An Examination of Estimation Methods Employed for Determining CO_2 Emissions at the Prefectural Level in Japan[1]

by

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Abstract

This paper estimates CO_2 emissions of all prefectures in Japan in 1995 and 2000 using a consistent estimation technique; the RAS method is applied to reflect the regional characteristics. Our results are compared with the findings in different studies to examine the reliability of our estimation method. Thereafter, on the basis our results, we investigate the trends and characteristics of CO_2 emissions at the prefectural level. Our conclusions show the importance of policymaking by local governments to reduce emissions in their own regions, especially from the residential sector.

Keywords: CO_2 emission, Modified RAS method, Prefectural data, Local government

1 Introduction

The Japanese government encourages municipalities to voluntarily seek global warming solutions by enacting the Law Concerning the Promotion of the Measures to Cope with Global Warming. As a result, many local governments in Japan have become increasingly concerned about global warming and have established programs for the reduction of green house gases (GHG). Global warming is an important issue that requires appropriate regional policies.

As a precondition for addressing global warming at the regional level, we need to identify the emission structure of GHGs in each region. Focusing on prefectures as a regional district, prefectural offices in Japan estimate regional emissions basically according to the guidelines established by Ministry of the Environment. However, estimation methods and statistics used by prefectures are not always consistent, and some prefectural offices do not go public with the details of estimation methods. Therefore, emissions estimated by different prefectural offices are not perfectly comparable across

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[1] This paper is the modified version of Hasegawa (2008), submitted to Business Journal of PAPAIOS. I would like to thank Assoc. Prof. Shigemi Kagawa (Kyusyu University) for encouraging me to submit to the JAIOA. I am also grateful to anonymous referees for their useful comments for revising. However, any remaining errors in this paper are mine.

prefectures.

Considering this situation, it is important that emission estimations be carried out according to a consistent method in all prefectures and that they reflect regional characteristics. Kainou (2007) has constructed a database[2] of energy consumption and CO_2 emissions at the prefectural level by dividing the energy balance table in Japan (*Sogo Enerugi Tokei*), published by Agency for Natural Resources and Energy, into prefectures, using what the author described as the "input-output estimation method." Although this database provides emission data for all prefectures based on the same estimation method, it does not include emissions in transportation other than private automobile and the energy conversion sector. Besides, it integrates some sectors in the energy balance table in Japan into one sector.

Matsuhashi et al. (2004) estimated CO_2 emissions from petrol-fueled vehicles at the municipality level in Japan in 1999. Yonezawa and Matsuhashi (2009) estimated the same type of emissions for all municipalities in 2005. They calculated emissions in each municipality in terms of home bases or travel destinations, using the master data of the origin-destination travel survey, and compared the results to other estimate based on person-trip data, traffic volume, and fuel sales volume data to investigate regional characteristics from estimation differences due to different methods and data sources. The results from Matsuhashi et al. (2004) are used by Kudoh et al. (2004) to analyze the relationship between the status of emissions from petrol-fueled passenger vehicles and various regional characteristics in Japan. Kudoh et al. (2004) consider improvement of fuel consumption in motorcars for reducing CO_2 emissions. Although the databases constructed by Matsuhashi et al. (2004) and Yonezawa and Matsuhashi (2009) identify emissions at the municipality level, smaller regions and reflect regional characteristics, the authors confine their analysis to emissions in automobile transport.

Focusing on the issues highlighted in the literature cited above, this paper estimates CO_2 emissions in 1995 and 2000 in all Japanese prefectures according to a consistent estimation method. To reflect on regional characteristics, we used the RAS method, described in this paper as the "modified RAS method." In the next section, we explain the estimation method for CO_2 emissions conducted in this study. In section 3, we examine the reliability of our results by comparing them with those of the databases constructed by Kainou (2007) and Yonezawa and Matsuhashi (2009), and investigate the trends and characteristics of CO_2 emissions at the prefecture level by using our results. Finally, we summarize our conclusions in section 4.

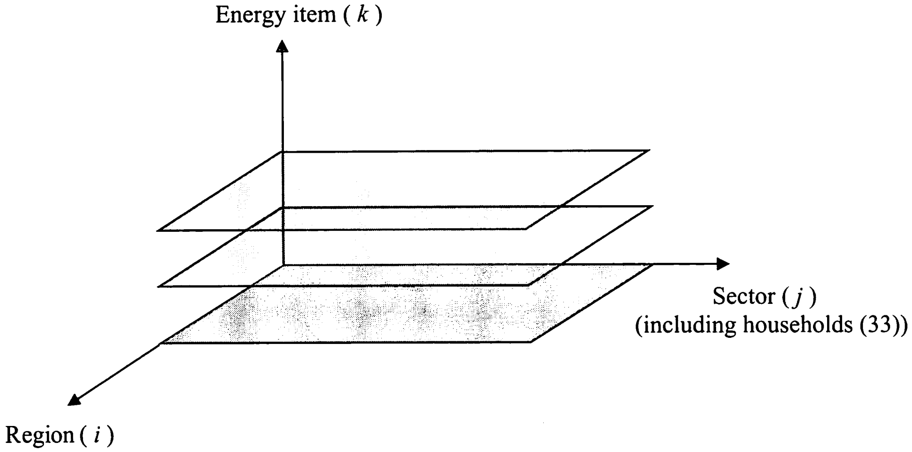
2 Estimation method for CO_2 emissions at prefecture level

2.1 The framework

This paper considers energy-related emissions and emissions from the use of lime-

[2] It is available from the web site of Agency for Natural Resources and Energy in Japan (http://www.enecho.meti.go.jp/info/statistics/regional-energy/index.htm)

Figure 1. The framework of the emission database



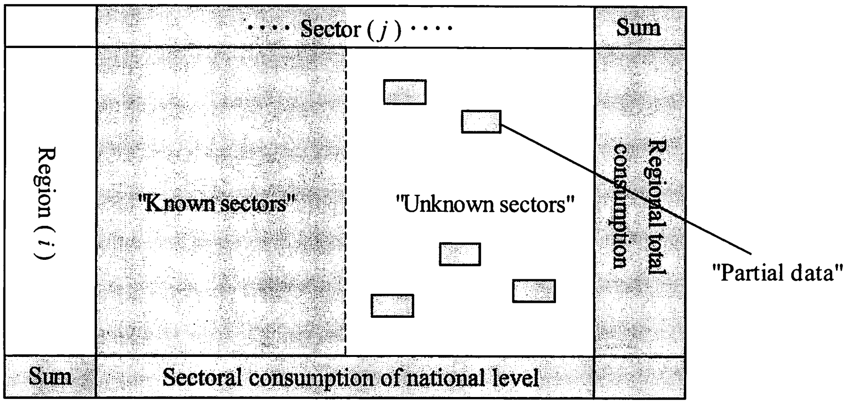
stone for cement production as emission sources. These two emission sources account for around 95% of total emissions in Japan. All inputted fossil fuels are not always combusted but partially used for materials in some industries such as electric power, iron and steel, chemical products, and so on. In calculating CO_2 emissions, it is important to identify actual combustion of fossil fuel among industries and regions. Therefore, this paper excludes fossil fuels used for materials from the calculation to the extent they can be identified from available statistics. In addition, this paper does not allocate emissions from electricity production to each user but regards them as emissions in the power companies themselves. It means, in using electricity itself, the emissions are not directly counted. The emissions from electricity are counted in power companies, according to their input of fossil fuel, but the emissions from self-power generation are in the sectors doing it, because they input fossil fuel to generate electricity. That is, this paper considers CO_2 emitted directly from sectors and regions.

Manufacturing industries have 95.6% of the total self-power generation in Japan according to the 2000 input-output table. Most of them use by-product such as blast furnace gases (BFG) and coke oven gases (COG) for self-power generation. The data concerning by-product are not always credible and counted in an input-output table, but we can identify fossil fuel including by-product in manufacture from the Structural Survey of Energy Consumption in Commerce, Mining, and Manufacturing (*Sekiyu Tou Shohi Kozo Tokei Hyo*). This statistics provides detailed information on self-power generation in each sector at the prefectural level. Other self-power generators such as wholesale, retail, hospital, and railway do not use by-product or other fossil fuel which are not counted in an input-output table, if any, it must be tiny volume.

In order to estimate prefectural emissions and construct the emission database at the prefecture level, this paper classifies energy consumption in Japan in 1995 and 2000 by regions (i), sectors (j), and energy items (k) as in Figure1, and constructs region-industry energy consumption matrices as in Figure 2 for each energy item. The divisions of regions are by prefecture -there are 47 prefectures in Japan (see Appendix 1 for locations). The sectors are 33 in number -32 industrial[3] and 1 household sector[4].

In Figure 2, there are two kinds of summation: by row and by column, that is, regional total consumption and sectoral consumption at the national level -not to men-

Figure 2. The region-industry energy consumption matrix



tion, the total consumption in Japan shown on the right down corner in Figure 2. These two parameters, -the data on these are relatively credible in Japan- are used as control totals in estimating the elements in the energy matrices[5]. In Figure 2, the elements are divided into "known sectors" and "unknown sectors." These categories are determined according to whether or not the data for all prefectures concerning energy consumption are available from existing statistics. There exist several credible individual data for some energy types in some sectors in a few prefectures even within "unknown sectors." This paper refers to such data as "partial data," and uses them directly to reflect regional characteristics in "unknown sectors."

"Known sectors" includes manufacture[6] and electric power, gas supply, and steam and hot water supply (18) in almost all energy types. In addition, agriculture, forestry, and fisheries (1), transport (23), and households (33) are also included in "known sectors" in some energy types. The ratio of the number of "known sectors" to "unknown sectors" is around 50: 50, and 19 "partial data" are used in this paper[7]. As a result, 36% of the total emissions in Japan need to be estimated without a direct data source.

[3] This category is based on the large classification of the Japan I-O table. The 32 industries consist of (1) agriculture, forestry, and fisheries; (2) mining; (3) food; (4) textiles; (5) pulp, paper, and wooden products; (6) chemical products; (7) petroleum refinery and coal; (8) ceramic, stone, and clay products; (9) iron and steel; (10) non-ferrous metal; (11) metal products; (12) general machinery; (13) electrical devices; (14) transport equipments; (15) precision machinery; (16) miscellaneous manufacturing products; (17) construction; (18) electric power, gas supply, and steam and hot water supply; (19) water supply and waste disposal services; (20) trade; (21) finance and insurance; (22) real estate; (23) transport; (24) communication and broadcasting; (25) public administration; (26) education and research; (27) medical service, health, social security, and nursing service; (28) other public service; (29) business service; (30) personal service; (31) office supplies; and (32) activities not elsewhere classified.

[4] This paper regards households as the 33rd sector.

[5] Regarding limestone for cement production, we distribute the emission at the national level among prefectures according to prefecture-country ratio of the corresponding monetary output because of the restriction of available data.

[6] This paper defines "manufacture" as the sum of sectors from food (3) to miscellaneous manufacturing products (16).

Figure 3. The region-industry energy consumption matrix in "unknown sectors"

	Sector 1	Sector 2	Sector 3	Sum
Region 1	e_{11}	θ	e_{13}	$\sum_j e_{1j}-\theta$
Region 2	e_{21}	e_{22}	e_{23}	$\sum_j e_{2j}$
Region 3	e_{31}	e_{32}	e_{33}	$\sum_j e_{3j}$
Region 4	e_{41}	e_{42}	e_{43}	$\sum_j e_{4j}$
Sum	$\sum_i e_{i1}$	$\sum_i e_{i2}-\theta$	$\sum_i e_{i3}$	$\sum_i\sum_j e_{ij}-\theta$

Figure 4. The monetary output matrix corresponding to Figure 3

	Sector 1	Sector 2	Sector 3	Sum
Region 1	x_{11}	0	x_{13}	$\sum_j x_{1j}-x_{12}$
Region 2	x_{21}	x_{22}	x_{23}	$\sum_j x_{2j}$
Region 3	x_{31}	x_{32}	x_{33}	$\sum_j x_{3j}$
Region 4	x_{41}	x_{42}	x_{43}	$\sum_j x_{4j}$
Sum	$\sum_i x_{i1}$	$\sum_i x_{i2}-x_{12}$	$\sum_i x_{i3}$	$\sum_i\sum_j x_{ij}-x_{12}$

2.2 Estimating "unknown sectors" with the modified RAS method

We estimate the elements in "unknown sectors" except "partial data" by applying the modified RAS method. The RAS method, one of the estimation methods for technical coefficients in input-output tables, is highly appreciated in many studies[8], and is used to estimate elements in various matrices other than technical coefficients. For example, Ohira et al. (1998) apply the RAS method to construct industrial waste matrices classified by industry and waste type.

The modified RAS method estimates the area of "unknown sectors" shown in Figure 2 by approximating it to the corresponding monetary output matrices[9]. Figure 3 assumes the area of "unknown sectors" shown in Figure 2, and Figure 4 shows a monetary output matrix of which regions and sectors correspond to those in Figure 3. The shaded parts in Figure 3 and Figure 4 indicate that data are available; the other areas are estimated by the modified RAS method. Before conducting RAS calculation, we deduct "partial data" (θ) from the region-industry energy consumption matrix shown in Figure 3. Similarly, in the monetary output matrix, an approximated matrix in the RAS calculation, we deduct the element corresponding to "partial data" (θ) in Figure 3 as shown Figure 4.

7 See Hasegawa (2004, 2008) regarding the data sources of "partial data" and other data used for constructing the energy consumption matrices in this paper.

8 For example, see Toh (1998).

9 Instead for monetary output, total consumption expenditure is used for households (33).

The modified RAS method needs to assume coefficients, corresponding to ordinal technical coefficients in input-output tables. Instead of technical coefficients, this paper uses the prefecture-to-Japan ratio of each sector for approximation. First, we obtain these coefficients from Figure 3 and Figure 4 as follows.

$$a_{ij}^{e} = \frac{e_{ij}}{\sum_i e_{ij}} \quad \Leftrightarrow \quad e_{ij} = a_{ij}^{e} \sum_i e_{ij} \tag{1}$$

$$a_{ij}^{x} = \frac{x_{ij}}{\sum_i x_{ij}} \quad \Leftrightarrow \quad x_{ij} = a_{ij}^{x} \sum_i x_{ij} \tag{2}$$

where a_{ij}^{e} is the prefecture-to-Japan ratio of energy consumption and a_{ij}^{x} is the prefecture-to-Japan ratio of monetary output.

Note that a_{ij}^{e} is unknown. Therefore, we introduce a_{ij}^{x} in Equation (2) into a_{ij}^{e} in Equation (1), which leads to $e_{ij}^{(1)}$.

$$e_{ij}^{(1)} = a_{ij}^{x} \sum_i e_{ij} \tag{3}$$

We assume $s_j^{(1)} = \frac{\sum_i e_{ij}}{\sum_i e_{ij}^{(1)}}$ and $r_i^{(1)} = \frac{\sum_j e_{ij}}{\sum_j e_{ij}^{(1)}}$, which leads to $a_{ij}^{(1)}$.

$$a_{ij}^{(1)} = r_i^{(1)} a_{ij}^{x} s_j^{(1)} \tag{4}$$

Similarly, we introduce $a_{ij}^{(1)}$ in Equation (4) into a_{ij}^{e} in Equation (1), which leads to $e_{ij}^{(2)}$, $s_j^{(2)}$, $r_i^{(2)}$, and $a_{ij}^{(2)}$as follows.

$$e_{ij}^{(2)} = a_{ij}^{(1)} \sum_i e_{ij} \tag{3$'$}$$

$$a_{ij}^{(2)} = r_i^{(2)} a_{ij}^{(1)} s_j^{(2)} \tag{4$'$}$$

Where $s_j^{(2)} = \frac{\sum_i e_{ij}}{\sum_i e_{ij}^{(2)}}$, $r_i^{(2)} = \frac{\sum_j e_{ij}}{\sum_j e_{ij}^{(2)}}$

If $s_j^{(n)}$ and $r_i^{(n)}$ approximate 1, that is, $s_j^{(n)} = r_i^{(n)} = 1$, after repeating these procedures n times, a_{ij}^{e} is calculated approximately as follows.

$$a_{ij}^{e} = r_i^{(n)} r_i^{(n-1)} \cdots r_i^{(1)} a_{ij}^{x} s_j^{(1)} s_j^{(2)} \cdots s_j^{(n)}$$

The element e_{12} in Figure 3, where "partial data" is included, is estimated to be zero. The other estimated elements are consistent in that the summation of elements in the rows and the columns are simultaneously equal to the regional total consumption and sectoral consumption at the national level, respectively, with "partial data" excluded. Therefore, adding "partial data" (θ) to the element e_{12} in Figure 3, we construct region-industry energy consumption matrices that not only reflect regional characteristics but also keep the two summations, by rows and columns, consistent. We convert energy and limestone consumption data to CO_2 emissions using the emission transform factors provided by the "3EID[10]."

3 Results

3.1 Comparisons to different studies

Before considering our results we must examine their reliability by comparison with different studies. First, we compare our findings with the database constructed by Kainou (2007), which is most related to this study.

Table 1 shows CO_2 emissions in 2000 based on this paper as well as Kainou (2007), integrating into three manufacture, non-manufacture, and households (33) sectors, because the sectorwise classifications in both studies are different; besides, it is difficult to compare detailed sectorwise results. In addition, Table 1 integrates prefectures into 10 regions (see Appendix 2 for locations). As aforementioned, Kainou (2007) excludes the emissions in transportation and energy conversion sectors; therefore, our results in Table 1 also exclude these emissions. Moreover, Table1 shows the emissions from direct consumption of fossil fuels, because Kainou (2007) allocates emissions from electricity generation among users while this study regards them as emissions of power companies themselves.

Although the values of the non-manufacture sector in Table 1 based on this paper and Kainou (2007) are relatively close to each other[11], both values are significantly different in most sectors and regions. These differences are mainly due to the differences in estimation methods, statistics used, definition of sectors, and energy types considered.

In particular, it is clear that the large differences in manufacture are attributable to self-power generation and emission sources considered. The energy balance table in Japan (*Sogo Enerugi Tokei*) published by Agency for Natural Resources and Energy, which is used as the main data source in Kainou (2007), counts consumption of fossil fuel used for self-power generation for their own consumption as consumption of electricity. On the other hand, this paper considers this as fossil fuel consumption. Further-

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[10] The "3EID" is short for "embodied energy and emission intensity data for Japan using input-output tables", developed by Nansai, Keisuke and Yuichi Moriguchi. It is available from the website of National Institute for Environmental Studies in Japan. (http://www-cger.nies.go.jp/publication/D031/index.html)

[11] The non-manufacture sector also has self-power generation. Its volume accounts for 3.15% of total self-power generation in Japan (in monetary output) according to the 2000 input-output table, which calculates self-power generation based on several statistics including the energy balance table in Japan (*Sogo Enerugi Tokei*). This ratio is considerably inconsistent with the difference between these two studies in Table 1 (37,010 vs. 36,803, i.e. 0.56%). On the other hand, the energy balance table in Japan does not always identify the volume and composition of fossil fuel used for self-power generation from credible statistics or its original survey, but depends on estimation or assumption to large extent as far as the author checked its explanatory report. Therefore, the figure in Kainou (2007) is not always absolute credible. However, this contradiction is not clearly explained and remaining issue in this paper.

Table 1. CO_2 emissions[1)] in 2000 based on this paper and Kainou (2007)

(1000t-C, %)

	Manufacture		Non-manufacture[2)]		Household(33)[3)]	
	This paper	Kainou (2007)	This paper	Kainou (2007)	This paper	Kainou (2007)
Hokkaido	5,079 (4.1)	1,377 (1.6)	3,507 (9.5)	2,068 (5.6)	3,097 (6.5)	3,071 (8.3)
Tohoku	4,855 (3.9)	1,635 (1.9)	3,424 (9.3)	3,074 (8.4)	4,434 (9.4)	3,830 (10.4)
Kanto	30,000 (24.3)	31,942 (37.0)	11,692 (31.6)	12,257 (33.3)	15,427 (32.6)	10,807 (29.3)
Shinetsu, Hokuriku	4,029 (3.3)	1,459 (1.7)	2,278 (6.2)	2,280 (6.2)	3,670 (7.7)	2,587 (7.0)
Tokai	15,448 (12.5)	8,803 (10.2)	3,361 (9.1)	3,907 (10.6)	5,398 (11.4)	4,272 (11.6)
Kinki	17,498 (14.2)	10,172 (11.8)	4,920 (13.3)	5,232 (14.2)	6,533 (13.8)	4,733 (12.8)
Chugoku	26,725 (21.7)	18,695 (21.7)	2,089 (5.6)	2,222 (6.0)	2,713 (5.7)	2,258 (6.1)
Shikoku	4,558 (3.7)	1,689 (2.0)	1,233 (3.3)	1,285 (3.5)	1,309 (2.8)	1,284 (3.5)
Kyusyu	14,821 (12.0)	10,435 (12.1)	4,029 (10.9)	4,115 (11.2)	4,455 (9.4)	3,735 (10.1)
Okinawa	268 (0.2)	70 (0.1)	477 (1.3)	363 (1.0)	345 (0.7)	306 (0.8)
Japan	123,282 (100)	86,277 (100)	37,010 (100)	36,803 (100)	47,382 (100)	36,883 (100)

Note 1) It indicates emissions from direct consumption of fossil fuels but excludes the emissions in transportation and energy conversion sectors.

Note 2) It indicates all industries other than manufacture, transportation and energy conversion sectors. That is, it consists of agriculture, forestry, and fisheries (1), mining (2), construction (17), from water supply and waste disposal services (19) to real estate (22), and from communication and broadcasting (24) to activities not elsewhere classified (32).

Note 3) It includes emissions from private automobiles.

Note 4) Figures in parentheses indicate the region–country ratio of emissions in each category (%).

more, regarding emission sources, opposite to this paper, Kainou (2007) does not consider important emission sources for manufacture, limestone and black liquor[12].

It is also clear that the large differences in household (33) are caused by different

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[12] According to the 2000 input-output table, 28.6% of electricity consumed in manufacture is self-power generation at the national level. Using this ratio (28.6%) and the data in Kainou (2007), the emissions from self-power generation in manufacture are estimated to be 14,412 (1000 t-C). Furthermore, according to this paper, the emissions from limestone and black liquor in Japan is 4,881 and 13,680 (1000 t-C), respectively. Therefore, if we include the emissions from self-power generation, limestone, and black liquor in the data in Kainou (2007), the emissions in manufacture in Kainou (2007) in Table 1 become 119,250 (=14,412+13,680+4,881+86,277).

Figure 5-a. CO_2 emissions per capita from automobiles at prefecture level (part 1)

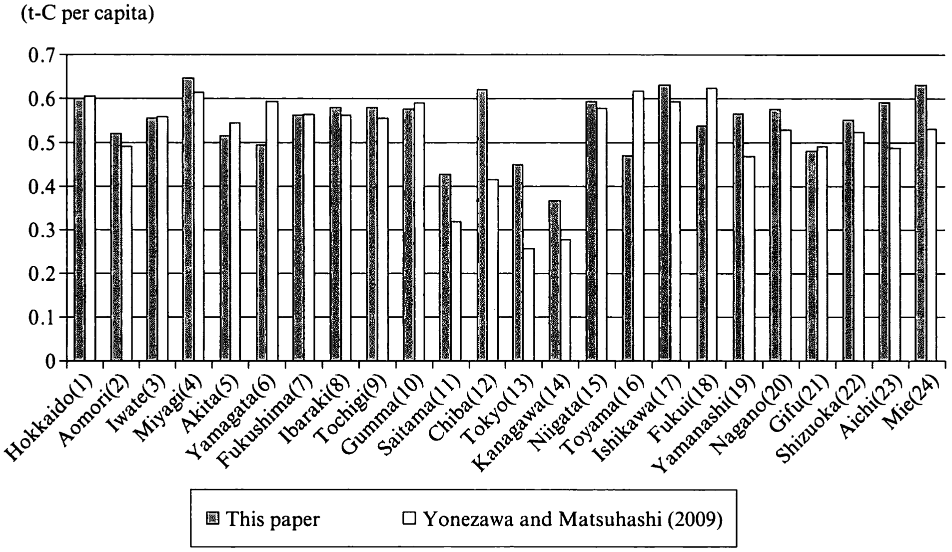
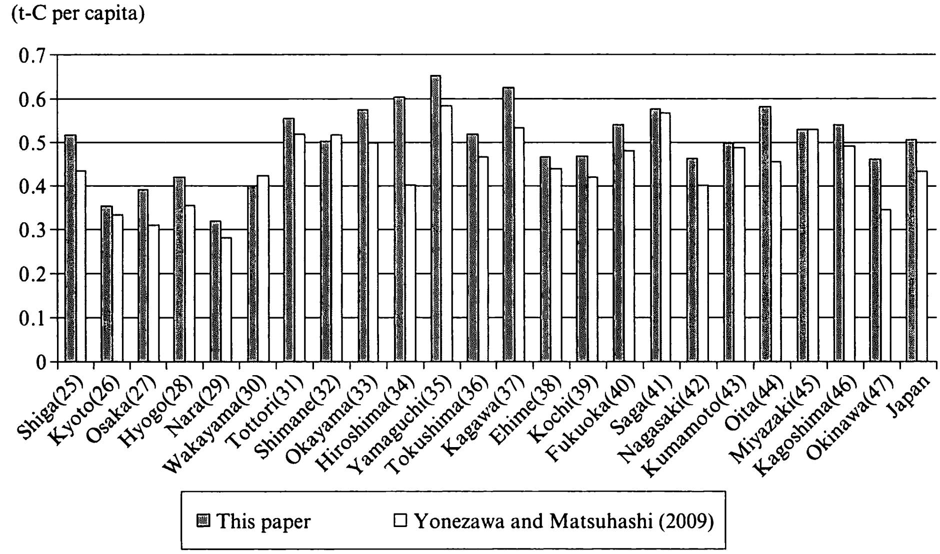


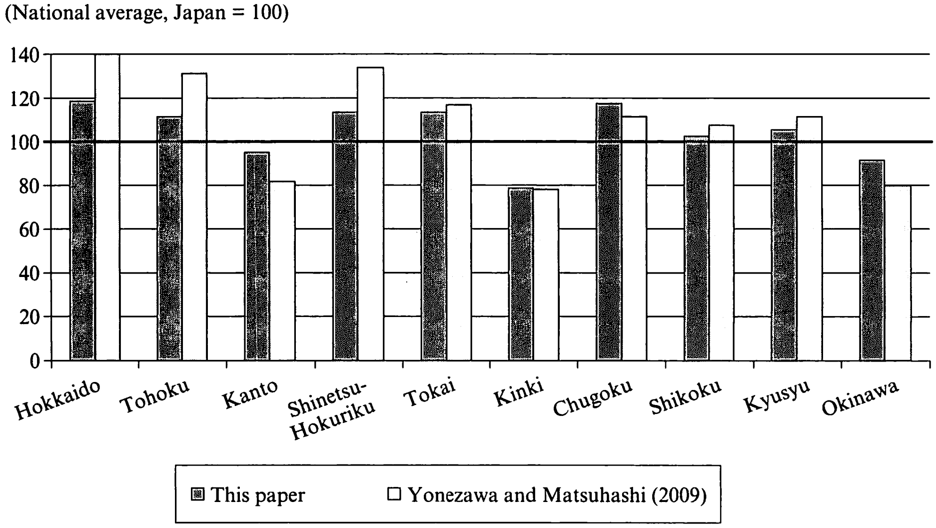
Figure 5-b. CO_2 emissions per capita from automobiles at prefecture level (part 2)



definitions of the household. The household in input-output tables includes self-employed, and the residual of other final demands is also regarded as the household. On the other hand, the household in the energy balance table excludes the household who do not have jobs and the self-employed household[13].

[13] According to the 3EID, the volume of emissions in household is 47,269 (1000 t-C), which is extremely close to our result (47,382). It is notable that the household in the 3EID is based on the definition of final demand in input-output tables, because it is a database constructed for input-output analysis.

Figure 6. Ratios of the 10 regions' per capita emissions to the national average



Therefore, it would be expected that the volume of emissions in manufacture and household (33) is much larger in this paper compared to Kainou (2007). However the ratios of regional to Japanese emissions are relatively consistent between the two studies.

Next, we focus on the database constructed by Yonezawa and Mastuhashi (2009), which estimates CO_2 emissions from all kinds of automobiles at the municipality level in 1999 and 2005. We must compare the results of Yonezawa and Mastuhashi (2009) with those of this study with regard to emissions from gasoline, light oil, and LPG in transport (23), and from gasoline and light oil in households (33). However emissions in transport (23) according to this study include those from trains and ships; therefore, it is difficult to compare the two studies rigidly. Moreover, it must be remembered that Yonezawa and Mastuhashi (2009) and this study investigated emissions of different years-1999 and 2000, respectively.

Figure 5-a and Figure 5-b indicate CO_2 emissions per capita from automobiles at the prefecture level (see Appendix 1 for locations). It is understandable that per capita emission of Japan according to this paper (0.507t-C) is higher than the corresponding figure in Yonezawa and Matsuhashi (2009) (0.434t-C), because emissions from trains and ships, in addition to those from automobiles, are included in this paper. Although the two studies show large differences for some prefectures such as Chiba (12), Tokyo (13), and Hiroshima (34), both of them capture the trend that urban areas such as Tokyo (13) and Osaka (27) have small emissions while the northern and inland areas have large emissions. This trend reflects the fact that public transportation systems are more developed in urban areas and more heating is demanded in cars in the northern and inland areas in winter.

Figure 6 indicates the ratio of regional per capita emissions to the national average (i.e., the figure if the per capita emission of Japan were 100), integrating prefectures into 10 regions (see Appendix 2 for locations as aforementioned). We can also recognize in Figure 6 that the two studies capture relatively the same regional characteristics although they show large differences in Hokkaido, Tohoku, and Shinestu-Hokuriku. It is notable that the sectors considered in Figure 5-a, Figure 5-b, and Figure 6 are "unknown sectors" in these three energy types in this study, in which emissions are estimated by the modified RAS method in the absence of a direct data source.

3.2 Consideration from our results

Table 2 shows total CO_2 emissions in 2000 in each prefecture (see Appendix 1 for locations as aforementioned). For total emissions, the top prefecture is Chiba (12), followed by Aichi (23) and Kanagawa (14). Tokyo (13) and Osaka (27) are ranked fifth and eighth, respectively. Focusing on these five prefectures, first, we investigate the sectoral emission structure in Table 3. Table 3 indicates the top 10 prefectures in 2000 in different sectors -manufacture, electric power, gas supply, and steam and hot water supply (18), transport (23), and households (33), in addition to population.

The volume of emissions from manufacture and electric power, gas supply, and steam and hot water supply (18) accounts for around 60% of the total in Japan, and Chiba (12) is the top emitter in both of these sectors. In particular, our results indicate that Chiba (12) has significantly large emissions in material heavy industries. Further-

Table 2. Total CO_2 emissions in 2000 in each prefecture

(1000t-C)

	Emission	Ranking		Emission	Ranking
Hokkaido (1)	19,508	4	Shiga (25)	2,475	40
Aomori (2)	3,591	26	Kyoto (26)	2,664	36
Iwate (3)	2,505	39	Osaka (27)	14,903	8
Miyagi (4)	5,910	20	Hyogo (28)	17,620	6
Akita (5)	4,051	24	Nara (29)	912	47
Yamagata (6)	2,528	38	Wakayama (30)	5,358	23
Fukushima (7)	11,618	13	Tottori (31)	1,177	45
Ibaraki (8)	13,222	11	Shimane (32)	2,413	41
Tochigi (9)	3,044	30	Okayama (33)	13,241	10
Gumma (10)	2,788	35	Hiroshima (34)	17,193	7
Saitama (11)	6,673	19	Yamaguchi (35)	12,298	12
Chiba (12)	30,881	1	Tokushima (36)	5,456	22
Tokyo (13)	18,491	5	Kagawa (37)	2,660	37
Kanagawa (14)	20,288	3	Ehime (38)	5,504	21
Niigata (15)	8,213	16	Kochi (39)	1,507	43
Toyama (16)	3,026	31	Fukuoka (40)	14,449	9
Ishikawa (17)	3,430	27	Saga (41)	1,197	44
Fukui (18)	2,979	32	Nagasaki (42)	7,092	18
Yamanashi (19)	1,024	46	Kumamoto (43)	3,301	28
Nagano (20)	2,953	34	Oita (44)	10,338	14
Gifu (21)	3,274	29	Miyazaki (45)	2,140	42
Shizuoka (22)	7,334	17	Kagoshima (46)	2,979	33
Aichi (23)	25,288	2	Okinawa (47)	3,698	25
Mie (24)	9370	15	Japan	362561	—

Table 3. The top 10 prefectures in each sector in 2000

(1000t–C, Thousand)

Ranking	Manufacture (37.7%)[1]		Electric power, gas supply, and steam and hot water supply (18) (23.6%)		Transport (23) (15.4%)		Households (33) (13.1%)		Population[2]	
1	Chiba (12)	14,584	Chiba (12)	9,442	Tokyo (13)	7,362	Tokyo (13)	4,449	Tokyo (13)	12,064
2	Hiroshima (34)	11,053	Fukushima (7)	8,224	Hokkaido (1)	3,618	Hokkaido (1)	3,097	Osaka (27)	8,805
3	Hyogo (28)	10,294	Aichi (23)	7,940	Aichi (23)	3,425	Kanagawa (14)	3,017	Kanagawa (14)	8,490
4	Aichi (23)	9,573	Kanagawa (14)	5,928	Osaka (27)	3,129	Osaka (27)	2,897	Aichi (23)	7,043
5	Okayama (33)	9,516	Nagasaki (42)	5,120	Chiba (12)	2,813	Aichi (23)	2,708	Saitama (11)	6,938
6	Kanagawa (14)	7,213	Hokkaido (1)	3,810	Fukuoka (40)	2,607	Chiba (12)	2,523	Chiba (12)	5,926
7	Oita (44)	7,037	Tokushima (36)	3,751	Ibaraki (8)	2,196	Saitama (11)	2,348	Hokkaido (1)	5,683
8	Fukuoka (40)	6,768	Mie (24)	3,657	Hyogo (28)	1,948	Fukuoka (40)	1,720	Hyogo (28)	5,551
9	Yamaguchi (35)	6,624	Yamaguchi (35)	3,417	Kanagawa (14)	1,918	Hyogo (28)	1,552	Fukuoka (40)	5,016
10	Ibaraki (8)	6,578	Hiroshima (34)	2,920	Shizuoka (22)	1,735	Shizuoka (22)	1,214	Shizuoka (22)	3,767

Note 1) Figures in parentheses indicate the ratio of emissions in each sector to total emissions at the national level (%).
Note 2) Source: Population census of Japan.

more, Chiba (12) is ranked fifth in transport (23) and sixth in households (33), respectively, the sectors accounting for around 30% of the total emissions in Japan. In other words, Chiba (12) is the top generator of total emissions since it is ranked high in all sectors that have the largest volume of emissions in Japan. Aichi (23) and Kanagawa (14) also show similar trends.

On the other hand, although Tokyo (13) and Osaka (27) are ranked high in transport (23) and households (33), they are ranked below the top 10 in manufacture and electric power, gas supply, and steam and hot water supply (18), where emissions account for around 60% of the total in Japan. This is the reason they are relatively low ranked as far as total emissions are concerned, compared to the population ranking.

Next, we focus on the change of emission patterns from 1995 to 2000. Table 4 indicates the change in total emissions in each prefecture with population and gross re-

Table 4. Changes in population, GRP, and CO_2 emissions in each prefecture (1995–2000)

(%)

	Emission	Population[1]	GRP[2]		Emission	Population[1]	GRP[2]
Hokkaido (1)	6.2	−0.2	3.7	Shiga (25)	−9.1	4.3	5.6
Aomori (2)	−2.9	−0.4	6.5	Kyoto (26)	−13.3	0.6	3.2
Iwate (3)	1.5	−0.2	11.4	Osaka (27)	−6.8	0.1	3.8
Miyagi (4)	7.2	1.6	6.3	Hyogo (28)	−1.1	2.8	-3.5
Akita (5)	4.6	−2.0	4.0	Nara (29)	−13.5	0.8	6.1
Yamagata (6)	1.1	−1.0	7.7	Wakayama (30)	−22.8	−1.0	3.1
Fukushima (7)	20.7	−0.3	6.3	Tottori (31)	12.5	−0.3	4.5
Ibaraki (8)	−0.6	1.0	3.0	Shimane (32)	118.4	−1.3	8.1
Tochigi (9)	−5.8	1.0	6.4	Okayama (33)	2.7	0.0	−1.9
Gumma (10)	−1.7	1.1	3.8	Hiroshima (34)	10.8	−0.1	3.3
Saitama (11)	−6.2	2.6	4.9	Yamaguchi (35)	2.6	−1.8	3.5
Chiba (12)	4.8	2.2	0.8	Tokushima (36)	139.5	−1.0	4.7
Tokyo (13)	15.0	2.5	8.1	Kagawa (37)	−2.8	−0.4	0.9
Kanagawa (14)	−1.9	3.0	2.7	Ehime (38)	7.3	−0.9	1.8
Niigata (15)	12.0	−0.5	4.1	Kochi (39)	0.3	−0.3	4.7
Toyama (16)	−17.4	−0.2	2.9	Fukuoka (40)	−2.0	1.7	4.4
Ishikawa (17)	21.9	0.1	6.0	Saga (41)	−11.8	−0.9	5.3
Fukui (18)	19.7	0.2	3.0	Nagasaki (42)	15.1	−1.8	1.0
Yamanashi (19)	−1.9	0.7	6.9	Kumamoto (43)	3.9	0.0	8.6
Nagano (20)	−7.0	1.0	11.3	Oita (44)	7.0	−0.8	10.0
Gifu (21)	−15.4	0.4	6.4	Miyazaki (45)	−5.4	−0.5	6.2
Shizuoka (22)	2.5	0.8	5.6	Kagoshima (46)	−0.9	−0.4	8.3
Aichi (23)	−6.0	2.5	7.2	Okinawa (47)	5.4	3.5	11.0
Mie (24)	20.3	0.9	5.8	Japan	3.5	1.1	4.9

Note 1) Source: Population census of Japan.
Note 2) Values are based on 1995 price. Source: Annual report on prefectural accounts.

gional products (GRP). The shaded parts indicate the decrease from the 1995 level. Prefectures that have shown significant increase in emissions are Tokushima (36), Shimane (32), Ishikawa (17), Fukui (18), and Mie (24). Tokushima (36) and Shimane (32), in particular, show increases of more than two times, mainly from newly built thermal power stations. On the other hand, Wakayama (30), Toyama (16), and Gifu (21) decreased their emissions significantly. In any case, you may notice that the change in total emissions at the prefecture level does not always correspond to that of population and GRP.

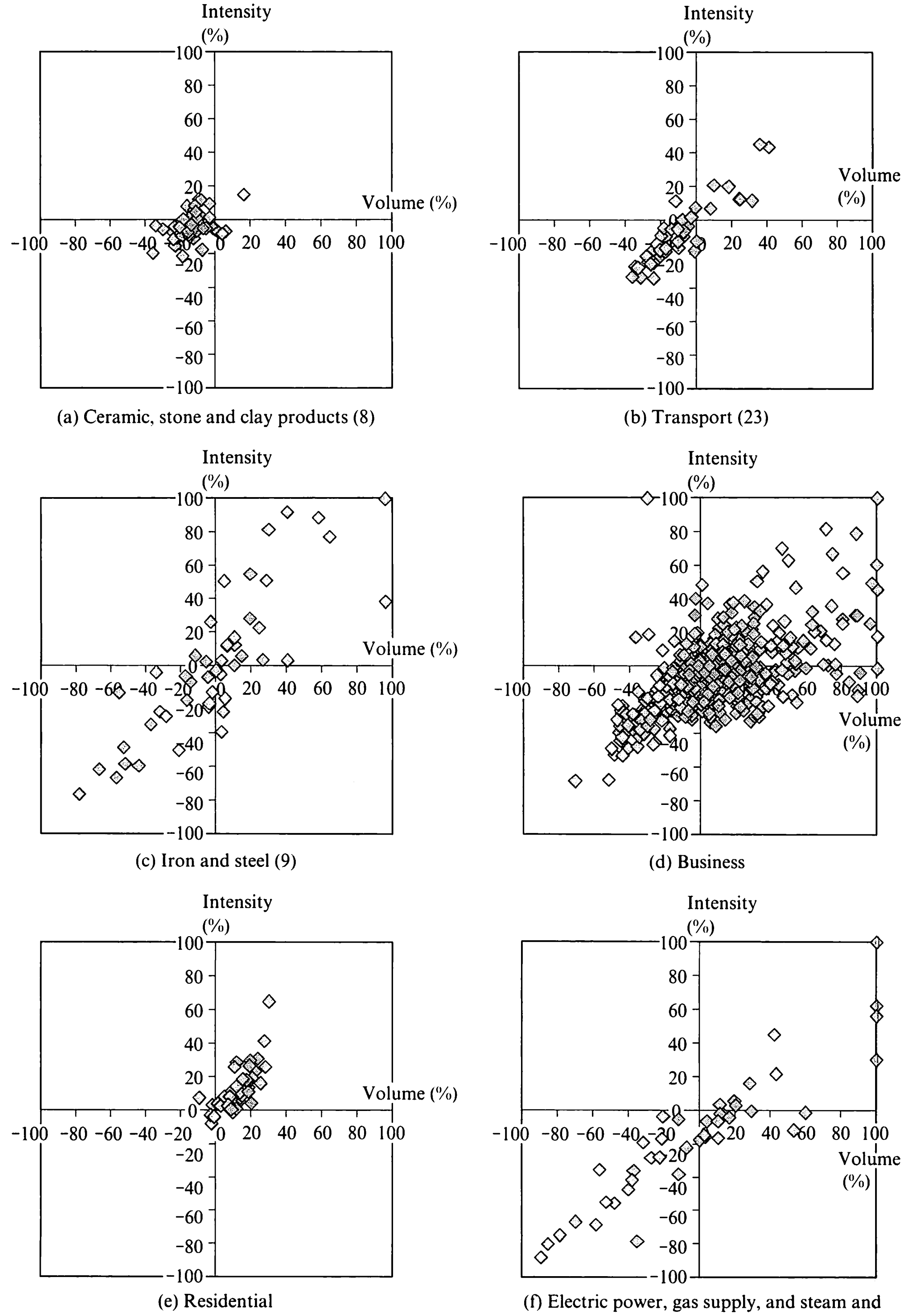
Moreover, we investigate changes in emissions at the prefectural level, focusing on some industries. Figure 7 compares prefectures on the basis of change in emission volume and emission intensity. Emission intensity is defined in this paper as emissions per output of 1 million yen in industries, and as emissions per consumption expenditures of 1 million yen in households (33). In Figure 7, the horizontal axis represents change in emission volume, and the vertical axis change in emission intensities; each marker indicates a prefecture. Therefore, the first quadrant in Figure 7 shows the increase in both volume and intensity; the second, decrease in volume and increase in intensity; the third, decrease in both; and the fourth, increase in volume and decrease in intensity.

First, we focus on (a) ceramic, stone, and clay products (8), (b) transport (23) and, (c) iron and steel (9). The change in ceramic, stone, and clay products (8) and transport (23) are relatively small. These two industries decrease emissions in most prefectures, although transport (23) significantly increases emissions in some prefectures. Moreover, we may notice that transport (23) in many prefectures decreases both the intensity and volume of emissions. On the other hand, iron and steel (9) shows significant change in both the volume and intensity. With regard to iron and steel (9), prefectures are mainly classified into two types: those increasing volume and intensity and those decreasing both.

Next, we focus on (d) business and (e) residential. In Figure 7, (d) business includes trade (20), finance and insurance (21), real estate (22), communication and broadcasting (24), public administration (25), education and research (26), medical service, health, social security and nursing service (27), other public service (28), business service (29), and personal service (30). Needless to mention, (e) residential corresponds to households (33). The pattern of change in (d) business has a large variety because many prefectures are placed on all quadrants in Figure 7. On the other hand, almost all prefectures increase both the volume and intensity as far as (e) residential is concerned, implying the necessity of a reduction policy for the household emissions in all municipalities.

Finally, we investigate the status of (f) electric power, gas supply, and steam and hot water supply (18). Around half of all prefectures in Japan increase the volume, some of them by more than 100%, apparently due to newly built thermal power stations. On the other hand, 33 prefectures, more than half of all prefectures, decrease the intensity. In fact, although power companies in Japan increase the ratio of coal input to all fossil fuels during this period, the number of prefectures where the coal ratio increases in power companies are only 14, meaning that the increase of the coal ratio is confined to specific regions. In addition, many plants increase the consumption of NG or LNG in this sector. Therefore, many prefectures fulfill the reduction of intensity in this sector.

Figure 7. Ratio of change in emission volume and emission intensity[1](1995-2000)



(a) Ceramic, stone and clay products (8)

(b) Transport (23)

(c) Iron and steel (9)

(d) Business

(e) Residential

(f) Electric power, gas supply, and steam and hot water supply (18)

Note 1) The 2000 price based on the 1990–1995–2000 linked input–output tables in Japan is used to compare emission intensities.

4 Conclusions

This paper estimated CO_2 emissions at the prefecture level in Japan in 1995 and 2000 by using the modified RAS method in the context of the increasing concern about global warming by local governments in Japan and their need to identify the emission structures of GHGs in their own regions. Furthermore, we compared our empirical results with the databases constructed by Kainou (2009) and Yonezawa and Matsuhashi (2009) in order to verify the reliability of our estimation method, and we investigated regional differences of CO_2 emissions among all prefectures from different perspectives.

Although our results were not perfectly consistent with the findings in these two studies because of the differences in estimation methods, statistics used, and energy types considered, both our study as well as these two studies did capture common regional characteristics in several points. Both this paper and Yonezawa and Matsuhashi (2009), in particular, found small per capita emissions in the urban area and large emissions per capita in the northern and inland areas in transport, while the corresponding sectors in this study are "unknown sectors," where emissions are estimated by the modified RAS method in the absence of a direct data source. This implies our estimation method could reflect regional characteristics with high reliability.

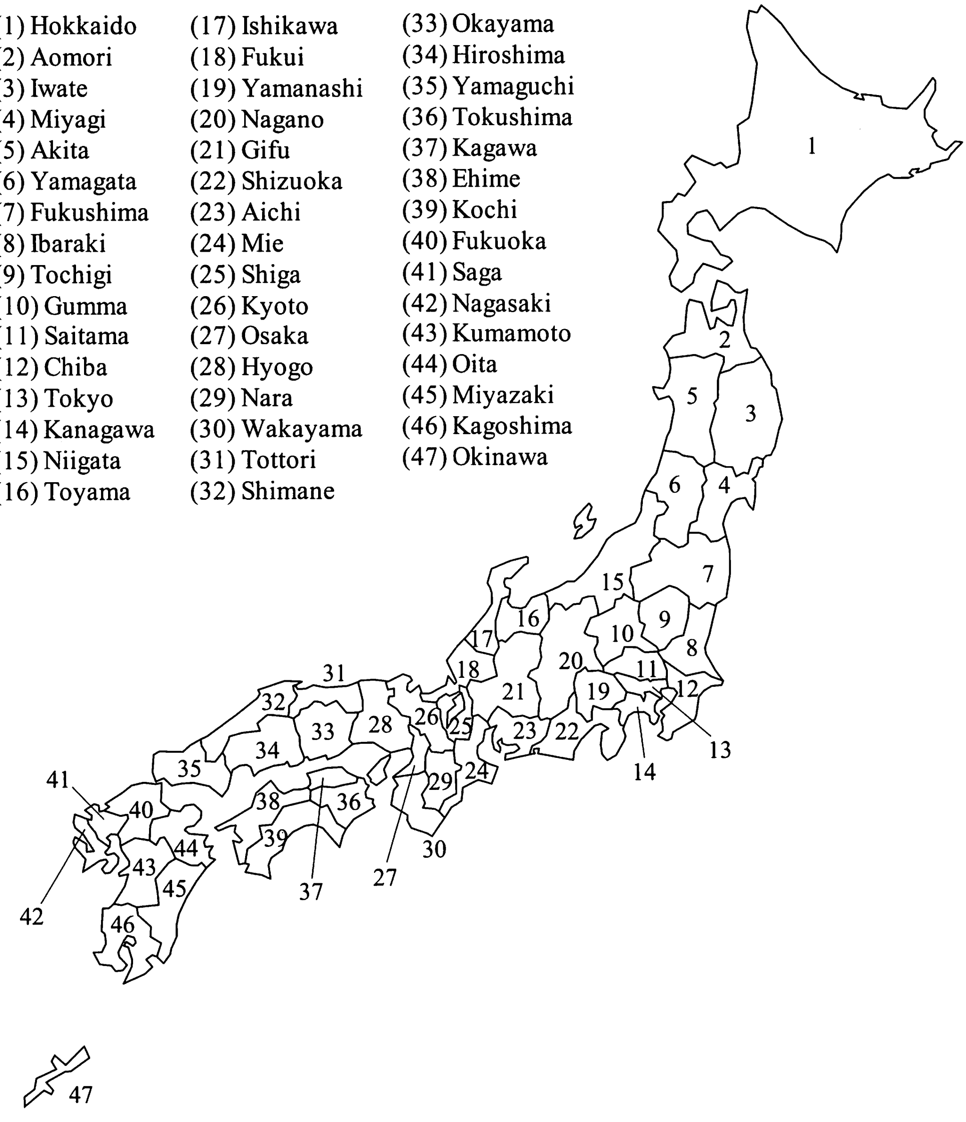
Our results revealed that the magnitude and change of total emissions at the prefecture level do not merely depend on the size of the economy or population but are influenced by various regional characteristics such as industrial structures, location of industry, consumption patterns, climate, and so on. We also investigated changes in emission volume and emission intensity by focusing on some industries, and it turned out that almost all prefectures show increases in both emission volume and emission intensity in the residential sector. This shows the importance of policymaking by local governments to reduce CO_2 emissions from households in their own regions, because they have relatively more discretionary powers in the residential sector and are better-informed of the circumstances of their own regions.

There remain issues for further examination. First, we did not consider the influence of movement across prefectural borderlines on the transportation sector, including private automobiles. If movements across borders are frequent, the estimated emissions would deviate from the reality to a great extent. Second, we must acknowledge that there exist "partial data" other than those considered in this paper, because "partial data" are used only when they turned out to be credible, originally constructed, and their constructed methods are clearly reported as far as the author investigated. Therefore, this paper did not assume theoretical and objective criteria to determine what "partial data" should or should not be used. Third, we considered CO_2 emitted directly from sectors and regions as the emissions in a prefecture. In other words, we estimated "production-based" emissions except for households. On the other hand, we can also consider "consumption-based" emissions as regional emissions -which mean CO_2 emitted both within and outside the region in order to satisfy demand in the region concerned. It is necessary to identify not only production-based but also consumption-based emissions in order to establish effective policies for the reduction of GHGs especially, at the municipality level. However, in order to estimate consumption-based emissions at the regional level, we need information on production-based emissions, that is, direct emissions in the supply-side regions to satisfy the demand in other regions. In this sense, our results are used as a useful database of regional emissions, too, for the analysis of consumption-based emissions at the regional level.

Input-output theory is highly established as a strong analysis tool in environmental economics, and environmental analyses based on input-output theory are widely applied at various spatial scales. However, the databases of CO_2 emissions or other environmental burdens used with input-output tables are not sufficiently developed at the regional level, compared to those at the national or international level. Therefore, an approach such as this study is expected to expand the scope of input-output analysis in environment or regional studies.

Appendix 1. The locations of prefectures in Japan

(1) Hokkaido
(2) Aomori
(3) Iwate
(4) Miyagi
(5) Akita
(6) Yamagata
(7) Fukushima
(8) Ibaraki
(9) Tochigi
(10) Gumma
(11) Saitama
(12) Chiba
(13) Tokyo
(14) Kanagawa
(15) Niigata
(16) Toyama
(17) Ishikawa
(18) Fukui
(19) Yamanashi
(20) Nagano
(21) Gifu
(22) Shizuoka
(23) Aichi
(24) Mie
(25) Shiga
(26) Kyoto
(27) Osaka
(28) Hyogo
(29) Nara
(30) Wakayama
(31) Tottori
(32) Shimane
(33) Okayama
(34) Hiroshima
(35) Yamaguchi
(36) Tokushima
(37) Kagawa
(38) Ehime
(39) Kochi
(40) Fukuoka
(41) Saga
(42) Nagasaki
(43) Kumamoto
(44) Oita
(45) Miyazaki
(46) Kagoshima
(47) Okinawa



Appendix 2. The locations of the 10 regions in Japan

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