2 Maximum abatement costs for calculating cost-effectiveness of green activities with multiple environmental effects

Tosihiro Oka[a], Yoshifumi Fujii[b], Masanobu Ishikawa[c], Yu Matsuno[d] and Shu Susami[e]
[a]*Graduate School of Economics and Administration,Fukui Prefectural University, 4-1-1 Kenjojima Matsuoka-cho, Japan*
[b]*Bunkyo University*
[c]*Kobe University*
[d]*Meiji University*
[e]*Ebara Corporation*

2.1 Introduction

We have proposed a Maximum Abatement Cost (MAC) method as a means of assessing preferential purchasing with multiple environmental effects (Oka et al., 2005). The MAC method allows assessment of the cost-effectiveness of introducing a product with less emissions of some pollutants than conventional products. In the MAC method, the reduction of a pollutant is multiplied by the MAC, the maximum unit cost of the measures taken elsewhere in society to reduce the pollutant, and is added up over the relevant pollutants. The total sum, called Avoidable Abatement Cost (AAC), is compared with the additional private cost of the product for the purchaser. When the additional private cost is smaller than the AAC, the product is regarded as relatively efficient.

Our previous article (Oka et al. 2005) described the MAC method in detail, as well as presenting an application of the method, and discussing differences between the MAC method and several existing weighting methods for life cycle assessment (LCA), along with the advantages and limitations of the MAC method. The purpose of this article is to provide

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a basis for calculation and report some results on the estimated maximum cost of reducing the environmental burden for various parameters required for this method. The Mac values are presented for nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon dioxide (CO_2), particulate matter (PM), theoretical oxygen demand (TOD), trichloroethylene (TCE) and perchloroethylene (PCE), heavy metals (HM), volatile organic compounds (VOC) and dioxins (DXN).

This paper first presents an explanation of the concept of MAC, as far as necessary for the following description of the estimated MAC values for the individual parameters. Next, the estimations are described in detail.

2.2 Maximum Abatement Cost (MAC)

MAC is defined as the highest unit cost, i.e., the cost per kilogram of emission reduction, of the activity that has the highest unit cost among all the activities carried out or expected to be carried out shortly to reduce the emission of a substance or a group of substances, here specified for Japan. These emission reducing activities are carried out on the basis of decisions by people and industries with the aim of complying with government regulations, earning a good reputation or obeying their own moral belief.

In order to determine the MAC, the activity incurring the highest unit cost must be specified. Strictly speaking, when a particular person or company is carrying out an activity with exceptionally high unit reduction cost, this very high unit cost may be adopted as the MAC value. Also, when an activity can be divided into several parts that have different unit costs, the partial activity with the highest unit cost may be adopted as the one representing the MAC. However, it is difficult to identify a small activity with very high unit cost contributing only a tiny part of the emission reduction, and it would not be appropriate to use the value for an exceptional activity as a reference value for assessing other activities. For these reasons, we have determined the MAC values from data on the unit cost of emission reduction for activities widely adopted in society.

One problem with the MAC method is how to allocate the cost of an activity that reduces emissions of several substances. We avoided this problem by identifying activities that predominantly reduce only one substance or one impact category, but this problem has remained for TOD, TCE and PCE. All the MAC values, except that for CO_2, are based on cost data for the reduction activities that have actually been carried out. For CO_2, we used estimates of abatement cost to meet the Kyoto target, as specified by the Central Environmental Council (Tyuuou-Kankyou-Singikai Tikyuu-Kankyou-Bukai 2001).

Measuring MAC involves assessing the ratio of cost and emission reduction. If the time of incurrence of cost does not coincide with that of the occurrence of reduction, it is justifiable to account for this difference by time discounting. Thus, if the discount rate changes, the results will change. In the present paper, based on the estimation of real interest rate for recent years (Oka 1999), a 3% discount rate is applied, unless otherwise stated.

2.3 NO_x

2.3.1 MAC related to legally mandated automobile NO_x controls

Legally mandated automobile NO_x controls

Since meeting the environmental standard on nitrogen dioxide (NO_2) in metropolitan areas was poor under existing Japanese regulations, new measures to reduce nitrogen oxides in motor vehicle exhaust gas emissions were introduced in 1992 as the `Special Measures Law on Reduction of Total Emissions of Nitrogen Oxides from Automobiles in Designated Areas (Automobile $NO_x$ Law)'. This law was amended in 2001 and was renamed `Special Measures Law on Reduction of Total Emissions of Nitrogen Oxides and Particulate Matter from Automobiles in Specified Areas (Automobile NO_x, PM Law)'. In order to obtain the MAC for NO_x reduction only, we here estimate the NO_x reduction under the old NO_x Law and the cost of this reduction.

One of the key elements of this law was that for areas where it had been difficult to meet the environmental standard for nitrogen dioxide with conventional control measures (the so-called designated areas), emissions limits for vehicles used in these areas (designated vehicles) were set at stricter levels than previous emission limits. The designated areas were the Tokyo area and the Osaka area[1]. Designated vehicles included trucks, buses and specially permitted commercial vehicles based in the designated areas. An emissions standard equivalent to the strictest standard for each gross vehicle mass class under the Air Pollution Control Law was applied to these designated vehicles. A key point is that the same standards were applied to both gasoline and diesel vehicles. Another feature of the regulations under this law was that they were applied not only to newly produced or registered vehicles but also to vehicles that were already being used. Designated vehicles that did not meet these standards would not pass the mandatory vehicle inspections and could not be used. However, a grace period was included in view of the large impact of these regulations. In addition to the grace period, a notice period and severe change mitigation period have been defined. Thus, the actual application to operating vehicles for regular trucks is shown in Table 2.1.

Even with the grace period, notice period and severe change mitigation period, once these periods are exceeded, not being able to continue the use of vehicles that do not meet the standard means a cost burden to the vehicle user. This should be measurable in terms of the loss to the user caused by the compulsory shortening of the amortization period.

Table 2.1 Application of regulations for in-use vehicles

Year	Vehicles that cannot be used
1995	Vehicles registered in 1984 or before, not meeting the emission standards for designated vehicles
1996	Vehicles registered in 1985 to 1987, not meeting the emissions standards for designated vehicles
1997	Vehicles registered in 1988, not meeting the emissions standards for designated vehicles
1998~	Vehicles registered since 1989, not meeting the emissions standards for designated vehicles

[1] Later, the Aichi and Mie regions were added to the designated area by the Automobile NO_x and PM Law.

Cost related to tightening NO_x regulations

If the price of the vehicles is P, the number of years of shortening is t and the time discount rate is *i*, the cost is expressed as:

$$P(1 - e^{-it}) \qquad (2.1)$$

The number of years of shortening is given by the average number of remaining service years in the absence of the regulation. This is estimated as follows.

The second column of Table 2.2 shows the scrapping rate for standard diesel trucks, with vehicle age in 1994. The vehicle age 1.25, for example, has a value of 0.86%. This means that 0.86% of the standard diesel trucks aged 0.25 year (3 months) to 1.25 year (1 year and 3 months) in

Table 2.2 Scrapping rate and average remaining service life of standard diesel trucks by age class (1994)

Vehicle age	Scrapping rate[a]	Remaining service life[b]
0.25	0.86%	11.60
1.25	0.96%	10.69
2.25	1.01%	9.79
3.25	1.54%	8.87
4.25	2.52%	7.99
5.25	4.60%	7.17
6.25	8.14%	6.47
7.25	10.70%	5.96
8.25	13.98%	5.55
9.25	16.79%	5.29
10.25	17.86%	5.16
11.25	17.07%	5.06
12.25	17.28%	4.90
13.25	17.42%	4.71
14.25	18.10%	4.49
15.25	17.44%	4.27
16.25	17.03%	3.96
17.25	-	3.56
18.25	-	3.09
19.25	-	2.52

[a] Calculated from Zidousya-Kensa-Touroku-Kyouryokukai (1994, 1995).
[b] The vehicle scrapping rate after vehicle age 17.25 years is assumed to remain constant.

March 1994 were scrapped during the 1 year period. This value was calculated based on data on the number of registered motor vehicles (Zidousiya-Kensa-Touruku-Kyoukai 1994, 1995). Based on these scrapping rates, the average remaining service life for each vehicle age can be calculated from the following formula:

$$L(t)=\Sigma_{k=t}^{T} s(k)/s(t)$$

where $L(t)$ is the average remaining service life for vehicle age t, T is the maximum, and $s(k)$ is the rate of remaining in service at vehicle age k, which is defined by the following:

$$s(0)=1$$

$$s(k)=s(k-1)[1-d(k-1)]$$

where $d(k)$ is the scrapping rate at vehicle age k. The third column of Table 2.2 shows the average remaining service life by vehicle age based on the 1994 scrapping rate.

As shown in Table 2.1, vehicles that could not be used as of 1995 were vehicles registered up to 1984. This is equivalent to a vehicle age of 10.25 years or over. The average remaining service life of these vehicles can be obtained by weighting the average value for remaining service life for vehicles aged 10.25 years and older from Table 2.2. The number of registered diesel trucks by age class in 1995 (Zidousya-Kensa-Touruku-Kyouryokukai 1995) was used as a weighting factor. Vehicles that could not be used as of 1996 were those aged between 8.25 years and 10.25 years. The average remaining service life was obtained by the same method. Vehicles that could not be used as of 1997 were those aged 8.25 years. Table 2.3 shows the average remaining years of service life for these vehicles from 1995 to 1999.

Table 2.3 Average remaining service life for vehicles scrapped due to the automobile NO_x law

1995	**1996**	**1997**	**1998**	**1999**
4.49	5.38	5.55	5.55	5.55

Table 2.4 Standard diesel truck average price (Yen/truck)

1995	**1996**	**1997**	**1998**	**1999**
2,549,756	2,472,581	2,205,592	1,927,197	1,871,119

Table 2.5 Cost of service life reduction for standard diesel trucks (yen/truck)

1995	1996	1997	1998	1999
321,235	368,726	338,392	295,679	287,075

Table 2.6 Scrapping age of small trucks and buses

	1995	1996	1997	1998	1999
Small trucks	> 9.25	7.25-9.25	7.25	7.25	7.25
Buses	> 12.25	10.25-12.25	10.25	10.25	10.25

Table 2.7 Cost of NO_x reduction for small trucks and buses (yen/vehicle)

	1995	1996	1997	1998	1999
Small trucks	127,132	148,424	162,967	173,746	180,448
Buses	435,444	468,880	470,850	463,492	462,008

The average price for a standard diesel truck, taken from the `Machinery Statistics Annual' (Tuusyou-Sangyou-Daizin-Kanbou-Tyousa-Toukeibu, 1995-1999) is shown in Table 2.4. From the above data, the cost of the reduction of service life can be calculated per truck, according to formula (2.1), assuming a 3% discount rate. The results of this calculation are shown in Table 2.5.

The same method can be used to calculate the cost of reducing the service life for small trucks and buses. The age at which small trucks and buses can no longer be used differs from that for standard trucks and is shown by year in Table 2.6. For buses, the median between large buses and microbuses was taken. The cost of service life reduction for small trucks and buses per unit is shown in Table 2.7.

Amount of NO_x reduction

When designated vehicles not meeting the emissions standards are scrapped, it is anticipated that these would be replaced by vehicles meeting the standard. Changes in NO_x emissions were estimated as follows.

Table 2.8 shows the NO_x unit emissions in 1996 for standard trucks, small trucks and buses from the Environment Agency's `Report on Vehicle Unit and Total Emissions' (Kankyoutyou 1998). For medium and light standard trucks and buses and small trucks, the emissions standards for designated vehicles were set to be the same as for recent gasoline vehicles. The scrapping of vehicles not complying with the standards has resulted in an assumed reduction of annual per vehicle NO_x emissions of 112.5-35.0=77.5g for standard trucks, 12.1-7.4=4.7g for small trucks and 103.8-37.1=66.7g for buses.

For heavy standard trucks and buses, the emissions standards for designated vehicles were set at the same level as for recent diesel vehicles. Emissions were estimated based on the changes in emission standards over time, and the reduction rate for scrapped vehicles by initial registration year is shown in Table 2.9. The average NOx reduction rate for each scrapping year was calculated as a weighted average of the values in Table 2.9 taking the number of the heavy vehicles with each initial registration year as a weightig factor, as in the above cost calculation. The resulting average NO_x reduction for each scrapping year is shown in Table 2.10.

The unit NO_x emissions prior to scrapping were assumed to be the same as for the diesel vehicles in Table 2.8, and the reduction rates from Table 2.10 were applied to obtain the reduction rate.

Table 2.8 NO_x emissions (1996, units: kg/vehicle/year)

	Diesel	**Gasoline**
Standard trucks	112.5	35.0
Small trucks	12.1	7.4
Buses	103.8	37.1

Table 2.9 NO_x emission reduction rate due to replacement of heavy vehicles

Initial registration year	**Reduction rate**	**Initial registration year**	**Reduction rate**
1988	14.3%	1981	35.7%
1987	14.3%	1980	35.7%
1986	14.3%	1979	35.7%
1985	26.5%	1978	47.1%
1984	26.5%	1977	47.1%
1983	26.5%	1976	55.0%
1982	35.7%		

Note: Calculated assuming a 50:50 split between auxiliary chamber and direct injection types, based on Environment Agency Air Quality Bureau (1994), p7, NO_x Reduction Effects of Automobile Exhaust Regulations.

Table 2.10 NO_x emission rate for heavy vehicles by year of scrapping

	1995	1996	1997	1998	1999
Standard trucks	35.5%	26.5%	14.3%	14.3%	14.3%
Buses	38.9%	26.5%	26.5%	26.5%	14.3%

Table 2.11 NO_x emission reduction due to scrapping of vehicles not meeting emission standards (kg/vehicle/year)

Year of scrapping	1995	1996	1997	1998	1999
Standard trucks	53.8	47.5	38.8	38.8	38.8
Small trucks	4.7	4.7	4.7	4.7	4.7
Buses	50.1	42.0	42.0	42.0	34.0

Table 2.12 Present value of NO_x reduction due to scrapping of designated vehicles not meeting emission standards (kg/vehicle)

Year of scrapping	1995	1996	1997	1998	1999
Standard trucks	226.1	236.0	198.4	198.4	198.4
Small trucks	19.3	21.7	22.4	22.4	22.4
Buses	159.6	165.9	177.7	177.7	143.9

According to the Environment Agency's report (Kankyoutyou 1998), the contribution of heavy standard trucks and buses to the total emissions is 63%. The combined average reduction for medium and light vehicles and heavy vehicles for NO_x emissions is shown in Table 2.11. Here, the average remaining service life from Table 2.3 was used to obtain the present value of the total emission reduction per vehicle during the remaining service life period, as shown in Table 2.12. The present value of the total emission reduction was calculated by the following equation:

$$\int_0^T Qe^{-it}dt=Q/i\ (1-e^{-it}) \qquad (2.2)$$

Here Q is the annual emission reduction per vehicle, *i* the annual discount rate, *T* the remaining service life.

NO_x unit price for NO_x emission reduction and MAC

The unit reduction cost for all vehicles can be obtained using the ratio of the values in Tables 2.5, 2.7 and 2.12, multiplied by the number of scrapped vehicles. The data and results are shown in Table 2.13. The number of scrapped vehicles in this table was obtained from the year of initial registration, assuming that the ratio of the number of diesel vehicles with each year of initial registration to the total number of registered diesel vehicles in the designated area is the same as that for the whole country. Based on these results, the unit price for NO_x emission reductions is between 2.13 and 2.68 million yen/ton.

Table 2.13 Unit cost of NO_x reduction due to scrapping of designated vehicles not meeting emission standard (10,000 yen/ton)

		1995	**1996**	**1997**	**1998**	**1999**
Scrapped vehicles	Standard trucks	94,822	78,912	44,724	50,854	55,462
	Small trucks	169,268	181,131	84,336	85,812	85,890
	Buses	6,899	7,583	2,841	2,956	3,283
Cost (100 million yen)	Standard trucks	305	291	151	150	159
	Small trucks	215	269	137	149	155
	Buses	30	36	13	14	15
	Total	550	595	302	313	329
NO_x reduction	Standard trucks	21437	18622	8873	10089	11003
	Small trucks	3,274	3,932	1,892	1,925	1,927
	Buses	1,101	1,258	505	525	472
	Total	25,812	23,812	11,270	12,540	13,402
Unit cost (10,000 yen/t)		213	250	268	250	246

2.3.2 Other NO_x control measures

2000 Control regulations for gasoline vehicles

The cost per ton of NO_2 reduction to meet the 2000 regulations for gasoline vehicles is estimated to be 2 million yen (Nihon-Sougou-Kenkyuusyo 1998).

Stationary source NO_x control

The construction cost of flue gas NO_x control systems for xxx ammonia catalytic reduction (dry method), which have a high NO_x reduction efficiency in electric power plants, is reported to be 3,000 to 6,000 yen/kW (Nihon-Sangyou-Kikai-Kougyoukai 1993). From this data, the cost per ton of NO_2 reduction is estimated to be 120,000 to 170,000 yen. The cost of NO_x control for sintering furnaces and coking ovens at steel works near urban areas and new coal-fired power plants is assumed to be 6,500 to 8,000 yen per kW (Ando, 1990), the cost per ton of NO_2 reduction being 200,000 to 280,000 yen. The estimated NO_x control costs per ton of NO_2 reduction for a sintering furnace at a steel works, based on equipment investment costs of 5.6 billion yen (total investment cost for construction), running costs of about 200 million yen and an annual NO_x reduction of 2,000 tons, is estimated to be 270,000 to 300,000 yen.

2.3.3 MAC for NO_x reduction

Based on the above estimation, the MAC for NO_x reduction is estimated to be 2.5 million yen/ton or 2,500 yen/kg.

2.4 SO_x

2.4.1 SO_x emissions control methods

Sulfur oxides are a traditional air pollutant derived from the sulfur in crude oil, heavy coal and other fuels and raw materials for steel production. When these sulfur-containing materials are combusted, sintered, etc., the sulfur reacts with the oxygen in the air and sulfur oxides are formed. The following equation is useful in understanding the method for reducing SO_x emissions from a given source.

$$SO_x \text{ emission} = \text{production} \times (\text{fuel consumption/production}) \times (SO_x/\text{fuel}) \times (SO_x \text{ emission}/SO_x \text{ generation}) \quad (2.3)$$

Japan began to implement measures to reduce SO_x emissions from the second half of the 1960s. By the second half of the 1970s, SO_x emissions had been reduced to the point that almost all areas of the country were meeting the environmental standard. Equation (2.3) suggests that the measures to reduce SO_x emission are classified into four categories: (i) production reduction, (ii) (fuel consumption/production) reduction, (iii) (SO_x /fuel) reduction, and (iv) (SO_x emission/ SO_x generation) reduction.

Production reduction belongs to the first category, energy conservation to the second, use of low sulfur fuel to the third, and flue gas desulfurization and use of fluidized bed boilers to the fourth category.

Of these measures, those that substantially contribute to reducing pollution include energy conservation, fuel switching and flue gas desulfurization. Reduced production was a measure applied in response to local government request to address emergency conditions and/or address short-term local pollutant concentration reduction. There were also a number of cases where a given site had become the subject of attention and the production facility was relocated domestically or internationally. However, from an LCA perspective, this cannot be said to be a reduction of pollution. Additionally, production reductions have occurred during economic recessions on an unplanned basis. The approach of reducing fuel consumption/production means improved efficiency in fuel consumption, and has probably been implemented in many cases. However, no information is available on the quantitative relationship between this approach and SO_x emission reductions. Although energy conservation can greatly contribute to SO_x emission reductions, the net costs of energy conservation would have been less than zero in many cases and it is uncertain to what degree SO_x emission reductions were the objective. In other words, it is unclear how much of a motivating factor the need for SO_x emission reduction was in achieving the progress in energy conservation measures. On the other hand, reducing the sulfur content of fuel and flue gas desulfurization are measures that were implemented with the specific objective of SO_x emission reduction, and have contributed greatly to such emission reductions (Purozyekuto Nyuusu Sya, 2001). Fluidized bed boilers and circulating fluidized bed boilers were introduced from the mid 1980s primarily for coal-fired boilers. As desulfurization occurs in the boiler, the use of flue gas desulfurization is unnecessary. However, the use of this technology has not increased as much as was originally anticipated. On the basis of the above observation, we concentrate on two measures: use of low sulfur fuels and flue gas desulfurization.

2.4.2 Use of low-sulfur fuels

Table 2.14 shows recent fuel prices for the same heating value. If LNG is excluded, it can be seen that fuels with low S content tend to have higher prices. The low price of electric power and LNG is thought to be the result of long-term contracts. One of the causes is also that LNG is imported in massive amounts. This is supplied to other industries in the form of gas at somewhat higher prices than heavy oil and other fuels. Also, power plants that can burn crude oil can achieve SO_x reductions at lower cost than those using heavy oil with reduced sulfur content, although this is not shown, since precise data cannot be obtained[2].

Let us calculate the marginal abatement cost for the case where an existing facility switches fuels to reduce SO_x. This is appropriate for a facility that can only use the fuels listed in Table 2.14. One type of facility meeting these criteria are heavy oil fired thermal power plants. As the fuel oil for thermal power plants is C heavy oil, price differences related to the sulfur is the marginal abatement cost. This is shown in Table 2.15.

It is clear that the unit reduction cost increases gradually with decreasing sulfur content. During this period, the marginal reduction cost for a heavy oil fired thermal power plant using C heavy oil with 0.1% sulfur content was about 312 yen/kg-S[3]. The average unit cost of reducing S from 3% to 0.1% is 156.8 yen/kg-S, almost half of the marginal cost.

2.4.3 Flue gas desulfurization

Flue gas desulfurization was introduced in about 1970, mainly for boilers. More recently, desulfurization installations for waste incinerators have increased and currently account for about 40% of installations, although the treatment capacity is no more than 10% of total capacity. Although boiler installations account for less than 30% of installations, these account for about 70% of treatment capacity (Purozyekuto Nyuusu Sya 2001).

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[2] Matsuno and Ueta (1997) shows this using the case of a power plant of the Kansai Electric Power Company

[3] It was 5,376 yen/kg S content in 1980, as stated in the footnote to Table 2.14

Table 2.14 Fuel price for the same heating value and sulfur content

	S Content [Weight %]	Specific Gravity	Price [yen/kl]	Heatinging Value [kcal/l]	S content [kg/10^6 kcal]	Cost [yen/ 1000kcal]
C Heavy Oil HPP	0.2	0.93	17540	9800	0.190	1790
General Sales Jan-Mar 1999	1.5	0.93	15000	9800	1.423	1531
C Heavy Oil LPP-	0.3	0.93	19840	9800	0.285	2024
General Sales	1.5	0.93	15200	9800	1.423	1551
Jan-Mar 1999	1.6	0.93	14800	9800	1.518	1510
	2.6	0.93	13800	9800	2.467	1408
	3.0	0.93	13600	9800	2.847	1388
C Heavy Oil HPP-	0.2	0.93	19110	9800	0.190	1950
General Sales Apr-Jun 1999	1.5	0.93	16220	9800	1.423	1655
C Heavy Oil LPP-	0.3	0.93	21440	9800	0.285	2188
General Sales	1.5	0.93	16420	9800	1.423	1676
Apr-Jun 1999	1.6	0.93	15800	9800	1.518	1612
	2.6	0.93	14800	9800	2.467	1510
	3	0.93	14600	9800	2.847	1490
C Heavy Oil	0.1	0.93	17830	9800	0.095	1819
ElectrUtilityity	0.2	0.93	17540	9800	0.190	1790
General Sales	1.6	0.93	14800	9800	1.518	1510
Jan-Mar 1999	2.6	0.93	13800	9800	2.467	1408
	3	0.93	13600	9800	2.847	1388
Kerosene Large Steel Company Sales Jan-Mar 1999	0.02	0.79	27000	8900	0.018	3034
Kerosene Large Steel Company Sales Apr-Jun 1999	0.02	0.79	29000	8900	0.018	3258
L/S A Heavy Oil Large Steel Comp. Sales Jan-Mar 1999	0.1	0.83	27000	9300	0.089	2903
L/S A Heavy Oil Large Steel Comp Sales Apr-Jun 1999	0.1	0.83	29000	9300	0.089	3118

Table 2.14 (cont.)

Table 2.14 (cont.)

A Heavy Oil Large Steel Comp Sales Jan-Mar 1999	0.5	0.85	26000	9300	0.457	2796
A Heavy Oil Large Steel Comp. Sales Apr-Jun 1999	0.5	0.85	28000	9300	0.457	3011
Propane Large Steel Comp. Sales Jan-Mar 1999	0.01		41400	12000	0.008	3450
Propane Large Steel Comp. Sales Apr-Jun 1999	0.01		37800	12000	0.008	3150
LPG Osaka Gas Mar 1999	0.01		30290	12000	0.008	2524
LNG Osaka Gas Mar 1999	0.001		18000	13000	0.001	1385
LNG Tokyo Electric Power FY1998	0.001		20614	13000	0.001	1586
LNG Kansai Elcetric Power FY1998	0.001		19797	13000	0.001	1523

Source: Sekitu (1999).
Note: The cost differential related to sulfur content has shown a decreasing trend. For example, the cost for the cleanest grade of C heavy (electric power use) 0.1% was about 5,000 yen/0.1% in 1980 and from the table above was 290 yen/0.1%, about 17 times.

Table 2.15 Price difference by S content for electric utility use of C heavy oil (Jan-Mar 1999) S content S content Price difference/S content

S content [Weight %]	**S content** [kg/10^6 kcal]	**Price difference/S content** [yen/kg S content]
0.1-0.2	0.09-0.19	311.8
0.2-1.6	0.19-1.52	210.4
1.6-2.6	1.52-2.47	107.5
2.6-3.0	2.47-2.85	53.8

The Flue Gas Treatment Technology Manual (For Government Agencies) Heisei 3 Environment Agency Contract by the Japan Industrial Machinery Society (Nihon-Kikai-Kougyou-Rengoukai 1992) contains several examples of flue gas desulfurization costs. The average costs of the limestone gypsum method, which is the most common method, were estimated. The input data are shown in Table 2.16.

For a C heavy oil fired boiler, it can be assumed that 10,000 Nm^3 would be handled for 0.85kl. The sulfur content is calculated to be 3.6%, thus assuming a fairly dirty fuel in the calculation. With due caution (as the data relates to different periods), it can be calculated that desulfurization to 0.4 kg/million kcal can be done for 86 yen/kg-S. A comparison with Table 2.15 shows that, for this degree of desulfurization, the cost of using flue gas desulfurization equipment is less than that of using low-sulfur fuel oil.

This is the reason for the large number of flue gas desulfurization units that have been installed (2,075 as of March 1998).

The Japan Research Institute (Nihon-Sougou-Kenkyuusyo 1998) has calculated the average cost of flue gas desulfurization by compiling data on cumulative investments, etc. (see Table 2.17) This is the cost data for emission sources and it is possible to compare this with our data. Their data shows that 2.6667 million tons of SO_2 (1.3335 million tons as sulfur) were removed by flue gas desulfurization. The average cost was 104.9 (yen/kg S), which is close to our results. In addition, their study used the shortened legal service life (7 years). If a period of 14 years had been used, an excess of 19.4 billion of amortization would have been included. This adjustment yields a value of 90.4 (yen/kg S), which is almost the same as our results. Their research yielded the overall average cost of flue gas desulfurization, and the results do not necessarily have to agree with our work, which is based on point data. However, it is likely that the average cost of SO_x reduction by flue gas desulfurization is roughly at this level.

In a mix with fuel sulfur reduction, the sulfur removal by the flue gas desulfurization is equal to the fuel sulfur reduction x (1-desulfurization efficiency). Thus, the SO_x emissions are reduced by less than the amount of fuel sulfur reduction. The gradual increase in cost is magnified and the efficiency of sulfur removal is reduced by the reduction of the fuel sulfur content. In other words, it can be anticipated that this method would

Table 2.16 Cost and other data for flue gas desulfurization

	Facility cost 1000yen/(Nm^3/h)	Running cost 1000yen/year/ (Nm^3/h)	Efficiency %
Limestone-gypsum method	4-8	0.83	90-95
Conditions for calculating running costs:			
Capacity	660,000 Nm^3/h (200MW)		
SO_2 concentration	2,000 ppm		
Desulfurization rate	90%		
Operation time	6100 h/year		

Table 2.17 Estimation of average cost of flue gas desulfurization

	Cost	
Annual oparating cost	547,800	1000yen/year
Facility cost[a]	3,960,000	1000yen
Facility cost annualization[b]	340,354	1000yen/year
Total (A)	888,154	1000yen/year
	Sufur reduction	
Annual flue gas discharge	4,026,000,000	Nm3/year
Amount SO_2	8,052,000	Nm3/year
Amount SO_2 removed	7,246,800	Nm3/year
Converted to kg sulfur (B)	10,352,571	kg/year
	Average cost (A/B)	
	85.79	yen/kg

[a] Equipment cost is 6000 yen/(Nm3/h).
[b] Facility cost is annualized according to $S=Cr(1+r)^{n-1}/[(1+r)^n-1]$, where S is the amount value, C is the equipment cost, r is the service life, and n is the depreciation period with r=0.03 and n=14 [years].

result in increased maximum cost of reducing SO_x emissions as SO_x emissions decrease.

2.4.4 MAC for SO_x Reduction

The estimated maximum costs are 85.79 yen/kg S for flue gas desulfurization and 312 yen/kg S for heavy oil desulfurization, and the average cost is 156.8 yen/kg S. Taking the lower flue gas desulfurization cost of 85.79 yen and converting kg S to kg SO_2 yields a MAC for SO_x reduction of 43 yen/kg.

2.5 CO_2

With regard to the MAC for CO_2, we have assumed that the emission target for 2008–2012, given by the Kyoto Protocol to the United Nations Framework Convention on Climate Change, i.e. a 6% reduction relative to 1990, will be met, taking into account the COP7 agreement about the inclusion of forest sinks and the use of Kyoto Protocol Mechanisms.

There are two methods to estimate the MAC for CO_2. One approach involves estimating the direct cost of each policy or technology. The other approach is an indirect estimate based on estimated CO_2 emission demand coefficients. The former approach involves the cumulative estimating costs of CO_2 reduction by individual technologies. The method with the highest reduction cost is taken to provide the MAC. The second approach involves the construction of a model to explain CO_2 emissions by explanatory variables including a logarithm of energy price, the estimated coefficient of which represents the price elasticity of CO_2 emissions. When the ratio of the emissions for the standard year and the target year are determined, and the energy price for the standard year is defined, the elasticity value obtained from the model can be used to obtain the energy price that guarantees that the emission target is met, and the MAC can be derived.

2.5.1 Cumulative Method

The Central Environmental Council [Interim Report of Target Achieving Scenario Subcommittee] (Tyuuou-Kankyou-Singikai Tikyuu-Kankyou-Bukai 2001) examined the reduction potential for domestic CO_2 control technologies (in the wider sense of the term technology, i.e. including measures such as the introduction of summer time) and the relationship between cost and reduction for measures that might be implemented to meet the requirements of the Kyoto Protocol. The equation for calculating the additional cost of reduction is shown below:

$$\text{Increased reduction cost} = \\ \text{reduction cost}(C) \text{ - energy mitigation cost}(P) \text{ - other profit}(E)$$

The scenario indicates that, assuming the construction of 7 nuclear reactors, CO_2 emissions in 2010 will be 355 million tons of carbon or 108% of the 330 million tons in the 1990 reference year. However, the target that must be achieved in 2010 is a 6% emission reduction relative to 1990, or 310 million tons of carbon. Although it is not explicitly stated in the report, if the forest sink that was permitted at COP7 and the 1.8% credit under the Kyoto Protocol Mechanism are subtracted, this leaves 26.7 million CO_2-C that must be addressed in Japan using various technologies. Converting this to CO_2 yields a value of 98 million tons (in the Interim Report, the analysis is written in terms of tons of CO_2, and this convention will be followed here).

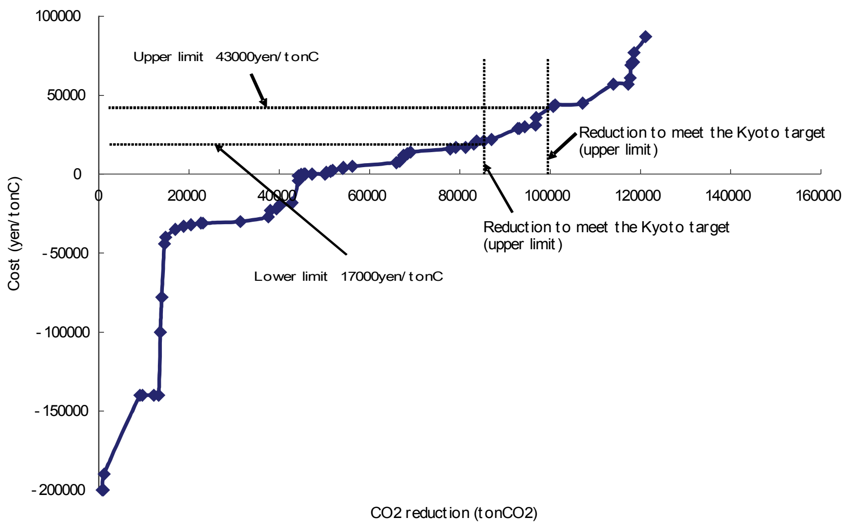

Figure 2.1 Estimated MAC for CO_2 from the Ministry of the Environment's Assessment of Technological Reduction Potential

Figure 2.1 lists the reduction potential and cost of technologies from the Interim Report, in the order from least to greatest cost. Since control technologies include control measures that are either substitutes or supplements, the potential for each of these could not be covered. Therefore, each control measure was considered independently, and the highest reduction cost to meet the target was estimated for two cases:

— the case where inestimable costs are included in the target achievement;

— the case where inestimable costs are all excluded.

The highest cost to meet the reduction target of 98 million tons of CO_2 was 17,000 yen/ton CO_2-C (4,600 yen/ton CO_2) for case 1 and 43,000 yen/ton CO_2-C (11,700 yen/ ton CO_2) for case 2.

2.5.2 MAC from Demand Model

There are a number of examples of estimates of price elasticity values obtained from macroeconomic models. The Ministry of the Environment's report used a bottom-up analysis as well as five macroeconomic and other models to analyze carbon tax simulations. Although these models did not rigorously address the CO_2 emission scenarios discussed above, the models were used to calculate the carbon tax required to reduce carbon dioxide emissions in 2010 to 2% below the 1990 level. As shown in Table 2.18, the carbon tax required to achieve this reduction in the simulation results ranged from 13,000 to 35,000 yen per ton of carbon. Converted to CO_2, this is about 3,500 to 9,500 yen per ton. It should be noted that the model assumed that technology is selected in an economically rational way and that changes in energy price elastically improve energy efficiency. Existing socioeconomic system barriers against individual countermeasures were not addressed.

These results do not differ greatly from the estimation results obtained using the bottom-up method. The results are summarized in Table 2.19.

2.5.3 MAC for CO_2 Reduction

The estimated results yield a MAC for CO_2 reduction of about 7,000 yen/t or 7.0 yen/kg.

Table 2.18 Carbon tax amounts required for the model to achieve a 2% reduction of CO_2 emissions

Model	Case	Amount of carbon tax in 2010 [yen/tonC]
AIM End Use Model	Carbon tax case	30,000
	Carbon tax + subsidy case	3,000
GDMEEN	Carbon tax case	34,560
MARIA	Carbon tax case 1	13,148
	Carbon tax case 2	14,359
SGM	Increase of government expenditure case	20,424
	Government deficit reduction case	21,100
	Income tax refund case	21,080
AIM Material Model	Carbon tax case	15,587

Table 2.19 MAC for CO_2 derived by two methods based on the Central Environmental Council's 2001 estimate

	CO_2 MAC [yen/ton-CO_2]
Bottom-up method	4,600-11,700 (8150)
Demand model	3,500-9,500 (6500)

Note: the values in parentheses are averages of the upper and lower limits.

2.6 SPM (suspended particulate matter)

2.6.1 Introduction

The minute particulate matter (PM) in the atmosphere is generically referred to as floating dust and is measured using methods including light scattering. In Japan, floating dust with a particle diameter less than 10 μm is defined as SPM (suspended particulate matter).

The Japanese government amended the Automobile NO_x-PM Law (Special Measures Law on Reduction of Total Emissions of Nitrogen Oxides and Particulate Matter from Automobiles in Specified Areas) in 2001. Based on this amendment, 276 cities, towns and villages were designated as NO_x and PM control regions, for which PM reduction plans were established by prefectural governors.

The following control measures are expected to be taken to reduce SPM.

1. *Stationary source control measures*

(a) Flue gas emissions sources

i. Waste incinerator measures. To control primary particle emissions from waste management incinerators, the emissions standard for particulate emissions from incinerators with an incineration capacity greater than 200 kg/h was set at 0.04 g/m^{3}N. Also, to control secondary particulate matter formation, the hydrogen chloride emissions standard was reduced to half of the national standard, to 250 mg/m^{3}N for incinerators with an incineration capacity of 200 to 500 kg/h and 100 mg/m^{3}N for incinerators with an incineration capacity greater than 500 kg/h.

ii. NO_x Control Prefectural Ordinance. The Guidance Policy for NO_x Emissions from Factories/Business was enacted as a prefectural ordinance to strengthen the management of combustion sources, etc. and reduce NO_x emissions by 5%.

iii. Strengthening Regulations for Liquid Fuel Boiler Particulate Emission (amendment to prefectural ordinance). Special emissions standards were applied to liquid fuel boilers. Particulate emission standards for liquid fuel boilers with flue gas discharge greater than 200,000 m^{3}N/h were set at 0.04 g/m^{3}N and 0.05 g/m^{3}N for liquid fuel boilers with 40,000 to 200,000 m^{3}N/h flue gas discharge.

(b) VOC control measures

For existing sources, the enacting of a prefectural ordinance based on the Guidance Policy for VOC Control was anticipated to reduce VOC emissions by 20% between 1996 and 2005. For the period from 1990 to 2000, the concentrations of non-methane VOCs decreased by about 20%, and this effect was included.

(c) Small incinerator control measures

With the enforcement of the ordinance, all small incinerators with a capacity of less than 30 kg/h capacity used in homes, etc. were assumed to be removed.

(d) Rice straw burning

Enforcement of the Waste Management Law amendments and prefectural ordinances resulted in a total ban on open air burning. Rice straw burning was originally exempted but was banned as part of the strengthening of control measures. Thus, emissions from rice straw burning are not included.

2. *Mobile source control – enforcement of vehicle regulations from the Amended* NO_x *Law.*

Enforcement by vehicle type started in April 2002 for new vehicles and from April 2003 for vehicles in use. The long-term standards are assumed to be applied (the vehicles that meet only the short-term standards (the 1988 standards) are due for replacement). Standards for vehicles with capacities of less than 3.5 ton were set at the same level as those for gasoline vehicles. The grace period for small trucks and passenger vehicles was 8 years, while that for standard trucks was 9 years, that for special vehicles 10 years and that for buses 12 years. In this case, the new longer-term regulations were brought forward by two years to 2005 and the diesel fuel sulfur content was reduced from 500 ppm to 50 ppm.

3. *Vehicle control – enacting Ordinance to Strengthen Vehicle Type Control.*

In addition to the vehicle control measures discussed under (2), enforcement of the ordinance for vehicle types led to a shortening of the grace period (8 years for small trucks and passenger vehicles, 9 years for standard trucks, 10 years for special vehicles and 12 years for buses) to a uniform 7 years, and the replacement of vehicles with models meeting new standards was accelerated.

2.6.2 MAC for SPM

The vehicle control system based on the Automobile NO_x - PM Law was estimated to result in a total of 7,215 vehicles being removed from service. When the ordinance to shorten the grace period was introduced, it was estimated that a total of 21,102 vehicles would be removed from service. Available choices include replacement of these vehicles with those meeting regulatory requirements and installation of control equipment.

The cost of control equipment for two companies was investigated, and the results are shown in Table 2.20.

The average cost per vehicle was estimated from the Machinery Statistical Annual Report published by the Ministry of International Trade and Industry (currently Ministry of Economy, Trade and Industry) Ministry Secretariat Statistical Study Department, as shown in Table 2.21 below.

These results show that small trucks and special vehicles were all replaced by new vehicles meeting the latest regulatory requirements. In this case, the price of a new vehicle was taken to be the cost. For standard trucks, installation of control equipment on all vehicles was assumed and the cost per vehicle was assumed to be a uniform 1 million yen. The amortization period for this cost is seven years, with straight-line amortization.

Table 2.20 DPF equipment type and cost

DPF type	Fuel used	Cost
A type of DPF where the material collected by filter is incinerated using external electric power without removing the filter from the vehicle when the vehicle is not in use	Ordinary diesel fuel	800,000 yen
A type of DPF where the material collected by filter is incinerated using external electric power on the filter removed from the vehicle	Ordinary diesel fuel	1,000,000 yen (DPF); 600,000 yen (Regenerating equipment)
A type of DPF using oxidizing catalyst and heat of exhaust gas to combust the materials collected by filter	Low sulfur diesel fuel	1,000,000 yen

Table 2.21 Estimated average cost per vehicle

	Cost [yen/vehicle]
Standard trucks	2,445,114
Small trucks	1,038,705
Buses	4,282,386
Special use vehicles	816,487

Table 2.22 Number of vehicles requiring control measures

		Vehicle control I[a]		Vehicle control II[a]	
		No. of Vehicles	Cost [10^6 yen]	No. of Vehicles	Cost [10^6 yen]
Replacement	Small trucks	194	2,015	438	4,550
	Special use vehicles	78	64	356	291
Control equipment	Sandard trucks	6,924	6,924	20,182	20,182
	Buses	19	19	126	126
Total		7,215	9,022	21,102	25,149
Annualized cost (10^6 yen/year)			1,289		3,593

[a] Under vehicle control I, vehicle type control under the amended Automobile NO_x, PM Law is assumed to implemented, while under vehicle control II, in addition to the vehicle control I, the grace period is assumed to be shortened to 7 years.

Table 2.23 MAC calculation results for SPM concentration reduction

	SPM conc [μg/m^3]	Cumulative conc. reduction [μg/m^3]	Cumulative added cost [10^6yen/year]	Individual conc. reduction [μg/m^3]	Individual added cost [10^6yen/Year]	Maximum reduction cost [10^6yen/(μg/m^3)]
1996 base case	52.9	-	-	-	-	-
2001 BAU	42.3	-	-	-	-	-
Control case 1	41.3	1.0	1,289	1.0	1,289	1,289
Control case 2	41.3	1.5	3,593	1.53	3,593	2,395
Control case 3	38.9	3.4	4,502+	1.9	909+	478+

Calculation of MAC for SPM Reduction

Table 2.23 shows the reduction of SPM concentrations and the cost for the control cases. The results show that the highest reduction cost is that for mobile sources: 2.395 billion yen per 1 μg/m^3 for shortening the grace period to meet vehicle control regulations. The lowest reduction cost is that for stationary source emissions control: 478 million yen per 1 μg/m^3.

The particulate matter emissions from vehicles would be reduced from 2,962 tons to 2,529 tons, a difference of 430 tons of particulate matter. Assuming installation of DPF equipment (1 million yen per unit), case 3 would mean that all standard trucks and buses (20,182 trucks and 126 buses for a total of 20,308 vehicles, see Table 2.22) would have this equipment installed. Assuming a service life for the equipment of 7 years, the simple annual costs for one unit would be 1 million yen/7, assuming that no maintenance cost would be incurred. From the reductions of 430 tons of particulate matter, the average cost of DPF equipment installation would be

$$(1000000/7) \times (20182 + 126)/(2962 - 2519) =$$
$$6.7 \text{ million yen/ton particulate matter.}$$

This is taken as the MAC for SPM reduction.

2.7 Eutrophication-causing substances

2.7.1 Industrial wastewater treatment

Lake Biwa Research Institute has reported data on the costs to reduce the discharge of chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) to Lake Biwa from industries in 1991 (Sigaken Biwako Kenkyuusyo 1994). According to the report, the emissions of theoretical oxygen demand (TOD), where TOD=3COD+[19.7TN+ 143TP]/2) (Ukita 1982), reduced from 21 factories amounted to 3,096 ton/year, the unit costs of which are shown in Table 2.24 by the cumulative percentage of reduction. Most of the last 7% of the reduction was at a cost of 1,300 to 1,600 yen/kg.

Data from Ebara Corporation on plant waste unit treatment costs is shown in Table 2.25.

Table 2.24 Unit costs of reducing TOD from the industries in the Lake Biwa area

Cumulative percentage of reduction	Unit cost [yen/kg]
29.0%	40
46.7%	43
50.9%	53
71.3%	138
75.1%	176
78.7%	312
79.2%	513
82.5%	538
86.6%	547
87.2%	714
92.4%	772
92.6%	827
93.7%	1,312
96.2%	1,357
99.4%	1,361
99.5%	1,526
99.8%	1,576
99.9%	6,149
99.9%	7,126
100.0%	18,645
100.0%	28,209

Table 2.25 Unit cost of factory wastewater load reduction

Industry	Reduced Load [kg/year]				Annual cost [1000 yen/year]	Reduction cost [yen/ kg-TOD]
	COD	TN	TP	TOD		
Livestock processing	78,750	14,700	6,300	831,495	28,365	34
Semiconductor	109,760	49,280	0	814,688	62,757	77
Automobile	0	3,142.6	0	30,945	15,362	496
Total				1,677,128	106,484	63

2.7.2 Reduction of pollutants by sewerage systems in the Lake Biwa area

On the basis of cost estimates for the sewerage system in the Lake Biwa area, also obtained from Lake Biwa Research Institute, we can calculate the unit cost for TOD. The total construction and operating costs of the North East Watershed Sewerage System of Lake Biwa, including projection to 2023, was estimated to be 418 billion yen. Subtracting the savings on the existing costs of human waste treatment and the benefits from being able to use flush toilets, i.e. 115 billion yen and 106 billion yen, respectively, the net cost of improving environmental water quality is 197 billion yen, the present value of which is 159 billion yen under a 3% discount rate.

Table 2.26 shows the allocation of the costs to COD, total nitrogen (TN) and total phosphorus (TP). The costs of construction and maintenance of sewers and 76% of the sewage treatment costs are attributed to COD, while 24% of the sewage treatment costs are attributed to TN and TP. The cost savings from ending existing human waste treatment and the benefits from the ability to use flush toilets are all attributed to COD. Reductions of COD, TN and TP are estimated as net values, subtracting the existing reductions by human waste treatment. The present values of the reductions are shown in Table 2.26. The unit cost for TOD is also shown in the table as 1,700 yen/kg, along with the unit costs for COD, TN, TP and TOD (TN,TP), where TOD (TN,TP) is defined as (19.7 TN+143 TP)/2.

Table 2.26 Unit cost for sewerage system (Lake Biwa North East, projection and actual)

Cost [billion yen]		Reduction		Unit cost	
Total	159	92,348	ton-TOD	1,700	yen/kg-TOD
COD	137	17,059	ton-COD	8,000	yen/kg-COD
TN, TP	23	1,918	ton-TN	5,900	yen/kg-TN[a]
		312	ton-TP	36,000	yen/kg-TP[a]
		41,170	ton-TOD[b]	550	yen/kg-TOD

Note: Data are recalculated from Oka (1992).
[a] The cost allocated to TN and TP was evenly reallocated to TN and to TP to calculate unit costs for TN and TP.
[b] TOD(TN,TP)=(19.7 TN+143 TP)/2.

2.7.3 MAC for TOD

Reducing the wastewater load from factories around Lake Biwa by 99% costs less than 1,600 yen/kg-BTOD, and the unit cost of reducing the wastewater load from the Ebara Corporation factory was less than 1,600 yen/kg-TOD for all units. The unit cost of reducing the domestic wastewater burden was 1,700 yen/kg-TOD. We conclude that the MAC for TOD is 1,700 yen/kg-TOD.

2.8 TCE and PCE

Based on the February 1996 report entitled 'Towards Restoring the Famous Hadano Basin Springs' by the Hadano City Environment Department, we calculated the cost of remediation for trichloroethylene (TCE) and perchloroethylene (PCE). As the methods for treating either substance are basically the same, the average unit treatment costs (treatment costs per amount recovered) for these two substances was also assumed to be the same. The amount recovered and the costs (survey cost, cleanup cost) were compiled, and the average treatment cost (treatment cost per

Table 2.27 Treatment cost for TCE, PCE

Treatment method	No.of cases	Average cost [1000yen/year]		Maximum cost [1000yen/kg]	
		Cleanup cost	Total cost	Cleanup cost	Total cost
In Situ Vacuum Extraction Method	20	1,362	3,138	21,667	31,667
In Situ Gas Aspiration Method	13	177	1,150	1,000	10,000
Excavated Low Temp. Heat Treatment	2	15,053	17,097	30,000	34,000
Excavation Industrial Waste Disposal	4	2,767	5,580	10,000	20,000
Excavation Sealing Treatment	2	6,335	6,335	10,345	10,345
All Treatment Cases	41	2,034	3,583	30,000	34,000

Note: Total cost includes survey and cleanup costs, all excavation treatments are the total of excavation low emperature heat treatment, excavation industrial waste disposal and excavation sealing treatment.

unit recovered) was calculated. For cases where treatment was implemented repeatedly by the same method at the same location, the total was counted as one treatment. In cases where both substances were treated simultaneously, the calculation was made for the total cost of the combined treatment (only the combined treatment is shown, cases where individual treatment amounts could be assessed were treated the same). There were cases where the survey cost and cleanup costs were not distinguished, or where there was no clear and detailed definition of the costs of survey and treatment. The results are shown in Table 2.27. The MAC for treating trichloroethylene and perchloroethylene were found to be 15,053,000 yen/kg.

2.9 Heavy metals

2.9.1 Range of study

The technologies covered in this study are technologies for treating heavy metals in wastewater from plating plants and wastewater from municipal solid waste treatment facilities. The facilities covered, types and concentrations of heavy metals are shown in Table 2.28.

Heavy metal species and concentrations

The heavy metals covered in this study were Fe, Cu, Zn, Ni, Sn, Pb, As, Cd, Cr, Hg and Mo. Concentrations in wastewater ranged from 43 ppm to 1,310 ppm. As shown in Table 2.28, the concentrations in wastewater from electronic parts production facilities vary by a factor of 30. The concentration of heavy metals in the wastewater from the municipal waste treatment plant was 386 ppm and fell within the range of wastewater concentrations from plants manufacturing electronic parts.

Table 2.28 Heavy metal wastewater data

Facility	Heavy Metals	Waste water discharge [m^3/d]	Quantity of heavy metals [Kg/d]	Waste water concentration [ppm]
LCD Production	Fe Zn Cu Ni	46.1	22.9	497.0
Electronic Parts Production	Fe Pb Cu Sn	264.0	32.8	124.0
Plastic Plating	Fe Cu Ni	46.1	13.8	300.0
Electronic Parts Production	Ni Sn Pb Cu	752.7	32.0	42.5
Electronic Parts Production	Fe Cu Ni	67.2	88.5	1,310.0
Zinc Plating	Fe Zn	80.0	31.7	396.0
Landfill	Sb As Cd Cr Cu Pb Hg Mo Ni	756.0	291.8	386.0

2.9.2 Estimation method

To assess plating plant wastewater treatment, we interviewed companies producing systems to treat sewage which contains heavy metals, asking about capacity and costs. Operating costs included those of chemicals and other consumable supplies, waste treatment cost, energy cost (electric power), facility amortization and personnel costs. The calculation of cost amortization for facilities and construction assumed 275 operating days per year, 7.2% discount rate, a 7 year amortization period and 10% scrap value for equipment, and a 30 year amortization period and no scrap value for buildings and structures. For municipal solid waste treatment facilities, the calculation of facility construction cost (including water treatment facilities) assumed that the buildings and equipment account for 50% each, with 365 operating days per year. The equation to calculate amortization is shown below.

$$\theta=(1-v_s)(1+r)^n/[\Sigma_{k=1}{}^n(1+r)^k] \quad (2.4)$$

Here, θ, v_s, r and n, are the annual cost rate, scrap value, discount rate and amortization period in years.

2.9.3 Calculation results and comments

Results are compiled in Table 2.29.

The cost of reducing heavy metal levels ranges from 1,766 yen/kg to 20,626 yen/kg, with 20,626 yen/kg being the highest cost. Although the number of samples was relatively small, the data provides several useful pieces of information. In general, costs of end-of-pipe technologies are dominated either by the amount of material discharged or by the amount of material treated. Cases where the pretreatment levels are relatively high compared to the discharge standard fall into the former category, while cases where the pretreatment concentrations are relatively low fall into the latter category. Treatment of waste liquids from plating plants falls into the former category.

A comparison of plants D and E shows that, although the wastewater concentrations differ by a factor of 300, the treatment costs only differ by a factor of 3. The wastewater treatment cost for the municipal waste treatment facility was less than that for plating plants, at 1,766 yen/kg.

Table 2.29 Heavy metal treatment cost

Facility	Heavy Metals	Waste water concentration [ppm]	Treatment cost [yen/kg]	Labor cost [yen]
LCD Production	Fe Zn Cu Ni	497	20,626	54.1
Electronic Parts Production	Fe Pb Cu Sn	124	10,793	72.3
Plastic Plating	Fe Cu Ni	300	7,572	61.0
Electronic Parts Production	Ni Sn Pb Cu	43	9,163	76.5
Electronic Parts Production	Fe Cu Ni	1,310	3,192	68.3
Zinc Plating	Fe Zn	396	3,667	55.0
Landfill	Sb As Cd Cr Cu Pb Hg Mo Ni	386	1,766	N.A.

Table 2.30 Regression statistics

Regression results			
	Coefficient	**Standard error**	**t value**
Intercept	6.939	1.140	6.089
Waste water volume	-0.6103	0.2513	-2.428
Concentration	-0.7402	0.2875	-2.575
Regression statistics			
Multiple correlation coefficient R		0.8109	
Coefficient determination R^2		0.6576	
Compensating coefficient of determination R'^2		0.4864	
Standard error		0.2579	
Number of samples		7	

In order to analyze the scale effects related to the wastewater volume treated and the concentration in the treated discharge, a logarithmic multivariate analysis was conducted, with the cost of treatment for heavy metals (Cost: yen/kg) as an explained variable, and the amount of wastewater per day (Q: m^3/day) and the total heavy metal concentration (C: ppm) as explanatory variables.

Although 7 samples is a small number, the value of t was greater than 2, a result that was anticipated from the sign conditions obtained:

$$\text{Cost} = 10^{6:939} \,.\, Q^{-0:6103} \,.\, C^{-0:7403} \qquad (2.5)$$

the regression statistics of which are summarized in Table 2.30.

2.9.4 MAC for heavy metals

Within the range included in this study, the highest cost of reducing heavy metals was 20,626 yen/kg. It was inferred that the MAC was higher than 20,626 yen/kg. A logarithmic regression analysis, using the cost of treatment for heavy metals (Cost: yen/kg) as an explained variable and the amount of wastewater per day (Q: m^3/day) and the total heavy metal concentration (C: ppm) as explanatory variables, showed that the treatment costs rose with wastewater volume by a power of -0.6103 and rose with wastewater concentration by a power of -0.7403 (Equation 2.5). Thus, a noticeable scale effect related to wastewater volume and concentration was observed.

2.10 Volatile organic compounds (VOC)

2.10.1 Range of study

The technologies covered in this study are those for the removal of VOC from the exhaust gas of printing facilities for plastic films or metal cans. The technologies used for VOC treatment are direct incineration, catalyst deodorizer, self-sustained combustion, regenerative deodorizer and solvent recovery, as well as combinations of these technologies. All facilities are used to remove toluene.

2.10.2 Data and estimation method

A major converting company and a major packaging manufacturer provided actual operating data, investments and running costs for a one-year period. Data collected by the Japan Printing Machinery Association (JPMA) was also used.

The costs comprise amortization, utilities and personnel costs. The calculation of amortization cost assumed a 7-year amortization period, 7.2% discounting rate and 10% scrap value. The equation is the same as that for heavy metals. The plant was assumed to operate for 6,000 hours per year.

Because the data supplied by JPMA did not include removal efficiency, we assumed the average removal efficiency of the observed data, which was 63.9%.

Because the running costs of packaging manufacture were more than one order of magnitude higher than other corresponding data, we did not used this data to calculate the MAC. The difference may have been caused by differences in the scope of personnel costs.

2.10.3 MAC for VOC

Calculation results are compiled in Table 2.32. The cost of removing VOC from exhaust gas lies within a range of 24 to 157 yen/kg. The highest cost of 157 yen/kg might be an underestimation, because we assumed the average removal efficiency for data from JPMA. Therefore, the MAC for VOC is higher than or equal to 157 yen/kg.

2.11 Dioxin

According to Kishimoto et al. (2001), 358 billion yen of investments were necessary up to 2002 to meet the emission standards on dioxins. This corresponds to 17.2 billion yen per year, converted to an annual basis.

Adding this to the increase in operation cost of 24 billion yen per year yields an annual cost of 41.2 billion yen. The amount reduced by these measures was estimated to be 2,210 g-TEQ/year. Therefore, the unit cost is 19 million yen/g-TEQ. Based on this, the MAC for dioxin is taken to be 19 billion yen/kg-TEQ.

2.12 Summary

The MAC results obtained are compiled in Table 2.31. These values can be used to assess green activities, an example of which is shown in Oka et al. (2005).

Table 2.31 MAC values (yen/kg)

	NO_x	**SO_x**	**CO_2**	**SPM**	**TOD**	**TCE, PCE**	**HM**	**VOC**	**DXN**
MAC	2,500	43	7.0	6,700	1,700	1.5×10^7	20,000	160	1.9×10^{10}

Table 2.32 Cost for reducing volatile organic compounds

Data source	Input [ton/year]	Removal [ton/year]	Investment [1000yen/ year]	Running [1000yen/ year]	MAC [yen/kg]
converter	170	165	147,291	535	144
converter	239	224	135,000	535	97
converter	650	452	171,500	589	61
converter	962	897	245,431	535	44
converter	388	255	115,000	10,657	113
packaging	241	44	26,531	23,226	-
packaging	510	235	196,260	64,118	-
packaging	350	126	115,593	43,740	-
packaging	625	448	775,442	92,130	-
packaging	420	282	456,163	112,237	-
packaging	3,420	1,222	574,775	99,767	-
packaging	388	245	340,800	68,907	-
packaging	559	384	730,667	129,683	-
packaging	367	232	200,000	32,649	-
packaging	264	134	168,331	22,488	-
JPMA	296	189	33,500	3,636	47
JPMA	591	378	50,000	7,272	40
JPMA	591	378	55,000	3,246	31
JPMA	296	189	35,000	17,790	123
JPMA	591	378	52,000	35,586	116
JPMA	296	189	56,000	2,088	58
JPMA	591	378	83,000	4,176	45
JPMA	296	189	35,000	-	-
JPMA	591	378	100,000	-	-
JPMA	96	61	46,000	1,518	142
JPMA	185	118	57,500	2,112	94
JPMA	222	142	44,000	3,360	72
JPMA	96	61	35,000	4,188	157
JPMA	185	118	39,000	7,164	112
JPMA	222	142	44,000	7,044	98
JPMA	296	189	30,000	5,400	53
JPMA	591	378	60,000	6,000	41
JPMA	591	378	70,000	2,100	35

Table 2.32 (cont.)

Table 2.32 (cont.)

JPMA	887	567	85,000	2,760	28
JPMA	1,183	756	95,000	3,600	24
JPMA	96	61	48,000	1,080	140
JPMA	96	61	32,000	2,520	123
JPMA	185	118	57,500	1,500	89
JPMA	185	118	37,500	5,100	93
JPMA	222	142	59,000	1,800	78
JPMA	222	142	39,000	5,760	84
JPMA	296	189	31,000	5,346	54
JPMA	591	378	54,000	14,622	61

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