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CO_2 EMISSIONS FROM ENERGY USE IN EAST ASIAN MEGA-CITIES: DRIVING FACTORS AND THEIR CONTRIBUTIONS

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This paper estimates and analyzes CO_2 emissions from energy use in Beijing and Shanghai and compares them with Tokyo and Seoul. The contributions of selected driving factors in total and sectoral CO_2 emissions are investigated by factor decomposition method. In 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_2 emissions. The structures of factors in transportation, residential and commercial sectors are different in each city and time, owing to each city's distinguish features. Especially in Beijing and Shanghai the behavior of such factors are relatively unstable.

Key Words : *greenhouse gas emissions, mega-city, factor decomposition*

1. INTRODUCTION

The role of cities in global climate debate is important, as cities are often responsible for emitting large amount of Carbon dioxide (CO_2). In particular, if the energy system in rapidly industrializing cities is dominated heavily by coal (such as Indian and China), such rapid industrialization results into rapid increase in CO_2 emissions.

An earlier paper of authors had estimated CO_2 emission from Tokyo and Seoul based on energy statistics using local and IPCC emissions factors and compared their emissions volumes and driving factors using factor decomposition method [1]. Authors have pointed out in earlier paper that the analyses of energy and CO_2 emissions at national scale have been vigorously done in the past but at city scale such analyses, especially international comparisons, are limited. At national scale some such studied have been reported [2]. Most of the existing researches at city scale are yet trying to cover all urban sectors whose focus is at methodological development for estimating urban energy and making CO_2 inventory. This paper skips all those discussions made earlier by authors[1]; it estimates CO_2 emissions from Beijing and Shanghai and compares them with earlier estimates of Tokyo and Seoul; so four cities are compared in this paper for CO_2 emissions from energy use, their past trend, and contributions of driving factors for total and sectoral (transportation, residential and commercial sectors) CO_2 emissions by factor decomposition method.

2. METHODOLOGY AND DATA

Various methods are being used for factor analyses in existing literatures. Factor Decomposition, Vector Auto Regression (VAR), Correlation Analysis[3] and others can analyze the role of various factors. Factor decomposition method, in particular, is popular to understand the historical transition of emissions by using selected exogenous indicator variables[4, 5), 6), 7), 8), 9), 10), 11)]. This paper follows earlier paper of authors [1]; the decomposition method is based on Sun[12] and Luukkanen & Kaivooja[8]. This is illustrated below.

If CI, EI, PC and P are denoted by carbon intensity, energy intensity, per capita GRP and population, respectively then the increase in emissions (C) 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 increment amount is denoted by Δ, then

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

R is residual. Authors distributed R to (1), (2), (3) and (4) in such as a way that each incremental term gets an equal share of R[1].

This gives perfect decomposition with no residuals such that change in emissions C is,

$C = CI\ effect + EI\ effect + Income\ Effect + Population\ Effect$

Similar approach of decomposition was used for CO_2 emissions from different sectors as in Table 1.

Table 1: Decomposition variables for sectors

Sector	Factors			
Transportation	Carbon intensity: amount of CO_2 emissions per unit energy consumption, reflect fuel quality and substitution	Energy intensity: amount of energy consumption per vehicle travel distance (aggregate)	Vehicle utilization: vehicle kilometers traveled per vehicle	Population: number of registered vehicles
Residential	Carbon intensity: amount of CO_2 emissions per unit energy consumption	Energy intensity: amount of energy consumed per unit of household income*	Income: net disposable income per household	Scale: number of households
Commercial	Carbon intensity: amount of CO_2 emissions per unit energy consumption	Energy intensity: amount of energy consumed per unit service sector value added*	Productivity: service sector value added per labor	Scale: number of labors

*Due to data problems energy consumption per unit floor space couldn't be used.

Table 2. Economic and emission growth in Beijing and Shanghai

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

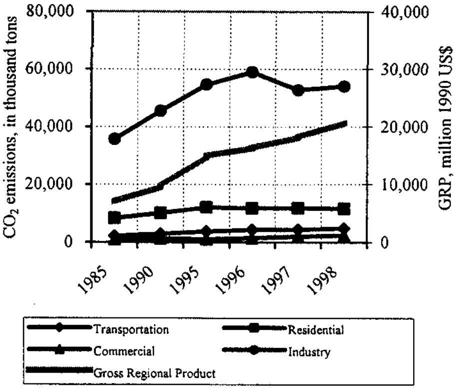
Definition for *high* and *low* are specific to Chinese context. If compared with Tokyo or Seoul, *low* economic growth numbers for of Beijing and Shanghai itself are quite *high* growth for Tokyo and Seoul. Similarly, *low* economic growth rate for Beijing and Shanghai is indeed quite *high* for Tokyo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

Database development for 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 factors, defined as CO_2 emissions per unit energy consumption by type, are obtained from IPCC[13]. 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. Major data sources are Shanghai and Beijing's Statistical Yearbook 2001 (transportation data), Urban Statistics Yearbook of China (residential sector data), China Statistics Yearbooks of China (population, income and commercial sector data), and China Energy Statistical Yearbooks (detailed energy balance tables)[14, 15, 18, 19, 20, 21]. Definitions for Beijing and Shanghai "city" are the areas administered by respective local governments. Due to data unavailability, Beijing and Shanghai are analyzed for 1985-1998 period. The effects of changes in economic growth are highlighted where applicable. The results for Tokyo and Seoul are borrowed from author's previous paper[1].

3. EMISSION TRENDS OF CITIES

Beijing and Shanghai's estimated emission 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% (Table 2). This could be due to ongoing fuel switching, increasing productivity and improving energy efficiency. These numbers are significantly higher than Tokyo and Seoul (see[1] for Tokyo and Seoul).

Emission 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 (8% and 0.6% decline in emission volume in 1996-98 in Beijing and Shanghai respectively); in terms of shares as well as absolute volume of emissions despite maintaining past trends of economic growth. Transportation sector contributed around 4-6% of total emission in Beijing and about 6-10% in Shanghai (in 1985-98) unlike other mega-cities (in case of Tokyo and Seoul such shares are 34% and



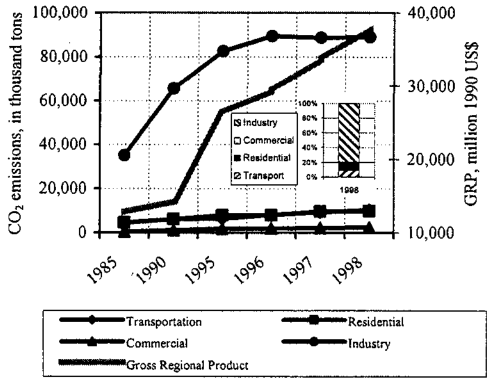
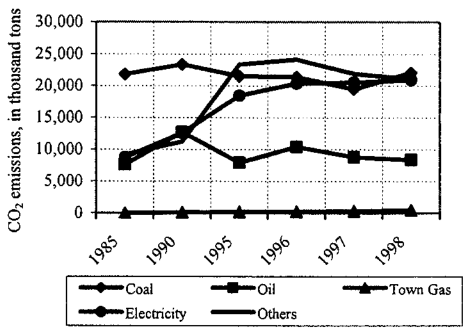


Figure 1. Sectoral CO_2 emissions in Beijing

Figure 2. Sectoral CO_2 emissions in Shanghai

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



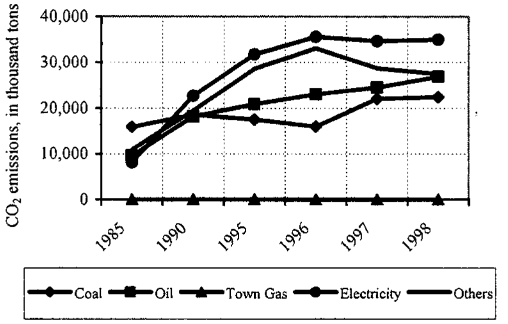


Figure 3. CO_2 emissions of Beijing by fuel type

Figure 4. CO_2 emissions of Shanghai by fuel type

(*Others* mean coking gas, coke, coking products and heat supply. Almost all energy sources for electricity, coking and heat supply are coal).

28% for 1998). However, since 1990 the shares of transportation sector emissions have an increasing trend (about 8% annual growth rate for Beijing and Shanghai in 1990-98). Per capita car ownership in Beijing and Shanghai are much lower compared to Tokyo and Seoul; a low contribution of transportation sector may be justified looking to the industry sector's dominance. For long time, there are some doubts about China's energy statistics due to their own sectoral aggregation procedure (such as accounting 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 in this study by using detail energy balance table. Coal is the major source of CO_2 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_2 emissions are increasing from about 18% in 1985 to 30% in 1998 in both cities (Figures 1-4)

In Tokyo, despite the slowing economy and negative economic growth in 1990's, emissions from only industrial sector has declined (from about 34% in 1970 to about 10% in 1998)[1]. The emissions from all other sectors, *i.e.* residential, transportation and commercial sectors, continue to grow. The share of tertiary industry in total industrial value added has increased from 67% in 1980 to 77% in 1998[14]. Basically, oil and electricity (electricity is converted to CO_2 emissions based on TEPCO's average electricity generation mix by fuel type and using fuel's emission factor) are responsible for the majority of CO_2 emissions[1]. In case of Seoul, emission from residential sector is the largest 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. Oil contributes to over 70% of total CO_2 emissions due to its dominant use in buildings and transportation sector because of the oil based centralized heating systems unlike Tokyo[1].

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

(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 5. As mentioned earlier, results for Tokyo and Seoul are taken from author's earlier paper[1]. 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. Especially in 1990s, energy intensity of Tokyo contributed unfavorably to CO_2 emissions. Some of the reasons are increasing energy use in large-scale businesses and offices due to office automation, electric appliances and use of computers. In transportation sector despite improvements in fuel efficiency, there is a structural shift towards bigger size cars so the energy performances have worsened. Due to unprecedented economic growth, it is obvious that income effect is the major factor behind increasing emissions in Beijing and Shanghai. 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 better industrial process efficiency, increasing productivity and improving energy management in industries in these cities. Privatization and closing down of energy intensive and inefficient state enterprises could be partly the reason. Since coal continues dominating energy sector, the CO_2 emissions benefits from carbon intensity effect seems to be evident only after 1995 due to some fuel switching (natural gas use and increasing use of clean coal from SOx mitigation

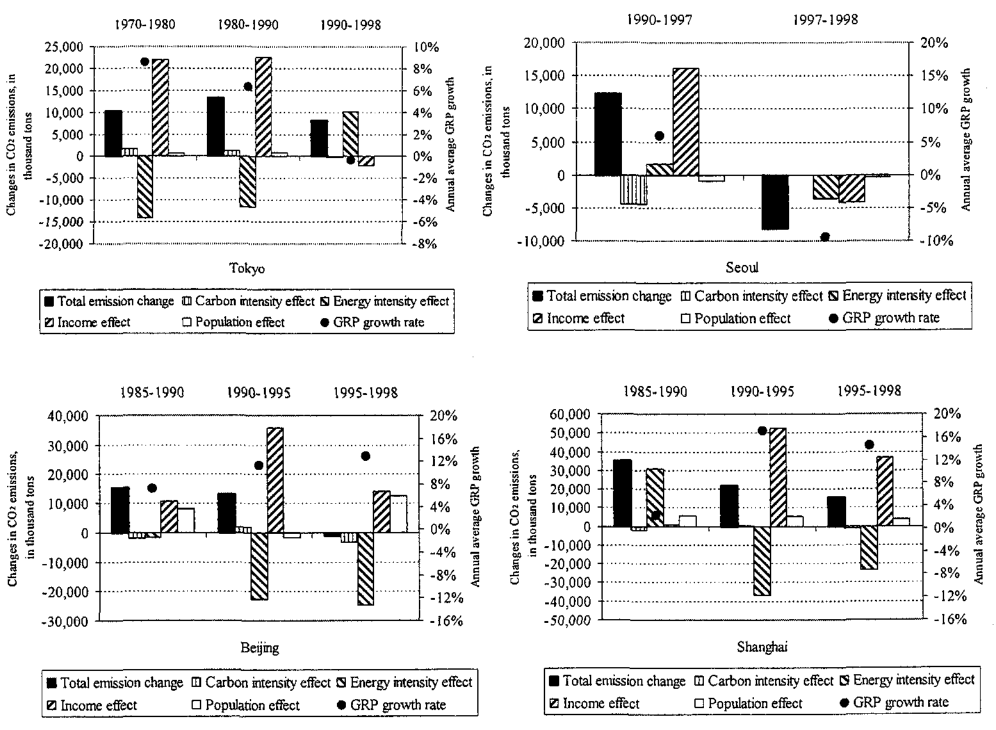


Fig. 5 Factor decomposition of CO_2 emissions from energy uses

Note: Results for Tokyo and Seoul are taken from authors' earlier study [1].

point of view) but not before that. The role of population effect was small in Shanghai but in case of Beijing it is contributing significantly. Such effect could be due to the changes in population as a result of frequent changes in the boundary of cities, for e.g. after 1996 some big counties surrounding Beijing was merged into Beijing and population data surged. At least, the implication from temporary resident should not produce such drastic changes.

Income effect was responsible for reducing CO_2 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_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 changed from 28.8% in 1990 to 1.3% in 1998) to oil and electricity is major reason for positive contribution of carbon intensity in Seoul[16),17)].

(2) Contribution of factors in sectoral emissions

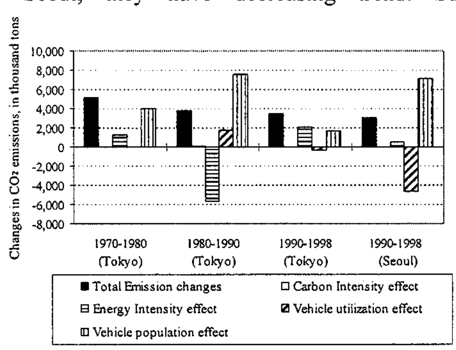
Transportation sector

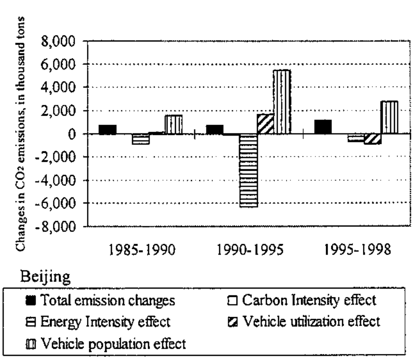
Factor analyses for transportation sector show that passenger vehicle population was responsible for most of the increase in CO_2 emissions from transportation sector in all four cities. The effect of carbon intensity was found negligible in all cases since oil remains dominant fuel for road transportation.

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. This could be due to the fact that Beijing is picking up more auto-dependency trend than Shanghai and Shanghai has attempted to control vehicle number and vehicle use than Beijing since early 90s'. In Tokyo, vehicle utilization effect contributed significantly in increasing CO_2 emissions during high growth period (80's) only[1)]. The results also indicate that energy intensity was responsible for decreasing CO_2 emissions in large amount in 80's. However, in 90's energy intensity was found to be the major cause behind increased CO_2 emissions. 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_2 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 fluctuating significantly [1)].

Residential Sector

CO_2 emissions from energy use of residential sector are relatively stable in Tokyo in recent years; in Seoul, they have decreasing trend. Such





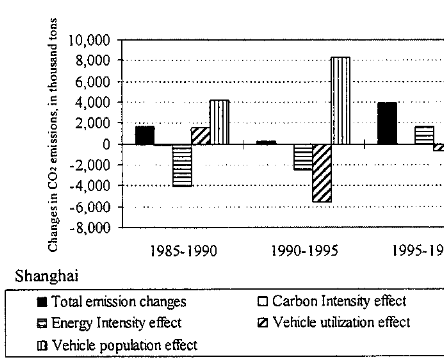
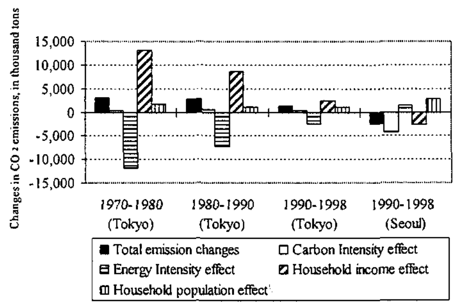


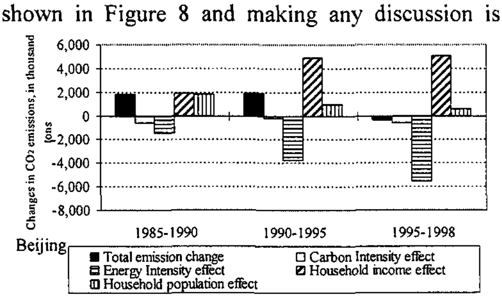
Figure 6. Factor decomposition for CO_2 emissions from transportation sector in cities

decreasing (or rather stagnated) trend is also observed for Beijing and Shanghai after 1996. Figure 7 shows the estimated contribution of each factor in the increase of CO_2 emissions from residential sector for Tokyo, Seoul, Beijing and Shanghai. Among the four factors, household income effect was mostly responsible for increasing CO_2 emissions in Tokyo followed by changes in household population. Carbon intensity effect contributed negligibly in Tokyo but energy intensity effect played important role in reducing CO_2 emissions by large amount. Also, there is less structural change of factors despite evident differences in economic growth. In case of Seoul, for 1990-98, carbon intensity effect is most prominent and it contributed to reduce CO_2 emissions. 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 domestics 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 1998 compared to 1995 unlike Beijing; inability of energy intensity to play role on reducing emissions seems the major reason for such increase in Shanghai.

Commercial sector

Commercial sector is the biggest contributor of CO_2 emissions in Tokyo but is the lowest contributor in Seoul, Beijing and Shanghai. In case of Beijing and Shanghai, the preliminary analyses shows that the factors are unstable as shown in Figure 8 and making any discussion is difficult. This could be due to the fact that factors are based on per unit service sector value added basis rather than per unit floor space basis. The authors believe that some better discussion would have been possible but lack of data on commercial floor space hindered greatly. Figure 8 has shown that energy intensity effect contributed to reduce emissions only in 1990-95 periods in Beijing and Shanghai and labor productivity effect contributed to increase emissions in 90s'. Further analyses would be required to explain the behavior of these factors. In both cities, the speed of economic growth and tertiary sector's growth has increased after 1990. Past analyses by authors for 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[1]. 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. The labor population effect has a negative effect (increased emissions) to CO_2 emissions in all the analyzed periods. Fuel switching in central heating and cooling plants from coal to oil, and increasing use of electricity in Seoul largely explains the behavior of energy intensity effect on CO_2 emissions in Seoul.





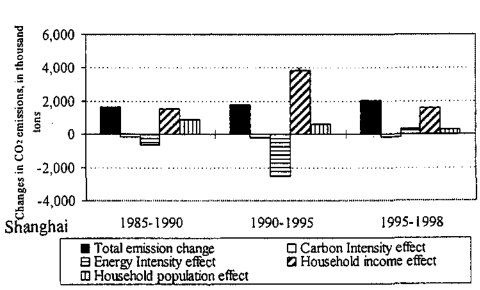


Fig. 7 Factor decomposition for CO_2 emissions from residential sector
Results for Tokyo and Seoul is taken from authors' earlier paper[1].

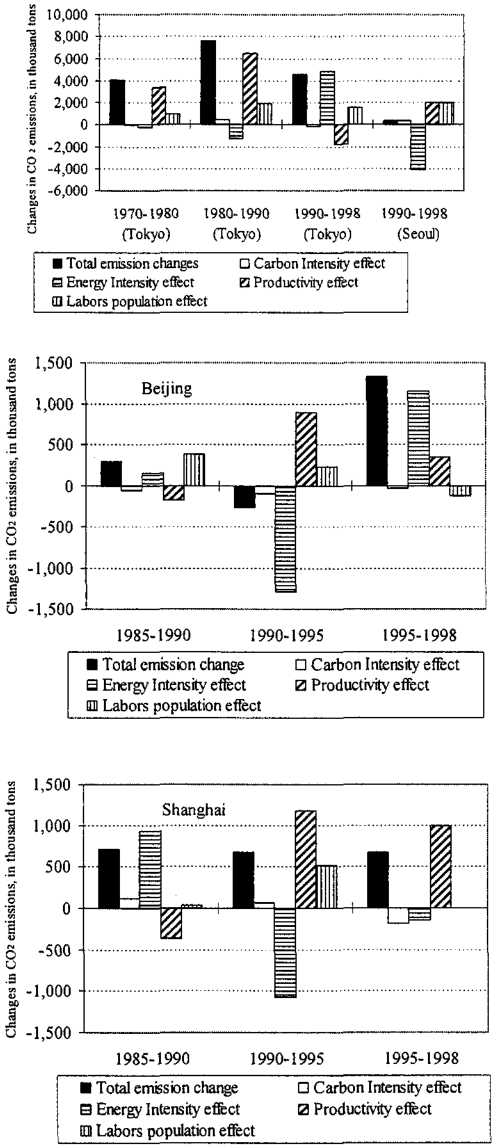


Fig. 8 Factor decomposition for CO_2 emissions from commercial sector

Results for Tokyo and Seoul are taken from authors' earlier paper[1].

5. DISCUSSIONS AND CONCLUSION

The commonality of four cities considered in this analyses has been that all of them are converging to a point for per capita energy use over the time but on other hand they are not converging on per capita CO_2 emission basis. CO_2 emissions from sectors show that transportation and commercial sectors dominate Tokyo, transportation and residential sectors dominate Seoul and industry sector dominate Beijing and Shanghai. Coal is majorly responsible CO_2 emissions in Beijing and Shanghai while oil and electricity in Tokyo and Seoul.

The results have suggested that the economic activity was primarily responsible for increasing emissions in all four cities and contribution of other factors varies from city to city. Energy intensity effect, in particular, is found to be an important factor that mostly (not always though) played an important role in reducing emissions. The role of fuel quality improvement and structural change in fuel mix is nominal except in Seoul.

In transportation sector, vehicle population effect is responsible for the majority of CO_2 emissions in all four cities due to increasing motorization. Though Beijing and Shanghai are constantly growing economically, the nature of contributions of energy intensity and vehicle utilization after 1990 seems a little different. The differences are due to the nature of these two cities as Beijing is more auto-dependent than Shanghai. Shanghai has implemented relatively stringent measures for vehicle use, such as Singapore style vehicle licensing system. Accordingly, the effect of vehicle utilization on emissions in Shanghai is favorable than Beijing. However, Shanghai's energy intensity is un-favorable to emissions than Beijing in 1995-95; one of the reasons could be due to the slow modernization of fleet (thus efficiency) in face of strong control over vehicle number. For residential sector, the difference in nature of contributing factors for Tokyo and Seoul are primarily due to the differences in building heating and cooling systems and fuel switching. In Beijing and Shanghai, fuel quality and type and energy efficiency improvement contributed to reduce emissions while growing income and household population to increase 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. 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 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'.

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REFERENCES

1) Dhakal, S., Kaneko, S. and Imura, H. : An analysis on driving factors for CO_2 emissions from energy use in Tokyo and Seoul by factor decomposition method. *Environmental systems Research*, Vol 30. pp. 295-303, 2002.
2) Hanaki, K. and Ichinose, T. ; Efficient energy use in Japanese cities, in Japanese Urban Environment, Pergamon Press, 1998, pp 178-192.
3) 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.
4) 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.
5) 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.
6) 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.
7) 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.
8) 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.
9) Nag, B. and Parikh, J : Indicators of carbon emission intensity from commercial energy use in India, *Energy Economics*, Vol. 22, pp. 441-461, 2000.
10) Hamilton, C. and Turton, H. : Determinants of emissions growth in OECD countries, *Energy Policy*, Vol. 30, pp. 63-71, 2002.
11) 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.
12) Sun, J. W. : Changes in energy consumption and energy intensity: a complete decomposition model, *Energy Economics*, Vol. 20, No. 1, pp. 85-100, 1998.
13) IPCC/OECD/IEA: *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Bracknell UK Meteorological Office, 1997.
14) Department of Industry and Transportation, National Bureau of Statistics China, *China energy statistical yearbook 1991-1996 Beijing*, China Statistical Publishing House, 1998.
15) Department of Industry and Transportation, National Bureau of Statistics China, *China energy statistical yearbook 1997-1999, Beijing*, China Statistics Press, 2001.
16) Korea Energy Economics Institute: *Yearbook of Regional Energy Statistics 1998*, Euiwang-Shi: Korea Energy Economics Institute, 1998.
17) Korea Energy Economics Institute: *Yearbook of Regional Energy Statistics 1999*, Euiwang-Shi: Korea Energy Economics Institute, 1999.
18) Beijing Municipal Statistics Bureau: *Beijing Statistical Yearbook 2001*, China Statistics Press, National Bureau of Statistics, the People's Republic of China.
19) Shanghai Municipal Statistics Bureau: *Shanghai Statistical Yearbook 2001*, China Statistics Press, National Bureau of Statistics, the People's Republic of China.
20) China Statistics Press: *China Statistical Yearbook 1990-2001*, National Bureau of Statistics, the People's Republic of China.
21) China Statistics Press: *Urban Statistical Yearbook of China 1998*, National Bureau of Statistics, the People's Republic of China.

東アジアメガシティにおけるエネルギー消費による二酸化炭素排出：要因及びその寄与

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本研究は北京市、上海市におけるエネルギー消費による二酸化炭素排出量を推計・分析し、東京とソウルとの比較を行う。総二酸化炭素排出量あるいは部門別二酸化炭素排出量に対する各要因の寄与について、要因分析法によって明らかにする。急速な発展段階にある北京市や上海市では、エネルギー消費原単位は改善されているものの、所得増加が二酸化炭素排出量増加の第一要因であることが判明した。交通部門では、自動車台数の増加が概ね唯一の原因である。交通部門、業務部門、家庭部門のそれぞれにおける要因の寄与構造は、各都市それぞれの特徴を反映して、各都市間さまざまであり時間的にも変化する。特に、北京市と上海市における各要因の寄与構造の時間変化は比較的不安定であるといえる。