

### 1.1.1. Comparative Analysis of CO<sub>2</sub> Emission in Beijing, Seoul, Tokyo and Shanghai

#### (1) Introduction

The volumes of Gross Domestic Product (GDP) and energy demand (or CO<sub>2</sub> emissions) have direct co-relation since economic growth increases use of energy whose major source in the fossil fuel. The pattern of energy consumption in Japan shows that per capita energy consumption in urban area is lower than that of non-urban areas<sup>1</sup>. On contrary, opposite trend is reported in developing countries, such as China and Thailand<sup>2</sup>. In volume basis, a large city contributes significantly to total national CO<sub>2</sub> emissions due to higher energy demand in cities. If indirect emissions embodied in consumption goods and services are considered 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 an energy footprint of a city.

The analyses of energy and CO<sub>2</sub> emissions at national scale have been done in uncountable published literatures but at city scale, such analyses are limited. Such city scale studies are trying to cover all urban sectors comprehensively and yet are under the stage of methodological development on estimating urban energy or CO<sub>2</sub> inventory<sup>3 4 5 6 7 8 9</sup>. The limitations emerge from difficulties in getting city scale data and the fact that major policy decisions on energy issues are made at national level. Other technical limitations to estimate CO<sub>2</sub> emissions are due to the differences in political boundary of the city and functional boundary of the city. Therefore, many studies on just focus on selected sectors of the city, mostly transportation and building sectors<sup>10</sup>. A comprehensive analysis of the macro driving factors at city level, particularly international comparison, covering all of the major sectors is seldom done in past literatures. Our paper addresses this important aspect for selected East Asian cities that have seen unprecedented industrialization in last few decades. In the beginning of this paper, an inseparable link between sustainability, cities and energy use are established. Then, authors have estimated the CO<sub>2</sub> emissions from energy use in Tokyo, Seoul, Beijing and Shanghai and compared their CO<sub>2</sub> emissions in per capita and per unit gross regional product (GRP) basis. To understand the further intricacies of urban energy use in terms of CO<sub>2</sub> emissions, past trends of CO<sub>2</sub> emissions were analyzed for these cities

<sup>1</sup> Literally means Beijing, Seoul and Tokyo.

<sup>2</sup> 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.

<sup>3</sup> 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.

<sup>4</sup> McEvoy, D. W., Longhurst, K. W. S. and Gibbs, D. C. : A framework for the construction of bcal CO<sub>2</sub> inventories, in Air pollution V –modeling, monitoring and management, edited by Power, H., Tiranassi, T. and Brebbia, C. A., 3-13. Southampton, Computational Mechanics Publications, 1997.

<sup>5</sup> 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.

<sup>6</sup> 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.

<sup>7</sup> Bennett, M. and Newborough, M. : Auditing energy use in cities, Energy Policy, Vol. 29, pp. 125-134, 2001.

<sup>8</sup> Newman, P.W.G. : Sustainability and cities: extending metabolism model, Landscape and Urban Planning, Vol. 44, pp. 219-226, 1999

<sup>9</sup> ICLEI : Local government implementation of climate protection: case studies. <http://www.iclei.org/CO2/fact/cpcs97.htm> (Aug. 1, 2002), 1997.

<sup>10</sup> 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.

and contributions of driving factors for total and sectoral CO<sub>2</sub> emissions are investigated by factor decomposition method. These cities have relatively better data availability (compared to other Asian cities) and they are affluent mega-cities of Asia that shares many common features. These cities are front-runners in terms of economic growth, rapid lifestyle changes and high demand for goods and services. Cities can also play a vital role in international ongoing climate policy debate, as locally operation policies are key in any drastic cutback of emissions due to their large contributions. City scale analysis would assist policy makers in cities to understand various factors that influence CO<sub>2</sub> emissions and initiate appropriate policy measures. At the end of the paper few observations are drawn and policy urgency in few areas are highlighted.

Database development for Tokyo, Seoul, Beijing and Shanghai was the primary task in the study. Collected data included energy data by sector and fuel type and key macro-level driving forces of each sector. Emission factor, defined as CO<sub>2</sub> emissions per unit energy consumption by type, are obtained from locally available sources (such as Ministry of Environment of Japan) and IPCC<sup>11</sup>. BeSeTo 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. Energy and CO<sub>2</sub> emission data for Japanese large cities were obtained from official documents on master plans against global warming published by each cities, and national level data from OECD's energy statistics<sup>12</sup>. Major data sources are internal reports of Tokyo Metropolitan Government on energy supply and demand of Tokyo, Tokyo Statistical Yearbook since 1970, Regional Energy Statistics of Korea, Seoul Statistical Yearbook from 1990, Shanghai and Beijing's statistical yearbooks and China Energy Statistical Yearbooks<sup>13 14 15 16 17 18 19 20 21</sup> 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. Definitions for Beijing and Shanghai are the areas administered by respective local governments.

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<sup>11</sup> IPCC/OECD/IEA: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Bracknell UK Meteorological Office, 1997.

<sup>12</sup> OECD/IEA : IEA energy statistics 2000, International Energy Agency, Paris, 2000.

<sup>13</sup> TMG : Tokyo Statistical Yearbook, Annually published (1970-2001) by Tokyo Metropolitan Government, Tokyo, Japan.

<sup>14</sup> TMG : Tokyo Vision 2000, Tokyo Metropolitan Government, Tokyo, 2000.

<sup>15</sup> TMG : TDM Tokyo Action Plan. Tokyo Metropolitan Government, Tokyo, 2000.

<sup>16</sup> Korea Energy Economics Institute: Yearbook of Regional Energy Statistics 1998, Euiwang-Shi: Korea Energy Economics Institute, 1998.

<sup>17</sup> Korea Energy Economics Institute: Yearbook of Regional Energy Statistics 1999, Euiwang-Shi: Korea Energy Economics Institute, 1999.

<sup>18</sup> Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1991-1996 Beijing, China Statistical Publishing House, 1998.

<sup>19</sup> Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1997-1999, Beijing, China Statistics Press, 2001.

<sup>20</sup> Korea National Statistical Office : Gross regional domestic product and expenditure -1998 edition, Daejeon, Korea, 2000.

<sup>21</sup> Korea National Statistical Office : Gross regional domestic product and expenditure -1999 edition, Daejeon, Korea, 2001.

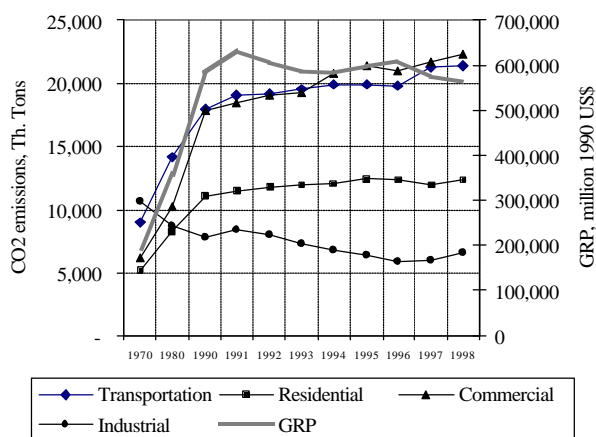


Fig. 4-4-2-1: Sectoral emissions profile of Tokyo

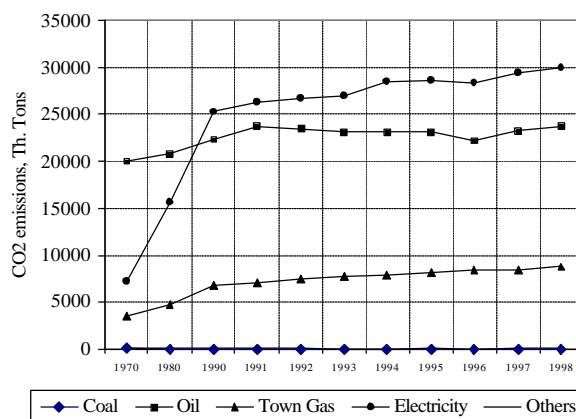


Fig.4-4-2-2: CO<sub>2</sub> emission of Tokyo by fuel type

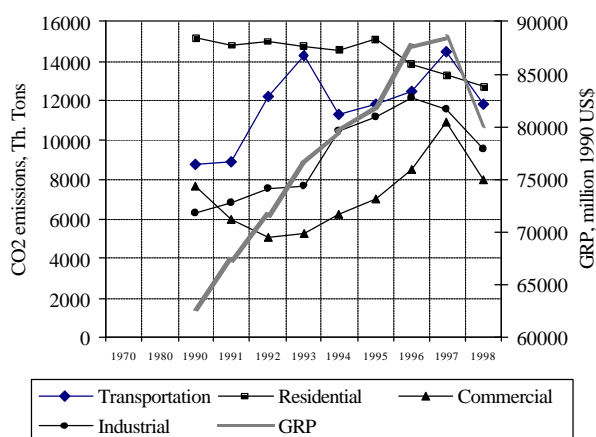


Fig.4-4-2-3: Sectoral emissions profile of Seoul

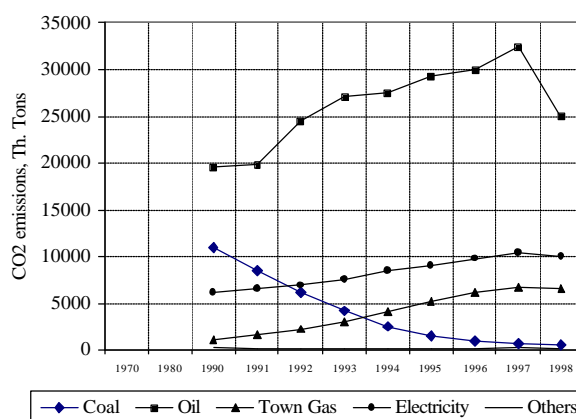


Fig. 4-4-2-4: CO<sub>2</sub> emission of Seoul by fuel type

## (2) GHG Emissions from Energy Use in East Asian Mega-cities

### Emission trends

The estimation of CO<sub>2</sub> emissions by sector and fuel type suggests that CO<sub>2</sub> 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<sub>2</sub> emissions for Tokyo and Seoul are estimated to 1.7% and 1.63%, respectively. **Figure 4-4-2-1** and **Figure 4-4-2-3** show the emission profile by sector for Tokyo and Seoul and **Figure 4-4-2-2** and **Figure 4-4-4-4** by fuel type. Beijing and Shanghai's emission growths are significantly higher than Tokyo and Seoul; the estimated annual emissions growths for 1985-1998 are 3.9% and 12.3% respectively while economic growth was about 15% for both cities. In 90's (1990-98) however, the annual growth of emissions are around 2% for Beijing and 5% for Shanghai despite the fact that economic growth rates are over 15%. This could be due to ongoing fuel switching, increasing productivity and improving energy efficiency.

**Table 4-4-2-1: Economic and emissions growth in Beijing and Shanghai**

City	1985-90	1990-98
Beijing	Moderate economic growth (7.25%)	High economic growth (14.5%)
	Low emissions growth (5.7%)	Low emissions growth (2.2%)
Shanghai	Low economic growth (2.3%)	High economic growth (20.7%)
	High emissions growth (15.6%)	Low emissions growth (5.8%)

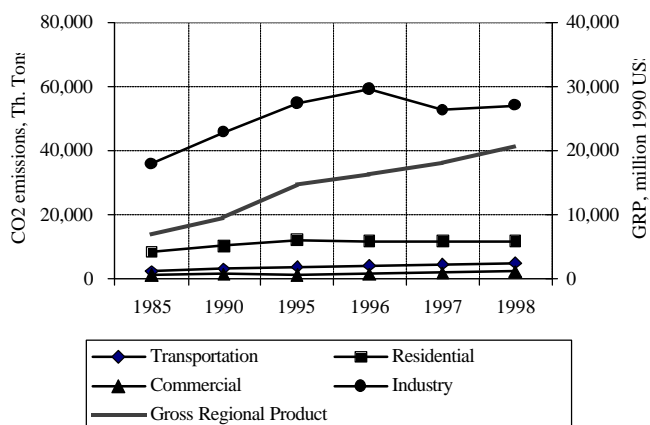
Definition for *high* and *low* are specific to Chinese context. If we compare with Tokyo or Seoul, low economic growth numbers for of Beijing and Shanghai itself are quite high growth for Tokyo and Seoul. Similarly, low economic growth rate for Beijing and Shanghai is indeed quite high for Tokyo and Seoul.

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<sub>2</sub> 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<sub>2</sub> emissions based on average electricity generation mix) are responsible for the majority of CO<sub>2</sub> emissions (**Figure 4-4-2-2**). 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<sub>2</sub> emissions due to its dominant use in buildings and transport sector (**Figure 4-4-2-2 and 4**) because most of the big buildings in Seoul use oil based centralized heating system unlike Tokyo.

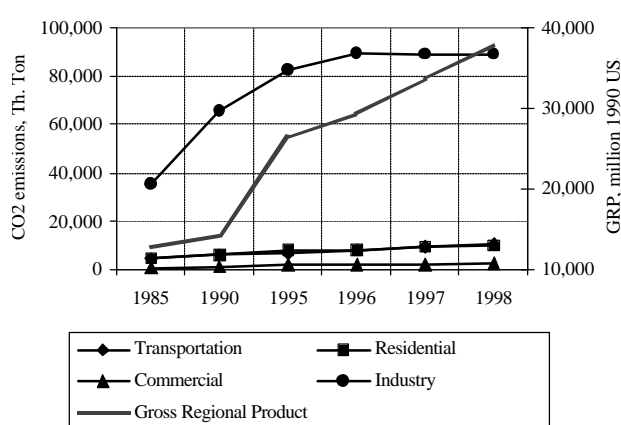
Emissions in Beijing and Shanghai are mostly dominated by industry sector whose shares were at peak in 1996 (77% and 83% respectively). Since 1996, this sector has shown a declining trend in terms of shares as well as absolute volume of emissions while maintaining past trends of economic growth. Transport sector contributed around 4-6% of total emission in Beijing and about 6-10% in Shanghai (in 1985-98) unlike other mega-cities. However, since 1990 the shares of transport sector emissions have an increasing trend. As per capita car ownership in Beijing and Shanghai are much lower compared to Tokyo and Seoul, a low contribution of transport sector may be justified looking to the industry sector's dominance. Some inaccuracies may have resulted from accounting problems such as counting gasoline consumption by automobiles used in industries to industry sector and by households in household sector. Efforts have been made to limit such accounting problems. Coal is the major source of CO<sub>2</sub> emissions (over 75%), which are used as energy sources in industries and power plants. Coal is also used in producing coking products, coke oven gas and cogeneration systems.

Shares of electricity in CO<sub>2</sub> emissions are increasing from about 18% in 1985 to 30% in 1998 in both cities (**Figures 4-4-2-5 to 8**)

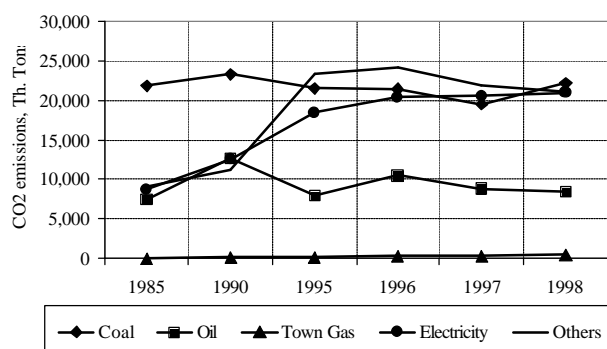


**Fig.4-4-2-5: Sectoral CO<sub>2</sub> emissions in Beijing**

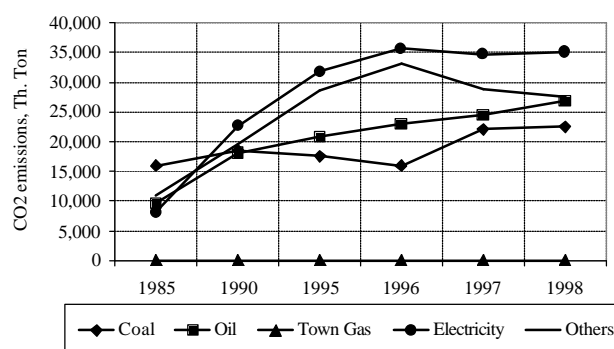
Construction and agriculture sectors are included in Industry as their shares are very small.



**Fig.4-4-2-6: Sectoral CO<sub>2</sub> emissions in Shanghai**



**Fig.4-4-2-7: CO<sub>2</sub> emissions of Beijing by fuel type**



**Fig.4-4-2-8: CO<sub>2</sub> emissions of Shanghai by fuel type**

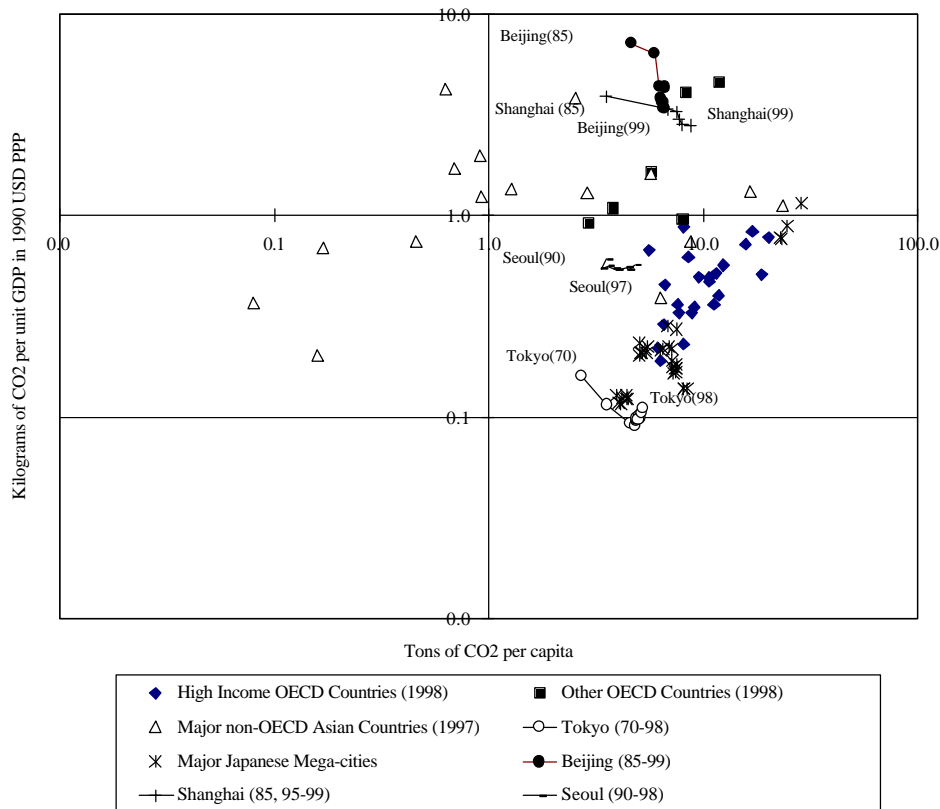
(Energy consumption calculations are made on primary energy basis. *Others* mean coking gas, coke, coking products and heat supply. Almost all energy sources for electricity, coking and heat supply are coal).

### CO<sub>2</sub> emission performance of cities in per capita and per unit economic activities

In this section we measured performance of the cities in terms of CO<sub>2</sub> emissions per capita and CO<sub>2</sub> emissions per unit GDP or GRP. CO<sub>2</sub> 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<sub>2</sub> emissions in electricity use in the cities are covered by the data. Due to data problems, CO<sub>2</sub> emissions could only be estimated for selected north Asian cities (Tokyo, Seoul, Beijing, Shanghai, and large Japanese cities), OECD countries and major non-OECD countries. Here, CO<sub>2</sub> emissions for Beijing and Shanghai are estimated by regional energy balance tables for respective cities<sup>22 23</sup> and IPCC emission factors. Furthermore, GRP for Beijing and Shanghai are obtained from Beijing Statistical Yearbook and Shanghai Statistical Yearbooks, respectively. Estimated CO<sub>2</sub> emission per unit 1990 GDP or GRP and per

<sup>22</sup> Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1991-1996 Beijing, China Statistical Publishing House, 1998

<sup>23</sup> Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1997-1999, Beijing, China Statistics Press, 2001.



**Figure. 4-4-2-9 CO<sub>2</sub> emissions in per capita and per unit GRP/GDP (in log-log scale).**

capita CO<sub>2</sub> emissions are plotted on logarithmic scale. Figure 9 shows the performance of cities. In **Figure 4-4-2-9**, 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<sub>2</sub> 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<sub>2</sub> emission. CO<sub>2</sub> per unit GRP in Seoul is found to stagnate in 1990-1997 but CO<sub>2</sub> per capita is increasing. Beijing and Shanghai's CO<sub>2</sub> performance in terms of GRP is improving rapidly. This may be due to shift from traditional coal based technology. However, CO<sub>2</sub> emissions are found to slightly increase in per capita terms. Reducing CO<sub>2</sub> emissions in per capita seems major difficulty for cities and all cities have failed in that.

In deriving the per capita CO<sub>2</sub> emissions for **Figure 4-4-2-9** the daytime population was used. However, studies have reported that 33% of workforces of Tokyo commute from outside Tokyo<sup>24</sup>. The ratio of daytime to nighttime population in Tokyo and Seoul is 1.25 and 1.04 in 1999, respectively<sup>25 26</sup>. After, such commuting population is included

<sup>24</sup> TMG : TDM Tokyo Action Plan. Tokyo Metropolitan Government, Tokyo, 2000.

<sup>25</sup> TMG : TDM Tokyo Action Plan. Tokyo Metropolitan Government, Tokyo, 2000.

<sup>26</sup> 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.

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<sub>2</sub> 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<sup>27</sup>. If such technological measures could be implemented in the future, Tokyo's performance might improve further.

### Factor Decomposition of CO<sub>2</sub> Emissions

Determining factors for the changes in CO<sub>2</sub> emissions from energy use are estimated for total as well as sectoral emissions. Due to data unavailability, contributions of factors were estimated for Tokyo since 1970 while that for Seoul from 1990. Beijing and Shanghai are analyzed for 1985-1998 period. The effects of changes in economic growth are highlighted where applicable.

#### a. Decomposition Method

Analyses on driving factors for CO<sub>2</sub> emissions from energy use can be done by different methods. At macro-scale, Factor Decomposition, Vector Auto Regression (VAR), Correlation Analysis<sup>28</sup> and others can analyze the role of various factors. Factor decomposition method in particular, is an "identity approach". This method is not for forecasting purpose but to understand the historical transition by using exogenous variables and to estimate their contribution to the changes in CO<sub>2</sub> 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 cited more than one hundred published literatures<sup>29</sup>. In our study, we reviewed many literatures particularly by Shrestha and Timilsina<sup>30 31</sup>, Ang and Liu<sup>32</sup>, Greening et al.<sup>33</sup>, Luukkanen & Kaivooja<sup>34</sup>, Nag and Parikh<sup>35</sup>, and Hamilton and Turton<sup>36</sup>. Our choice of

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<sup>27</sup> 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.

<sup>28</sup> 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.

<sup>29</sup> 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.

<sup>30</sup> Shrestha, R. M. and Timilsina, G. : A division decomposition analysis of NO<sub>x</sub> emission intensities for the power sector in Thailand and South Korea, *Energy*, Vol. 23, No. 6, pp. 433-438, 1998.

<sup>31</sup> Shrestha, R. M. and Timilsina, G. : Factors affecting CO<sub>2</sub> intensities of power sector in Asia: A division decomposition analysis, *Energy Economics*, Vol. 18, pp. 265, 1996.

<sup>32</sup> 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.

<sup>33</sup> 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.

<sup>34</sup> Luukkanen, J. and Kaivooja, J. : ASEAN tigers and sustainability of energy use-decomposition analysis of energy and CO<sub>2</sub> efficiency dynamics, *Energy Policy*, Vol. 30, pp. 281-292, 2002.

technique is subtractive decomposition that follows Sun and Luukkanen & Kaivooja<sup>37</sup>. 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 year 0 is,

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

If we denote increment amount by **D**, then

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

We distributed residual R to (1), (2), (3) and (4) in such as way those terms with change are equally shared. Therefore,

This gives decomposition with no residuals such that,

$$C = CI \text{ effect} + EI \text{ effect} + IncomeEffect + PopulationEffect$$

Similar approach of decomposition was used for CO<sub>2</sub> 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, Ct = CO<sub>2</sub> emissions from transportation sector, in thousand Tons; CI<sub>t</sub> = Carbon Intensity, defined as the amount of CO<sub>2</sub> emissions per unit energy consumption, in Tons/GJ; EI<sub>t</sub> = Energy intensity, defined as the amount of energy consumption per vehicle travel distance, in KJ/km; VKT<sub>pv</sub> = Vehicle Kilometers Traveled per vehicle, and Pt = Number of vehicle registered, in thousands.

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<sup>35</sup> Nag, B. and Parikh, J : Indicators of carbon emission intensity from commercial energy use in India, Energy Economics, Vol. 22, pp. 441-461, 2000.

<sup>36</sup> Hamilton, C. and Turton, H. : Determinants of emissions growth in OECD countries, Energy Policy, Vol. 30, pp. 63-71, 2002.

<sup>37</sup> Hamilton, C. and Turton, H. : Determinants of emissions growth in OECD countries, Energy Policy, Vol. 30, pp. 63-71, 2002.

Data used to estimate contributing factors in transportation sector was historical trend of CO<sub>2</sub> 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, Cr = CO<sub>2</sub> emissions from residential sector in thousand Tons; CI<sub>r</sub> = Carbon Intensity, defined as the amount of CO<sub>2</sub> emissions per unit energy consumption, in Tons/GJ; EI<sub>r</sub> = Energy Intensity, defined as amount of energy consumed per unit of household income, in GJ/US\$ (1990); RFS<sub>ph</sub> = 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, Cc = CO<sub>2</sub> emissions from commercial in thousand Tons; CI<sub>c</sub> = Carbon Intensity, defined as the amount of CO<sub>2</sub> emissions, per unit energy consumption, in Tons/GJ; EI<sub>c</sub> = Energy Intensity, defined as amount of energy consumed per unit service sector value added, in MJ/1990 US\$; CVA<sub>pt</sub> = Service sector value added per labor, in thousand 1990 US\$ per labor; CFS = Number of labors, in thousands.

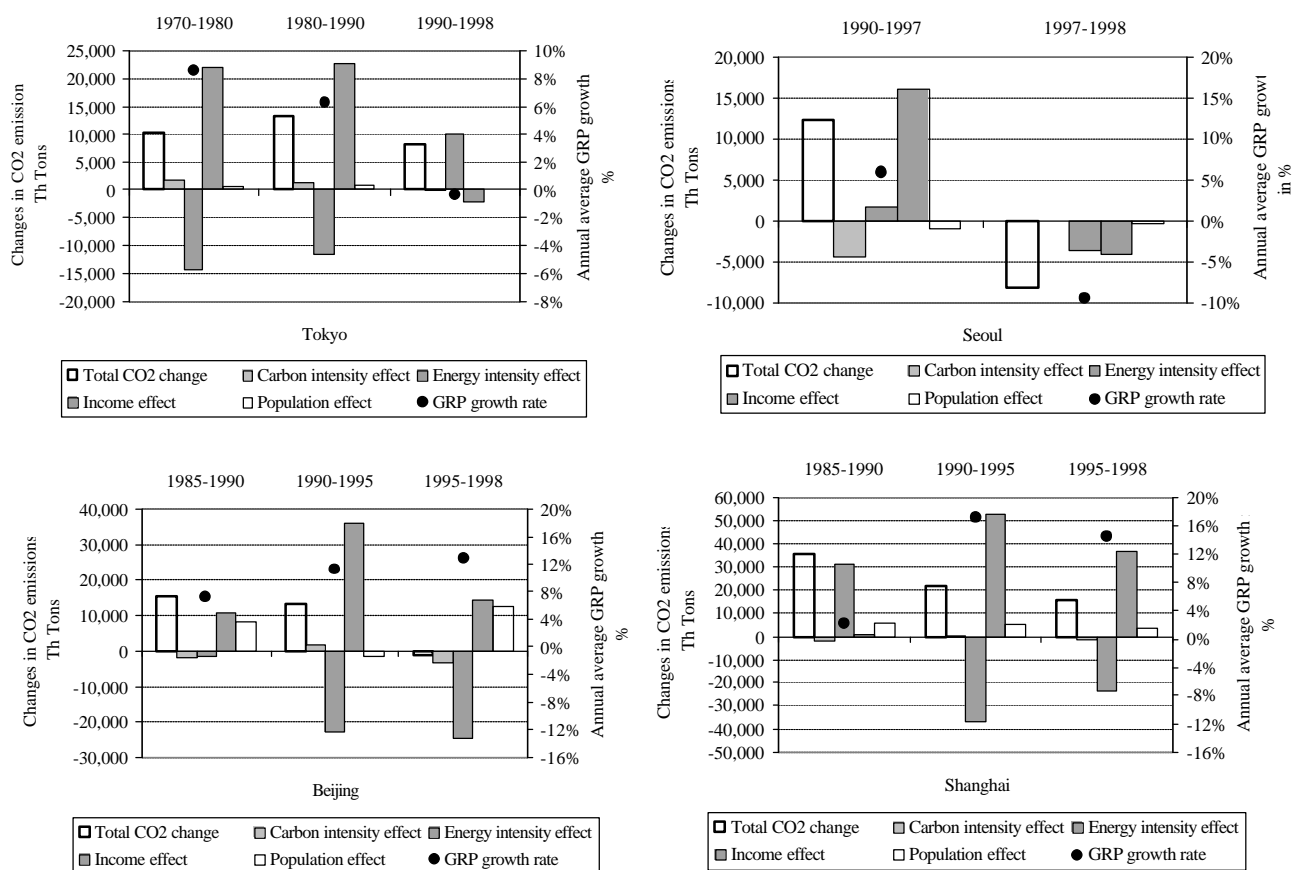
Therefore, in respective sectors, “Change in emissions” = “Carbon intensity effect” + “Energy intensity effect” + “Productivity effect” + “Scale effect”.

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

#### (b) Contribution of factors for changes in total CO<sub>2</sub> 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 4-4-2-10**. The results suggest that the economic activity, i.e. income effect, was the major driving force behind the changes in CO<sub>2</sub> 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 4-4-2-10**.

In Tokyo, though carbon intensity effects and population effects were found responsible for slightly increasing emissions in 70's and 80's, 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



**Figure 4-4-2-10: Factor decomposition of CO<sub>2</sub> emissions from energy uses**

produced a negative effect (increased emissions) during economic growth period but a substantive positive effect (reduced emissions) in economic recessions of 1997-98.

Income effect was responsible for reducing CO<sub>2</sub> emissions in Tokyo in 90's. Contribution of energy intensity in reducing emissions decreased over time in Tokyo since early 1970's; it was responsible for almost all increase in CO<sub>2</sub> 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 changed from 28.8% in 1990 to 1.3% in 1998<sup>38 39</sup> to oil and electricity is major reason for positive contribution of carbon intensity.

Due to unprecedented economic growth, it is obvious that income effect is the major factor behind increasing emissions in Beijing and Shanghai. The structure of contributing factors for these cities looks similar. Energy intensity is found to be the major driving factor responsible for reducing emissions after 1990. Some of the reason for this could be due to the increasing productivity and improving energy efficiency in these cities. Since coal continues dominating energy sector, the CO<sub>2</sub> emissions benefits from carbon intensity effect seems to be evident only after 1995 due to some fuel switching but not before that. The role of population effect was small in Shanghai but in case of Beijing it is contributing significantly. The temporary resident population of Beijing seems to increase in recent years while there is a moderate population growth for permanent residents itself.

<sup>38</sup> Korea Energy Economics Institute: Yearbook of Regional Energy Statistics 1998, Euiwang-Shi: Korea Energy Economics Institute, 1998.

<sup>39</sup> Korea Energy Economics Institute: Yearbook of Regional Energy Statistics 1999, Euiwang-Shi: Korea Energy Economics Institute, 1999.

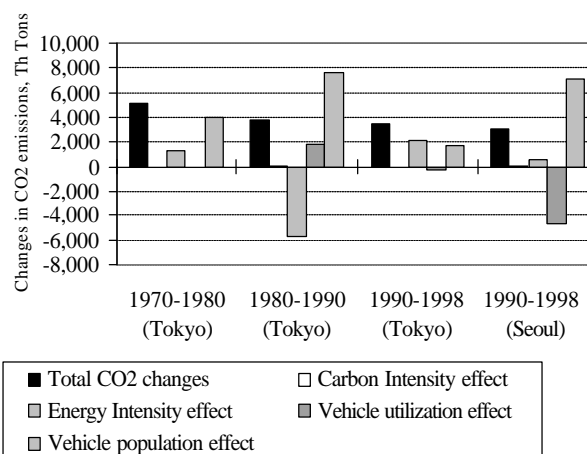
## Contribution of factors in sectoral emissions

### (a) Transportation sector

Factor analyses for transportation sector show that passenger vehicle population was responsible for most of the increase in CO<sub>2</sub> emissions from transportation sector in all four cities. The effect of carbon intensity was found negligible in all cases since oil remains dominant fuel for road transportation.

In Tokyo, vehicle utilization effect contributed significantly in increasing CO<sub>2</sub> emissions during high growth period (80's) only. The results also indicate that energy intensity was responsible for decreasing CO<sub>2</sub> emissions in large amount in 80's. However, in 90's energy intensity was found to be the major cause behind increased CO<sub>2</sub> emissions. Further analysis is required to explain this phenomenon, however, urban traffic congestion<sup>40</sup>, unchanged share of cars in total travel demand and increasing share of big engine cars may 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<sup>41</sup>. In Seoul, vehicle utilization effect is responsible for reducing emissions by large amount. In 1997-98, which is economic downturn period, all the factors contributed to reduce CO<sub>2</sub> emissions; the major contribution was from energy intensity effect, followed by vehicle utilization effect. 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.

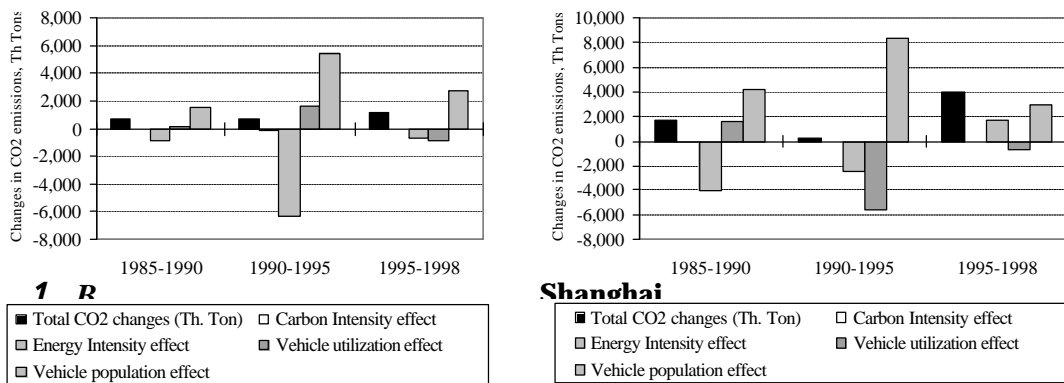
Though Beijing and Shanghai are constantly growing economically, the contributions of energy intensity and vehicle utilization effects are different in these cities. Energy intensity contributed in reducing emissions since 1985 in Beijing, especially in 1990-95 periods. This was also the case in Shanghai except 1995-98 periods where it contributed in increasing emissions. The structures of contributing factors in Beijing and Shanghai are similar for 1985-90 only.



**Figure 4-4-2-11: Factor decomposition for CO<sub>2</sub> emissions from transportation sector**

<sup>40</sup> TMG : Tokyo Vision 2000, Tokyo Metropolitan Government, Tokyo, 2000.

<sup>41</sup> MITI : Annual Automobile Transportation Statistics 1998, Ministry of International Trade and Industry, Japan., 1998.



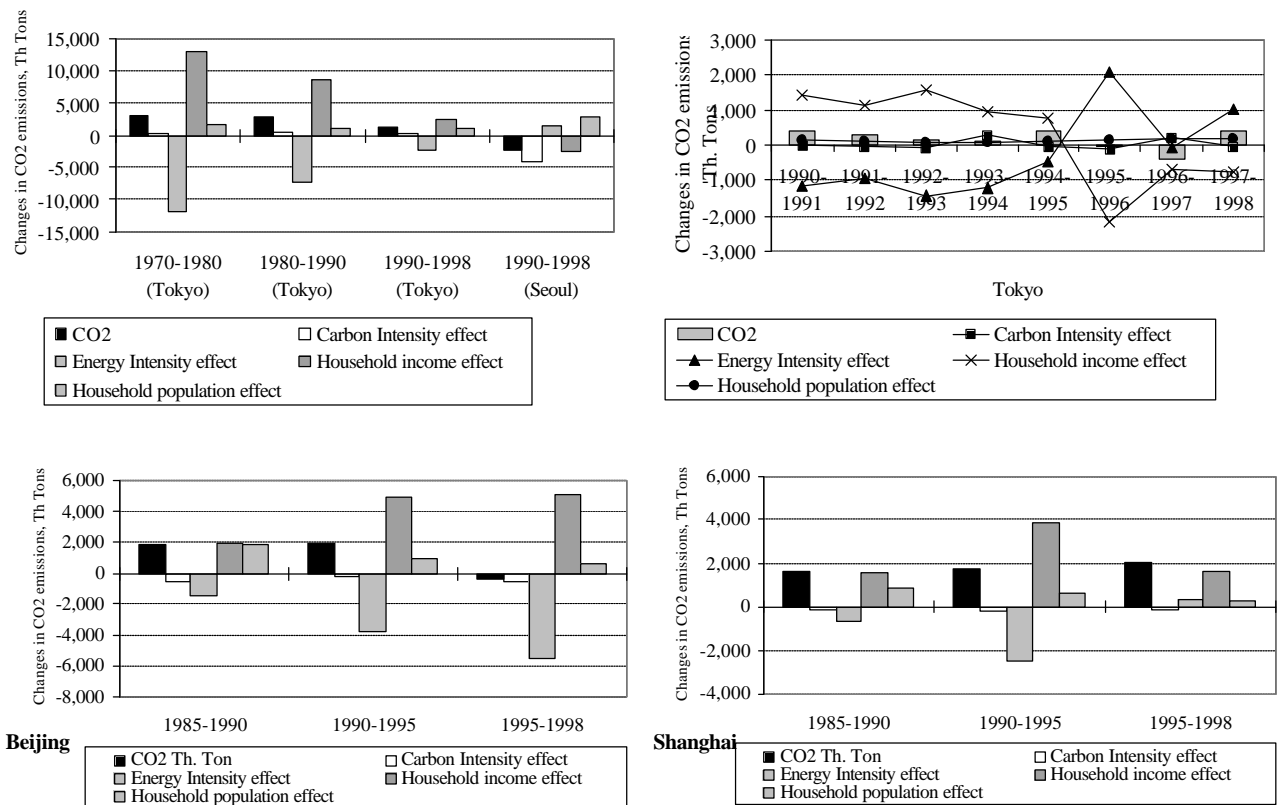
**Figure 4-4-2-12: Factor decomposition for CO<sub>2</sub> emissions from Beijing and Shanghai transportation sector in Beijing**

### (b) Residential Sector

CO<sub>2</sub> 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 4-4-2-13**. Such decreasing trend is also observed for Beijing in 1996-98 periods. **Figure 4-4-2-13** shows the estimated contribution of each factor in the increase of CO<sub>2</sub> emissions from residential sector for Tokyo and Seoul. Energy intensity 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<sub>2</sub> 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<sub>2</sub> emissions by large amount. The nature of factor's contribution (magnitude as well as positive or negative effect to CO<sub>2</sub> 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<sub>2</sub> 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 13, household income effect is also responsible for reducing emissions. Role of household number and energy intensity is quite significant for increasing CO<sub>2</sub> 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 4-4-2-13**.

The structure of factors for Beijing and Shanghai are similar for 1985-1990 periods. During this period, carbon intensity and energy intensity effects contributed to reduce emissions while income effect and household population effect were majorly responsible for increasing emissions. Fuel substitution from coal to gas, technological improvements of domestic heating systems, improved building insulations in new buildings, and efficiency improvements of household appliances could partly explain such trends. In Beijing, the volume of emissions has actually decreased in 1995-98 while factors' contributions followed past trends. In case of Shanghai, the emissions volume increased in 1995-98 unlike Beijing; energy intensity actually contributed to increase emissions.

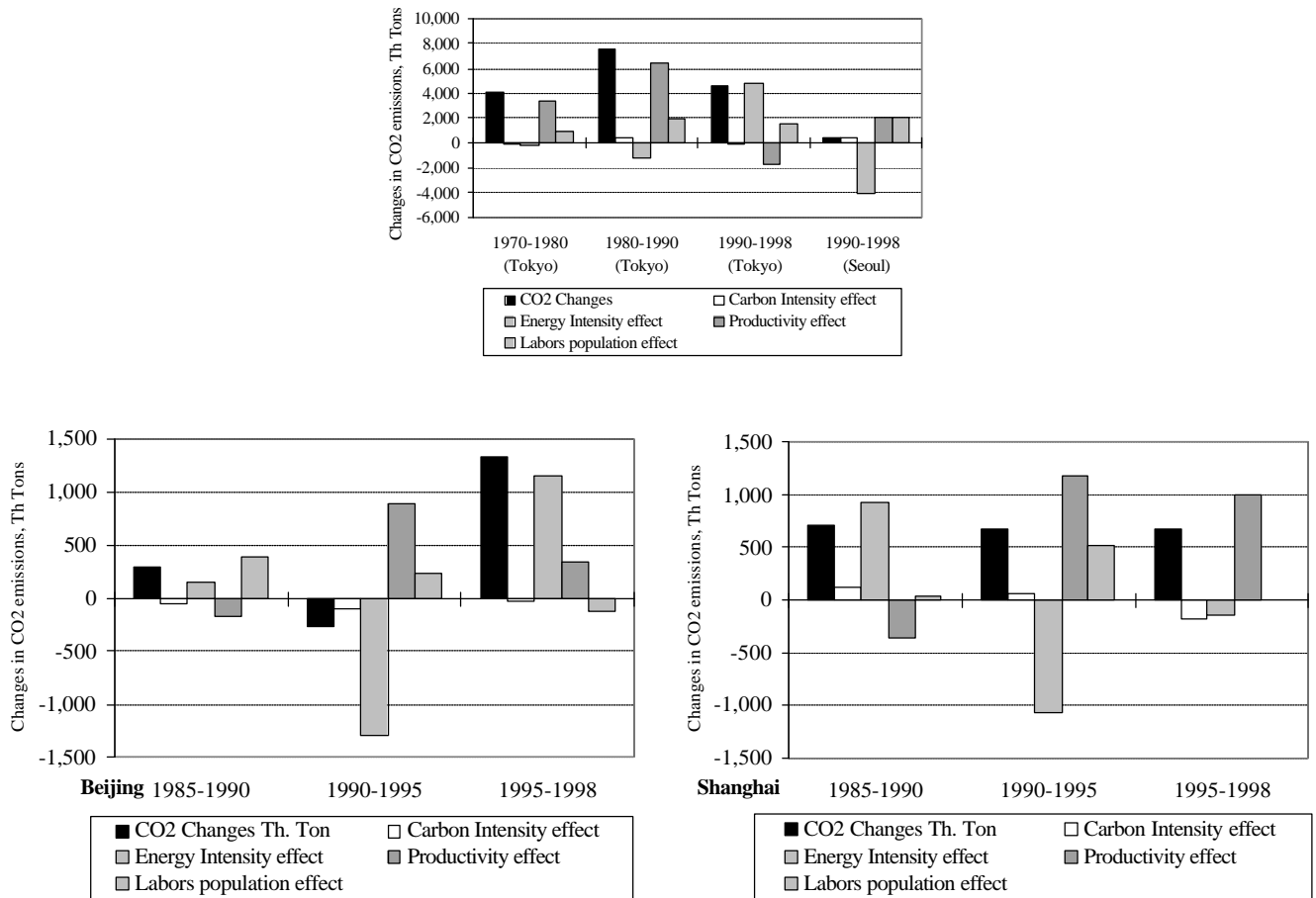


**Figure 4-4-2-13: Factor decomposition for CO<sub>2</sub> emissions from residential sector**

(c) Commercial sector

Commercial sector is the biggest contributor of CO<sub>2</sub> emissions in Tokyo but is the lowest contributor in Seoul, Beijing and Shanghai. 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<sub>2</sub> emissions in Tokyo and Seoul, except for the recession period of Tokyo (see **Figure 4-4-2-14**). Energy intensity effect was responsible for most of the reduction in CO<sub>2</sub> 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 negative effects (increased emissions) to CO<sub>2</sub> emissions in all the analyzed periods. The large impact of energy intensity on CO<sub>2</sub> 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.

In case of Beijing and Shanghai, the preliminary analyses showed that the factors are unstable as in **Figure 4-4-2-14**. Energy intensity effect contributed to reduce emissions only in 1990-95 periods. Labor productivity effect contributed to increase emissions in 90s'. Further analyses would be required to explain the behavior of these factors.



**Fig. 4-4-2-14 Factor decomposition for CO<sub>2</sub> emissions from residential sector**

(d) Summary of decomposition analyses

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<sub>2</sub> emissions. Data used was for 1970-98 for Tokyo, 1990-98 for Seoul, and 1985-98 for Beijing and Shanghai. The results have suggested that income effect was primarily responsible for majority of CO<sub>2</sub> 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<sub>2</sub> emissions in Seoul and Tokyo, respectively in that period. Despite economic recession, CO<sub>2</sub> emissions continue to grow in Tokyo in 1990-98, largely due to energy intensity effect. In case of rapidly industrializing Beijing and Shanghai, income effect was found primarily responsible for increasing emissions while energy intensity effect for decreasing emissions.

In transportation sector, vehicle population effect was responsible for the majority of CO<sub>2</sub> emissions in all four 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<sub>2</sub> 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. In Beijing and Shanghai, carbon intensity and energy intensity effects contributed to reduce emissions while income effect and household population effect were majorly responsible for increasing emissions in 1985-90. In Beijing, the volume of emissions has actually decreased in 1995-98 while factors' contributions followed past trends. In case of Shanghai, the emissions volume increased in 1995-98 unlike Beijing; energy intensity actually contributed to increase emissions. For commercial sector, labor productivity effect is dominant in increasing CO<sub>2</sub> emissions in high growth period and energy intensity for reducing CO<sub>2</sub> emissions in Tokyo and Seoul. In Beijing and Shanghai, energy intensity effect contributed to reduce emissions only in 1990-95 periods. Labor productivity effect contributed to increase emissions in 90s'.

However, the meaning of decomposition analysis should be traded carefully. For example, energy intensity effect of transportation sector is the changes in CO<sub>2</sub> 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 the future research such behavior of these factors should be co-related with actual policies.