AN ANALYSIS ON DRIVING FACTORS FOR CO_2 EMISSIONS FROM ENERGY USE IN TOKYO AND SEOUL BY FACTOR DECOMPOSITION METHOD

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This paper estimates and analyzes CO_2 emissions from energy use in Tokyo and Seoul and analyzes performance of cities in East Asia, measured by CO_2 emissions per capita and CO_2 emissions per unit gross regional product (GRP). The contributions of selected driving factors for total and sectoral CO_2 emissions are also investigated by factor decomposition method. The results suggest that the performance of Tokyo is outstanding in comparison to major Japanese large cities, Seoul, Beijing, Shanghai, major OECD and major non-OECD countries. Income effect was primarily found responsible for majority of CO_2 emissions in Tokyo and Seoul in high growth period, *i.e.* 1970-90 for Tokyo and 1990-97 for Seoul. Despite economic recession, continued CO_2 emissions in Tokyo in 1990-98 is largely attributed to energy intensity effect. Similarly, the contributions of fuel quality effect, energy intensity effect, vehicle utilization effect, household income, labor productivity effect and scale effect etc. are analyzed for sectoral CO_2 emissions.

Keywords: *Global warming and city, CO_2 emission, mega-city, factor decomposition*

1. INTRODUCTION

The volume of Gross Domestic Product (GDP) and energy demand (or CO_2 emissions) have direct co-relation since economies heavily rely on the fossil fuels as sources of energy. Although, environmental Kuznet curve suggested the inverted U-shaped curve, it is yet to be seen such behavior in Asian cities. The pattern of energy consumption in Japan shows that per capita energy consumption in urban area is lower than that of non-urban areas[1]. On contrary, opposite trend is reported in developing countries, such as China and Thailand[1]. However, in absolute terms, a large city contributes significantly to total national CO_2 emissions due to higher energy demand in cities. If indirect emissions embodied in goods and services are estimated such contribution is expected to increase significantly. Economic growth, transportation system, industrial structure, building floor space, urban growth structure, population and many other factors play complex role in shaping the energy footprint of a city.

The analyses of energy and CO_2 emissions at national scale have been done in uncountable published literatures but at city scale, such analyses are limited (many related studies covering all urban sectors comprehensively are still under the stage of methodological development on urban energy or CO_2 inventory[2),3),4),5),6),7),8)]. This might be due to the difficulties in getting city scale data and may also be due to the fact that major policy decisions on energy issues are made at national level. There are also many technical limitations to estimate CO_2 emissions primarily due to the differences in *political boundary* of the city and *functional boundary* of the city. Many studies on selected sectors of the city, mostly transportation and building sectors exist in past literatures[9)]. A comprehensive analysis of the macro driving factors at city level, particularly international comparison, covering major sectors is seldom done in past literatures. Our paper addresses this important aspect. In this paper, authors have estimated the CO_2 emissions from energy use in selected cities and analyzed their CO_2 emissions in per capita and per unit gross regional product (GRP). To understand the further intricacies of urban energy use (in terms of CO_2 emissions), past trends of CO_2 emissions were analyzed for Tokyo and Seoul and contributions of driving factors for total and sectoral CO_2 emissions are investigated by factor decomposition method. These cities are selected because of data availability and also because they are affluent mega-cities of Asia that shares many common features. Mega-cities are front runners in terms of economic growth, hub for lifestyle changes and thus high demand for goods and services. Locally operation policies are key in any drastic cutback of emissions from cities. Therefore, such city scale analysis would assist policy makers in cities to understand various factors and to address policy element associated with these factors.

2. METHODOLOGY AND DATA

Analyses on driving factors for CO_2 emissions from energy use can be done by different methods. At macro-scale, Factor Decomposition, Vector Auto Regression (VAR), Correlation Analysis[10] and others can analyze the role of various factors. Factor decomposition method, in particular, is an "identity approach" where left and right hand side of the equation is equal. This method is not for forecasting purpose but to understand historical transition by using all exogenous variables that are the decomposed components of CO_2 emissions. This methodology facilitates greatly to do analysis based on selected indicators. Several past studies have already been reported on factor decomposition analysis. Ang and Zhang surveyed such decomposition analyses used in energy and environmental studies and the survey cited more than one hundred published literatures[30]. In our study, we reviewed many literatures, particularly, by Shrestha and Timilsina[11), 12)], Ang and Liu[13)], Greening et al.[14)], Luukkanen & Kaivooja[15)], Nag and Parikh[16)], and Hamilton and Turton[17)]. Our choice of technique is *subtractive decomposition* that follows Sun[18)] and Luukkanen & Kaivooja[17)]. The major issue in any such decomposition analysis is how to handle the residual component, as perfect decomposition is difficult. This is illustrated below.

$$C = C/E \times E/GRP \times GRP/P \times P = CI \times EI \times PC \times P$$

Where C is the total emissions in thousand tons, E is energy consumption in TJ, *GRP* is gross regional product in million 1990 US$ and P is population in millions. *C/E* is defined as carbon intensity (*CI*), *E/GRP* by energy intensity (*EI*) and *GRP/P* by per capita GRP (*PC*). *I*, *EI*, *PC* and *P* are explanatory variables. The increase in emissions in year t from

$$C_t - C_0 = CI_t \times EI_t \times PC_t \times P_t - CI_0 \times EI_0 \times PC_0 \times P_0$$

year 0 is,

$$\begin{aligned}
\Delta C &= (CI_0 + \Delta CI) \times (EI_0 + \Delta EI) \times (PC_0 + \Delta PC) \times (P_0 + \Delta P) \\
&\quad - CI_0 \times EI_0 \times PC_0 \times P_0 \\
&= \Delta CI \times EI_0 \times PC_0 \times P_0 \ldots\ldots (1) \\
&\quad + CI_0 \times \Delta EI \times PC_0 \times P_0 \ldots\ldots (2) \\
&\quad + CI_0 \times EI_0 \times \Delta PC \times P_0 \ldots\ldots (3) \\
&\quad + CI_0 \times EI_0 \times PC_0 \times \Delta P \ldots\ldots (4) \\
&\quad + R \ldots\ldots (5)
\end{aligned}$$

If we denote increment amount by Δ, then

Where,

$$\begin{aligned}
R = {} & \Delta CI \times \Delta EI \times PC_0 \times P_0 + \Delta CI \times EI_0 \times \Delta PC \times P_0 \\
& + \Delta CI \times EI_0 \times PC_0 \times \Delta P + \Delta CI \times \Delta EI \times \Delta PC \times P_0 \\
& + \Delta CI \times \Delta EI \times PC_0 \times \Delta P + \Delta CI \times EI_0 \times \Delta PC \times \Delta P \\
& + \Delta CI \times \Delta EI \times \Delta PC \times \Delta P + CI_0 \times \Delta EI \times \Delta PC \times P_0 \\
& + CI_0 \times \Delta EI \times PC_0 \times \Delta P + CI_0 \times \Delta EI \times \Delta PC \times \Delta P \\
& + CI_0 \times EI_0 \times \Delta PC \times \Delta P
\end{aligned}$$

We distributed residual terms R to (1), (2), (3) and (4) in such as a way that,

$$\begin{aligned}
CI\ Effect = {} & \Delta CI \times EI_0 \times PC_0 \times P_0 + 1/2 \times \Delta CI \times \Delta EI \times PC_0 \times P_0 \\
& + 1/2 \times \Delta CI \times EI_0 \times \Delta PC \times P_0 + 1/2 \times \Delta CI \times EI_0 \times PC_0 \times \Delta P \\
& + 1/3 \times \Delta CI \times \Delta EI \times \Delta PC \times P_0 + 1/3 \times \Delta CI \times \Delta EI \times PC_0 \times \Delta P \\
& + 1/3 \times \Delta CI \times EI_0 \times \Delta PC \times \Delta P + 1/4 \times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P
\end{aligned}$$

$$\begin{aligned}
EI\ Effect = {} & CI_0 \times \Delta EI \times PC_0 \times P_0 + 1/2 \times \Delta CI \times \Delta EI \times PC_0 \times P_0 \\
& + 1/2 \times CI_0 \times \Delta EI \times \Delta PC \times P_0 + 1/2 \times CI_0 \times \Delta EI \times PC_0 \times \Delta P \\
& + 1/3 \times \Delta CI \times \Delta EI \times \Delta PC \times P_0 + 1/3 \times \Delta CI \times \Delta EI \times PC_0 \times \Delta P \\
& + 1/3 \times CI_0 \times \Delta EI \times \Delta PC \times \Delta P + 1/4 \times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P
\end{aligned}$$

$$\begin{aligned}
Income\ Effect = {} & CI_0 \times EI_0 \times \Delta PC \times P_0 + 1/2 \times \Delta CI \times EI_0 \times \Delta PC \times P_0 \\
& + 1/2 \times CI_0 \times \Delta EI \times \Delta PC \times P_0 + 1/2 \times CI_0 \times EI_0 \times \Delta PC \times \Delta P \\
& + 1/3 \times \Delta CI \times \Delta EI \times \Delta PC \times P_0 + 1/3 \times \Delta CI \times EI_0 \times \Delta PC \times \Delta P \\
& + 1/3 \times CI_0 \times \Delta EI \times \Delta PC \times \Delta P + 1/4 \times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P
\end{aligned}$$

$$\begin{aligned}
Population\ Effect = {} & CI_0 \times EI_0 \times PC_0 \times \Delta P + 1/2 \times \Delta CI \times EI_0 \times PC_0 \times \Delta P \\
& + 1/2 \times CI_0 \times \Delta EI \times PC_0 \times \Delta P + 1/2 \times CI_0 \times EI_0 \times \Delta PC \times \Delta P \\
& + 1/3 \times \Delta CI \times \Delta EI \times PC_0 \times \Delta P + 1/3 \times \Delta CI \times EI_0 \times \Delta PC \times \Delta P \\
& + 1/3 \times CI_0 \times \Delta EI \times \Delta PC \times \Delta P + 1/4 \times \Delta CI \times \Delta EI \times \Delta PC \times \Delta P
\end{aligned}$$

This gives perfect decomposition with no residuals,

$$\begin{aligned}
C = {} & CI\ effect + EI\ effect \\
& + Income\ Effect + Population\ Effect
\end{aligned}$$

Similar approach of decomposition was used for CO_2 emissions from different sectors. The choice of explanatory variables for each sector is different which reflects the sector in concern. The explanatory variables for sectoral analyses are described below.

For transport sector,

$$C_t = CI_t \times EI_t \times VKT_{pv} \times P_t$$

Where, C_t = CO_2 emissions from transportation sector, in thousand Tons; CI_t = Carbon Intensity, defined as the amount of CO_2 emissions per unit energy consumption, in Tons/GJ; EI_t = Energy intensity, defined as the amount of energy consumption per vehicle travel distance, in KJ/km; VKT_{pv} = Vehicle Kilometers Traveled per vehicle, and P_t = Number of vehicle registered, in thousands.

Data used to estimate contributing factors in transportation sector was historical trend of CO_2 emissions (including subway and trains), passenger vehicle population, energy consumption (including trains or subway), and road passenger traffic volume.

For residential sector,

$$C_r = CI_r \times EI_r \times RFS_{ph} \times H$$

Where, C_r = CO_2 emissions from residential sector in thousand Tons; CI_r = Carbon Intensity, defined as the amount of CO_2 emissions per unit energy consumption, in Tons/GJ; EI_r = Energy Intensity, defined as amount of energy consumed per unit of household income, in GJ/US$ (1990); RFS_{ph} = Income per household, in 1990 US$/household, and H = Number of households, in thousands.

Therefore, "Change in emissions" = "Carbon intensity effect" + "Energy intensity effect" + "Household Income effect" + "Scale effect".

Data used to estimate the factors are energy consumption by residential sector, emission factors, household income and number of households.

For commercial sector,

$$C_c = CI_c \times EI_c \times CVA_{pt} \times CFS$$

Where, C_c = CO_2 emissions from commercial in thousand Tons; CI_c = Carbon Intensity, defined as the amount of CO_2 emissions, per unit energy consumption, in Tons/GJ; EI_c = Energy Intensity, defined as amount of energy consumed per unit service sector value added, in MJ/1990 US$; CVA_{pf} = Service sector value added per labor, in thousand 1990 US$ per labor; CFS = Number of labors, in thousands.

Therefore, in respective sectors, "Change in emissions" = "Carbon intensity effect" + "Energy intensity effect" + "Productivity effect" + "Scale effect".

Data used to estimate factors are commercial sector energy consumption, emissions factor, service sector value added and labor population.

Database development for Tokyo and Seoul, was the primary task in the study. Collected data included energy data by sector and fuel type and data on key macro-level driving forces of each sector. Emission factor, defined as CO_2 emissions per energy by type, are obtained from locally available sources (Ministry of Environment of Japan) and IPCC[19]. BeSeTo[1] Database, which is under continuous update and expansion at Institute for Global Environmental Strategies (IGES), is used to obtain most of the required data for case study cities. BeSeTo Database incorporates primary data from census and from local authority's publications in Tokyo and Seoul. Energy and CO_2 emission data for Japanese large cities are obtained from official documents on master plan against global warming published by each cities, and national level data from OECD's energy statistics[20]. Major data sources are internal reports of Tokyo Metropolitan Government on energy supply and demand of Tokyo and Tokyo Statistical Yearbook since 1970, Regional Energy Statistics of Korea and Seoul Statistical Yearbook from 1990[21),22),23),24),25),32),33)]. City definition of Tokyo in this paper is Tokyo-to or Tokyo Metropolitan Government administered area while that for Seoul is Seoul City. Seoul Metropolitan Area includes Seoul City and Kyongi Province.

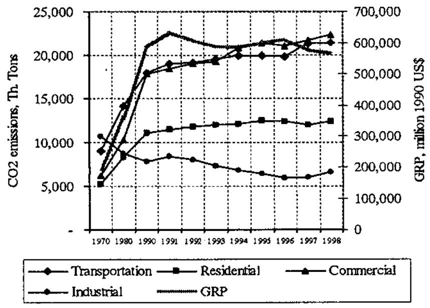

Fig.1 Sectoral emissions profile of Tokyo

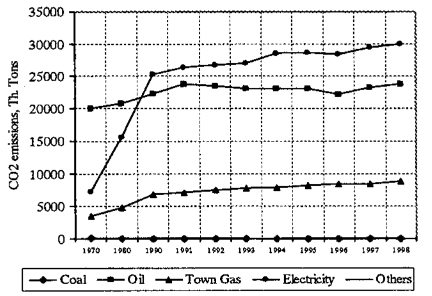

Fig.2 CO_2 emission of Tokyo by fuel type

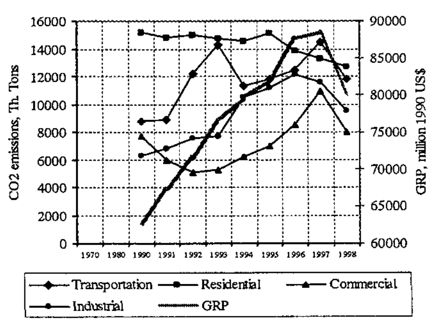

Fig.3 Sectoral emissions profile of Seoul

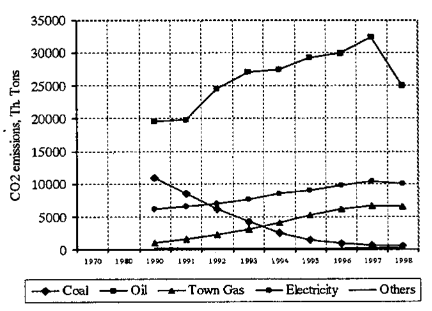

Fig. 4 CO_2 emission of Seoul by fuel type

[1] Literally means Beijing, Seoul and Tokyo.

3. EMISSION PERFORMANCE OF TOKYO AND SEOUL

3.1 Emission trends

The estimation of CO_2 emissions by sector and fuel type suggests that CO_2 emissions in Tokyo has increased more than two times in last three decades with 2.5 % annual average growth rate (1970-1998). During the same time, the annual average growth rate of economy (GRP) was 6.87%.

For 1990-98, annual average growth rates of CO_2 emissions for Tokyo and Seoul are estimated to 1.7% and 1.63%, respectively. Figure 1 and 3 show the emission profile by sector for Tokyo and Seoul and Figure 2 and 4 by fuel type.

In Tokyo, despite the slowing economy and negative economic growth in 1990's, emissions from only industrial sector has declined. The emissions from all other sectors, *i.e.* residential, transportation and commercial sectors, continue to grow. Industrial sector's contribution in CO_2 emissions has gradually decreased from about 34% in 1970 to about 10% in 1998. The lower share is due to relatively smaller industrial sector's contribution as Tokyo is basically a commercial city and decreasing trend is due to gradual dominance of tertiary sector within industrial sector. The share of tertiary industry in total industrial value added has increased from 67% in 1980 to 77% in 1998[21]. Basically, oil and electricity (converted to primary energy and CO_2 emissions based on average electricity generation mix) are responsible for the majority of CO_2 emissions (Figure 2). Majority of these oil and electricity are used by transport, residential and commercial sectors.

In case of Seoul, emission from residential sector is the largest and that of commercial sector is the lowest. But, the share as well as emission volume of residential sector is gradually decreasing since early 90s while emissions from all other sectors continue to increase. Economic crisis, that gripped South Korea in 1997, has evident influence on emission profile of 1998 as demonstrated in the figures. Small contribution of industrial sector in total emissions can be partly explained by the dominance of tertiary sector. The share of tertiary sector in industrial valued added has increased from 74% in 1980 to 81% in 1997 (Korea National Statistical Office, 2000 and 2001). Similarly, oil contributes to over 70% of total CO_2 emissions due to its dominant use in buildings and transport sector (Figure 2 and 4) because most of the big buildings in Seoul use oil based centralized heating system unlike Tokyo.

3.2 CO2 emission performance of cities in per capita and per economic activities

In this section we measured performance of the cities in terms of CO_2 emissions per capita and CO_2 emissions per unit GDP or DRP. CO_2 emissions are estimated from energy data by using local or IPCC default emissions factors. In case of electricity, national average of electricity production by fuel type is assumed and national average emissions factors are used. Therefore, embedded CO_2 emissions in electricity use in the cities are covered by the data. Due to data problems, CO_2 emissions could only be estimated for selected north Asian cities (Tokyo, Seoul, Beijing, Shanghai, and large

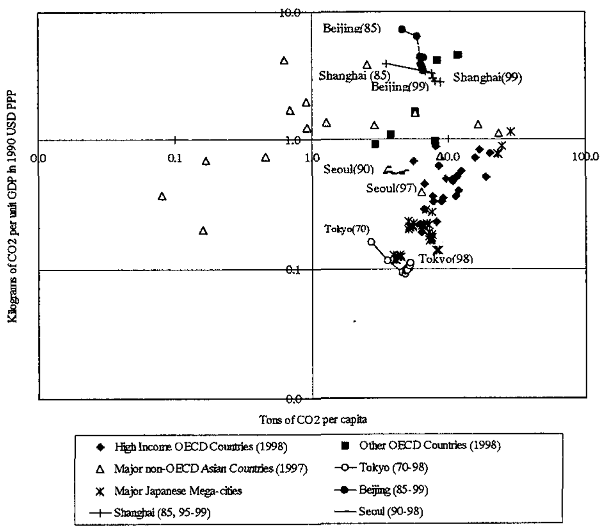

Fig. 5 CO_2 emissions in per capita and per unit GRP/GDP (in log-log scale).

Japanese cities), OECD countries and major non-OECD countries. Here, CO_2 emissions for Beijing and Shanghai are estimated by regional energy balance tables for respective cities[26),27)] and IPCC emission factors. Furthermore, GRP for Beijing and Shanghai are from Beijing Statistical Yearbook and Shanghai Statistical Yearbook, respectively. Estimated CO_2 emission per unit 1990 GDP or GRP and per capita CO_2 emissions are plotted on logarithmic scale. Figure 5 shows the performance of cities. In Figure 5, the desired situation over time is the transition of the city towards the origin.

The comparison reveals that the performance of Japanese large cities is better, in general, than other cities and countries, and performance of Tokyo is outstanding. In recent years, especially after 1990, performance of Tokyo is seen to be slightly worsening mainly due to the slowing down of economy and inability to cut down CO_2 volume. In Tokyo, slowing down of the economy is not cutting down lot of emissions because share of industrial sector is small in total CO_2 emission. CO_2 per unit GRP in Seoul is found to stagnate in 1990-1997 but CO_2 per capita is increasing. Beijing and Shanghai's CO_2 performance in terms of GRP is improving rapidly. This may be due to shift from traditional coal based technology. However, CO_2 emissions are found to slightly increase in per capita terms. Reducing CO_2 emissions in per capita seems major difficulty for cities and all cities have failed in that aspect.

In deriving the per capita CO_2 emissions for Figure 5 the daytime population was used. However, studies have reported that 33% of workforces of Tokyo commute from outside Tokyo[23)]. The ratio of daytime to nighttime population in Tokyo and Seoul is 1.25 and 1.04 in 1999, respectively [23), 28)]. After, such commuting population is included in per capita estimation, performance of Tokyo improved little while no noticeable effect is found in case of Seoul (not shown in figures).

This suggests that Tokyo is already operating at relatively better performance stage. In that sense, Tokyo might be able to serve as a desirable model to catch up with for rapidly developing mega-cities, particularly cities in North Asia. However, each city grows differently and, in reality, one city cannot serve as a complete model for another city, only suitable elements can be utilized. Future CO_2 cut down responsibility for Tokyo may be higher than other cities due to contribution towards meeting Japan's Kyoto commitment (6% reductions of 1990 level). Bottom-up modelers have demonstrated that significant cut down in Tokyo is possible from different technological measures[29)]. If such technological measures could be implemented in the future, Tokyo's performance might improve further.

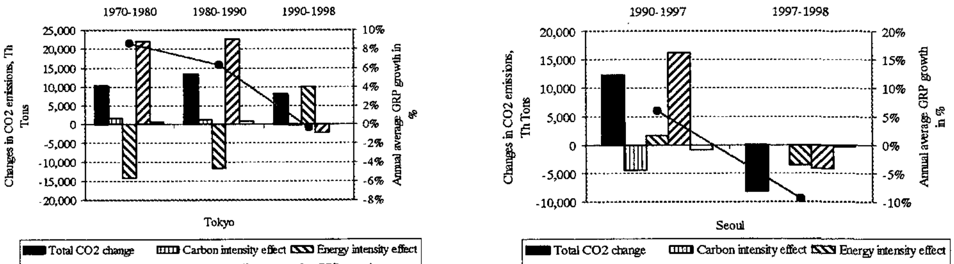

Fig. 6 Factor decomposition of CO_2 emissions from energy use.

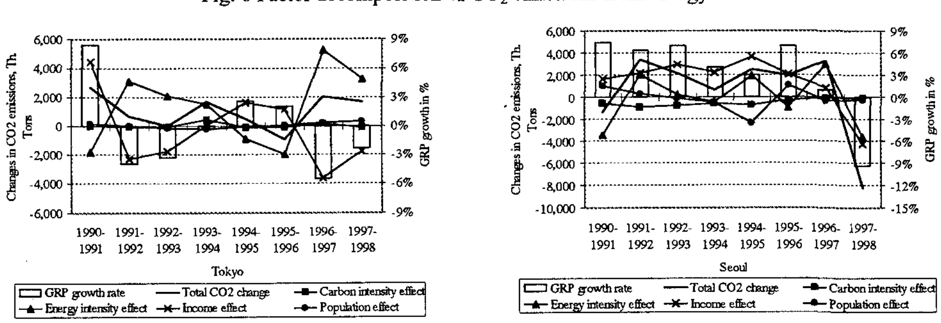

Fig. 7 Factor decomposition of CO_2 emissions from energy use.

4. FACTOR DECOMPOSITION OF CO_2 EMISSIONS

Determining factors for the changes in CO_2 emissions from energy use are estimated for total as well as sectoral emissions. Due to data unavailability, contributions of factors were estimated for Tokyo from 1970 while that for Seoul from 1990. The effects of changes in economic growth are highlighted where applicable.

4.1 Contribution of factors for changes in total CO_2 emissions

The decomposition results are presented in absolute terms where total change in emissions is the sum of carbon intensity effect, energy intensity effect, income effect and the population effect as in Figure 6. The results suggest that the economic activity, *i.e.* income effect, was the major driving force behind the changes in CO_2 emissions in Seoul during economic growth as well as economic recession period. In case of Tokyo, economic activity was the major driving force behind majority of the emissions in high growth period, but its contribution to reduce emissions in economic recession period is found smaller. Tokyo experienced economic recession after so-called *bubble-brust* in late 80's while Seoul experienced economic recession after 1997 as shown in Figure 6.

In Tokyo, carbon intensity effects and population effects are found responsible for increasing emissions in 70's and 80's, but with a very little contribution. Their contribution was negligible in 90's. Unlike Tokyo, carbon intensity effect was found responsible for reducing a large amount of emissions in Seoul during high growth period (1990-97) but its contribution was negligible in recession of 1997-98. Energy intensity, which indicates the direction of technological changes and structural shift of activities, was responsible for the reduction of emissions by large amount in Tokyo during economic growth periods. However, it contributed in an opposite way during recession period. The role of energy intensity effect was found opposite in Seoul as compared to Tokyo. In Seoul, it produced a positive effect (increased emissions) to emissions during economic growth period but a substantive negative effect (reduced emissions) in economic recessions of 1997-98. The dynamic behavior of these determinants by year is analyzed for 1990-98 in Figure 7. The economy of Tokyo and Seoul are clearly different in this period as Tokyo was in deep economic recession while Seoul was in growing rapidly before the economic collapse of 1997.

Economic activities were responsible for reducing CO_2 emissions in Tokyo in 90's. Contribution of energy intensity in reducing emissions decreased over time in Tokyo since 1970's and it was responsible for almost all increase in CO_2 emission in 90s. Apart from energy intensity, carbon intensity was responsible for reducing emission in Seoul significantly. Shifting structure of energy consumption from coal (the share of coal has been shifted from 28.8 in 1990 to 1.3 in 1998[24),25)]) to oil and electricity is major reason for positive contribution of carbon intensity. The effect of population and carbon intensity was found minimal in Tokyo.

4.2 Contribution of factors in sectoral emissions

The factors whose contributions were evaluated for each sector in this section are illustrated in methodology section of this paper.

Transportation sector

Factor analyses for transportation sector show that passenger vehicle population was responsible for most of the increase in CO_2 emissions from transportation sector in Tokyo and Seoul in 1970-98 and 1990-98, respectively. The effect of carbon intensity was found negligible. This seems reasonable as oil remains to dominate fuel for road transportation. In Tokyo, during high growth period in 80's, vehicle utilization effect contributed significantly in increasing CO_2 emissions while it contributed to decrease CO_2 emissions a little bit in 90's. The results also indicate that energy intensity was responsible for decreasing CO_2 emissions in huge amount in 80's. Between 1980 and 1990, road traffic volume (vehicle-km) had almost doubled in Tokyo. However, in 90's energy intensity was found to be the major cause behind increased CO_2 emissions. Further analysis is required to explain this phenomenon, however, urban traffic congestion[22)], constant share of cars in total travel demand and increasing share of big engine cars may

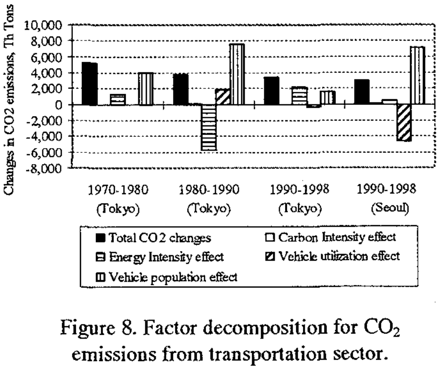

Figure 8. Factor decomposition for CO_2 emissions from transportation sector.

have been responsible. At national level, shares of car with 2000 cc or more has increased from 6% in 1990 to 27.5% in 1997, and energy intensity at national level for transportation sector is reported to increase from 885 Kcal/km in 1989 to 995 Kcal/km in 1997 while in late 80's this energy intensity had decreasing trend[31)]. In Seoul, vehicle utilization effect is responsible for reducing emissions by large amount. For economic downturn period of Seoul that is reflected in data of 1997-98, the factors contributed to reduce CO_2 emission in 1997-98 with most significant contributions from energy intensity effect, followed by vehicle utilization effect. The transitions of different effects in 90's are shown in Figures 9 and 10, respectively. Only vehicle population effect and carbon intensity effect is stable for both Tokyo and Seoul on yearly basis. Energy intensity effect is found to fluctuate significantly.

Residential Sector

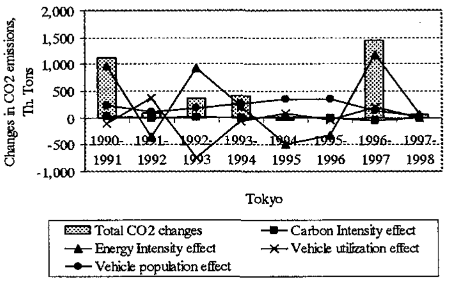

Fig. 9 Factor decomposition for CO_2 emissions from transportation sector in Tokyo.

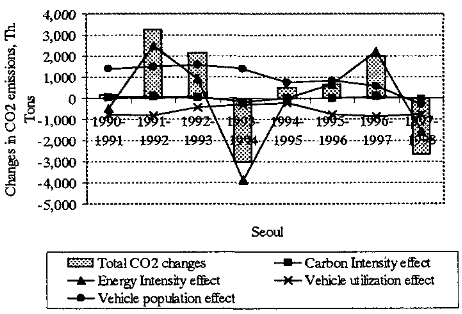

Fig. 10 Factor decomposition for CO_2 emissions from transportation sector in Seoul.

CO_2 emissions from energy use of residential sector seems to have saturated in recent years in Tokyo while, in Seoul, it has decreasing trend as demonstrated in Figure 11. Figure 11 shows the estimated contribution of each factor in the increase of CO_2 emissions from residential sector. Energy intensity, measured in MJ per unit of household income, represents lifestyle related to efficient utilization of household income in terms of energy consumption. Among the four factors shown earlier in the methodology section, household income effect was mostly responsible for increasing CO_2 emissions in Tokyo followed by changes in the number of households. Fuel quality effect, represented by carbon intensity, contributed a little only in Tokyo. The role of energy intensity effect was very strong that contributed towards reducing CO_2 emissions by large amount. The nature of factor's contribution (magnitude as well as positive or negative effect to CO_2 emissions) is similar for high growth period of 70's and 80's as well as economic crisis of 90's for Tokyo.

In case of Seoul, for 1990-98, carbon intensity effect is most prominent and it contributed to reduce CO_2 emissions. This is due to the fuel substitution in Seoul, where oil and electricity are gradually replacing coal and oil. Unlike Tokyo, residential sector of Seoul heavily relies on centralized heating and cooling systems. As shown in Figure 11,

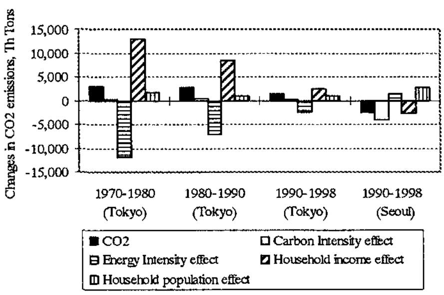

Fig. 11 Factor decomposition for CO_2 emissions from residential sector.

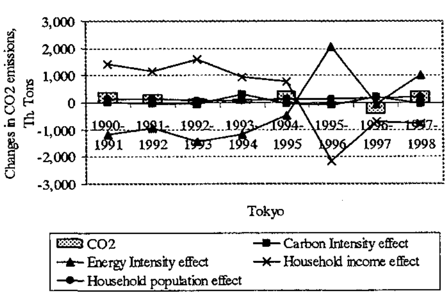

Fig. 12 Factor decomposition for CO_2 emissions from residential sector in Tokyo.

household income effect is also responsible for reducing emissions. Role of household number and energy intensity is most significant for increasing CO_2 emissions in Seoul. Yearly variations of various effects for 1990-98 for Tokyo and Seoul are also analyzed; for Seoul only carbon intensity effect was found stable and all other effects could not be explained; for Tokyo, factors were relatively stable as shown in Figure 12.

Commercial sector

Commercial sector is the biggest contributor of CO_2 emissions in Tokyo but is the lowest contributor in Seoul. Analyses of the driving factors suggested that labor productivity effect, which is defined by amount of service sector value-added produced by one labor, is the biggest factor to increase CO_2 emissions in Tokyo and Seoul, except for the recession period of Tokyo (see Figure 13). Energy intensity effect was responsible for most of the reduction in CO_2 emissions in Tokyo and Seoul except in the Tokyo's recession period, *i.e.* 1990's. In this period the effect of all the factors except labor population are opposite from that of high growth period of 80's. The labor population effect, which can also be called as Scale Effect, has positive effect to CO_2 emissions in all the analyzed periods. The large impact of energy intensity on CO_2 emissions in Seoul may be due to the fuel switching in central heating and cooling plants from coal to oil, and increasing use of electricity.

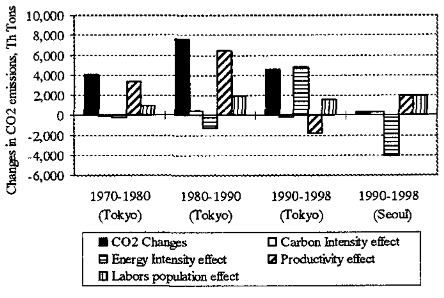

Fig. 13 Factor decomposition for CO_2 emissions from commercial sector.

5. CONCLUSION

Although national scale analyses of the CO_2 emissions from energy use are very common, similar analyses at city scale are not common. This paper has estimated CO_2 emissions from energy use in four mega-cities in Asia, Tokyo, Seoul, Beijing and Shanghai and analyzed them. The results have shown that the performance of Tokyo (in terms of CO_2 emissions per unit GDP and per capita) is outstanding in comparison to major Japanese large cities, Seoul, Beijing, Shanghai, major OECD and major non-OECD countries.

In this study, factor decomposition method was used to show the impacts of carbon intensity effect, energy intensity effect, income effect (or productivity effect in case of commercial sector) and scale effect on CO_2 emissions. Data used was for 1970-98 for Tokyo and 1990-98 for Seoul. The results have suggested that income effect was primarily responsible for majority of CO_2 emissions in Tokyo and Seoul in high growth period, *i.e.* 1970-90 for Tokyo and 1990-97 for Seoul. Fuel quality effect and energy intensity effects were largely responsible for reducing CO_2 emissions in Seoul and Tokyo, respectively in that period. Despite economic recession, CO_2 emissions continue to grow in Tokyo in 1990-98, largely due to energy intensity effect.

In transportation sector, vehicle population effect was responsible for the majority of CO_2 emissions in both cities. In case of Seoul, vehicle utilization effect (travel demand per vehicle) was primarily responsible for reducing emissions but in Tokyo, energy intensity effect was primarily responsible. For residential sector, the effects of contributing factors to CO_2 emissions are different for Tokyo and Seoul primarily due to the differences in building heating and cooling systems and fuel switching. In Tokyo, most of the emissions from residential sector are attributed to household income effect unlike scale effect (household population effect) to Seoul. Similarly, in Tokyo, energy intensity effect is responsible for reducing emissions but in Seoul, fuel quality effect and income effects are responsible. Finally, for commercial sector, labor productivity effect is dominant in increasing CO_2 emissions in high growth period and energy intensity for reducing CO_2 emissions in both cities.

Finally, the meaning of decomposition analysis should be traded carefully. For example, energy intensity effect of transportation sector is the changes in CO_2 emissions of transport sector that would have resulted only from the changes in gross energy consumed per unit of passenger travel demand while keeping all other factors constant. Such effects are only "what if" analysis. In this paper, only emissions per capita and emissions per unit GRP are used for comparing emission performance of cities. Other factors such as climate condition, fuel availability and other relevant factors are also needed in future such comparisons.

REFERENCES

1) Ichinose, T., Hanaki, K and Matsuo, T. : International comparison of energy consumption in urban area. *Proceedings of Environmental Engineering Research*, Japan society of Civil Engineers, Vol. 30, pp. 371-381 (in Japanese), 1993.

2) McEvoy, D. W., Gibbs, D. C. and Longhurst, J. W. S. : Assessing carbon flow at the local scale, *Energy and Environment*, Vol. 8, no. 4, pp. 297-311, 1997.

3) McEvoy, D. W., Longhurst, K. W. S. and Gibbs, D. C. : *A framekork for the construction of local CO_2 inventories, in Air pollution V–modeling, monitoring and management*,

editied by Power, H., Tiranassi, T. and Brebbia, C. A., 3-13. Southampton, Computational Mechanics Publications, 1997.
4) Kates, R. W., Mayfield, M. W., Torrie R. D. and Witcher. B.: Methods for estimating greenhouse gases from local places, *Local Environment*, Vol. 3, no. 3, pp. 278-298, 1998.
5) Baldasano, J. M.,, Soriano, C. and Boada, L. : Emission inventory for greenhouse gases in the city of Barcelona, 1987-1996, *Atmospheric Environment*, Vol. 33, pp. 3765-3775, 1999.
6) Bennett, M. and Newborough, M. : Auditing energy use in cities, *Energy Policy*, Vol. 29, pp. 125-134, 2001.
7) Newman, P.W.G. : Sustainability and cities: extending metabolism model, *Landscape and Urban Planning*, Vol. 44, pp. 219-226, 1999.
8) ICLEI : Local government implementation of climate protection: case studies. http://www.iclei.org/co2/fact/cpcs97.htm (Aug. 1, 2002), 1997.
9) Kenworthy, J. R. and Laube F.B. with Peter Newman, Paul Barter, Tamim Raad, Chamlong Poboon and Benedicto Guia (Jr): *An International Sourcebook of Automobile Dependence in Cities, 1960-1990*, University Press of Colorado, Boulder, 1999.
10) Yuan, W. and James, P. : Evolution of the Shanghai city region 1978-1998: an analysis of indicators, *Journal of Environmental Management*, Vol. 64, pp. 299-309, 2002.
11) Shrestha, R. M. and Timilsina, G. : A divisia decomposition analysis of NO_x emission intensities for the power sector in Thailand and South Korea, *Energy*, Vol. 23, No. 6, pp. 433-438, 1998.
12) Shrestha, R. M. and Timilsina, G. : Factors affecting CO_2 intensities of power sector in Asia: A divisia decomposition analysis, *Energy Economics*, Vol. 18, pp. 265, 1996.
13) Ang, B.W. and Liu, F. L. : A new energy decomposition method: perfect in decomposition and consistent in aggregation, *Energy*, Vol. 26, pp. 537-548, 2001.
14) Greening, L. A., Davis, W. B. and Schipper, L. : Decomposition of aggregate carbon intensity for the manufacturing sector: comparison of declining trends from 10 OECD countries for the period 1971-1991, *Energy Economics*, Vol. 20, pp. 43-65, 1998.
15) Luukkanen, J. and Kaivooja, J. : ASEAN tigers and sustainability of energy use-decomposition analysis of energy and CO_2 efficiency dynamics, *Energy Policy*, Vol. 30, pp. 281-292, 2002.
16) Nag, B. and Parikh, J : Indicators of carbon emission intensity from commercial energy use in India, *Energy Economics*, Vol. 22, pp. 441-461, 2000.
17) Hamilton, C. and Turton, H. : Determinants of emissions growth in OECD countries, *Energy Policy*, Vol. 30, pp. 63-71, 2002.
18) Sun, J. W. : Changes in energy consumption and energy intensity: a complete decomposition model, *Energy Economics*, Vol. 20, No. 1, pp. 85-100, 1998.
19) IPCC/OECD/IEA: *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Bracknell UK Meteorological Office, 1997.
20) OECD/IEA : *IEA energy statistics 2000*, International Energy Agency, Paris, 2000.
21) TMG : *Tokyo Statistical Yearbook*, Annually published (1970-2001) by Tokyo Metropolitan Government, Tokyo, Japan.
22) TMG : *Tokyo Vision 2000*, Tokyo Metropolitan Government, Tokyo, 2000.
23) TMG : *TDM Tokyo Action Plan*. Tokyo Metropolitan Government, Tokyo, 2000.
24) Korea Energy Economics Institute: *Yearbook of Regional Energy Statistics 1998*, Euiwang-Shi: Korea Energy Economics Institute, 1998.
25) Korea Energy Economics Institute: *Yearbook of Regional Energy Statistics 1999*, Euiwang-Shi: Korea Energy Economics Institute, 1999.
26) Department of Industry and Transportation, National Bureau of Statistics China, *China energy statistical yearbook 1991-1996 Beijing*, China Statistical Publishing House, 1998.
27) Department of Industry and Transportation, National Bureau of Statistics China, *China energy statistical yearbook 1997-1999, Beijing*, China Statistics Press, 2001.
28) Yoon, S. and Araki, K. : Scale of economy in urban energy use, Paper presented at IGES/APN Mega-city Project Workshop, January 23-24, Kitakyushu, Japan, 2002.
29) Hanaki, K. : Integrated approach for best mix of technologies of reduction of carbon dioxide emissions - Tokyo Half Project (THP). Paper presented at IGES/APN Mega-city Project Workshop, January 23-24, Kitakyushu, Japan. 2002.
30) Ang, B. W. and Zhang, F. Q. : A survey of index decomposition analysis in energy and environmental studies, *Energy*, Vol. 25, pp. 1149-1176, 2000.
31) MITI : *Annual Automobile Transportation Statistics 1998*, Ministry of International Trade and Industry, Japan., 1998.
32) Korea National Statistical Office : *Gross regional domestic product and expenditure -1998 edition*, Daejeon, Korea, 2000.
33) Korea National Statistical Office : *Gross regional domestic product and expenditure –1999 edition*, Daejeon, Korea, 2001.

東京とソウルのエネルギー消費による二酸化炭素排出の要因分析

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本研究は東京とソウルにおける二酸化炭素排出量について、1）一人当たり二酸化炭素排出量、GRP 当たり二酸化炭素排出量を東アジアの主要都市及び主要国と比較し、2）総排出量と部門別排出量の要因分析を行った。分析結果から東京は一人当たり及び GRP 当たりの双方において二酸化炭素排出がきわめて低い水準で推移していることが分かった。また、東京、ソウル共に高経済成長期（それぞれ 1970 年から 1990 年、1990 年から 1998 年）には所得増加が二酸化炭素増加の主要因であることが分かった。さらに、東京は低経済成長期である 1990 年から 1998 年においても二酸化炭素排出は増加を続け、著しく悪化したエネルギー効率が大きくこれに寄与した。同様に、東京、ソウルにおいて燃料質、自動車利用率、家計収入、労働生産性、スケール効果などを用い、部門別二酸化炭素排出量排出の要因分析を行った。