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Estimation of Air Pollutions and Evaluating CO_2 Emissions from Production Activities: Using Japan's 1985 Input–Output Tables[1]

By
Hitoshi Hayami*, Ayu Ikeda**, Mikio Suga***, and Kanji Yoshioka*

Abstract

The aim of this research is to extend the input–output tables for environmental analysis in the most detailed classification possible. It can also be shown that it plays an important role in evaluating accurately the emissions of CO_2, NOx and SOx. This paper decries the three points needed to understand our environmental extended input–output tables. Firstly, it explains how to estimate air pollution's from the 406 sectors in the 1985 input–output tables of Japan. Secondly, it shows an overview of our estimates of CO_2, NOx, and SOx emissions. Thirdly, it reports the CO_2 emission from 1 unit of production activities using our environmental input–output tables. Our estimates suggest that there are large differences in CO_2 emissions between sectors, even though the sectors belong to the same 2-digit category. This implies large potential of cutting CO_2 exists by recycling materials or through introducing alternative technologies.

1. Introduction

In order to realize "sustainable development", we must investigate whether an alternative technology reduces air pollution in the economic system. Although a new technology cuts CO_2 or NOx with the new equipment, it might increase CO_2 or NOx in other industries by demanding new inputs which were not required by old technology. To analyze the dependency of one sector's CO_2 emission on the other sectors, we must take into account the interdependence between industry sectors. This is our main purpose in constructing the environmental input–output tables, and its aim is similar to Leontief's pioneering works[2].

To evaluate the inter-sector effects precisely, we have developed "the 1985 406-sector Input–Output Tables for Environmental Analysis in Japan". We elucidate the difference of adopted technology between commodities, and we attempt to compare the alternative technologies producing the same kind of commodities. This 406 sectors Input–Output Table has the most detailed classification which is available for three types of pollutants, CO_2, NOx, SOx, in Japan[3].

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* Keio University, ** Tokai University, *** Graduate School of Keio University

[1] This paper is originally presented at the 10th Conference on International Input–Output Analysis at Sevilla in Spain on 29 March 1993. The authors are indebted to Dr.Y.Tonooka for verifying the estimations of fixed sources. We have received valuable comments from anonymous referee and workshop participants at Keio Economic Observatory. Any errors remain to be the responsibilities of the authors.

[2] Leontief(1970) considered anti-pollution activities which attempt to reduce pollutions. Although we did not divide an activity into production process and abatement process, we use emission factors after eliminating NOx and SOx. For SOx, it is better to incorporate abatement activities in order to consider the environment protection investment which induces SOx emission in the other sectors. For NOx, transportation activity is the main source of NOx emission. There is no abatement facility on automobile, and NOx emission depends on the driving condition.

[3] We have another extended version of 441 sectors table with detailed construction activities.

This paper contains three points to underśtand our extended input–output tables. Firstly, it briefly explains the estimation procedures of our environmental input–output table. Secondly, it shows an overview of our estimates of CO_2, NOx, SOx in 29 sectors. Thirdly, it elucidates the effects of 1 unit of production on CO_2 emissions for each economic activity.

2. Components of the Environmental Input–Output Table

Figure 1 shows the conceptual framework of the extended input–output table. Our Environmental Input–Output table contains 7 parts, that is,

(1) 406×406 basic table(its component is X_{ij}),

(2) 406+final demand sectors ×40 physical input table for fuel consumption and material use,

(3) 406+final demand sectors ×40 fuel/input ratio table for fuel and materials,

(4) 406+final demand sectors ×40 calorie input table as fuel consumption,

(5) 406+final demand sectors ×31–7 emission coefficients (per calorie unit) table ,

(6) 406+final demand sectors ×31–7 emission (volume) table,

(7) 406+final demand sectors ×3 emission coefficients (per production unit) table,

3. CO_2, NOx and SOx emissions from fixed sources

According to Leontief(1970), the input–output table for environmental analysis is incorporated with anti-pollution sectors. But in fact, it is difficult to divide the air pollution by NOx into generation and abatement activities [4].

For estimating NOx from fixed sources, we can get the emission coefficients after eliminating pollutions by sector and by type of boiler or furnace. Therefore, we can directly construct the table for emission (not for generation) after NOx eliminating activities. It is familiar that NOx emission greatly depends on thermal NOx, which varies with burning condition. Thus the reduction of NOx depends on both burning condition and abatement activity.

It is important to incorporate abatement activities in input–output tables for environmental analysis, when we take the stability of emission factors into consideration. Unfortunately we could not get enough information about abatement activity, and hence this remains to be improved in future research.

On the other hand, CO_2 originate mainly from fuels with some from material origins. For CO_2, since there is no abatement activity, we estimate CO_2 emission from its content in the fuel and the material(e.g. limestone in cement activity, pig iron in crude steel activity). Even if there is no abatement activity, energy transfer of by-products to other sectors exists. But the energy transfer activity can be adopted in only a few limited industries. With the exception of the following four sectors, we estimate CO_2 emission from fuel consumption and the ratio of carbon content.

For the following sectors, (1)coal products, (2)pig iron, (3)crude steel and (4)gas supply, they generate by-products(BFDust, BFG, COG, LDG, OFG etc.) with consume and transfer energy products with each other simultaneously. It is not proper to attribute CO_2 emission from fuel

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[4] However, there are a few pioneering works, see, S. Shishido and A. Oshizaka(1975). They analyze the effects of abatement activities and abatement activity related investment by using 60-sector input–output tables. Also MITI publishes 25-sector input–output tables for industry pollution with abatement activities in 1976. MITI estimates SOx, COD, SS, IW from many pollution surveys in addition to basic input–output tables.

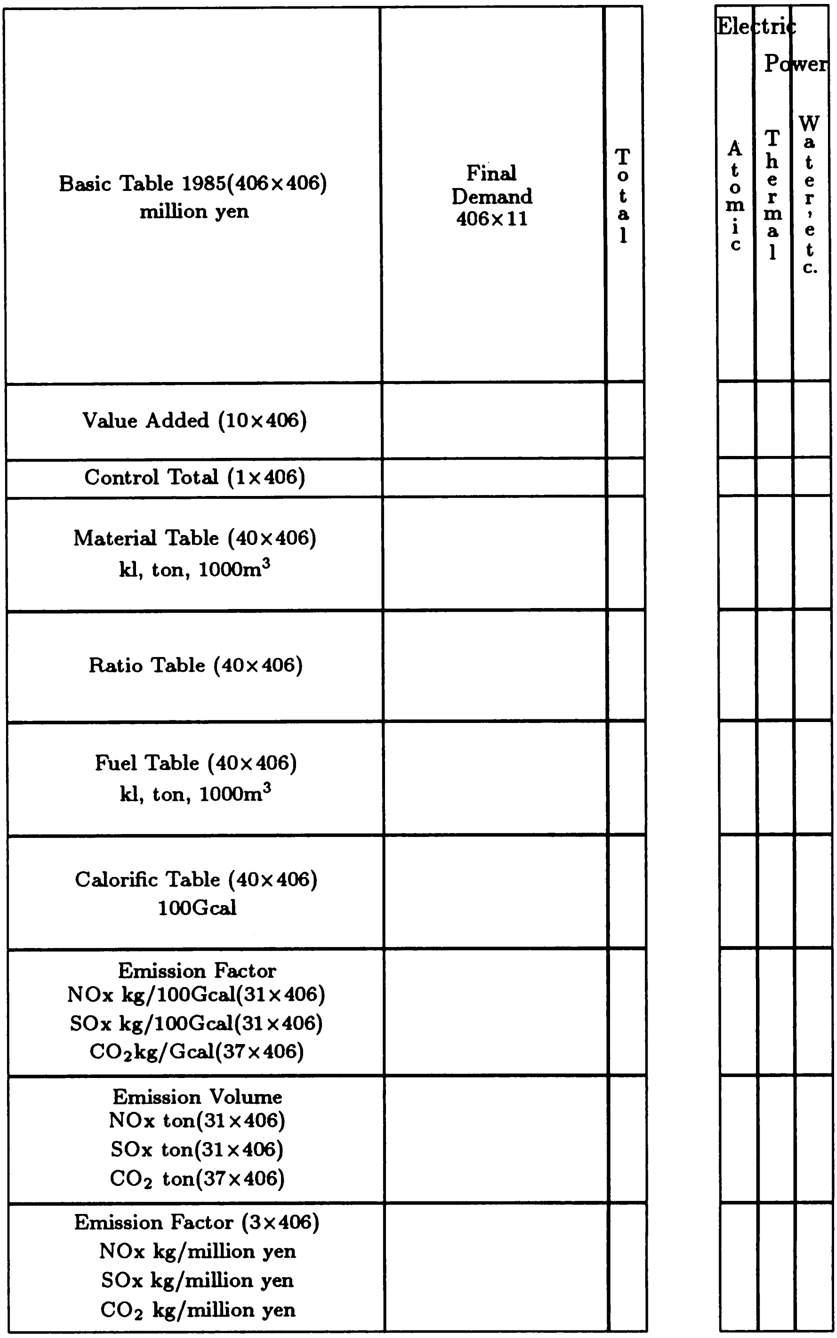

Figure 1: Components of the Environmental Input–Output Table in Japan

Table 1: Fuel / Material Classification

	Fuel/Material	Physical Unit	Calorific Volume per Physical Unit		CO_2 Emission Factor(kg/Gcal)
1	Limestone	t			440 kg/t
2	Iron ore	t			for SOx
3	Lead and Zinc ore	t			for SOx
4	Coking Coal(domestic)	t	6,530	kcal/kg	
5	Coking Coal(imported)	t	6,530	kcal/kg	
6	General Coal(domestic)	t	6,530	kcal/kg	366.3
7	General Coal(imported)	t	6,530	kcal/kg	366.3
8	Crude Petroleum	kl	9,400	kcal/l	286.5
9	LNG	t	13,300	kcal/kg	208.6
10	Gasoline	kl	8,600	kcal/l	281.877
11	Jet Fuel Oil	kl	8,700	kcal/l	269.3
12	Kerosene	kl	8,900	kcal/l	269.3
13	Light Oil	kl	9,200	kcal/l	294.9
14	Heavy Oil A	kl	9,200	kcal/l	277.9
15	Heavy Oil B and C	kl	9,900	kcal/l	306.1
16	Naphtha	kl	8,600	kcal/l	283.5
17	LPG	t	12,000	kcal/kg	251.7
18	Reformed Oil	kl	8,600	kcal/l	294.9
19	Hydrocarbon Oil	kl	9,900	kcal/l	322.7
20	Oil Hydrocarbon Gas	$10^3 m^3$	9,900	kcal/m^3	217.2
21	Oil Coke	t	9,400	kcal/kg	427.9
22	Coke	t	6,800	kcal/kg	453.0
23	Coke Furnace Gas	$10^3 m^3$	4,800	kcal/m^3	188.6
24	Blast Furnace Gas	$10^3 m^3$	800	kcal/m^3	910.0
25	Converter Gas	$10^3 m^3$	2,000	kcal/m^3	767.1
26	Electric Furnace Gas	$10^3 m^3$	2,000	kcal/m^3	767.1
27	Coal Mine Gas	$10^3 m^3$	8,550	kcal/m^3	210.4
28	Electric Power	$10^6 kwh$			
29	Supplied Gas	$10^3 m^3$	10,000	kcal/m^3	234.9
30	Steam and Hot Water	$10^6 kcal$			
31	Pulp Draining	t	3,000	kcal/kg	394.2
32	General Waste	t	1,580	kcal/kg	353.3
33	Industrial Waste	t	4,000	kcal/kg	322.3
34	Pig Iron	t			4.0% Carbon
35	Crude Steel(Converter)	t			0.3% Carbon
36	Crude Steel(Electric Furnace)	t			0.3% Carbon
37	Blast Furnace Dust	t			30.0% Carbon
38	Coal–tar	t			90.3% Carbon
39	Iron Scrap	t			4.0% Carbon
40	Steel Scrap	t			0.3% Carbon

Notes on emission factors.

(1): 10 Gasoline's emission is from automobile activity.

(2): 15 Heavy Oil B has the same coefficient as Heavy Oil C.

(3): 26 Electric furnace gas is the same coefficient as Converter Gas.

(4): Figures of 34–40 are the weight percentages of carbon contents.

(5): 37 Dust is assumed to be generated 15 kg per production of 1kg pig iron.

consumption to these sectors since there are considerable energy transfer. Thus carbon balance table for the four sectors was constructed(see Yoshioka et.al.[1992]).

For the estimations of the other sectors, fuel consumption is estimated from volume of physical input and the ratio of fuel to material use. For example, petrochemical aromatic products require 76.9% coal-coke for material in total inputs, and the carbon(CO_2) contents of coke is 453(CO_2)kg/t. By multiplying these figures to physical volume of energy input, we get the volume of CO_2 emission.

In estimating SOx, we use the emission coefficients after eliminating sulfur, since there are abatement activities. As the SOx coefficients include material originated sulfur such as copper, iron ore, lead and zinc, we assume these material inputs are proportional to fuel consumption. As these coefficients are based on the fuel consumption calorific value, we estimate SOx emission from fuel consumption with calorific unit. Unlike CO_2 emission, we do not make sulfur balance table for the above four sectors.

4. CO_2, NOx and SOx emissions from mobile sources

For NOx from automobile they are estimated from the emission coefficients by using the experimental fleet test data[5], which pollution has and has not been eliminated using catalyst.

The volume of NOx emission from an automobile depends on many factors such as driving velocity, weight of carried freight, road condition (highway, mountain road, or city road), and auto's age which determines the level of regulation.

Hence, estimation procedure of air pollution by mobile sources is very difficult and needs different estimating method from fixed sources.

The JEA's regulatory emission factors are applied to estimate the NOx emission volume in the published JEA's report[6]. Since it is not based on actual traveling, it is not sufficient to analyze the effect of economic activity on air pollution which depend on level of traffic congestion or velocity of automobile[7].

On the other hand, the Tokyo Environmental Research Institute's fleet test (experimental) data show the emission coefficient per mileage[g/km] by types of autos. It describes how the volume of pollution depends on the velocity of each types of traveling automobile and the vintage of existing automobile. But the experimental data is not simply applicable to economic data such as the Input–Output table. In order to incorporate engineering data and economic data, we must use at least 5 different statistical data. As a result, we estimate the 8,400 emission factors(by 35 roads, 16 auto types, 3 fuels[gasoline, diesel oil, LPG] and 5 vintages/regulatory year) for the automobile sources.

For SOx emission from mobile sources, we apply the same method as NOx from automobile. But for air, water and ocean transports, SOx emission was estimated from the sulfur contents of fuel-gasoline and fuel-heavy-oils(3 types).

For CO_2 emission from mobile sources, we apply the same method as for fixed sources, based on the carbon contents of fuels.

5. An Overview of the Japanese Air Pollutions in 29 sectors and final consumption

Figures 2–4 show CO_2, NOx, SOx emissions in 29 sectors and in final consumption which are aggregated from the 406-sector tables[8]. Sectors such as (1)Electricity, gas, thermal energy supply

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[5] See Hayami(1992) for automobile, and Suga(1992) for airplane.

[6] See the Institute of Behavioral Science ed.(1989)[8] and [9] for examples.

[7] See Bureau of Environmental Protection of Tokyo Metropolitan-city Government ed.(1987).

[8] Final consumption is classified into emissions from fuel consumption by automobile and from heating, etc.

are the main sources of CO_2 emissions in 29 sectors. Other sectors like (2)transport which includes self-transportations(self-passenger and freight transports by private motor cars) but does not include consumption expenditure of gasoline and diesel oil), (3)steel and its products and, (4)ceramic heavily generate CO_2 emission. CO_2 emission from these activities is due to coal and oil, except ceramic which includes cement production. Cement production consumes limestone in addition to oil and coal, which generates CO_2 during the burning at clinker formation.

NOx are emitted mainly from (1)transport activities. Next to transport, (2)agriculture, forestry and fishing are large sources of NOx emission. In the above three activities, fishing is the dominant source of NOx emission, because fishing shipment uses a lots of heavy oil. NOx from these activities is in fact emission from transportation activities.

Main SOx emission is due to (1)transport and (2)electricity, gas, and thermal energy supply. These activities use heavy oil and coal. SOx from transport is generated by shipment and freight transportation activities. Mobile sources are the dominant sources of NOx and SOx pollutions in Japan. We must take alternative mobile technologies into consideration in order to reduce NOx and SOx.

6. Evaluating CO_2 emissions from the production of 1 unit of commodity

6.1. Method of estimating CO_2 emissions from production activities

Estimating methodology is simple, using an open input–output model. That is, if 1 unit of j-th commodity(j=1,...,406) is produced as final demand, it induces directly or indirectly the production of commodities denoted by the vector x_j, as follows.

$$x_j = (I - (I - \tilde{M})A)^{-1} f_j, \tag{1}$$

where,

A : input coefficients matrix of 406 sectors
$\tilde{M}$: import coefficients matrix(diagonal)[9]
I : identity matrix
x_j : vector of derived productions from 1 unit of j–th commodity's production

$$f_j = \begin{pmatrix} 0 \\ \vdots \\ 0 \\ 1_{(jth)} \\ 0 \\ \vdots \\ 0 \end{pmatrix} \text{ : final demand vector of 1 unit of jth commodity production}$$

CO_2 emission factor based on 1 unit of production(1 million yen in 1985) is denoted as e_c(CO_2 kg/million yen). Hence, we can describe the derived CO_2 emission from 1 unit of j–th commodity $C^p{}_j$, as follows.

$$C^p{}_j = e_c \cdot x_j, \qquad (j = 1, ..., 406), \tag{2}$$

where $\cdot$ is an inner product of two vectors. We call $C^p{}_j$ the emission from production activities of the j-th commodity.

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[9] Import is assumed to be proportional to domestic demand.

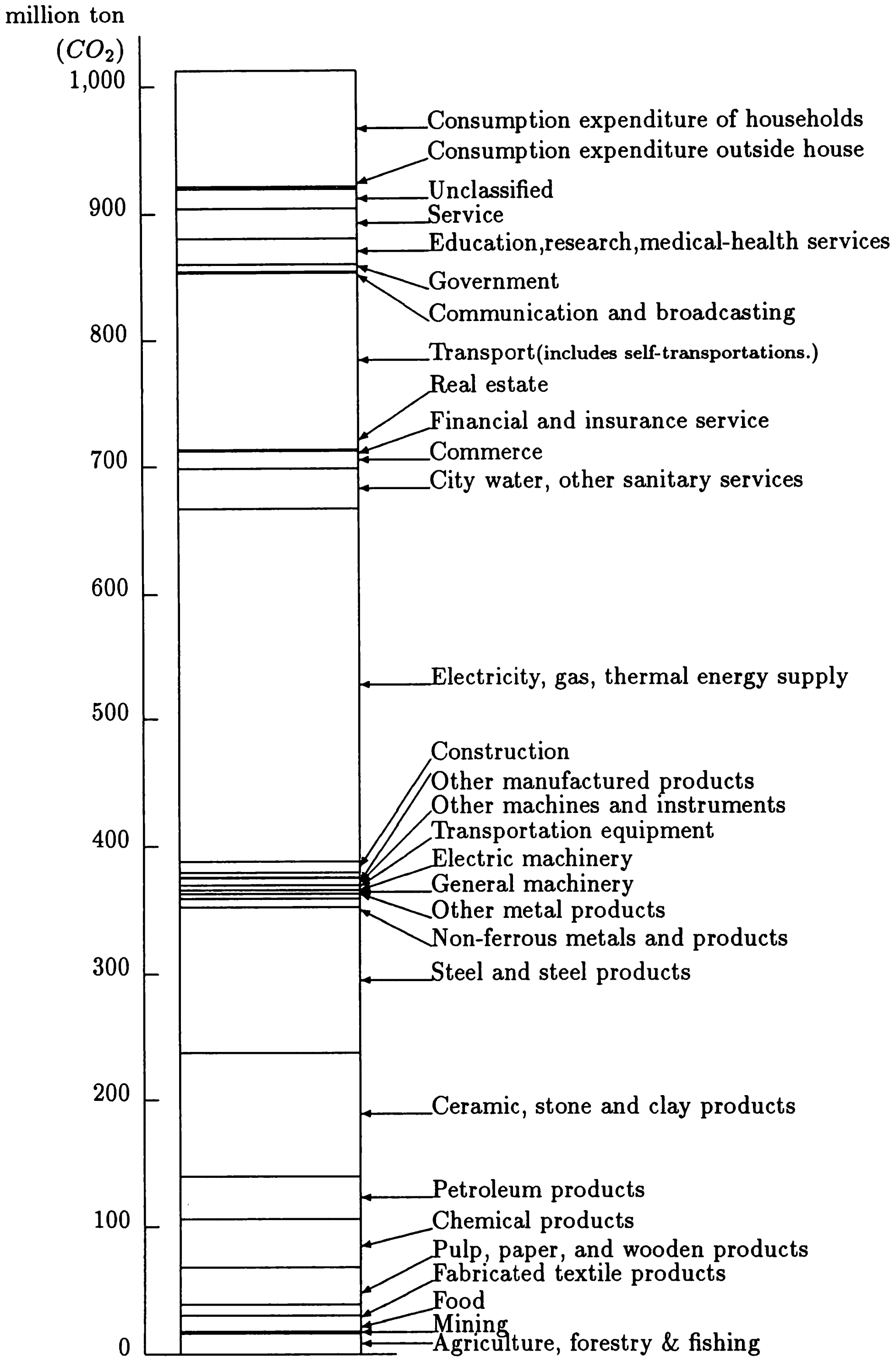

Figure 2: CO_2 Emissions in 29 sector and Final Consumption

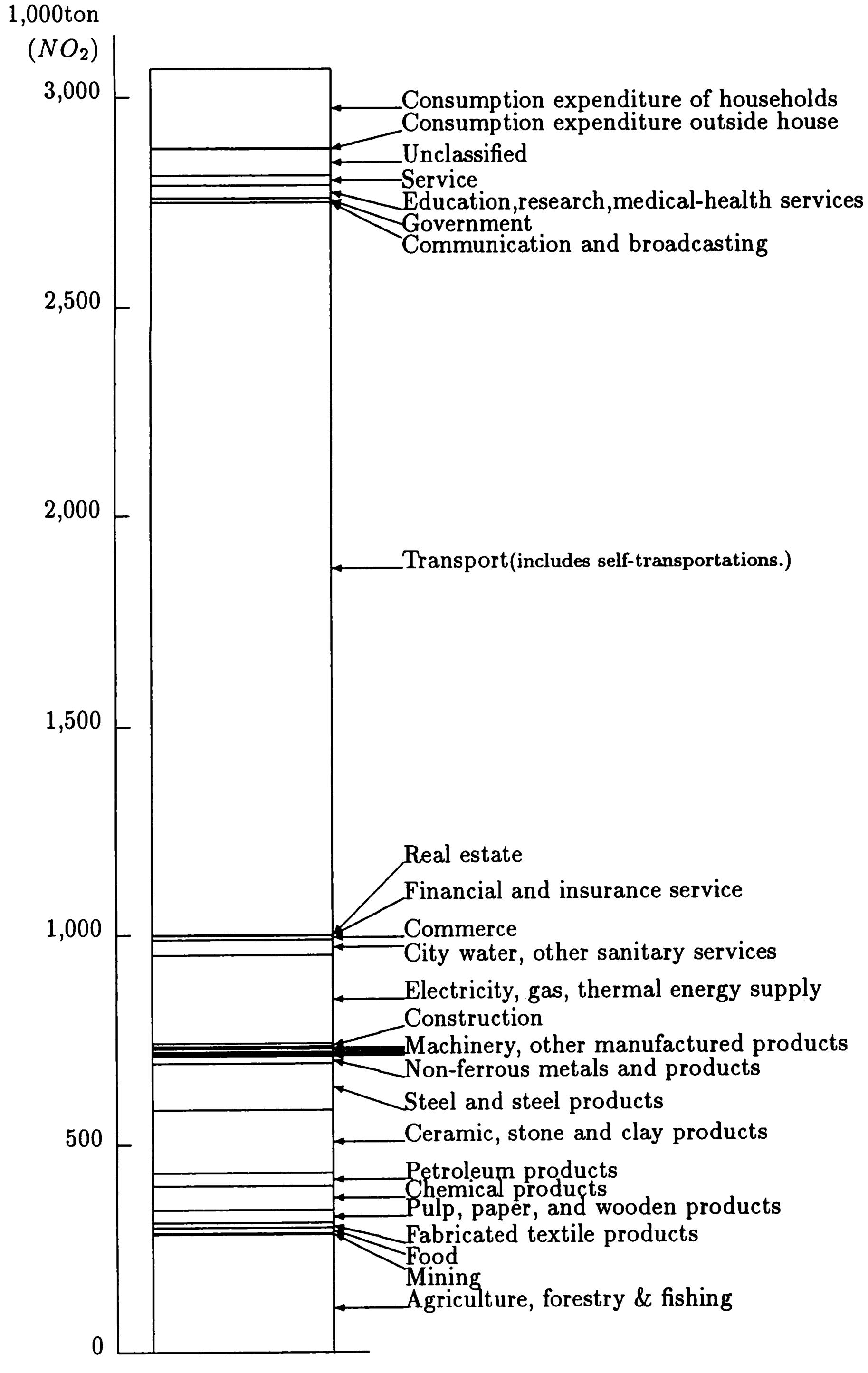

Figure 3: NOx Emissions in 29 sector and Final Consumption

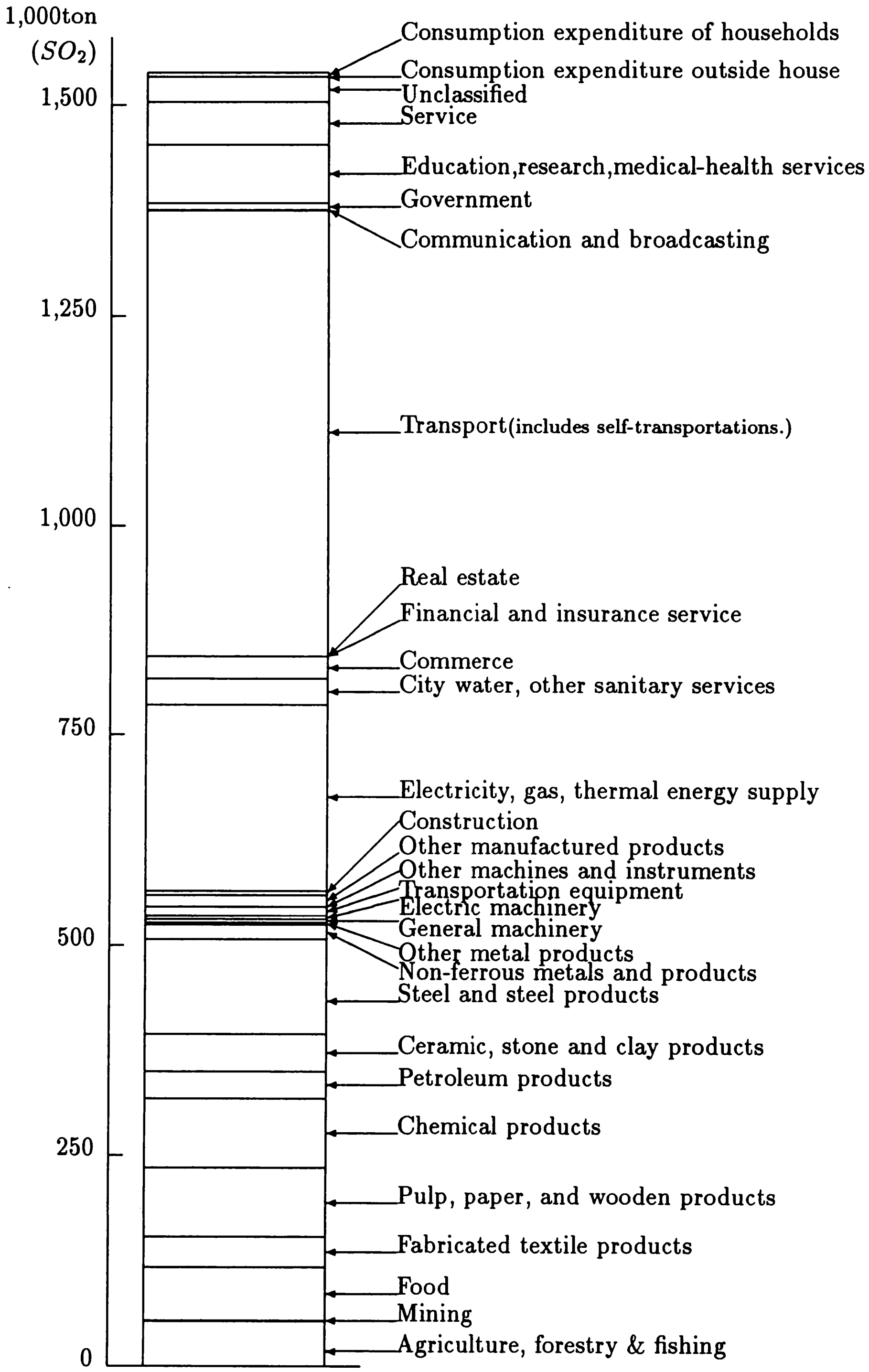

Figure 4: SOx Emissions in 29 sector and Final Consumption

Table 2: Top 10 sectors of CO_2 Emission induced by 1 unit of Production:CO_2kg

code	Sector	Total CO_{2j}	Emission in Production Process $C^p{}_j$	Emission by fuel in Final Consumption $C^e{}_j$
071101	Coal	202,052	6,080	195,972
252101	Cement	76,423	76,423	0
511104	Self-power Generation	70,865	70,865	0
072101	Crude Petroleum	68,167	3,913	64,255
2111018	LPG	49,676	1,985	47,692
073101	LNG	48,968	4,412	44,556
2111013	Kerosene	45,356	1,985	43,371
2111014	Light Oil	36,020	1,985	34,034
261101	Pig Iron	33,186	33,186	0
111901	Salt	30,920	30,920	0

Note(1):See Yoshioka et.al.(1992) for other sectors.

Note(2):The ranking order is sorted by total emission CO_{2j}.

Furthermore, if j–th commodity is an energy input, it is assumed to be burned and an emission factor $C^e{}_j$ is added. We call $C^e{}_j$ the emission from final consumption of the j-th energy. The total CO_2 emission is defined as the sum of emission from production activities of the j-th commodity and final consumption of the j-th commodity in the case of fossil fuel at final demand.

$$\begin{aligned} CO_{2j} &= C^p{}_j + C^e{}_j \\ &= e_c \cdot (I-(I-\tilde{M})A)^{-1} f_j + C^e{}_j, \qquad (j=1,...,406). \end{aligned} \tag{3}$$

6.2. CO_2 emission derived from 1 unit of production

Following the above formula, the estimation results by commodity are briefly shown in Table 2–3 and Figures 5–15. Table 2 shows the top 10 CO_2 generating sectors, Table 3 shows the bottom 10 sectors[10].

The results show that there are large differences between sectors, when the same economic value of 1 million yen is produced in each sector.

For example, 1 unit of coal production and its consumption as fuel generates 202 ton of CO_2, but 1 unit of electronic computing equipment renting generates 315 kg. The difference approaches 641:1. In the case of coal, CO_2 emission includes both emission from production process and emission from final consumption. Final consumption of coal contributes most of the CO_2 emission from coal, therefore if coal is not burned as fuel at all, CO_2 emission is reduced to 6,162 kg. This implies that liquefaction of coal before final consumption(burning) may decrease total emissions of CO_2, since hydrogen combines with carbon and hydrogen burns into H_2O.

On the other hand, cement production is highly CO_2 generating. One unit production of cement produces 76.4 ton of CO_2. This emission is 242.5 times the CO_2 emission from electronic computing equipment renting. Cement made from limestone(portland cements) contributes emissions of CO_2 in two processes. One is chemical reaction, $CaCO_3 \rightarrow CaO + CO_2$. Another is from heating in order to produce the above chemical reaction, which burns fossil fuel. If plants use blast-furnace slag and precipitated calcium carbonate which are by-products from iron industry, the CO_2 emissions from cement production can be reduced[11].

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[10] See Yoshioka et.al.(1992) for more detailed sectors.

[11] See for detail, Yoshioka et. al.(1993c)

Table 3: Bottom 10 sectors of CO_2 Emission induced by 1 unit of Production:CO_2kg

code	Sector	Emission in Production Process(=Total Emission) C^p_j
731201	Domestic telecommunication	748.2
114101	Tobacco	685.5
821104	School research institute(public, social sciences)	677.1
731909	Other service relating to communication	593.3
717903	Service relating to water transport	510.5
621201	Life insurance	460.4
642101	House rent	397.8
641102	Real estate rent	394.8
621101	Financial service	391.9
851301	Electronic computing equipment renting	315.1

Note:Refer notes on Table 3.

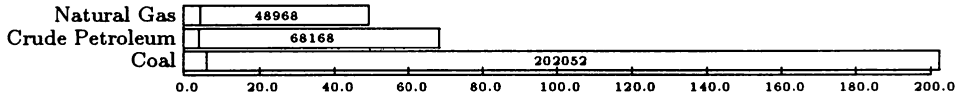

Figure 5: CO_2 Emission from Energy Related Mining(kg/million yen)

Figures 5–12 show CO_2 emissions of the selected sectors. Figure 5 shows energy related mining, and Figure 6 shows coal and oil manufacturings. In these sectors, CO_2 emission from the burning process is much larger than their production process. Figure 6 indicates a large difference between self–power generation and electric power. The reasons of this difference are due to (1) self–power generation does not contain value added, so that its estimated price is quite low compared to electric power, (2) electric power includes water and nuclear power generation which emit less CO_2. The issue of self–activity(self–power generation, self–transportation etc.) shows the limitations using the basic input–output table of Japan.

Figures 7–8 are related to foods and its products. It is shown in Figure 7 that fishery produces much more CO_2 than agriculture because of operating shipment. In Figure 8, salt emits a very high level of CO_2. Purifying salt needs a lot of heavy oil.

In Figure 9, pulp and paper emit much CO_2, since in these industry boiling process needs a lot of energy. In some chemical manufacturings, Figure 9 shows a large difference among the chemical products. Industrial soda chemicals has a very high CO_2 emission, because it uses salt for material.

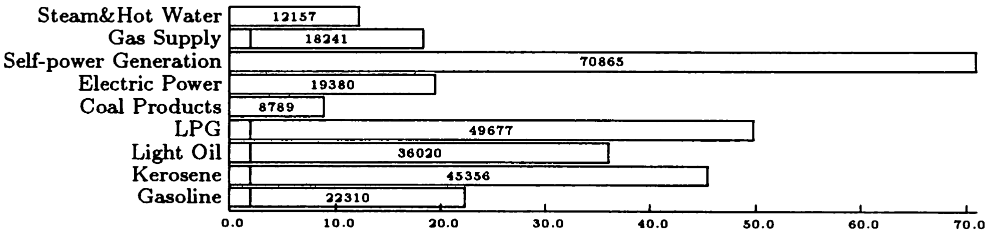

Figure 6: CO_2 Emission from Coal, Oil and Energy Products(kg/million yen)

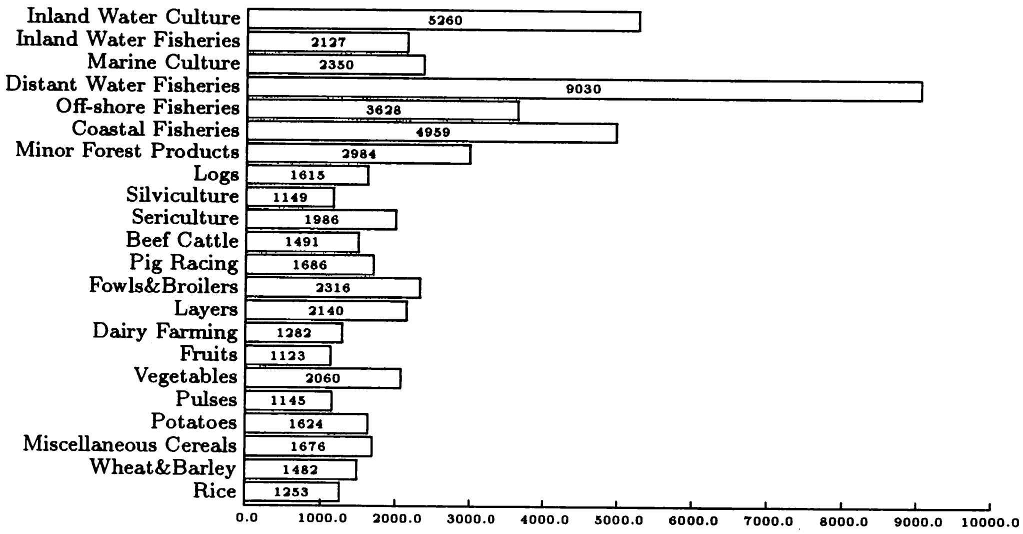

Figure 7: CO_2 Emission from Agriculture, Forestry, Fishery(kg/million yen)

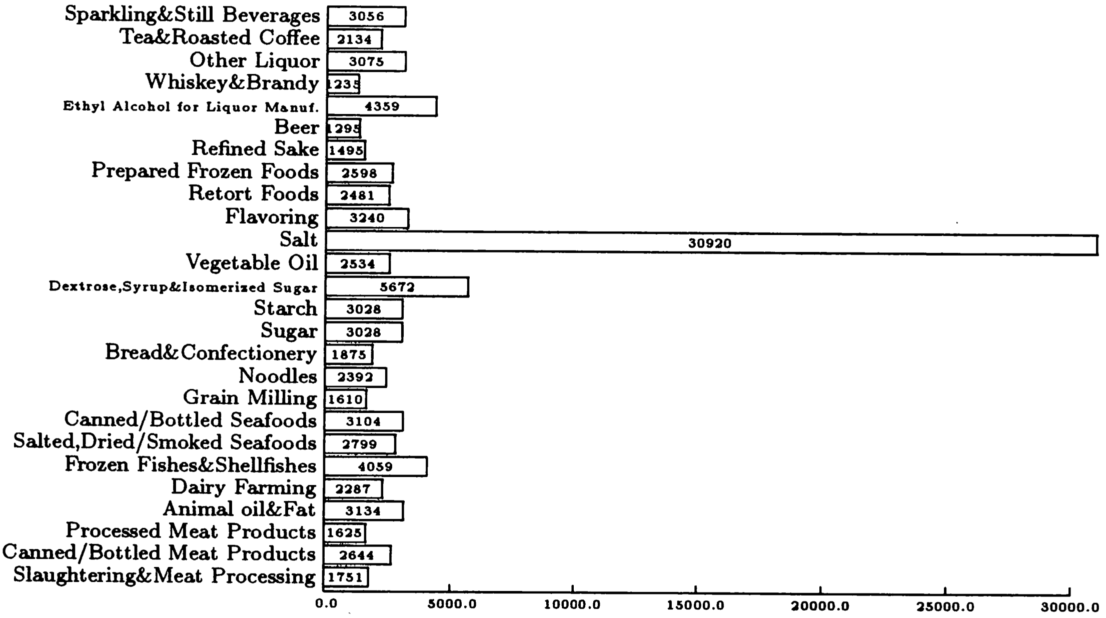

Figure 8: CO_2 Foods Manufacturing(kg/million yen)

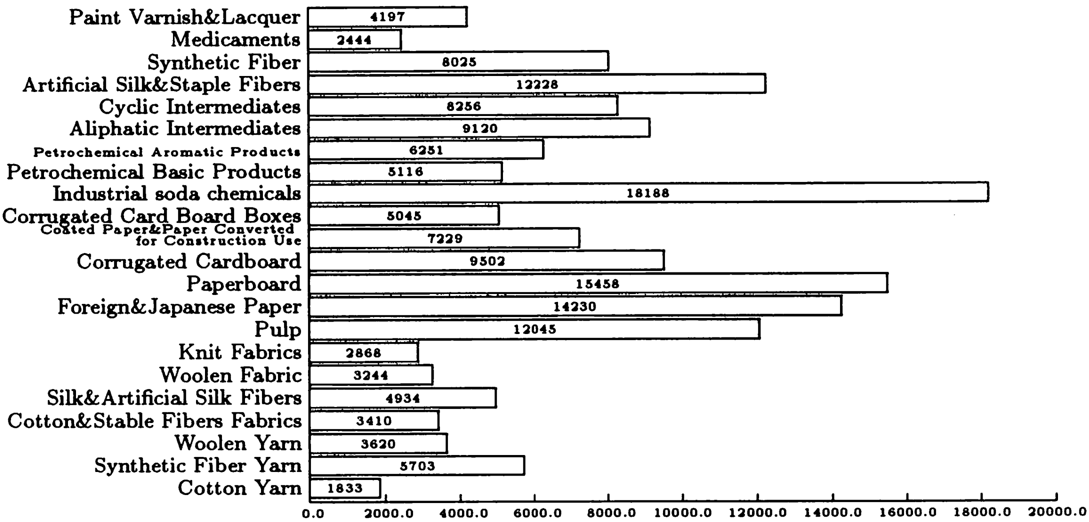

Figure 9: CO_2 Emission from Textile, Paper, Pulp, Chemical Manufacturings(kg/million yen)

Figure 10 is energy consuming heavy industries, like steel and iron, and cement. As mentioned previously, cement generates nearly 76 ton of CO_2 from every 1 million yen of output. Next to cement, pig iron shows a large amount of CO_2 emission. In ferro alloy, crude steel, hot rolled steel CO_2 emissions are two thirds of pig iron. Furthermore, in steel products, CO_2 emission are two thirds of crude steel. This fact implies that iron recycling is a very effective way to reduce CO_2 emission.

Figure 11 is related to machinery. In these industries, the varieties of the input materials are wider than that in material related industries, therefore the variance of CO_2 emission is decreased. However, the volume of CO_2 emission varies from 1,425kg to 4,855kg.

Finally, Figure 12 shows transportation. In these activities, self–transportations do not have value added, therefore evaluation of their prices is difficult. Furthermore, carrying capacity of each transportation is not considered in this analysis[12]. Besides self–transportation, ocean and water transport have heavy CO_2 emission, since they use heavy oil.

7. Concluding Remarks

We have developed the basic tool for the environmental analysis of economic activities. This study will extend to the various applications for testing alternative technologies. Among them, we have already evaluated the CO_2 contents of household activities[13] and we have proceeded to evaluating alternative technologies such as energy saving houses, slag cement and paper recycling, etc[14].

In this paper, we found that the induced CO_2 emission from 1 unit of production differs largely among commodities. Therefore if carbon tax is to be imposed, its burden will be widely different according to the amount of the induced CO_2 emission even within the same 2-digit category[15].

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[12] See Hayami[1992], Suga[1992], for the emission of CO_2 per mileage or per passenger.

[13] See, Yoshioka et.al.(1993a).

[14] See, for example, Yoshioka et.al.(1993b).

[15] The figures we get are under the condition that the final demand remains constant, since we use the open input-output model.

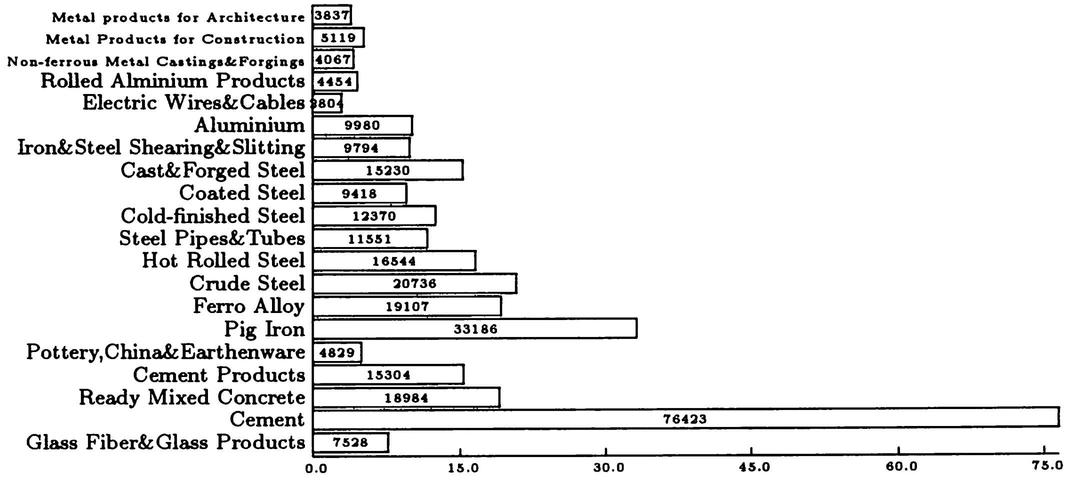

Figure 10: CO_2 Emission from Cement, Metal Manufacturings(kg/million yen)

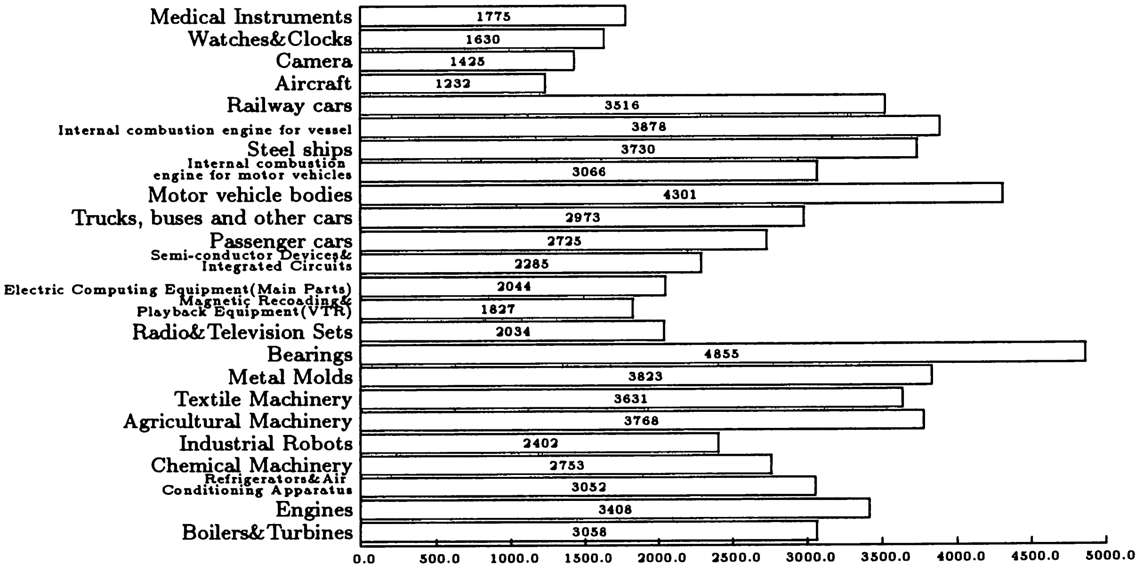

Figure 11: CO_2 Emission from Machinery(kg/million yen)

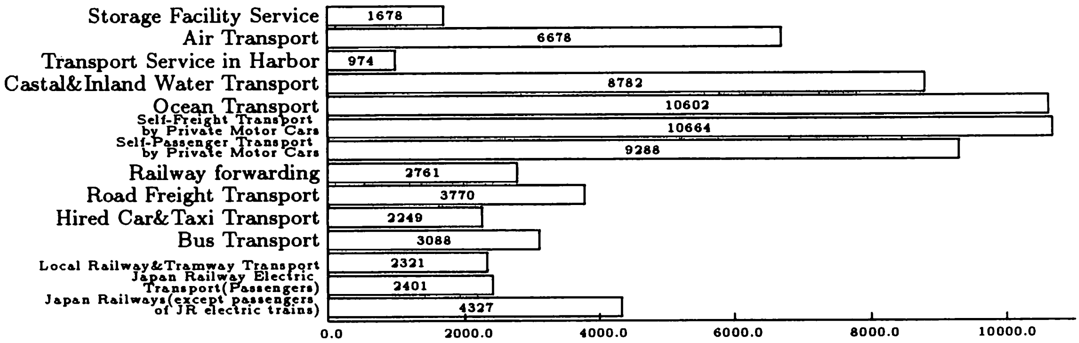

Figure 12: CO_2 Emission from Transportation(kg/million yen)

But on the other hand, it suggests many possibilities of reducing CO_2 emission through introducing various alternative technologies.

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