuoka	D	11,171	0.36	10,780	0.39	9,871	0.67	12,580	0.37	9,926	0.53	10,789	0.41	9,236	0.46
23	Aichi	D	30,980	0.75	29,677	**0.00**	25,200	0.70	24,100	0.61	23,271	0.79	21,011	0.77	17,631	0.76
24	Mie	E	18,720	0.58	12,691	0.90	11,809	0.85	19,434	0.91	14,731	0.69	10,743	0.89	9,060	0.63
25	Shiga	E	7,940	**0.00**	6,923	**0.00**	8,506	**0.00**	11,271	**0.00**	4,846	0.00	5,920	**0.00**	5,270	0.00
26	Kyoto	E	3,129	0.02	3,131	0.02	3,114	0.02	3,589	0.04	3,277	0.37	2,397	0.09	2,334	0.36
27	Osaka	E	4,717	**0.00**	2,797	**0.00**	3,389	0.08	4,189	0.08	3,831	0.07	3,931	0.28	2,453	0.11
28	Hyogo	E	15,646	0.50	16,900	0.59	23,860	0.67	16,131	0.37	17,091	0.71	12,271	0.56	14,247	0.66
29	Nara	E	1,366	**0.00**	1,000	**0.00**	1,240	**0.00**	1,491	**0.00**	1,340	**0.00**	1,043	**0.00**	696	0.00
30	Wakayama	E	12,209	0.61	11,103	0.55	13,623	0.52	14,426	0.63	13,783	0.79	13,906	0.80	8,968	0.69
31	Tottori	F	4,994	**0.00**	3,737	**0.00**	5,409	0.00	2,014	**0.00**	1,860	**0.00**	1,063	**0.00**	1,466	0.00

32	Shimane	F	3,637	0.04	2,663	0.04	3,574	0.05	2,754	0.31	2,923	0.35	3,400	0.53	6,180	0.76
33	Okayama	F	16,903	0.53	16,149	0.57	16,023	0.47	17,477	0.36	18,346	0.74	18,291	0.68	15,840	0.67
34	Hiroshima	F	25,937	0.69	26,340	0.74	27,040	0.71	24,911	0.58	24,909	0.79	24,269	0.85	22,591	0.80
35	Yamaguchi	F	31,269	0.75	31,371	0.78	39,146	0.78	26,800	0.58	27,131	0.83	24,803	0.77	23,349	0.78
36	Tokushima	G	6,643	0.20	8,291	0.61	7,063	0.30	7,551	0.70	5,997	0.66	5,029	0.65	7,186	0.75
37	Kagawa	G	13,011	0.51	11,963	0.59	12,257	0.44	14,174	0.55	16,260	0.80	15,251	**0.00**	12,361	**0.00**
38	Ehime	G	20,157	0.65	19,586	0.75	19,743	0.70	33,666	0.79	33,231	0.91	22,426	0.80	25,158	0.83
39	Kouchi	G	2,877	**0.00**	2,643	0.01	2,717	**0.00**	2,983	0.00	2,729	0.00	3,134	0.66	1,832	**0.00**
40	Fukuoka	H	17,446	0.55	16,726	0.58	13,637	0.44	10,486	0.18	7,440	0.27	11,391	0.85	11,444	0.58
41	Saga	H	4,863	0.12	4,183	0.08	4,380	0.21	3,091	**0.00**	3,511	**0.00**	3,791	0.53	3,256	0.63
42	Nagasaki	H	21,560	0.83	19,000	0.84	20,297	0.84	17,763	0.77	18,254	0.88	21,506	0.87	16,572	0.83
43	Kumamoto	H	7,269	0.66	6,403	0.72	4,837	0.60	6,820	0.58	6,997	0.68	4,983	0.64	6,181	0.65
44	Oita	H	23,926	0.71	23,951	0.76	23,386	0.68	27,911	0.71	23,754	0.85	32,011	0.86	34,554	0.88
45	Miyazaki	H	12,451	0.53	19,920	0.75	19,917	0.72	12,206	0.69	11,351	0.81	17,466	0.86	10,731	0.74
46	Kagoshima	H	14,103	0.59	11,671	0.85	13,974	0.84	18,023	0.89	11,574	0.84	5,891	0.78	13,283	0.92
47	Okinawa	H	20,734	0.75	20,180	0.80	19,769	0.73	18,580	0.91	18,949	0.92	16,697	0.94	19,916	0.96

Notes: 1. Actual emissions are in tons.
2. Abatement ratios are in percentage terms.
3. Notations of areas are as follows: A, Hokkaido; B, Tohoku; C, Kanto; D, Chubu; E, Kinki; F, Chugoku; G, Shikoku; H, Kyushu.

Table 5. Actual emissions and target abatement ratios of NOX for regions in Japan.

			1992		1993		1994		1995		1996		1999		2002	
ID	Region	Area		Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio
01	Hokkaido	A	50,766	0.66	46,027	0.65	48,530	0.64	51,518	0.63	53,666	0.60	68,610	0.87	57,498	0.94
02	Aomori	B	12,391	0.70	11,252	0.71	13,876	0.70	14,233	0.83	12,408	0.82	12,013	0.84	13,683	0.85
03	Iwate	B	10,395	0.72	9,683	0.69	10,005	0.58	10,202	0.75	9,882	0.75	12,650	0.84	10,668	0.75
04	Miyagi	B	9,814	0.20	9,278	0.27	9,699	0.29	8,477	0.21	10,245	0.16	15,375	0.89	17,525	0.67
05	Akita	B	6,389	0.65	8,011	0.67	8,705	0.61	8,477	0.59	8,867	0.65	9,670	0.41	10,652	0.37
06	Yamagata	B	5,545	0.33	4,970	0.36	4,959	0.26	5,085	0.29	5,522	0.41	4,545	0.19	8,627	0.24
07	Fukushima	B	18,478	0.42	17,995	0.41	20,074	0.40	20,222	0.36	27,276	0.52	31,350	0.70	30,083	0.62
08	Ibaraki	C	39,776	0.69	36,094	0.66	41,303	0.67	38,761	0.62	34,689	0.55	30,522	0.85	34,939	0.89
09	Tochigi	C	8,052	0.07	7,767	0.05	8,009	0.04	9,561	0.12	6,500	**0.00**	8,954	0.04	12,991	0.13
10	Gunma	C	3,883	0.01	2,729	0.00	3,772	**0.00**	3,707	0.00	2,731	0.01	3,953	0.05	6,329	0.22
11	Saitama	C	20,180	**0.00**	18,078	**0.00**	18,753	**0.00**	20,320	**0.00**	23,068	**0.00**	20,287	**0.00**	17,055	**0.00**
12	Chiba	C	55,325	0.78	49,590	0.75	49,530	0.72	50,479	0.70	48,076	0.68	55,235	0.91	53,477	0.93
13	Tokyo	C	12,248	**0.00**	12,192	**0.00**	11,673	**0.00**	11,829	**0.00**	11,471	**0.00**	8,995	**0.00**	8,346	**0.00**
14	Kanagawa	C	9,079	**0.00**	7,192	0.01	10,060	0.02	7,114	0.00	8,060	**0.00**	23,721	0.70	22,762	0.71
15	Niigata	D	32,323	0.64	30,754	0.61	31,502	0.58	35,151	0.59	35,952	0.59	33,030	0.95	32,077	0.70
16	Toyama	D	12,172	0.37	11,171	0.28	11,859	0.24	12,588	0.26	11,666	0.22	11,303	0.21	10,432	0.18
17	Ishikawa	D	2,195	0.41	2,164	0.07	2,735	0.08	3,569	0.10	3,752	0.12	5,325	0.29	5,263	0.09
18	Fukui	D	6,598	**0.00**	5,723	**0.00**	6,711	0.00	6,947	0.40	5,582	0.05	7,853	0.37	7,434	0.24
19	Yamanashi	D	1,119	**0.00**	737	0.00	717	0.00	1,304	**0.00**	887	**0.00**	1,203	**0.00**	1,988	0.00
20	Nagano	D	3,906	0.22	2,259	0.20	4,676	0.20	6,912	0.18	5,578	0.17	5,518	0.59	6,711	0.22
21	Gifu	D	8,609	0.16	6,549	0.14	5,633	0.16	7,325	0.17	8,563	0.16	7,097	0.69	8,699	0.75
22	Shizuoka	D	12,071	0.10	12,543	0.09	5,167	0.04	11,800	0.06	12,593	0.07	15,813	0.12	20,187	0.38
23	Aichi	D	32,890	0.67	32,455	**0.00**	34,091	0.66	34,395	0.65	34,215	0.65	34,412	0.67	35,689	0.71
24	Mie	E	23,318	0.54	22,257	0.93	23,715	0.88	32,311	0.94	23,125	0.51	23,228	0.93	25,078	0.70
25	Shiga	E	10,225	**0.00**	10,315	**0.00**	11,592	**0.00**	12,287	**0.00**	12,081	**0.00**	12,533	**0.00**	11,447	**0.00**
26	Kyoto	E	4,087	0.11	4,015	0.02	3,963	0.02	5,019	0.19	4,791	0.30	6,300	0.36	4,411	0.13
27	Osaka	E	12,535	**0.00**	11,028	**0.00**	10,724	0.45	13,601	0.47	12,882	0.42	15,494	0.56	13,944	0.55
28	Hyogo	E	35,379	0.70	39,817	0.73	35,962	0.68	34,087	0.64	34,475	0.65	31,167	0.62	23,723	0.54
29	Nara	E	1,080	**0.00**	1,105	0.00	1,606	**0.00**	1,497	**0.00**	1,236	**0.00**	1,121	**0.00**	1,891	0.00
30	Wakayama	E	12,057	0.67	11,213	0.57	13,083	0.58	13,147	0.60	12,816	0.57	12,919	0.60	10,005	0.43
31	Tottori	F	1,472	**0.00**	1,368	**0.00**	2,117	0.00	1,499	0.00	1,971	**0.00**	945	**0.00**	2,573	**0.00**
32	Shimane	F	3,996	0.04	2,764	0.59	3,530	0.57	3,735	0.61	3,674	0.04	3,616	0.39	7,442	0.63

33	Okayama	F	34,270	0.70	32,621	0.68	36,225	0.68	49,136	0.75	49,337	0.76	41,657	0.70	38,108	0.70
34	Hiroshima	F	24,762	0.56	24,090	0.55	23,651	0.48	27,163	0.51	26,902	0.51	27,857	0.72	30,672	0.67
35	Yamaguchi	F	59,346	0.83	58,149	0.82	57,981	0.80	60,003	0.80	58,851	0.80	56,615	0.78	56,635	0.80
36	Tokushima	G	8,229	0.71	1,746	0.06	9,093	0.70	9,112	0.79	7,629	0.66	7,107	0.64	12,697	0.72
37	Kagawa	G	8,906	0.37	9,498	0.45	8,296	0.21	9,198	0.29	9,929	0.35	10,214	**0.00**	9,617	**0.00**
38	Ehime	G	16,583	0.54	16,151	0.56	16,236	0.51	18,240	0.57	19,281	0.66	17,811	0.49	18,180	0.51
39	Kouchi	G	9,264	**0.00**	8,748	0.83	10,553	**0.00**	11,161	**0.00**	10,498	**0.00**	9,040	0.89	9,426	**0.00**
40	Fukuoka	H	30,758	0.65	34,707	0.68	29,787	0.58	31,865	0.63	24,516	0.43	44,636	0.93	39,893	0.72
41	Saga	H	2,415	0.11	1,852	0.07	2,023	0.08	1,807	**0.00**	2,008	**0.00**	2,859	0.07	2,805	0.20
42	Nagasaki	H	25,134	0.83	21,864	0.80	23,663	0.80	23,277	0.80	23,470	0.83	25,138	0.79	32,984	0.81
43	Kumamoto	H	3,957	0.20	3,302	0.21	3,972	0.21	4,666	0.23	5,288	0.23	6,095	0.51	7,360	0.32
44	Oita	H	32,845	0.79	32,434	0.78	28,044	0.71	34,422	0.76	33,102	0.76	27,183	0.67	30,689	0.72
45	Miyazaki	H	5,600	0.22	5,567	0.15	5,808	0.16	5,727	0.37	5,664	0.43	5,871	0.24	7,422	0.22
46	Kagoshima	H	9,596	0.46	10,313	0.72	10,447	0.66	11,748	0.74	9,522	0.70	5,734	0.70	17,971	0.86
47	Okinawa	H	13,625	0.80	13,582	0.81	15,168	0.79	15,950	0.91	15,400	0.91	14,687	0.93	21,020	0.90

Notes: 1. Actual emissions are in tons.
2. Abatement ratios are in percentage terms.
3. Notations of areas are as follows: A, Hokkaido; B, Tohoku; C, Kanto; D, Chubu; E, Kinki; F, Chugoku; G, Shikoku; H, Kyushu.

Table 6. Actual emissions and target abatement ratios of soot and dust for regions in Japan.

			1992		1993		1994		1995		1996		1999		2002	
ID	Region	Area	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio	Actual emission (*t*)	Abatement ratio
01	Hokkaido	A	9,186	0.81	9,881	0.84	9,547	0.84	9,350	0.78	8,381	0.74	8,379	0.90	6,491	0.97
02	Aomori	B	1,802	0.61	1,546	0.62	1,812	0.65	1,381	0.70	1,517	0.73	1,587	0.87	1,188	0.88
03	Iwate	B	953	0.45	995	0.51	837	0.26	827	0.48	1,099	0.61	1,623	0.86	788	0.79
04	Miyagi	B	1,720	0.54	1,767	0.62	1,477	0.60	1,588	0.56	1,578	0.45	3,468	0.95	1,235	0.76
05	Akita	B	1,980	0.82	1071.00	0.71	1,840	0.82	2,857	0.81	2,121	0.79	992	0.61	813	0.53
06	Yamagata	B	1,501	0.68	1,385	0.76	1,296	0.75	555	0.22	753	0.40	1,276	0.79	476	0.24
07	Fukushima	B	2,672	0.65	2,692	0.67	4,459	0.81	3,973	0.75	4,427	0.74	2,222	0.73	1,824	0.71
08	Ibaraki	C	3,187	0.64	2,792	0.62	3,056	0.67	2,908	0.56	2,976	0.51	1,944	0.78	1,816	0.86
09	Tochigi	C	1,278	0.34	1,670	0.58	1,443	0.58	1,237	0.43	1,096	**0.00**	611	0.10	564	0.06
10	Gunma	C	929	0.18	583	**0.00**	641	**0.00**	882	**0.00**	470	0.01	332	0.21	287	0.09
11	Saitama	C	2,006	**0.00**	1,738	**0.00**	1,573	**0.00**	2,183	**0.00**	2,305	**0.00**	1,845	**0.00**	1,136	**0.00**
12	Chiba	C	3,883	0.64	3,842	0.65	4,018	0.70	3,920	0.64	3,428	0.58	2,757	0.84	2,427	0.91
13	Tokyo	C	3,609	**0.00**	3,354	**0.00**	2,479	**0.00**	2,114	**0.00**	1,135	**0.00**	553	**0.00**	388	**0.00**
14	Kanagawa	C	1,017	**0.00**	1,581	0.09	2,063	0.38	604	**0.00**	570	**0.00**	1,251	0.53	1,173	0.67
15	Niigata	D	2,401	0.57	2,122	0.52	1,794	0.47	2,741	0.57	2,200	0.40	1,466	0.87	1,967	0.77
16	Toyama	D	2,422	0.70	1,324	0.47	1,565	0.56	1,511	0.39	1,512	0.43	785	0.27	899	0.51
17	Ishikawa	D	564	0.44	571	0.08	577	0.51	489	0.15	662	0.31	300	0.08	529	0.51
18	Fukui	D	3,205	**0.00**	2,831	**0.00**	3,506	**0.00**	811	0.03	822	0.20	796	0.58	653	0.47
19	Yamanashi	D	264	**0.00**	255	**0.00**	318	**0.00**	304	**0.00**	322	**0.00**	209	**0.00**	105	**0.00**
20	Nagano	D	928	0.46	662	0.44	958	0.55	1,386	0.53	1,030	0.42	586	0.64	560	0.51
21	Gifu	D	1,879	0.61	1,347	0.57	1,361	0.66	1,342	0.50	1,588	0.51	1,065	0.78	1,494	0.90
22	Shizuoka	D	1,345	0.10	1,372	0.15	1,781	0.64	1,500	0.29	3,015	0.63	1,933	0.48	1,661	0.60
23	Aichi	D	3,024	0.41	3,010	**0.00**	2,283	0.41	2,424	0.46	2,004	0.47	2,442	0.71	2,203	0.78
24	Mie	E	2,645	0.65	2,434	0.87	2,270	0.84	1,954	0.79	1,903	0.45	2,187	0.92	1,494	0.75
25	Shiga	E	824	**0.00**	787	**0.00**	743	**0.00**	837	**0.00**	1,025	**0.00**	783	**0.00**	536	**0.00**
26	Kyoto	E	1,100	0.45	981	0.40	882	0.45	570	0.05	505	0.06	406	0.19	664	0.67
27	Osaka	E	1,457	**0.00**	1,881	**0.00**	1,631	0.18	1,841	0.32	1,515	0.45	1,404	0.63	1,139	0.73
28	Hyogo	E	2,547	0.47	3,032	0.57	5,646	0.81	3,355	0.67	3,783	0.72	2,030	0.63	823	0.38
29	Nara	E	244	**0.00**	194	**0.00**	218	**0.00**	325	**0.00**	321	**0.00**	146	**0.00**	134	**0.00**
30	Wakayama	E	1,038	0.09	1,110	0.48	1,382	0.56	1,148	0.14	1,222	0.46	1,029	0.66	1,037	0.66
31	Tottori	F	518	**0.00**	448	**0.00**	529	**0.00**	1,132	**0.00**	472	**0.00**	97	**0.00**	246	**0.00**
32	Shimane	F	993	0.46	710	0.51	728	0.40	706	0.01	685	0.28	259	0.34	481	0.51
33	Okayama	F	4,356	0.79	4,307	0.80	4,337	0.82	4,408	0.80	4,573	0.78	4,842	0.84	3,447	0.85
34	Hiroshima	F	3,424	0.69	3,637	0.72	4,428	0.79	3,425	0.69	3,385	0.65	4,166	0.88	4,671	0.90

35	Yamaguchi	F	5,090	0.84	5,415	0.85	5,889	0.87	5,196	0.84	4,210	0.76	3,170	0.76	2,846	0.81
36	Tokushima	G	1,141	0.30	909	0.41	1,171	0.24	2,341	0.59	782	0.37	468	0.59	680	0.61
37	Kagawa	G	964	0.31	1,060	0.46	1,171	0.46	1,045	0.07	1,130	0.37	735	**0.00**	745	**0.00**
38	Ehime	G	2,141	0.65	1,950	0.70	2,232	0.75	2,955	0.79	2,824	0.76	1,943	0.70	1,575	0.71
39	Kouchi	G	779	**0.00**	732	0.37	544	**0.00**	679	**0.00**	747	**0.00**	395	0.71	214	**0.00**
40	Fukuoka	H	2,227	0.44	1,768	0.32	1,559	0.31	1,939	0.42	1,750	0.27	2,841	0.90	2,372	0.78
41	Saga	H	498	0.08	552	0.13	610	0.37	346	**0.00**	309	**0.00**	350	0.43	193	0.06
42	Nagasaki	H	2,529	0.82	2,899	0.86	4,096	0.91	1,951	0.75	2,018	0.75	1,887	0.80	1,413	0.76
43	Kumamoto	H	1,158	0.62	919	0.62	1,302	0.74	1,192	0.60	1,038	0.49	866	0.71	857	0.69
44	Oita	H	2,455	0.71	2,271	0.71	1,999	0.67	1,467	0.36	1,555	0.48	623	0.09	896	0.50
45	Miyazaki	H	921	0.33	901	0.36	1,008	0.47	706	0.16	641	0.23	556	0.43	629	0.45
46	Kagoshima	H	1,755	0.57	1,630	0.79	2,022	0.80	3,125	0.85	1,153	0.59	389	0.50	2,363	0.93
47	Okinawa	H	1,689	0.64	1,595	0.66	1,682	0.64	2,012	0.73	2,172	0.83	5,091	0.97	609	0.74

Notes: 1. Actual emissions are in tons.
2. Abatement ratios are in percentage terms.
3. Notations of areas are as follows: A, Hokkaido; B, Tohoku; C, Kanto; D, Chubu; E, Kinki; F, Chugoku; G, Shikoku; H, Kyushu.

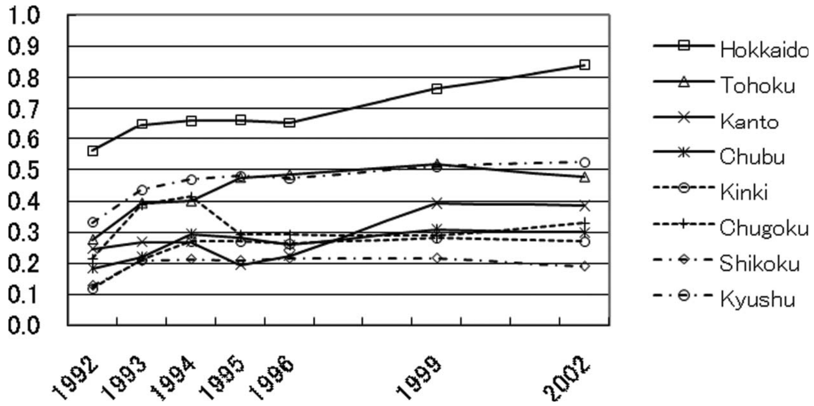


Figure 2. Average target abatement ratios for industrial waste production in the eight areas of Japan.

and Kagoshima (46) had target abatement ratios higher than 40% throughout the study period. Japan is divided into eight areas that will be referred to later, and each area includes several prefectures, except for Hokkaido area, which covers only Hokkaido (01), Japan's second largest island at the northern end of the country. Most regions in Japan have significant room to reduce their industrial waste. Hokkaido (01) is the least efficient region in all years and for all forms of wastes and pollutants. In addition, its target abatement ratios have worsened significantly over the last 2 years studied. Almost all prefectures in the Tohoku and Kyushu areas are inefficient in terms of industrial waste production, and this inefficiency worsened over the course of the study. In contrast, the Shikoku area was relatively efficient during the study period.

Sulfur oxides

Table 4 and Figure 3 describe the average sulfur oxide (SOX) emission abatement ratios in each region and area, respectively. There are 19 regions where sulfur dioxide emission target abatement ratios remained higher than 50% throughout the study. In particular, Hokkaido (01), Fukushima (07), Ibaraki (08), Chiba (12), Niigata (15), Ehime (38), Nagasaki (42), Oita (44), and Okinawa (47) always had target abatement ratios higher than 60%. Most regions in Japan have significant room to reduce their sulfur oxide emissions. Almost all prefectures in the Tohoku and Kyushu areas are inefficient for SOX as well as industrial waste. The Kanto and Kinki areas were relatively efficient during the study period.

Nitrogen oxides

Figure 4 and Table 5 describe the average nitrogen oxide (NOX) emission abatement ratios in each region and area, respectively. There are 13 regions where nitrogen dioxide emission target abatement ratios remained higher than 50% throughout the study. In particular, Aomori (02), Chiba (12), Okayama (33), Yamaguchi (35), Nagasaki (42), Oita (44), and Okinawa (47) always had target abatement ratios higher than 60%. Most regions in Japan have much room to reduce their NOX pollution emissions. However, the Kanto and Chubu areas were relatively efficient during the study period.

Soot and dust

Table 6 and Figure 5 describe the average soot and dust emission abatement ratios in each region and area, respectively. There are 12 regions where soot and dust emission target abatement ratios remained higher than

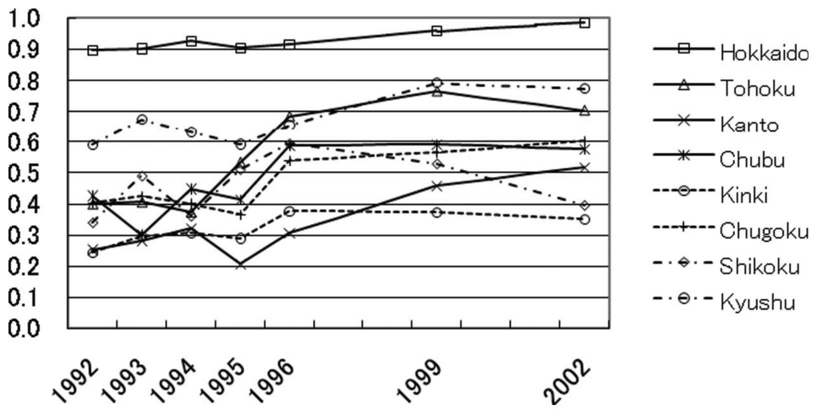


Figure 3. Average target abatement ratios for sulfur oxides production in the eight areas of Japan.

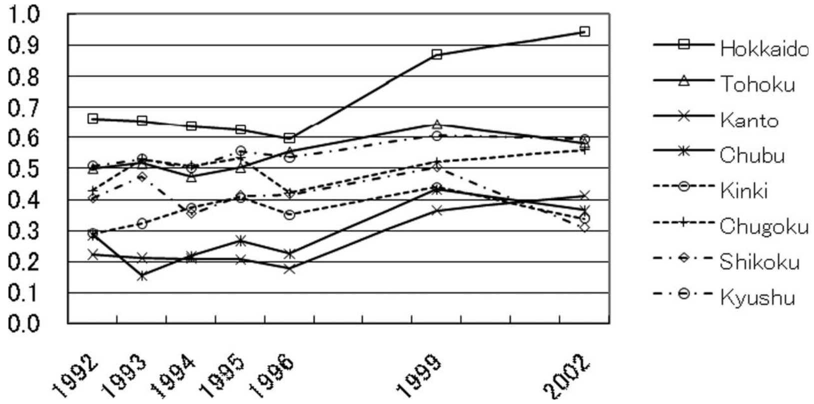


Figure 4. Average target abatement ratios for nitrogen oxide production in the eight areas of Japan.

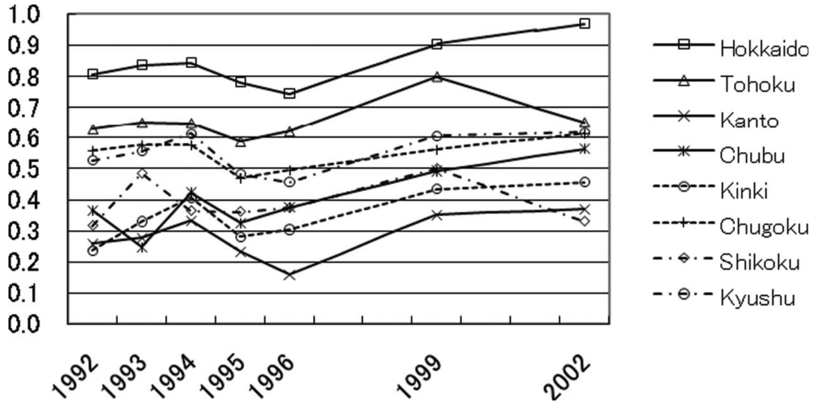


Figure 5. Average target abatement ratios for soot and dust production in the eight areas of Japan.

50% throughout the study. In particular, Hokkaido (01), Aomori (02), Fukushima (07), Okayama (33), Hiroshima (34), Yamaguchi (35), Ehime (38), Nagasaki (42), and Okinawa (47) always had target abatement ratios higher than 60%. Most regions in Japan have much room to reduce their soot and dust emissions. In contrast, the Kanto area was relatively efficient during the study period.

Relationship between regional waste efficiency and energy-intensive industry

Energy-intensive industries emit carbon dioxide and other pollutants, use materials, and produce industrial solid wastes. They should be given particular attention because of their impact on human health and the environment. We now consider the relationship between regional waste efficiency and the extent of energy-intensive industry. In this paper, chemical, ceramic, iron and steel, metal products, and pulp and paper industries are regarded as energy-intensive industries. Prefectures are divided into four groups based on the average ratio of a region's GDP from energy-intensive industries during the study period. Although the results in 1997, 1998, 2000, and 2001 are missing, we calculated the average ratios for energy-intensive industries based on the average from 1992 to 2002, including the above 4 years. The groups are as follows: the rates of the group A regions are higher than 10%, group B regions lie between 7.5% and 10%, group C regions lie between 5% and 7.5%, and group D regions are less than 5%. Figure 6 depicts the average target abatement ratios in each group. Groups C and D, where energy-intensive industries dominate, are less efficient than Groups A and B, where they do not.

Relationship between regional waste efficiency and per capita income

We next consider the relationship between per capita income and waste efficiency. The regions are divided into four groups based on the average per capita income at 1995 market prices. As in the case of energy-intensive industries, we calculated the average per capita income based on the average throughout the 11 years from 1992. The groups are as follows: low income, 2.5 million yen or less; lower middle income, 2.5–2.75 million yen; upper middle income, 2.75–3.0 million yen; and high income, 3.0 million yen or more. Figure 7 depicts the average target abatement ratios in each group. The low-income group has relatively high average target abatement ratios, whereas the high-income group has relatively low ratios. In particular, the average target abatement ratios of the bottom quartile are around twice as high as those of the top quartile. Figure 7 suggests that economic growth may improve environmental quality.

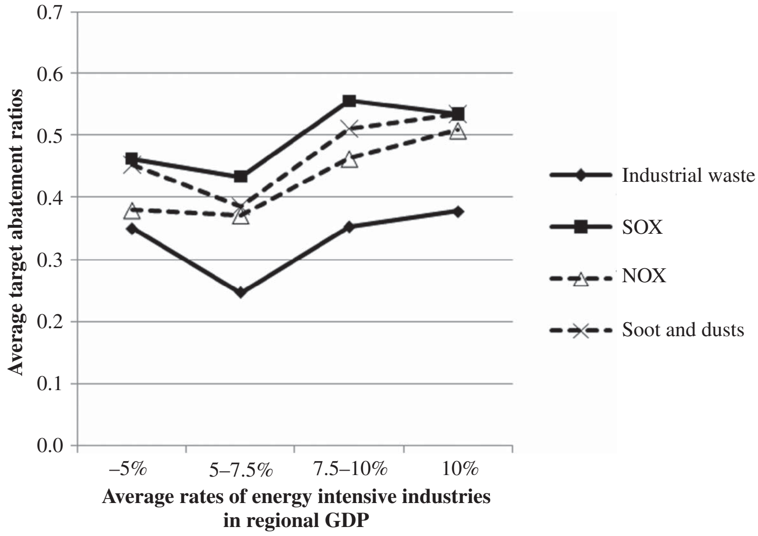


Figure 6. Relationship between regional waste efficiency and the extent of energy-intensive industry.

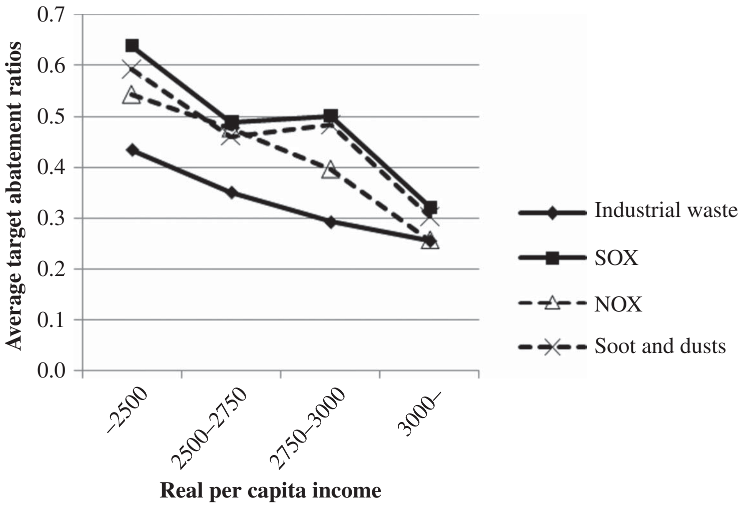


Figure 7. Relationship between regional efficiency in waste production and per capita income.

When arranged according to average per capita income during the study period, the six most efficient regions – Saitama (11), Tokyo (13), Yamanashi (19), Shiga (25), Nara (29), and Tottori (31) – are ranked, respectively as 8th, 1st, 22nd, 5th, 25th, and 33rd out of 47 regions. Interestingly, there are two patterns in the efficient regions. First, some regions operate at the efficiency frontier with high income, such as Saitama (11), Tokyo (13), and Shiga (25). Second, other regions operate at the efficiency frontier with lower or upper middle income, such as Yamanashi (19), Nara (29), and Tottori (31).

Concluding remarks

This study used DEA to analyze regional waste efficiency in Japan. The efficiency frontier is constructed using DEA based on data on waste emissions and other inputs. A data set of 47 prefectures in Japan for the period 1992–2002 was constructed. There are seven inputs, three production factors (labor employment, and private and public capital stocks) and four waste emissions (industrial waste, sulfur oxide, nitrogen oxide, and soot and dust). GDP was the sole output. Following Fukao and Yue (2000), data on private and social capital stocks are extended. All nominal variables are transformed into real variables at 1995 prices.

Saitama (11), Tokyo (13), Yamanashi (19), Shiga (25), Nara (29), and Tottori (31) always have zero target abatement ratios for industrial waste and air pollutants. This implies that they operate on the Japanese efficiency frontier. Interestingly, they can be broken down into two major categories: high-income regions and lower or upper middle regions. Hokkaido (01) was the least efficient region for all years studied and for all waste and pollutant categories, and its target abatement ratios fell significantly in the last two years studied. After Hokkaido, the Tohoku and Kyushu areas are less efficient than other areas. The government should promote recycling of waste and reducing air pollution. Many regions in the top quartile with respect to per capita income have lower target abatement ratios, suggesting that economic growth may contribute to mitigating environmental load. These results indicate that several regions in Japan can substantially reduce pollution and waste without reducing economic performance. Japan could improve the production efficiency of these regions by using the efficient regions as a reference.

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