Regional Comparisons and Decomposition Analyses of CO_2 Emission in Japan*

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Abstract

Many countries have been bound to reduce GHGs(greenhouse gasses) since COP3 was held at Kyoto in 1997. Japan also has a responsibility to reduce CO_2 emission by 6% from 1990 level between 2008 and 2012. In this situation, each local government in Japan established a scenario for GHGs reduction and is groping for various global warming mitigation programs. This paper investigates regional differences of environmental burdens by comparing energy consumption and CO_2 emission among all prefectures in Japan at 1995 using a database constructed in the author's previous studty. Furthermore, we apply Structural Decomposition Analysis (SDA) across prefectures to analyze regional structure of CO_2 emission in 1995 using regional I-O tables. Results show that: (1) the magnitude of energy consumption and CO_2 emission at prefecture level does not only depend on the size of economy but also various regional characteristics and (2) major factors generating regional discrepancy of CO_2 emission are emission intensities, the volume of regional export and the composition of regional export. These findings are useful to consider the potentiality of CO_2 emission reduction at prefecture level

JEL classifications: D57; Q40; R15

Keywords: Energy consumption; CO_2 emission; Input-output analysis; Structural Decomposition Analysis; prefecture data

1. Introduction

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Many counties have been implementing various projects to reduce GHGs(greenhouse gasses) emission which causes the global warming since COP3 was held at Kyoto in 1997. Particularly, as the Kyoto protocol was issued on February 16th in 2005, the need for such projects will increase even more. Japan has a responsibility to reduce CO_2 emission by 6% from 1990 level between 2008 and 2012. In this situation, recently each local government in Japan has been establishing a scenario for GHGs reduction and groping for various global warming mitigation programs. In fact, local governments as well as national governments have become increasingly concerned with the global warming problem.

The global warming problem tends to be discussed at international level or a country level. However the source of GHGs emission lies in all economic agencies including each business and citizenry in the sense that the emission of GHGs that leads to the global warming is mainly related to energy consumption. When we pay attention to the regional diversities of the source of emission, it is very significant to address the global warming problem in terms of region. These regional diversities stems from such factors as income, population, technology, climate, industrial structure, location of industry and housing, division of labor…etc. When we consider developing more effective reduction of GHGs, we inevitably need regional analyses of global warming.

In this paper, we investigate regional differences of environmental burdens by comparing energy consumption and CO_2 emission among all prefectures in Japan at 1995. Although for example Aldy (2005) examines the EKC(environmental Kuznets curve) of CO_2 emission at state level in U.S. during 1960-1999, the literatures analyzing regional CO_2 emission are not abundant so much partly due to lack of regional statistics regarding energy consumption and CO_2 emission. Hasegawa (2004), the author's previous study, constructs a novel database of prefecture-level energy consumption at 1995 in Japan. While Hasagawa (2004) puts stress on explaining and proposing a method of establishing the database, in this paper we investigate the regional trends of energy consumption and CO_2 emission at prefecture level by using the constructed database.

After that, we apply Structural Decomposition Analysis(SDA) of per capita CO_2 emission across prefectures by using regional I-O(input-output) tables. It is more reasonable to adopt SDA to CO_2 emission than to energy consumption for leading to more useful policy implications, because it is CO_2 emission that is the actual target of reduction as a global warming mitigation policy. Not to mention, environmental burdens that regional activities bring about are closely or complicatedly related to the regional economy. Therefore, it is expected that regional differences of CO_2 emission do not simply depend on the size of economy or population, but also various regional characteristics. You should notice it is useful to apply SDA among regions for environmental analyses. There are many literatures attempting to identify the relationship of environmental burdens with various economic factors by applying SDA techniques. Most of SDAs for environmental analysis in the framework of I-O model have been used in time series analysis (see e.g. Wier et al. 1999; Munksgaard et al. 2000; De Hann, 2001; Kagawa et al. 2001). De Nooij et al. (2003) proposes between-country SDA of per capita energy consumption among 8 OECD countries, but there is no study which deals with between-region SDA in a country (at least as long as the author knows).

In next section, we introduce the framework of database of prefecture-level energy consumption, and refer to calculating CO_2 emission from the database. In section 3, we develop the I-O model of per capita CO_2 emission, and explain the method of decomposing the CO_2 emission expressed by I-O model. In section 4, we show empirical results. Section 5 concludes and discusses the potentiality of CO_2 emission reduction at prefecture level.

2. The Framework of Database of Prefecture-level Energy Consumption

We classify energy consumptions in Japan at 1995 by regions(i), sectors(j) and energy items(k) as Figure.1, and construct region-industry energy consumption matrices as figure.2 for each energy item. The division of region is prefecture level, and there are 47 prefectures in Japan(these locations are indicated in the Appendix). The sectors include 32 industries[1] and household, that is there are 33 sectors, and energy is classified into 25 types. Therefore, we have 25 region-industry (47×33) energy matrices as Figure.2 in Hasegawa (2004).

In Figure.2, there are two kinds of summation in the direction of row and column, that is, regional total consumption and sectoral consumption at national level. These two summations, of which corresponding statistics are relatively credible in Japan, are

[1] This category is based on the large classification of 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.Electical 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 and social security, 28.Other public service, 29.Business service, 30.Personal service, 31.Office supplies and 32.Activities not elsewhere classified

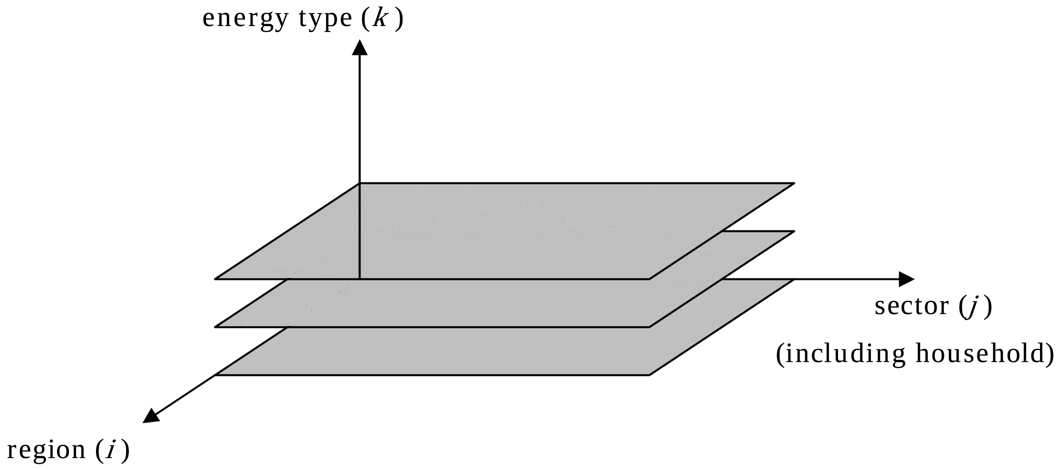

Figure.1 The framework of database

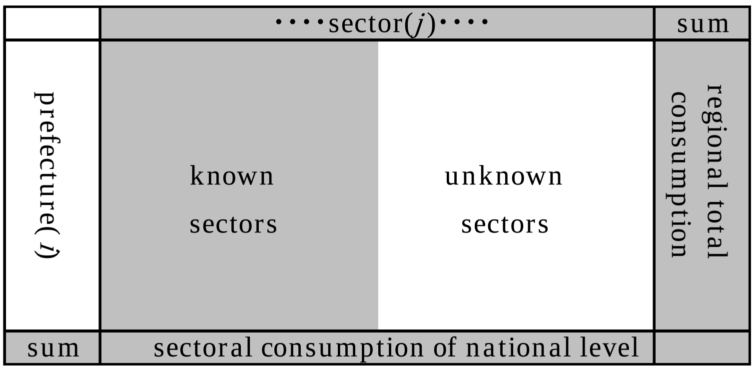

Figure.2 Region-industry energy consumption matrix

used as control totals in estimating elements in the energy matrices. In Figiure.2, the elements are divided into “known sectors” and “unknown sectors”. These categories are determined by whether the data of all prefectures about energy consumption is available from existing statistics or not. Regarding to unknown sectors, we apply RAS method, often used to estimate technical coefficients in I-O table, to estimating unknown elements taking advantage of corresponding monetary output matrices. It is most characteristic that the estimated elements are consistent in that the summation of elements in the row direction and the summation in the column direction are simultaneously equal to the regional total consumption and sectoral consumption at national level respectively.

We convert the energy consumption data to CO_2 emission by using emission transform factors provided in Nansai et al. (2002)[2]

3. Input-Output Model of CO_2 Emission

Before we conduct regional decomposition analyses of per capita CO_2 emission, we need to represent per capita CO_2 emission using regional I-O model. To begin with, we build up the equation of per capita CO_2 emitted from all industries within a prefecture as follows.

$$\mathbf{C} = \hat{\mathbf{c}}\,\mathbf{x} \tag{1}$$

When we image there are n industrial sectors, then $\mathbf{C}$ is a $(n \times 1)$ vector indicating sectoral per capita CO_2 emissions, $\hat{\mathbf{c}}$ is a $(n \times n)$ matrix of CO_2 emission intensity and $\mathbf{x}$ is a $(n \times 1)$ vector of sectoral per capita monetary output. CO_2 emission intensity, $\hat{\mathbf{c}}$ means the amount of CO_2 emission needed for a unit of production, specially we should notice the elements of $\hat{\mathbf{c}}$ are put on the diagonal and zeros elsewhere in the matrix.

Next, we represent per capita monetary output, $\mathbf{x}$ into Equation (1) as I-O model which treats import(including inter-regional trade as well as abroad) endogenously.

$$\begin{aligned} & \mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{d} + \mathbf{e} - \hat{\mathbf{M}}(\mathbf{A}\mathbf{x} + \mathbf{d}) \\ \Leftrightarrow\ & \mathbf{x} - \mathbf{A}\mathbf{x} - \hat{\mathbf{M}}\mathbf{A}\mathbf{x} = \mathbf{d} - \hat{\mathbf{M}}\mathbf{d} + \mathbf{e} \\ \Leftrightarrow\ & \{\mathbf{I} - (\mathbf{I} - \hat{\mathbf{M}})\mathbf{A}\}\mathbf{x} = (\mathbf{I} - \hat{\mathbf{M}})\mathbf{d} + \mathbf{e} \\ \Leftrightarrow\ & \mathbf{x} = \{\mathbf{I} - (\mathbf{I} - \hat{\mathbf{M}})\mathbf{A}\}^{-1}\{(\mathbf{I} - \hat{\mathbf{M}})\mathbf{d} + \mathbf{e}\} \end{aligned} \tag{2}$$

$\mathbf{A}$ is the $(n \times n)$ matrix of technical coefficients which indicates the composition of intermediate inputs among industries. $\mathbf{d}$ and $\mathbf{e}$ indicate a (intra-)regional final demand vector and an export(including inter-regional trade as well as abroad) vector, respectively. $\hat{\mathbf{M}}$ is a $(n \times n)$ matrix called import coefficients ,of which elements are put on the diagonal and zeros elsewhere. It is assumed that import depends on (intra-)regional demands in Equation (2). $\{\mathbf{I} - (\mathbf{I} - \hat{\mathbf{M}})\mathbf{A}\}^{-1}$ is the Leontief inverse matrix, which indicate a magnitude of economic multiplier effect.

Furthermore we divide regional final demand vector, $\mathbf{d}$ and export vector, $\mathbf{e}$ into the composition vectors and volume scholars. Therefore we rewrite Equation (2) as follows.

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[2] In addition to energy-related emission, we include emission from the combustion of limestone for cement production. We distribute limestone-related emission at the country level among prefectures according to prefecture-country ratio of monetary output in 8.Ceramic, stone and clay products.

$$\mathbf{x}=\{\mathbf{I}-(\mathbf{I}-\hat{\mathbf{M}})\mathbf{A}\}^{-1}\{(\mathbf{I}-\hat{\mathbf{M}})\mathbf{f_d}Y_d+\mathbf{f_e}Y_e\} \tag{3}$$

Of course, the $\mathbf{f_d}$ in Equation (3) denotes the composition of regional final demand, Y_d, the per capita volume of regional final demand, $\mathbf{f_e}$, the composition of export and Y_e, the per capita volume of export.

Eventually we build up the I-O model of per capita CO_2 emission by introducing Equation (3) into Equation (1).

$$\mathbf{C}=\hat{\mathbf{c}}\mathbf{BG} \tag{4}$$

$$\because \quad \mathbf{B}=\{\mathbf{I}-(\mathbf{I}-\hat{\mathbf{M}})\mathbf{A}\}^{-1} \quad , \quad \mathbf{G}=\{(\mathbf{I}-\hat{\mathbf{M}})\mathbf{f_d}Y_d+\mathbf{f_e}Y_e\}$$

After expressing per capita CO_2 emission as an I-O model such as Equation (4), we can decompose the difference in per capita CO_2 emission between two regions. If there are region 1 and region 0, the difference of Equation (4) between two region can be decomposed as follows.

$$\begin{aligned}
\Delta\mathbf{C}&=\mathbf{C}^1-\mathbf{C}^0=\hat{\mathbf{c}}^1\mathbf{B}^1\mathbf{G}^1-\hat{\mathbf{c}}^0\mathbf{B}^0\mathbf{G}^0\\
&=(\hat{\mathbf{c}}^1-\hat{\mathbf{c}}^0)\mathbf{B}^1\mathbf{G}^1+\hat{\mathbf{c}}^0\mathbf{B}^1\mathbf{G}^1-\hat{\mathbf{c}}^0\mathbf{B}^0\mathbf{G}^0\\
&=\Delta\hat{\mathbf{c}}\mathbf{B}^1\mathbf{G}^1+\hat{\mathbf{c}}^0\Delta\mathbf{B}\mathbf{G}^1+\hat{\mathbf{c}}^0\mathbf{B}^0\Delta\mathbf{G}\\
&=\Delta\hat{\mathbf{c}}\mathbf{B}^1\mathbf{G}^1+\hat{\mathbf{c}}^0\mathbf{B}^0\{(\mathbf{B}^0)^{-1}-(\mathbf{B}^1)^{-1}\}\mathbf{B}^1\mathbf{G}^1\\
&\quad+\hat{\mathbf{c}}^0\mathbf{B}^0\{(\mathbf{I}-\hat{\mathbf{M}}^1)\mathbf{f}_\mathbf{d}^1Y_d^1+\mathbf{f}_\mathbf{e}^1Y_e^1-(\mathbf{I}-\hat{\mathbf{M}}^0)\mathbf{f}_\mathbf{d}^0Y_d^0-\mathbf{f}_\mathbf{e}^0Y_e^0\}\\
&\quad\cdots\cdots\\
&=\Delta\hat{\mathbf{c}}\mathbf{x}^1 && \text{(CO}_2\text{ intensity effect)}\\
&\quad+\hat{\mathbf{c}}^0\mathbf{B}^0\Delta\mathbf{A}\mathbf{X}^1 && \text{(Intermediate input effect)}\\
&\quad+\hat{\mathbf{c}}^0\mathbf{B}^0(\Delta\mathbf{f_d}Y_d^1+\mathbf{f}_\mathbf{d}^0\,\Delta Y_d) && \text{(Regional final demand effect)}\\
&\quad+\hat{\mathbf{c}}^0\mathbf{B}^0(\Delta\mathbf{f_e}Y_e^1+\mathbf{f}_\mathbf{e}^0\,\Delta Y_e) && \text{(Export effect)}\\
&\quad-\hat{\mathbf{c}}^0\mathbf{B}^0\{\Delta(\hat{\mathbf{M}}\mathbf{A})\mathbf{X}^1+\Delta(\hat{\mathbf{M}}\mathbf{f_d}Y_d)\} && \text{(Import effect)}
\end{aligned} \tag{5}$$

The import effect in Equation (5) is divided into intermediate demand factor and regional final demand factor. In this paper, we decompose import effect into the composition and volume similar to decomposition form in regional final demand and export. Therefore, the import effect in Equation (5) is further decomposed as follows.

$$\Delta(\hat{\mathbf{M}}\mathbf{A}) = \hat{\mathbf{M}}^{\mathbf{1}}\mathbf{A}^{\mathbf{1}} - \hat{\mathbf{M}}^{\mathbf{0}}\mathbf{A}^{\mathbf{0}}$$

$$= \mathbf{D}^{\mathbf{1}} Y_{ma}^{1} - \mathbf{D}^{\mathbf{0}} Y_{ma}^{0} = \mathbf{D}^{\mathbf{1}} \varDelta Y_{ma} + \Delta \mathbf{D} Y_{ma}^{0} \tag{6}$$

$$\because \quad Y_{ma}^{i} = \begin{pmatrix} 1 & 1 & \cdots & 1 \end{pmatrix} \hat{\mathbf{M}}^{\mathbf{i}} \mathbf{A}^{\mathbf{i}} \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix}, \quad \mathbf{D} = \frac{\hat{\mathbf{M}}^{\mathbf{i}} \mathbf{A}^{\mathbf{i}}}{Y_{ma}^{i}}$$

$$\Delta(\hat{\mathbf{M}}\mathbf{f_d} Y_d) = \hat{\mathbf{M}}^{\mathbf{1}} \mathbf{f_d^1} Y_d^1 - \hat{\mathbf{M}}^{\mathbf{0}} \mathbf{f_d^0} Y_d^0 = \hat{\mathbf{M}}^{\mathbf{1}} \mathbf{f_d^1} \varDelta Y_d + \Delta(\hat{\mathbf{M}}\mathbf{f_d}) Y_d^0 \tag{7}$$

Equation (5) can be rewritten by using Equation (6) and (7).

$$\begin{aligned}
\Delta \mathbf{C} = {} & \Delta\hat{\mathbf{c}}\,\mathbf{x}^{\mathbf{1}} && (CO_2 \text{ intensity effect}) \\
& + \hat{\mathbf{c}}^{\mathbf{0}} \mathbf{B}^{\mathbf{0}} \Delta \mathbf{A} \mathbf{X}^{\mathbf{1}} && (\text{Intermediate input effect}) \\
& + \hat{\mathbf{c}}^{\mathbf{0}} \mathbf{B}^{\mathbf{0}} (\Delta \mathbf{f_d} Y_d^1 + \mathbf{f_d^0}\, \varDelta Y_d) && (\text{Regional final demand effect}) \\
& + \hat{\mathbf{c}}^{\mathbf{0}} \mathbf{B}^{\mathbf{0}} (\Delta \mathbf{f_e} Y_e^1 + \mathbf{f_e^0}\, \varDelta Y_e) && (\text{Export effect}) \\
& - \hat{\mathbf{c}}^{\mathbf{0}} \mathbf{B}^{\mathbf{0}} \{ \Delta \mathbf{D} Y_{ma}^0 \mathbf{X}^{\mathbf{1}} + \Delta(\hat{\mathbf{M}} \mathbf{f_d}) Y_d^0 \\
& \qquad + \mathbf{D}^{\mathbf{1}} \varDelta Y_{ma} \mathbf{X}^{\mathbf{1}} + \hat{\mathbf{M}}^{\mathbf{1}} \mathbf{f_d^1}\, \varDelta Y_d \} && (\text{Import effect})
\end{aligned} \tag{8}$$

We construct another decomposition form in addition to Equation (8) as below.

$$\begin{aligned}
\Delta \mathbf{C} = {} & \Delta\hat{\mathbf{c}}\,\mathbf{x}^{\mathbf{0}} + \hat{\mathbf{c}}^{\mathbf{1}} \mathbf{B}^{\mathbf{1}} \Delta \mathbf{A} \mathbf{X}^{\mathbf{0}} + \hat{\mathbf{c}}^{\mathbf{1}} \mathbf{B}^{\mathbf{1}} (\Delta \mathbf{f_d} Y_d^0 + \mathbf{f_d^1}\, \varDelta Y_d) + \hat{\mathbf{c}}^{\mathbf{1}} \mathbf{B}^{\mathbf{1}} (\Delta \mathbf{f_e} Y_e^0 + \mathbf{f_e^1}\, \varDelta Y_e) \\
& - \hat{\mathbf{c}}^{\mathbf{1}} \mathbf{B}^{\mathbf{1}} \{ \Delta \mathbf{D} Y_{ma}^1 \mathbf{X}^{\mathbf{0}} + \Delta(\hat{\mathbf{M}} \mathbf{f_d}) Y_d^1 + \mathbf{D}^{\mathbf{0}} \varDelta Y_{ma} \mathbf{X}^{\mathbf{0}} + \hat{\mathbf{M}}^{\mathbf{0}} \mathbf{f_d^0}\, \varDelta Y_d \}
\end{aligned} \tag{9}$$

Although the decomposition patterns are not only Equation (8) and (9), we take the average of two “polar decomposition” equations such as Equation (8) and (9), since Dietzenbacher and Los (1998) shows the average of two “polar decomposition” equations is approximately equivalent to the average of all decomposition equations.

In our actual application of SDAs, we decompose the difference in per capita CO_2 emission between a prefecture and the country, which means the region 1 and region 0 above mentioned correspond to a prefecture and the country respectively. By the way, our analyses need prefecture-level I-O tables, and each prefecture office publishes their own intra-regional I-O tables in Japan. Almost all prefecture I-O tables are easily available by downloading from prefecture's official web sites. Of course, used prefecture I-O tables are adjusted to 32 sectors, the large classification of Japan I-O table in order to conduct SDAs.

4. Empirical Results

Table.1 Population, GDP, energy consumption and CO_2 emission in each prefecture

		Population[a)]	GDP[b)]		Energy consumption		CO_2 emission	
			Total	Per capita	Total	Per capita	Total	Per capita
		Thousand	Billion yen	Million yen	Tcal	Gcal	1,000 t-c	t-c
1	Hokkaido	5692	19645	3.451	217277	38.2	17825	3.131
2	Aomori	1482	4453	3.006	45676	30.8	3523	2.377
3	Iwate	1420	4563	3.215	32517	22.9	2329	1.641
4	Miyagi	2329	8341	3.582	69754	30.0	5285	2.269
5	Akita	1214	3797	3.128	39998	33.0	3777	3.112
6	Yamagata	1257	3927	3.124	29433	23.4	2399	1.909
7	Fukushima	2133	7627	3.575	91263	42.8	9434	4.421
8	Ibaraki	2956	10700	3.620	144344	48.8	12958	4.384
9	Tochigi	1985	7897	3.980	49262	24.8	3058	1.541
10	Gumma	2004	7722	3.854	44150	22.0	2628	1.312
11	Saitama	6759	19500	2.885	105882	15.7	6391	0.946
12	Chiba	5798	18230	3.144	343314	59.2	28776	4.963
13	Tokyo	11772	84129	7.146	255791	21.7	15164	1.288
14	Kanagawa	8246	29218	3.543	268391	32.5	19943	2.419
15	Niigata	2488	9240	3.713	95032	38.2	7130	2.865
16	Toyama	1123	4342	3.866	43563	38.8	3557	3.167
17	Ishikawa	1180	4465	3.784	35143	29.8	2703	2.291
18	Fukui	827	3108	3.758	28500	34.5	2427	2.935
19	Yamanashi	882	3095	3.510	16736	19.0	997	1.130
20	Nagano	2194	7970	3.633	48465	22.1	3024	1.378
21	Gifu	2100	7082	3.372	48767	23.2	3577	1.703
22	Shizuoka	3738	14745	3.945	107117	28.7	6734	1.802
23	Aichi	6868	32208	4.689	302617	44.1	25756	3.750
24	Mie	1842	6253	3.396	97171	52.8	7633	4.145
25	Shiga	1287	5400	4.196	36086	28.0	2632	2.045
26	Kyoto	2629	9930	3.776	47549	18.1	2931	1.114
27	Osaka	8797	38862	4.417	235665	26.8	15029	1.708
28	Hyogo	5402	20038	3.709	208831	38.7	17112	3.168
29	Nara	1431	3521	2.460	18173	12.7	985	0.688
30	Wakayama	1080	3246	3.005	69785	64.6	6761	6.258
31	Tottori	615	2058	3.346	14745	24.0	1009	1.640
32	Shimane	771	2329	3.020	15733	20.4	1061	1.376
33	Okayama	1951	7488	3.839	139317	71.4	12558	6.438
34	Hiroshima	2882	10928	3.792	154808	53.7	15071	5.230
35	Yamaguchi	1556	5546	3.566	128844	82.8	11788	7.578
36	Tokushima	832	2540	3.052	27450	33.0	2252	2.706
37	Kagawa	1027	3645	3.549	35786	34.8	2599	2.531
38	Ehime	1507	4915	3.262	58949	39.1	4977	3.303
39	Kochi	817	2383	2.918	19569	24.0	1425	1.745
40	Fukuoka	4933	16904	3.426	174154	35.3	14011	2.840
41	Saga	884	2749	3.109	18276	20.7	1230	1.391
42	Nagasaki	1545	4807	3.112	53229	34.5	6046	3.913
43	Kumamoto	1860	5578	2.999	40373	21.7	3040	1.635
44	Oita	1231	4261	3.461	99344	80.7	9403	7.637
45	Miyazaki	1176	3138	2.669	30583	26.0	2119	1.802
46	Kagoshima	1794	4926	2.746	39300	21.9	2837	1.581
47	Okinawa	1274	3266	2.565	39992	31.4	3399	2.669
	Japan	125570	490715	3.908	4266709	34.0	337303	2.686

Data Source: a) 1995 Population Census of Japan
b) 1998 Annual Report on Prefectual Accounts

4.1. Investigation of Regional Energy Consumption and CO_2 Emission

Table.1 shows population, GDP, energy consumption and CO_2 emission in each prefecture at regional total level. The parts colored gray in Table.1 indicate the top 15 prefectures that have the largest magnitude in each category. In total energy consumption, the most-consuming prefecture is 12.Chiba, followed by 23.Aichi, 14.Kanagawa and 13.Tokyo. While 12.Chiba, 23.Aichi and 14.Kanagawa are also the top 3 in total CO_2 emission, 13.Tokyo is the 6th highest in total CO_2 emission. In both per capita energy consumption and per capita CO_2 emission, the top 3 prefectures that have the largest magnitude are 33.Okayama, 35.Yamaguchi and 44.Oita. You may notice from Table.1 that the magnitude of energy consumption and CO_2 emission does not correspond to population size or GDP size very much.

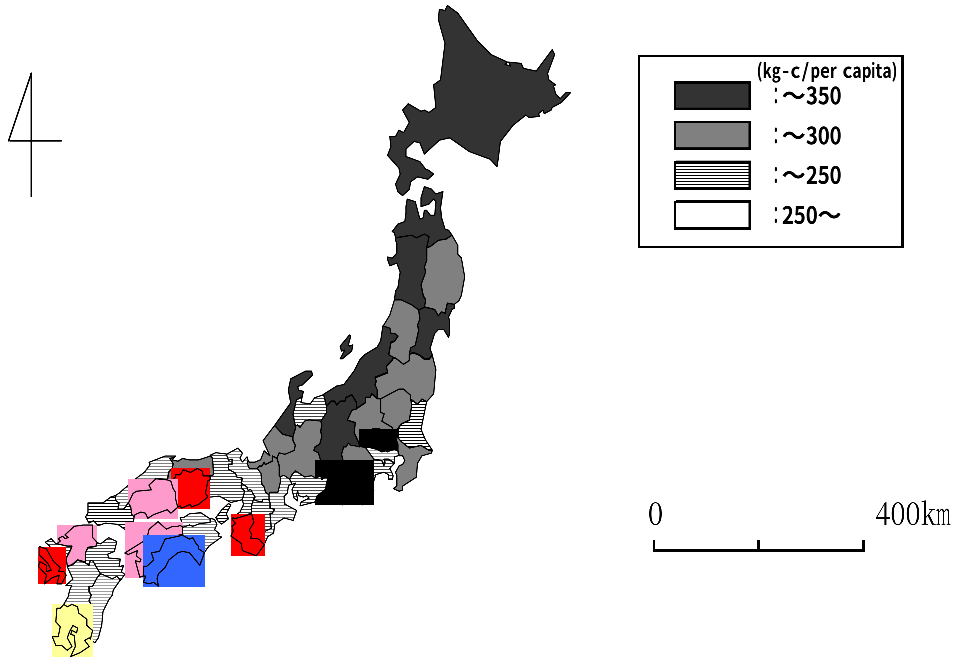
Next, we pay attention to per capita CO_2 emission in some sectors. Figure.3 indicates household's direct per capita CO_2 emission, and Figure.4, the emissions in material heavy industries [3] (see Appendix about the locations of prefecture). Household's emissions have a clear feature that the northern area is relatively high probably due to more heating in winter season. The emissions in material heavy industries have very large differences among regions. The most-emitting prefecture is 44.Oita, followed by 33.Okayama and 35.Yamaguchi, and the least-emitting prefecture is 13.Tokyo, followed by 29.Nara and 42.Nagasaki in these sectors. It is expected that the input of fossil fuel is extremely concentrated on specific industrial plants and the accumulation of these industrial location generates large regional differences.

In Figure.5, we compare the ratio of a prefecture to the country(prefecture/country) for energy consumption, CO_2 emission and monetary output at sector-aggregate level. The height of vertical axis stands for the share of environmental burdens(energy consumption and CO_2 emission) and the length of horizontal axis, the share of monetary output, and each marker indicates a prefecture in Figure.5. Many prefectures have large discrepancy between environmental burdens and monetary output in the prefecture-country ratio. Figure.5 clearly reveals that the magnitude of environmental burdens at prefecture level does not simply depend on its economic scale, implies that it is necessary to analyze factors generating these differences in more detail.

4.2. Results of Decomposition Analyses

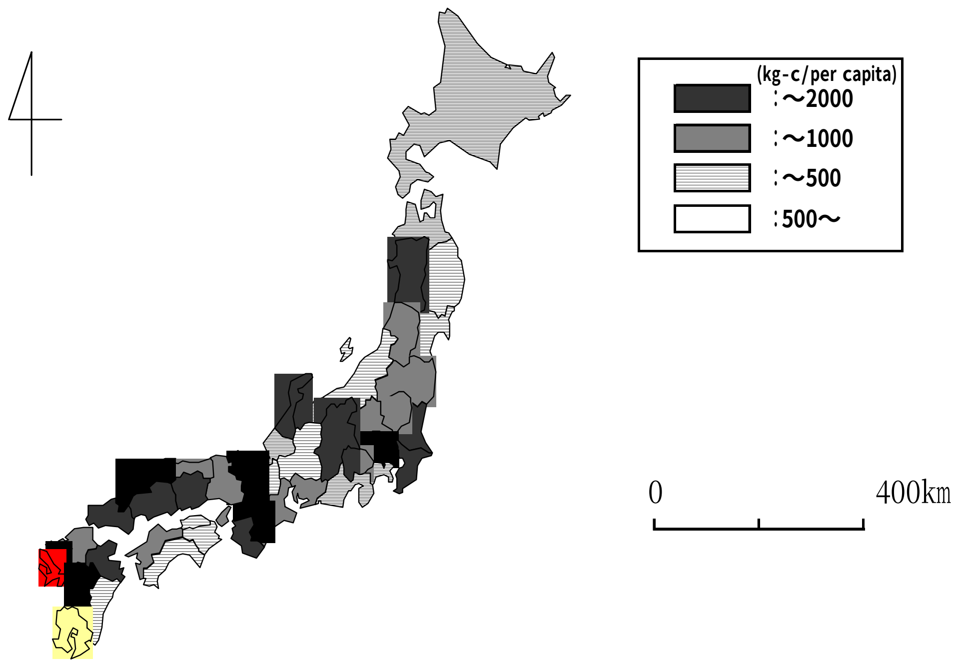
Table.2 shows the share of sector's CO_2 emission for total emission in each prefecture.

[3] Material heavy industries in this paper include 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 and 11.Metal products.



(National average: 284kg-c/per capita)

Figure.3 Per capita CO_2 emission in household



(National average: 931kg-c/per capita)

Figure.4 Per capita CO_2 emission in material heavy industries

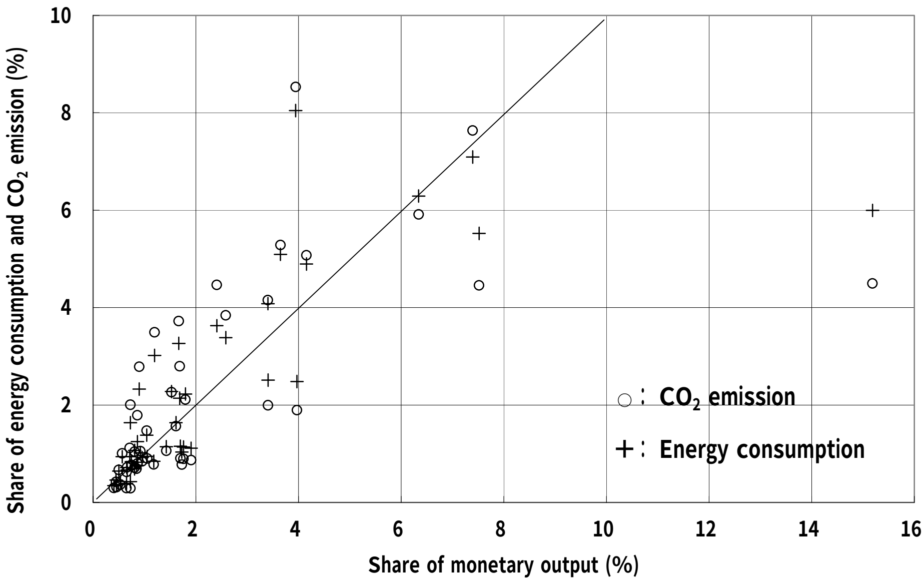


Figure.5 Ratio of a prefecture to the country (prefecture/country)

Table.2 The share of sector's CO_2 emission for total emission in each prefecture

		Manufacture	Electricity, gas supply and steam and hot water supply	Transport	Business and residential	Others	Total regional emission
1	Hokkaido	0.308	0.166	0.207	0.234	0.085	1.000
2	Aomori	0.342	0.110	0.192	0.262	0.094	1.000
3	Iwate	0.363	0.000	0.235	0.289	0.113	1.000
4	Miyagi	0.283	0.150	0.220	0.279	0.068	1.000
5	Akita	0.115	0.516	0.123	0.191	0.055	1.000
6	Yamagata	0.137	0.334	0.194	0.258	0.077	1.000
7	Fukushima	0.134	0.611	0.097	0.121	0.036	1.000
8	Ibaraki	0.489	0.278	0.115	0.094	0.024	1.000
9	Tochigi	0.349	0.000	0.259	0.308	0.084	1.000
10	Gumma	0.263	0.000	0.283	0.371	0.084	1.000
11	Saitama	0.321	0.000	0.289	0.348	0.042	1.000
12	Chiba	0.474	0.317	0.097	0.096	0.016	1.000
13	Tokyo	0.069	0.063	0.449	0.383	0.036	1.000
14	Kanagawa	0.352	0.336	0.118	0.173	0.021	1.000
15	Niigata	0.243	0.342	0.165	0.203	0.047	1.000
16	Toyama	0.321	0.370	0.117	0.154	0.038	1.000
17	Ishikawa	0.120	0.250	0.261	0.308	0.060	1.000
18	Fukui	0.257	0.407	0.127	0.164	0.044	1.000
19	Yamanashi	0.168	0.000	0.299	0.436	0.097	1.000
20	Nagano	0.192	0.003	0.275	0.417	0.113	1.000
21	Gifu	0.496	0.000	0.186	0.264	0.055	1.000
22	Shizuoka	0.467	0.008	0.251	0.219	0.057	1.000
23	Aichi	0.334	0.390	0.145	0.114	0.018	1.000
24	Mie	0.436	0.312	0.110	0.108	0.034	1.000
25	Shiga	0.561	0.000	0.169	0.226	0.045	1.000
26	Kyoto	0.253	0.079	0.231	0.392	0.044	1.000
27	Osaka	0.240	0.220	0.255	0.260	0.024	1.000
28	Hyogo	0.497	0.236	0.116	0.127	0.024	1.000
29	Nara	0.189	0.001	0.254	0.497	0.058	1.000
30	Wakayama	0.458	0.406	0.048	0.065	0.024	1.000
31	Tottori	0.300	0.001	0.276	0.315	0.108	1.000
32	Shimane	0.331	0.001	0.246	0.314	0.109	1.000
33	Okayama	0.667	0.180	0.079	0.060	0.015	1.000
34	Hiroshima	0.616	0.193	0.095	0.080	0.016	1.000
35	Yamaguchi	0.547	0.313	0.068	0.057	0.015	1.000

Figure.2 (Continued)

		Manufacture	Electricity, gas supply and steam and hot water supply	Transport	Business and residential	Others	Total regional emission
36	Tokushima	0.333	0.316	0.152	0.144	0.054	1.000
37	Kagawa	0.278	0.296	0.207	0.175	0.044	1.000
38	Ehime	0.537	0.190	0.130	0.099	0.044	1.000
39	Kochi	0.412	0.000	0.224	0.228	0.136	1.000
40	Fukuoka	0.471	0.166	0.192	0.141	0.030	1.000
41	Saga	0.249	0.035	0.295	0.308	0.113	1.000
42	Nagasaki	0.037	0.702	0.110	0.103	0.047	1.000
43	Kumamoto	0.219	0.196	0.240	0.251	0.093	1.000
44	Oita	0.702	0.168	0.056	0.054	0.020	1.000
45	Miyazaki	0.335	0.000	0.309	0.238	0.118	1.000
46	Kagoshima	0.176	0.100	0.374	0.231	0.118	1.000
47	Okinawa	0.106	0.384	0.329	0.146	0.035	1.000
	Japan	0.378	0.246	0.167	0.171	0.038	1.000

The ratio of composition among sectors in many prefectures is very different from that at the country level. The parts colored gray in Table.2 indicate the top 3 of the highest-ratio prefecture in each category. We show the results of decomposition analyses about these 14 prefectures, colored gray in Table.2.

At first, we consider production factors in Figure.6. It is easy to recognize from Figure.6 the CO_2 intensity effect is much more different among prefectures than the intermediate input effect. In 42.Nagasaki, 5.Akita and 47.Okinawa, the CO_2 intensity effect exceeds the total difference. Therefore the CO_2 intensity effect is a major factor

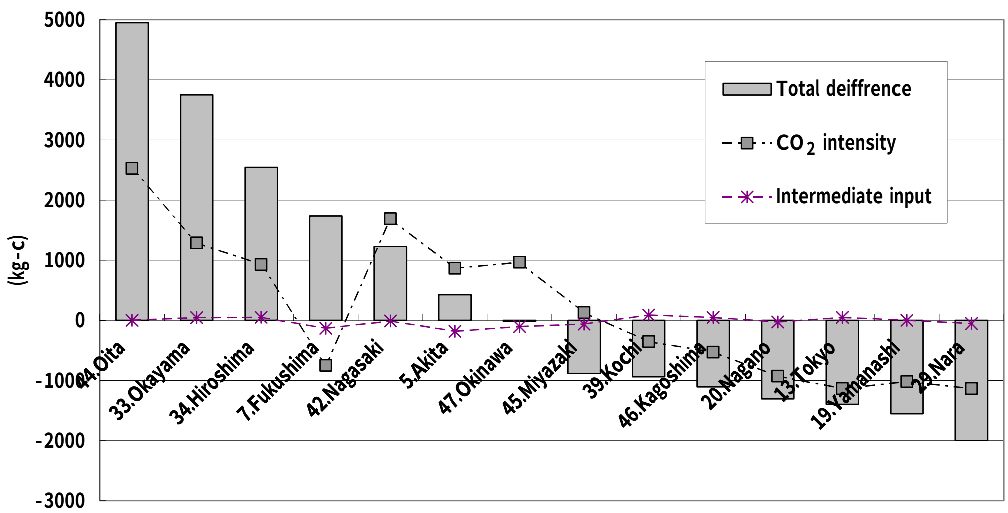


Figure.6 Production factors

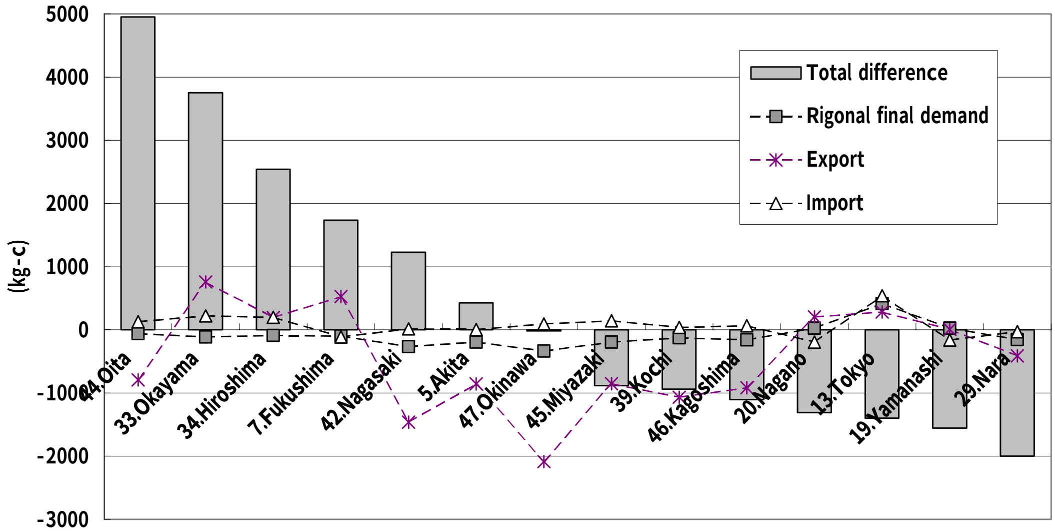


Figure.7 Volume factors of regional final demand, export and import

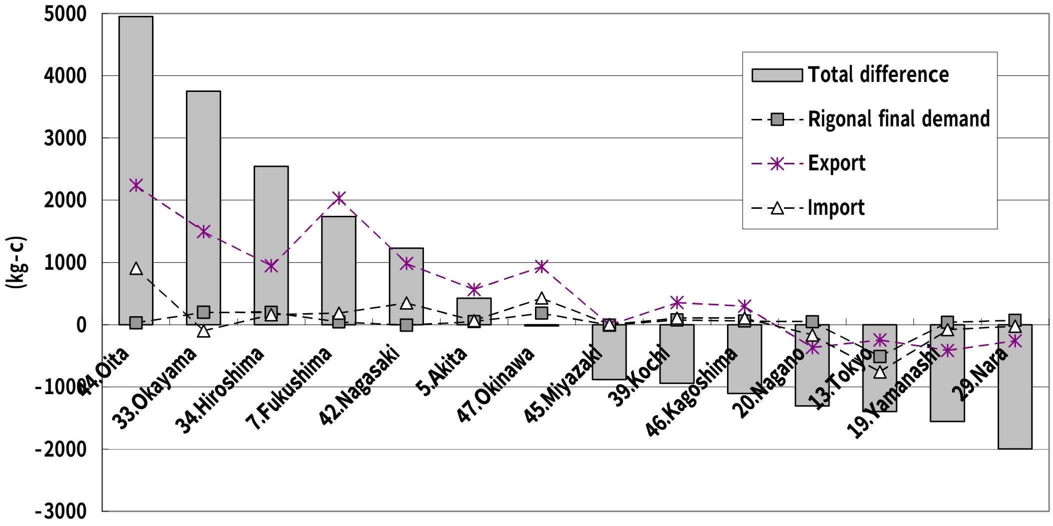


Figure.8 Consumption factors of regional final demand, export and import

pushing the total emission in these prefectures. By contrast, 7.Fukushima has small CO_2 intensity effect in spite of relatively high total emission, which means the CO_2 intensity effect mitigates the total emission.

In turn, we focus on factors of regional final demand, export and import in Figure.7 and 8. The export effect has the largest regional differences in the three factors in both volume and composition. Although 44.Oita, 42.Nagasaki, 5.Akita and 47.Okinawa have small volume factors of export, their composition factors of export are high. It means their total emissions are boosted by CO_2 intensive export industries in spite of small volume of export activity. In contrast to this, 20.Nagano and 13.Tokyo have large volume factors and small composition factors in respect to export. In these prefectures, the composition factor of export contributes to relatively low total emission.

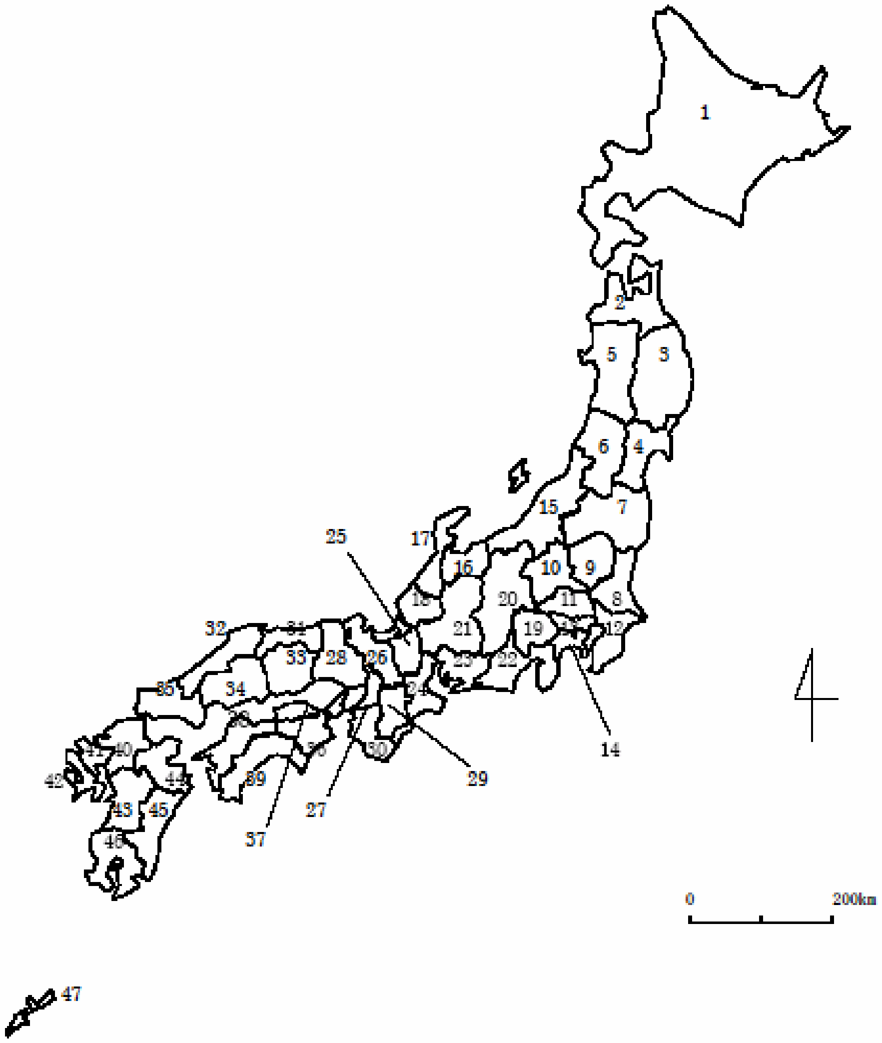
5. Conclusions

In this paper, we calculated CO_2 emissions at prefecture level in Japan by using the author's previous study, and investigated regional differences of environmental burdens among all prefectures from various aspects. As a result, we realized the magnitude of energy consumption and CO_2 emission at prefecture level does not only depend on the size of economy but also various regional characteristics. After that, we applied Structural Decomposition Analysis(SDA) of per capita CO_2 emission among prefectures, and it turned out that major factors generating regional discrepancy of CO_2 emission are CO_2 emission intensities, the volume of regional export and the composition of regional export.

In considering the potentiality of CO_2 emission reduction from the analyses, it is expected that regional environmental policies for CO_2 emission intensities in production activities or export industries have the potentiality of large reduction, particularly in a region where these factors are large, and their effects seem to be more different among regions. By contrast, in other factors, national-level policies are expected to affect regions equally.

However as De Nooij et al. (2003) points out, it is difficult to derive policy implications from SDA. It is not always cost-effective to target at components that have large difference among regions as objective of reduction. Moreover these factors decomposed by SDA are likely to have interdependent relation one another. Therefore when one factor is changed by some environmental policies, another factor dose not always remain constant. We should note that the results in this paper only suggest the first step for establishing more concrete regional environmental policies. Further analyses must be implemented in future.

Appendix: The locations of prefecture 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

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