URBAN CHARACTERISTICS AND CO_2 EMISSIONS: THE CASE OF JAPANESE CITIES

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©Ontario International Development Agency ISSN: 1923-6654 (print)
ISSN 1923-6662 (online). Available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

Abstract: In Japan, commercial & office, residential, and transport sectors have made less progress in reducing CO_2 emissions than has an industrial sector. CO_2 emissions in these three sectors account for a half of Japan's total CO_2 emissions as of 2010. Since 90% of Japanese population live in urban areas, the reduction of CO_2 emissions in the three sectors depends on how urban areas can reduce the consumption of fossil-fuel energy (for example, fossil-fuel oriented electricity and heating). To create low-carbon cities that depend on less fossil-fuel energy, both supply and demand sides of energy must be considered. In the energy supply side it is desirable to shift from fossil-fuel energy to renewable energy in all aspects of urban activities. This is particularly true for Japan since renewable energy accounts for only 6% of its total primary-energy supply. Besides the shift from fossil-fuel energy to renewable energy, efforts in energy demand side are also crucial. However, what kinds of efforts in energy demand side are effective to reduce urban CO_2 emissions is a complex issue. How to reduce the consumption of fossil-fuel energy (in other words, how to consume fossil-fuel energy efficiently) in all aspects of urban activities depends on environmental technologies, individual lifestyle, business style, and urban characteristics such as population, population density, demographic structure, industrial structure, per capita income, urban compactness, transportation system, temperature and so on, all of which are interlinked each other. What urban characteristics are significantly relevant in terms of consuming fossil-fuel energy efficiently? The purpose of this study is to investigate quantitatively the impacts of urban characteristics on CO_2 emissions for the case of Japanese cities. Firstly, using the cross-sectional data of 712 Japanese cities the relationship between CO_2 emissions and population, which is considered as the most influential urban characteristic in the consumption of fossil-fuel energy, was investigated. Correlation coefficients between population and CO_2 emissions show the strong relationships in all of three sectors, namely, commercial & office, residential, and transport sectors. But, there are no significant relationships between population and per capita CO_2 emissions, which reflect per capita consumption of fossil-fuel energy, in all of three sectors. Secondly, using the data of same 712 Japanese cities multiple regression analysis was conducted to investigate what urban characteristics have significant impacts on per capita CO_2 emissions. The results of multiple regression analysis show that, for three sectors as a whole, average annual temperature and population density have statistically significant negative impacts on per capita CO_2 emissions whereas population and share of elderly population have statistically significant positive impacts on per capita CO_2 emissions. In conclusion, the paper discusses the implications of research findings for the creation of low-carbon cities.

Keywords: CO_2 emissions, Japanese cities, low-carbon cities, urban characteristics

Table 1: Japanese CO_2 Emissions by Sector (2010)

Sectors	Emissions* (million tons)	Share in total emissions (%)	Change from 1990 (%)
Industry	422	35	-12.5
Commercial & office	217	18	31.9
Residential	172	14	34.8
Transport	232	19	6.7
Energy conversion	149	7	n/a
Others		7	n/a
Total	1,192	100	4.2

*Emissions in each sector are composed of the emissions from direct and indirect consumption of fossil fuel energy. The emissions from indirect consumption of fossil fuel energy are allocated based on the consumption of the electricity generated by power companies and the heat generated by heat supply operators. Emissions in a sector of energy conversion do not include the emissions from indirect consumption of fossil fuel energy in other sectors.
Data source: Japanese Ministry of the Environment (2012). Annual Report on the Environment

INTRODUCTION

In Japan, CO_2 emissions in an industry sector have decreased during 1990-2010 owing to voluntary efforts by firms[1]. On the contrary, CO_2 emissions in commercial & office, residential, and transport sectors have increased during the same period (See Table 1). Since 90% of Japanese population live in urban areas, the reduction of CO_2 emissions in these three sectors depends on how urban areas can reduce their direct and indirect consumption of fossil-fuel energy[2]. What urban characteristics are significantly relevant in terms of consuming fossil-fuel energy efficiently? The purpose of this study is to investigate the impacts of urban characteristics on CO_2 emissions for the case of Japanese cities.

There are several studies that investigated the impacts of urban characteristics on the urban environment. For example, Kahn investigated if urban growth hurts or helps the urban environment, more specifically the impacts of income growth, population growth and spatial growth on the urban environment using the data of U.S. cities [2]. Another example is the study by Glaeser and Kahn, which investigated the impact of urban development on the CO_2 emissions from driving, public transit, home heating and household electricity using the data of U.S. cities [3]. There is also the study on how residential density affects the energy consumption also using the data of U.S. cities [4]. However, there is not a similar study for the case of Japanese cities. Since Japanese cities are very different from U.S. cities in terms of urban characteristics such as land use, population density, transportation system, residential space and etc., this study could contribute to bringing new information to this research area.

The next section discusses the theoretical framework on urban CO_2 emissions. Then, using the cross-sectional data of 712 Japanese cities in 2000, the following sections first examine the relationships between urban scale and CO_2 emissions and also between urban scale and per capita CO_2 emissions, and then conduct a regression analysis to investigate the impacts of urban characteristics on per capita CO_2 emissions. The last section concludes summarizing the study findings and their implications for creating low carbon cities in Japan.

[1] To mitigate global warming, the reduction of CO_2 is crucial since CO_2 shares the most of greenhouse gases (GHG) emissions. For example, CO_2 shares 94.8% of Japan's GHG emissions [1].

[2] An indirect consumption of fossil-fuel energy includes the electricity generated by power companies and the heat generated by heat supply operators.

Table 2: Number, Population, and CO_2 Emissions of Japanese Cities by Urban Scale (2000)

Urban scale (in population size)	Number	Population		CO_2 emissions	
		persons	share	t-CO_2	share
Small cities (less than 300,000)	638	53,377,823	53.1%	441,566,557	60.2%
Medium cities (300,000-699,999)	57	23,405,626	23.2%	153,194,940	20.9%
Large cities (more than 700,000)	17	23,897,671	23.7%	138,339,245	18.9%
Total	712	100,681,120	100.0%	733,100,742	100.0%

Data source: Population - Japanese Ministry of Internal Affairs and Communications
CO_2 emissions - Coalition of Local Government for Environmental Initiative, Japan

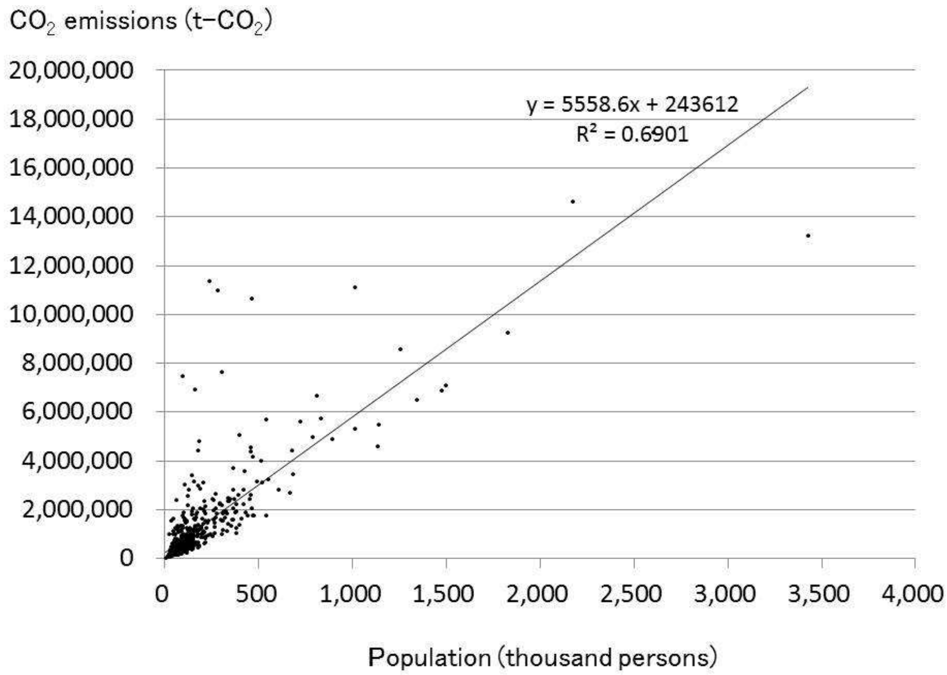

Figure 1: Population and CO_2 Emissions of 712 Japanese Cities (2000)

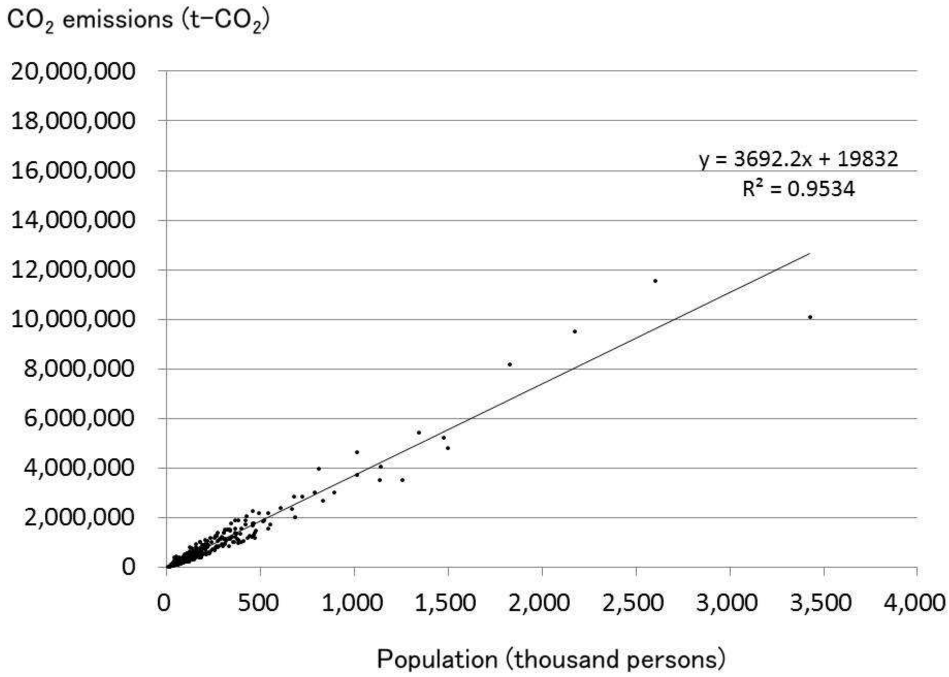

Figure 2: Population and CO_2 Emissions Excluding Industry Sector of 712 Japanese Cities (2000)

THEORETICAL FRAMEWORK

Urban CO_2 emissions are composed of the emissions from direct and indirect consumption of fossil fuel energy. Here the emissions from indirect consumption of fossil fuel energy are assumed to be allocated to respective sectors based on the consumption of the electricity generated using fossil fuel energy by power companies and the heat generated using fossil fuel energy by heat supply operators[3]. Urban consumption of fossil fuel energy is basically determined by per capita consumption of fossil fuel energy and population. Therefore, urban consumption of fossil fuel energy covering three sectors, namely commercial & office, residential, and transport sectors, can be expressed by an identity equation (1).

Urban consumption of fossil fuel energy =

$$\sum_{k=1}^{3} \sum_{j=1}^{3} \{(\text{urban consumption of energy } k \text{ in sector } j/\text{population}) \times \text{urban population}\} \quad (1)$$

where k = 1 (coal), 2 (oil), 3 (natural gas), and

j = 1 (commercial & office sector), 2 (residential sector), 3 (transport sector).

Then, urban CO_2 emissions from the consumption of fossil fuel energy can be expressed by an identity equation (2).

Urban CO_2 emissions =

$$\sum_{k=1}^{3} \sum_{j=1}^{3}[\{(\text{urban consumption of energy } k \text{ in sector } j/\text{population}) \times \text{urban population}\} \times CO_2 \text{ emissions coefficient of fossil fuel energy } k] \quad (2)$$

where k = 1 (coal), 2 (oil), 3 (natural gas), and

j = 1 (commercial & office sector), 2 (residential sector), 3 (transport sector).

[3] There is another way to measure urban CO_2 emissions only based on the emissions from direct consumption of fossil fuel energy. In this measurement, CO_2 emissions in an energy conversion sector (generating electricity and heat) become larger whereas those in industry, commercial & office and residential sectors become smaller. (There is no change in a transport sector.)

URBAN SCALE AND CO_2 EMISSIONS

In Japan there were 671 cities as of 1999. However, after the municipal mergers that started in 1999 and lasted until 2010, there are now 787 cities[4]. For this study, 712 cities are selected out of these 787 cities. Since the latest data available on CO_2 emissions of Japanese cities is of 2000 but compiled based on the list of cities as of 2005. Other data on Japanese cities such as population, area, and income of 2000, which are also used for a regression analysis in this study, is based on the list of cities as of 2000. Therefore, 75 out of 787 cities are not included in both data. Furthermore, 712 cities selected in this study do not include Tokyo's 23 special wards though they are generally counted as one city since their population is too big (8,134,688 in 2000) compared with other cities (the population of Yokohama, the second largest city after Tokyo's 23 wards, is 3,426,651). Table 2 shows the number, population, and CO_2 emissions of 712 cities classified into three different scales based on their population (small, medium and large cities). 712 cities share 79.3% of Japanese population and 58.6% of Japanese CO_2 emissions in 2000. As Table 2 shows, small cities account for a large share of Japanese urban population and also of Japanese urban CO_2 emissions. It suggests that small cities as well as medium and large cities are important in reducing Japanese urban CO_2 emissions.

As discussed in the previous section, per capita consumption of fossil fuel energy and population determine urban consumption of fossil fuel energy and thus urban CO_2 emissions. This section examines the relationship between urban scale which is a core of urban characteristics and CO_2 emissions. Figure 1 shows the linear correlation between population and CO_2 emissions covering all sectors, namely industry, commercial & office, residential, and transport sectors, of 712 Japanese cities. Remarkably larger CO_2 emissions of some cities compared to others result from their larger CO_2 emissions from an industry sector. As Figure 2 shows, the linear correlation between population and CO_2 emissions of 712 cities becomes stronger when excluding CO_2 emissions in an industry sector. The correlation coefficients between population and CO_2 emissions are 0.935 for an office & commercial sector, 0.984 for a residential sector, 0.934 for a transport sector, and 0.976 for these three sectors as a whole. On the other hand, the correlation coefficient for an industry sector is 0.469[5].

URBAN SCALE AND PER CAPITA CO_2 EMISSIONS

The previous section showed that the linear correlation between population and CO_2 emissions is very strong. However, the linear correlation between population and per capita CO_2 emissions is weak. Figure 3 shows the relationship between population and per capita CO_2 emissions covering all sectors of 712 cities. Remarkably larger per capita CO_2 emissions in some cities compared to others result from larger per capita CO_2 emissions in their industry sectors. Excluding per capita CO_2 emissions in an industry sector makes the difference in per capita CO_2 emissions much smaller as shown in Figure 4. The correlation coefficients between population and per capita CO_2 emissions are 0.275 for an office & commercial sector, -0.110 for a residential sector, -0.168 for a transport sector, and -0.101 for these three sectors as a whole. The correlation coefficient for an industry sector is -0.052[6].

Figure 4 indicates that there is not much difference in per capita CO_2 emissions covering three sectors, namely commercial & office, residential, and transport sectors, across 712 cities. Actually, as Figure 5 shows, average per capita CO_2 emissions covering the three sectors of small, medium and large cities are almost the same (3.92 t-CO_2 for small cities, 3.70 t-CO_2 for medium cities, and 3.77 for large cities). Figure 5 also shows that average per capita CO_2 emissions in commercial & office and transport sectors are different across different scales of cities whereas those in a residential sector are not. Furthermore, average per capita CO_2 emissions in an industry sector of small cities are more than twice as big as those of large cities.

REGRESSION ANALYSIS

The previous two sections showed that urban scale (in terms of population) has a strong relationship with CO_2 emissions but a weak relationship with per capita CO_2 emissions. This section investigates what urban characteristics are relevant to determining per capita CO_2 emissions in commercial & office, residential, and transport sectors by conducting a regression analysis. Sample size in the regression analysis is 712 Japanese cities.

[4] In Japan there were 3,229 municipalities (671 cities, 2,558 towns and villages) as of 1999. However, the number of municipalities is now almost the half after the municipal mergers. As of March 31, 2010, it is 1,728 (787 cities, 941 towns and villages).

[5] The correlation coefficient between population and CO_2 emissions is 0.831 for four sectors as a whole including an industry sector.

[6] The correlation coefficient between population and per capita CO_2 emissions is -0.066 for four sectors including an industry sector as a whole.

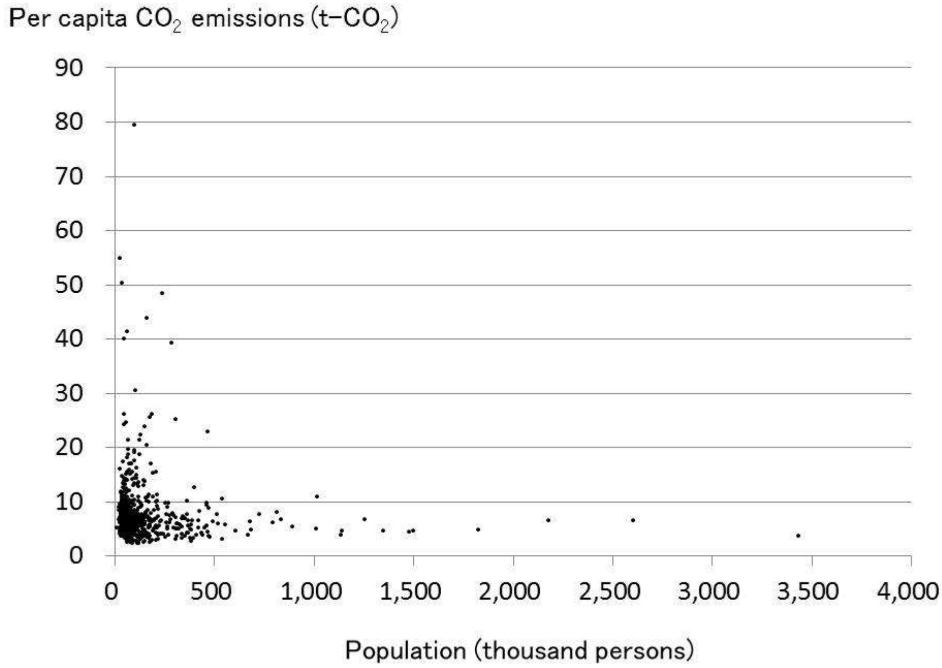

Figure 3: Population and Per capita CO_2 Emissions of 712 Japanese Cities (2000)

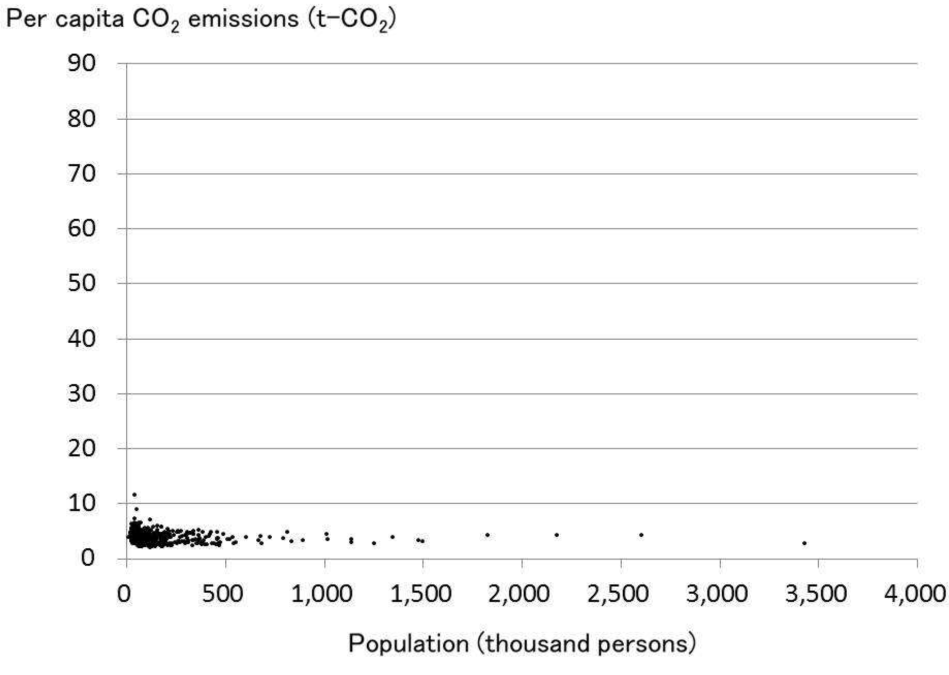

Figure 4: Population and Per capita CO_2 Emissions Excluding Industry Sector of 712 Japanese Cities (2000)

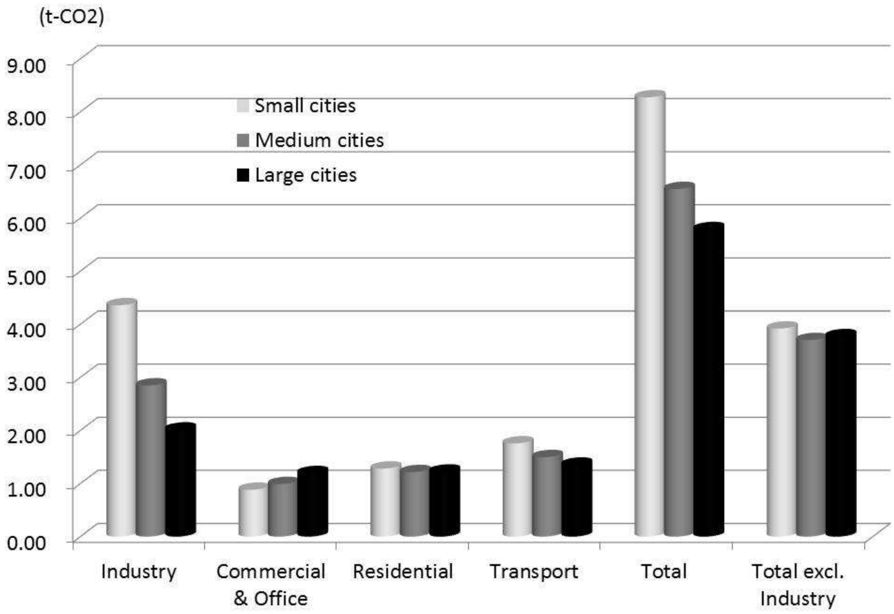

Figure 5: Average Per capita CO_2 Emissions in Four Sectors by Urban Scale (2000)

Table 3: Fundamental Statistics of Explained and Explanatory Variables

(n=712 cities)

Explained variables	Mean	Standard deviation	Explanatory variables	Mean	Standard deviation
Per capita CO_2: Com. & office	0.87 t-CO_2	0.23	Temperature	15.36 ^{o}C	2.28
Per capita CO_2: Residential	1.31 t-CO_2	0.29	Share of elderly population	19.14 %	5.30
Per capita CO_2: Transport	1.82 t-CO_2	0.73	Population density	20.52 persons/ha	24.04
Per capita CO_2: Three sectors	4.00 t-CO_2	0.92	Population	141,406 persons	250,254

Table 4: Correlation Coefficients among Explanatory Variables

(n=712 cities)

	Temperature	Share of elderly population	Population density	Population
Temperature	1.000			
Share of elderly population	-0.153	1.000		
Population density	0.272	-0.571	1.000	-
Population	0.059	-0.258	0.373	1.000

Table 5: Regression Results

(n=712 cities)

		Commercial & Office		Residential		Transport		Three sectors	
		Coefficient	t-value	Coefficient	t-value	Coefficient	t-value	Coefficient	t-value
Constant	β_0	1.08542	15.981*	2.64568	51.356*	2.34628	11.818*	6.07738	27.126*
Temperature	β_1	-0.01546	-4.262*	-0.09803	-35.639*	-0.02472	-2.332*	-0.13821	-11.554*
Share of elderly population	β_2	0.00021	0.115	0.00941	6.771*	0.00723	1.352	0.01685	2.789*
Population density	β_3	-0.00114	-2.646*	-0.00050	-1.527	-0.01471	-11.630*	-0.01636	-11.460*
Population	B_4	0.0000003	8.704*	-0.000000007	-0.236	0.00000009	0.906	0.0000004	3.388*
R^2		0.12322		0.69390		0.28218		0.41884	

*: Significant level of 1%.

Various data on 712 Japanese cities used for a regression analysis are as of 2000. The latest data on CO_2 emissions of 712 Japanese cities as of 2000 is available from the Coalition of Local Government for Environmental Initiative [5]. The data on share of elderly population (with the age of 65 and more) is available from e-Stat, a portal site of official statistics of Japan [6]. Population density was calculated from the data on population and habitable land area, both of which are available from e-Stat. Average annual temperatures of Japanese 47 prefectures are used for those of Japanese cities since the data on temperature for all of 712 Japanese cities were not available.

As an identity equation (2) in the section of THEORETICAL FRAMEWORK shows, urban CO_2 emissions covering three sectors, namely commercial & office, residential, and transport sectors, are determined by per capita consumption of fossil fuel energy *k* (*k* = coal, oil, natural gas) in sector *j* (*j* = commercial & office sector, residential sector, transport sector), population, and CO_2 emissions coefficient of fossil fuel energy *k*. It can be modified by taking logarithms of its both sides and then further simplified like an identity equation (3) since the data on urban CO_2 emissions used for a regression analysis are calculated based on urban energy consumption of different fossil fuel energy in respective sectors and also CO_2 emissions coefficient of different fossil fuel energy.

$$\ln \textit{urban } CO_2 \textit{ emissions}_i = \sum_{j=1}^{3} \ln \textit{per capita } CO_2 \textit{ emissions}_{ij} + \ln \textit{population}_i \quad (3)$$

where i = 1, 2, -----n (cities), and

j = 1 (commercial & office sector), 2 (residential sector), 3 (transport sector)

An identity (3) indicates that a city's CO_2 emissions covering three sectors are determined by its per capita CO_2 emissions in each of three sectors and its population. Then, what determines per capita CO_2 emissions? To identify urban characteristics having impacts on per capita CO_2 emissions, a regression model (4) was used. As explanatory variables, *temperature* (^oC), *share of elderly population* (%), *population density* (persons/ha) and *population* (persons) are selected[7]. Table 3 shows the fundamental statistics of these explained and explanatory variables. Casual observation of Japanese cities suggests that different scales of cities seem to be different in population density and demographic structure, particularly a share of elderly population (small cities are less densely populated and advancing in aging population). However, contrary to this casual observation, the correlations between population and population density and also between population and a share of elderly population are not strong than expected as shown in Table 4.

$$\textit{Per capita } CO_2 \textit{ emissions}_i = \beta_0 + \beta_{1*}\textit{temperature}_i + \beta_{2*}\textit{share of elder pop}_i + \beta_{3*}\textit{pop.density}_i + \beta_{4*}\textit{population}_i + \varepsilon_i \quad (4)$$

where i = 1, 2, -----n (cities)

[7] Though *per capita income* is assumed to have an impact on per capita CO_2 emissions, it was removed from the list of explanatory variables because of a problem of multicollinearity.

Regression analysis using the regression model (4) was conducted for three sectors as a whole and individually. Table 5 shows the regression results. Estimated coefficients of explanatory variables for three sectors as a whole indicate that temperature and population density have negative impacts on per capita CO_2 emissions while population and a share of elderly population have positive impacts. However, the impact of population is very small (a change of 10,000 persons in urban population brings a change of 0.004 t-CO_2 in per capita CO_2 emissions), which is consistent with Figure 4 and Figure 5 showing that there is not much difference in per capita CO_2 emissions covering three sectors across different scales of cities. Regarding estimated coefficients for each of three sectors, the same results are found in terms of the directions of the impacts on per capita CO_2 emissions for commercial & office and transport sectors. However, the impacts of share of elderly population are not statistically significant (event at the significant level of 10%) for commercial & office and transport sectors. Furthermore, the impact of population is not statistically significant for transport sector. For residential sector, the impacts of population density and population are not statistically significant.

CONCLUSION

The study found several interesting results with implications for the creation of low carbon cities in Japan. The first interesting result is that large cities need to make relatively more efforts to reduce per capita CO_2 emissions in a commercial & office sector whereas small cities need to make relatively more efforts to reduce per capita CO_2 emissions in a transport sector (refer to Figure 5). The second interesting result is the statistically significant negative impact of population density on per capita CO_2 emissions for three sectors as a whole and a commercial & office and transport sectors. It suggests that a concept of compact city where urban functions cluster in a compact way must be effective in reducing per capita CO_2 emissions. The third interesting result is the statistically significant negative impact of temperature on per capita CO_2 emissions for three sectors as a whole and individually. It suggests that the cities with higher average annual temperature consume less fossil fuel energy. The last one is the statistically significant positive impact of share of elderly population on per capita CO_2 emissions for three sectors as a whole and a residential sector. It suggests that under Japan's unprecedented super ageing society an increasing share of elderly population is likely to increase per capita CO_2 emissions. A possible reason behind this is that an increasing share of elderly population might increase the number of households because of an increase in one-person households or elderly-couple households[8]. An increase in a number of households is likely to increase per capita CO_2 emissions.

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[8] According to the statistics by Japanese Ministry of Internal Affairs and Communications, a total number of households in Japanese cities has increased by 27% during 1990-2010 while a total population in Japanese cities has increased only 4% during the same period. During this period, a total number of one-person households in Japanese cities has increased 1.8 times and the one of elderly-couple households 2.8 times.