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CO$_2$ Emissions from Energy Use in East Asian Mega-Cities: Driving Factors, Challenges and Strategies

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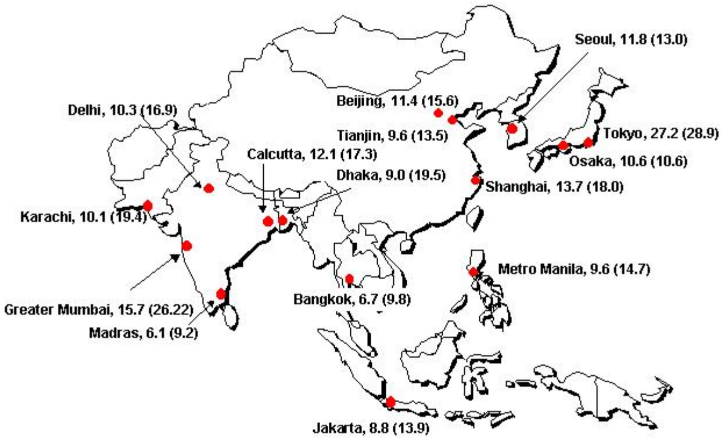
1. Sustainability, mega-cities and Asia

Human-imposed threat to global sustainability has two fundamental dimensions: *population growth* and the ever-increasing per capita *demand for good and services*, particularly material needs and energy. Both impose direct and indirect pressures on the human carrying capacity of the Earth. Today, 75% of the population in industrialized countries lives in urbanized area. Cities and sustainability are inseparably linked. Cities are centers of high living standards, population density, pollutants of air and water and producers of solid wastes. Massive infrastructure developments are underway and consumerism is spreading. The deteriorating environmental situation there has health and welfare implication for urban dwellers. In addition, a degradation of resources due to over-consumption of materials and services will also affect areas and people outside cities and have an impact on future generations.

Mega-cities are characterized by a high population density and material demands. They are also ‘front-runners’ in terms of urban development, economic growth, industrial transformation, lifestyle changes and policy implementation. From a demand point of view, mega-cities are a root cause of the sustainability problem. However, compact settlements and high population density reduce per capita infrastructure and distribution costs and also open up opportunities for economic scale effects. Thus, mega-cities can greatly facilitate the implementation of measures to reduce stress on sustainability.



Population in millions, 1996
Figures in parenthesis are for 2015

Source: UN, Population Division
Urban Agglomeration, 1950-2015 (The 1996 revision)

Rapid urbanization is a distinctive feature of Asia. For 1990-98, the average urban population growth per year was estimated at 3% for East Asia, 3.2% for South Asia and 2.1% for the world average (WDI, 2001). The potential of urban growth is tremendous in Asia: it is estimated that in developing countries the population in cities will increase

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from today‘s 40% to over 52% by 2020 (Habitat, 2001). This means that by 2030, 2.6 billion people will live in Asia, exceeding twice the current population of the People’s Republic of China and representing 53% of the world’s urban population (ECO ASIA Report, 2001). Predictions for 2015 show a total of 358 cities worldwide with a population of over a million people, of which 153 are expected to be in Asia (Habitat, 2001). From an estimated 27 mega-cities (exceeding a population of ten millions), 15 such cities will be in Asia. The sustainability implications of these mega-cities will be enormous. Thus a sustainable management of mega-cities is and will be a major issue for local as well as national policy-makers.

2. Research focus in this paper

The volumes of Gross Domestic Product (GDP) and energy demand (or CO_2 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 (Ichinose et al., 1993). On contrary, opposite trend is reported in developing countries, such as China and Thailand (Ichinose et al., 1993). In volume basis, a large city contributes significantly to total national CO_2 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_2 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_2 inventory (McEvoy et al, 1997a; McEvoy et al, 1997b; Kates et al, 1998), Baldasano et al, 1999; Bennette and Newborough, 2001; Newman, 1999; ICLEI, 1997). 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_2 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 (Kenworthy et al, 1999). 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, a inseparable link between sustainability, cities and energy use are established. Then, authors have estimated the CO_2 emissions from energy use in Tokyo, Seoul, Beijing and Shanghai and compared their CO_2 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_2 emissions, past trends of CO_2 emissions were analyzed for these cities and contributions of driving factors for total and sectoral CO_2 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 CO2 emissions and initiate appropriate policy measures. At the end of the paper few observations are drawn and policy urgency in few areas are highlighted.

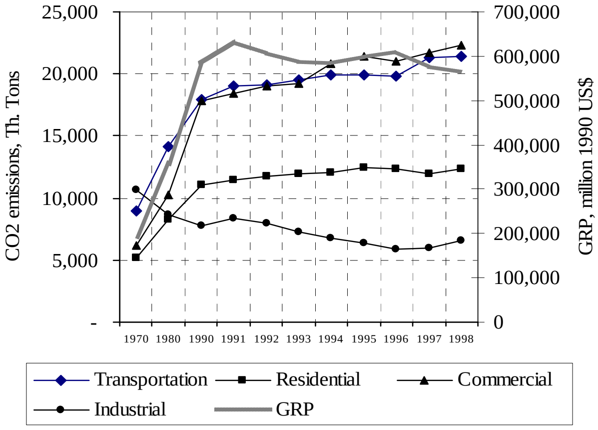

Figure 1. Sectoral emissions profile of Tokyo

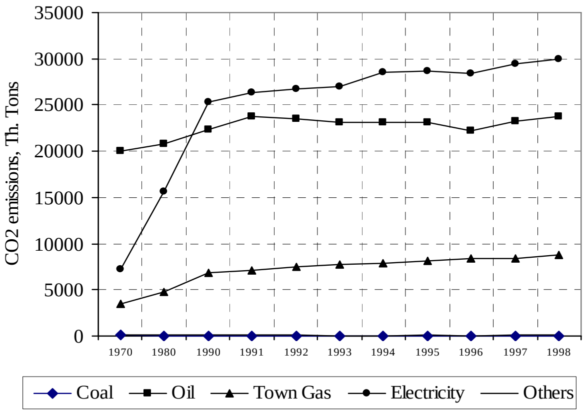

Figure 2. CO_2 emission of Tokyo by fuel type

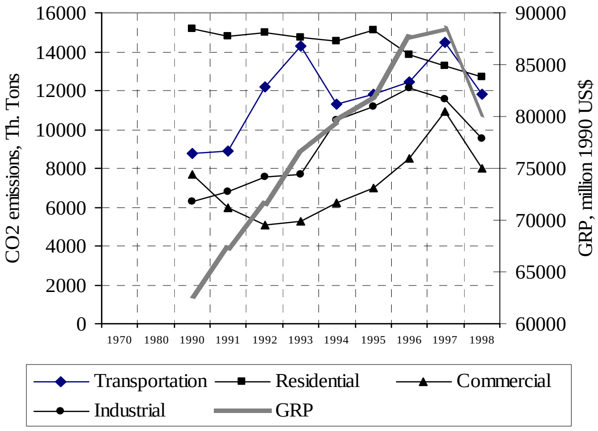

Figure 3. Sectoral emissions profile of Seoul

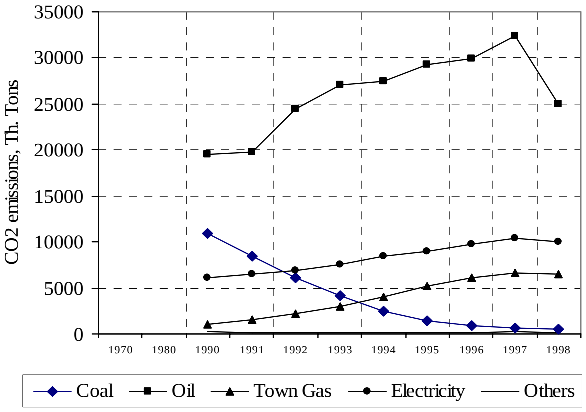

Figure 4. CO_2 emission of Seoul by fuel type

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_2 emissions per unit energy consumption by type, are obtained from locally available sources (such as Ministry of Environment of Japan) and IPCC (IPCC, 1997). BeSeTo[d] 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_2 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 (OECD, 2000). 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 (TMG, 1970-99); TMG, 2000a; TMG, 2000b; KEEI, 1998; KEEI, 1999; CESY, 1998; CESY 2001; KNSO, 2000; KNSO, 2001). City definition of Tokyo in this paper is Tokyo-to or Tokyo Metropolitan Government administered area while that for Seoul is Seoul

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[d] Literally means Beijing, Seoul and Tokyo.

City. Seoul Metropolitan Area includes Seoul City and Kyongi Province. Definitions for Beijing and Shanghai are the areas administered by respective local governments.

3. GHG Emissions from Energy Use in East Asian Mega-cities

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. 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 1. Economic and emissions growth in Beijing and Shanghai

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

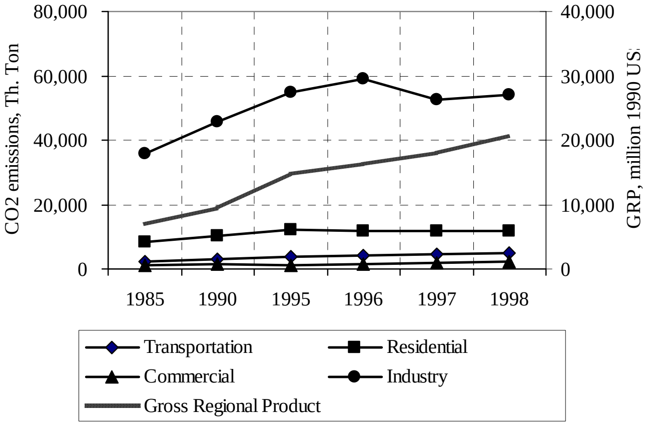

Figure 5. Sectoral CO_2 emissions in Beijing

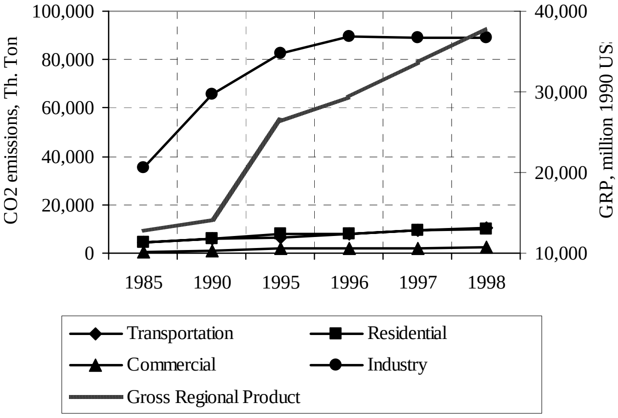

Figure 6. Sectoral CO_2 emissions in Shanghai

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

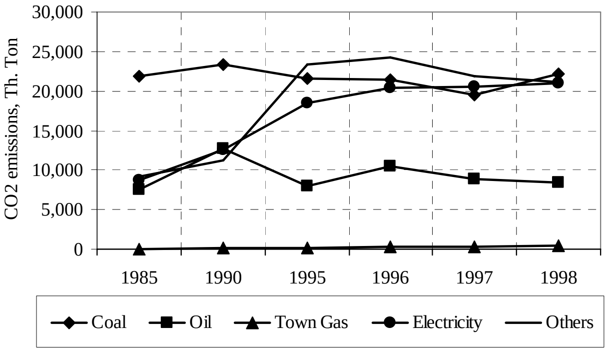

Figure 7. CO_2 emissions of Beijing by fuel type

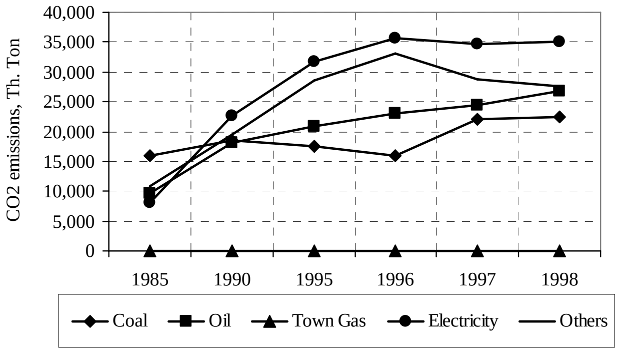

Figure 8. CO_2 emissions of Shanghai by fuel type

(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).

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_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 5-8)

3.2. CO_2 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_2 emissions per capita and CO_2 emissions per unit GDP or GRP. 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 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 (CESY, 1998; CESY, 2001) and IPCC emission factors. Furthermore, GRP for Beijing and Shanghai are obtained from Beijing Statistical Yearbook and Shanghai Statistical Yearbooks, respectively. Estimated CO_2 emission per unit 1990 GDP or GRP and per capita CO_2 emissions are plotted on logarithmic scale. Figure 9 shows the performance of cities. In Figure 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_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.

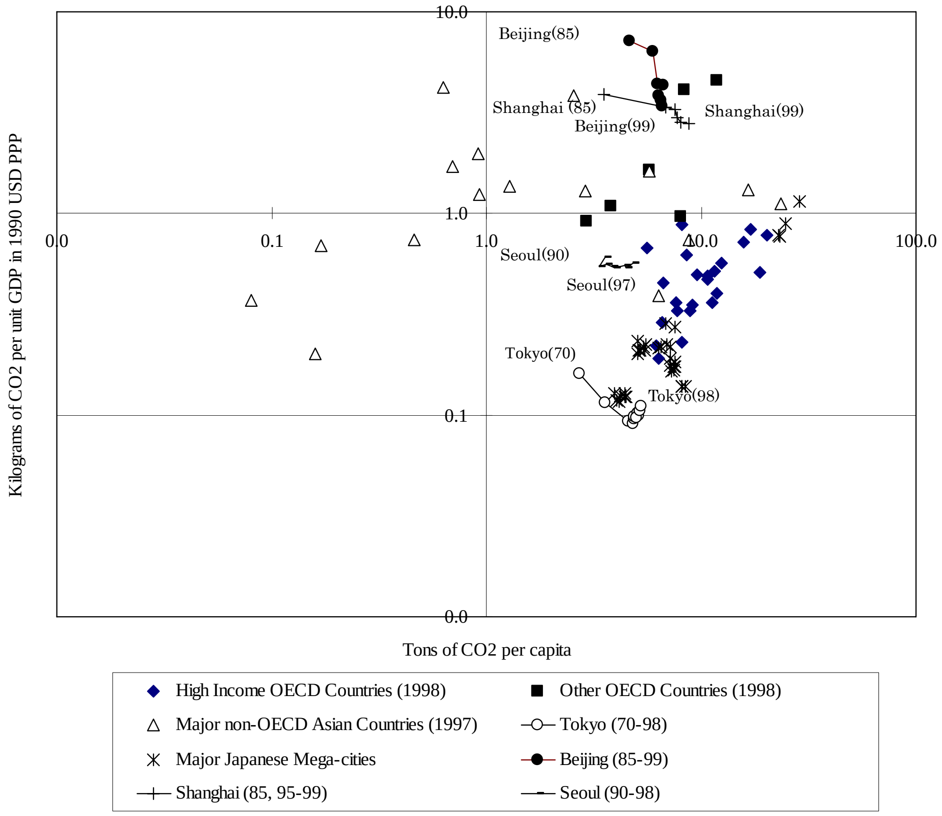

Figure 9. CO_2 emissions in per capita and per unit GRP/GDP (in log-log scale).

In deriving the per capita CO_2 emissions for Figure 9 the daytime population was used. However, studies have reported that 33% of workforces of Tokyo commute from outside Tokyo (TMG, 2000b)· The ratio of daytime to nighttime population in Tokyo and Seoul is 1.25 and 1.04 in 1999, respectively (TMG 2000b; Yoon and Araki, 2002). 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 Hanaki (2002). If such technological measures could be implemented in the future, Tokyo's performance might improve further.

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 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.

4.1. Decomposition Method

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 (Yuan and James, 2002) 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_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 cited more than one hundred published literatures (Ang and Zhang, 2000). In our study, we reviewed many literatures particularly by Shrestha and Timilsina (1996, 1998), Ang and Liu (2001), Greening et al (1998), Luukkanen & Kaivooja (2002), Nag and Parikh (2000), and Hamilton and Turton (2002). Our choice of technique is *subtractive decomposition* that follows Sun (1998) and Luukkanen & Kaivooja (2002. The major issue in any such decomposition analysis is how to handle the residual component, as perfect decomposition is difficult. This is illustrated below.

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

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

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

(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, If we denote increment amount by *Δ*, then

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

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,

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

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.

4.2. 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 10. 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 10.

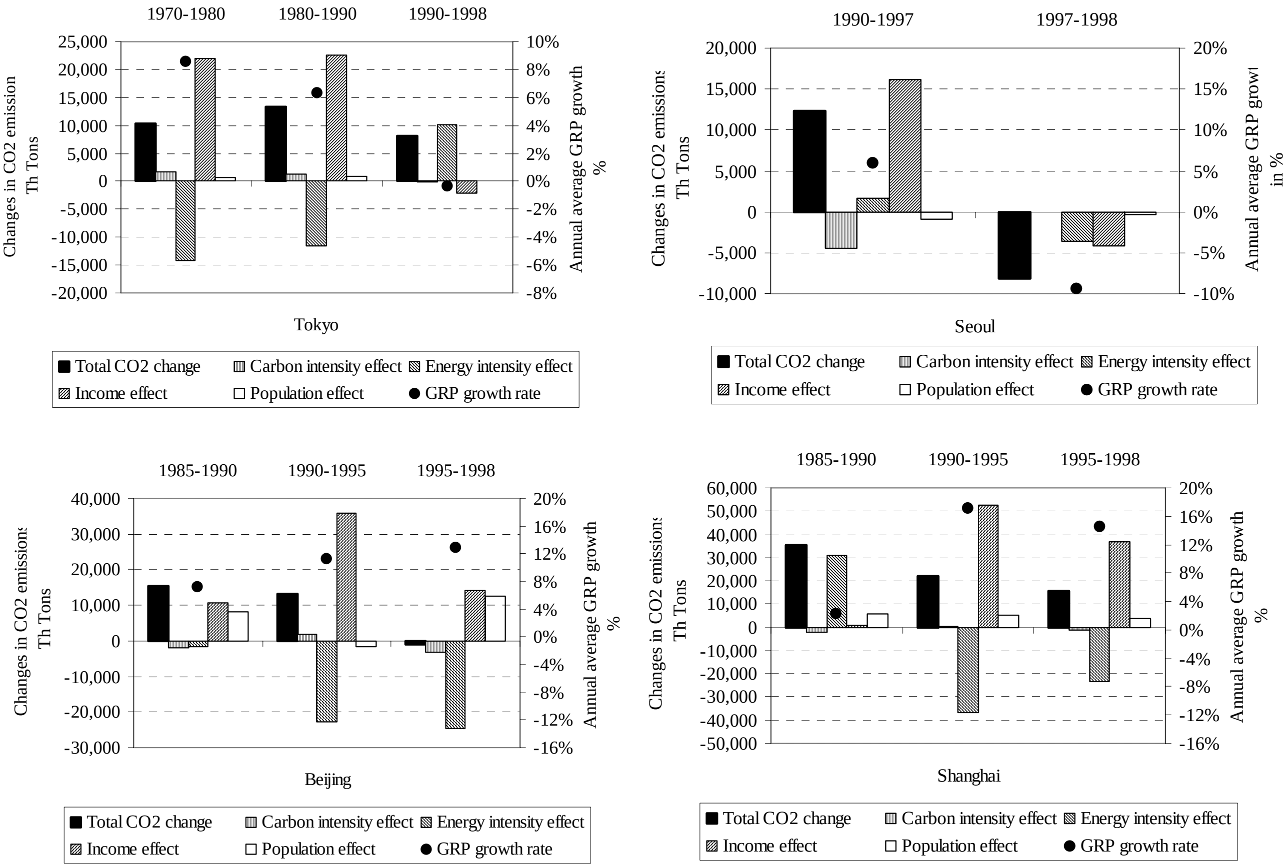

Figure 10. Factor decomposition of CO_2 emissions from energy uses

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 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_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 (KEEI, 1998; KEEI, 1999) 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_2 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.

4.3. Contribution of factors in sectoral emissions

4.3.1. 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.

In Tokyo, vehicle utilization effect contributed significantly in increasing CO_2 emissions during high growth period (80's) only. 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. Further analysis is required to explain this phenomenon, however, urban traffic congestion$^{22)}$, 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 (MITI 1998). In Seoul, vehicle utilization effect is

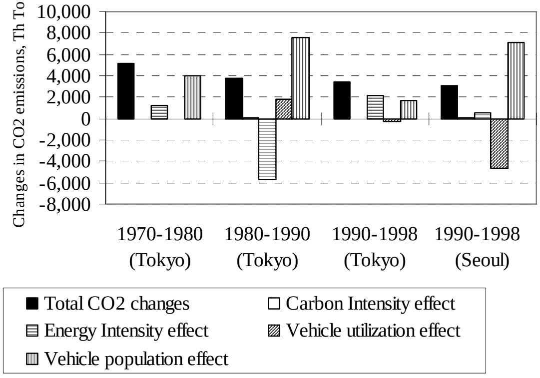

Figure 11. Factor decomposition for CO2 emissions from transportation sector

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 to fluctuate significantly.

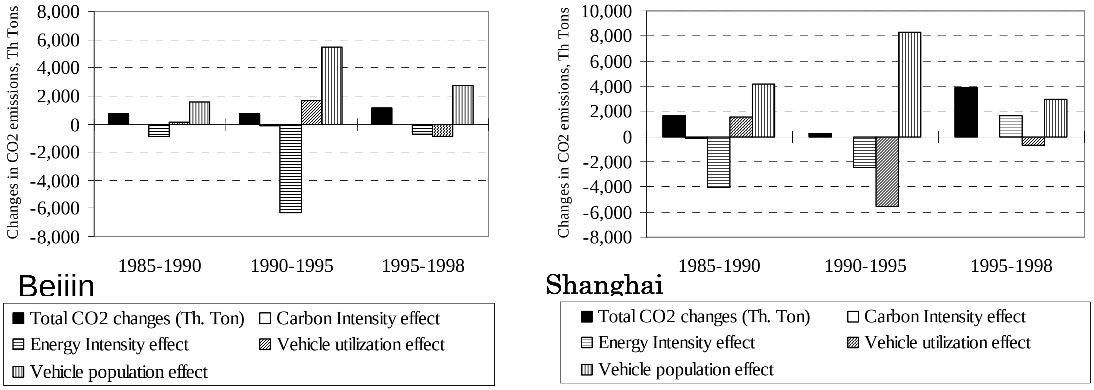

Figure 12. Decomposition for emissions from transportation sector in Beijing and Shanghai

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.

4.3.2. Residential Sector

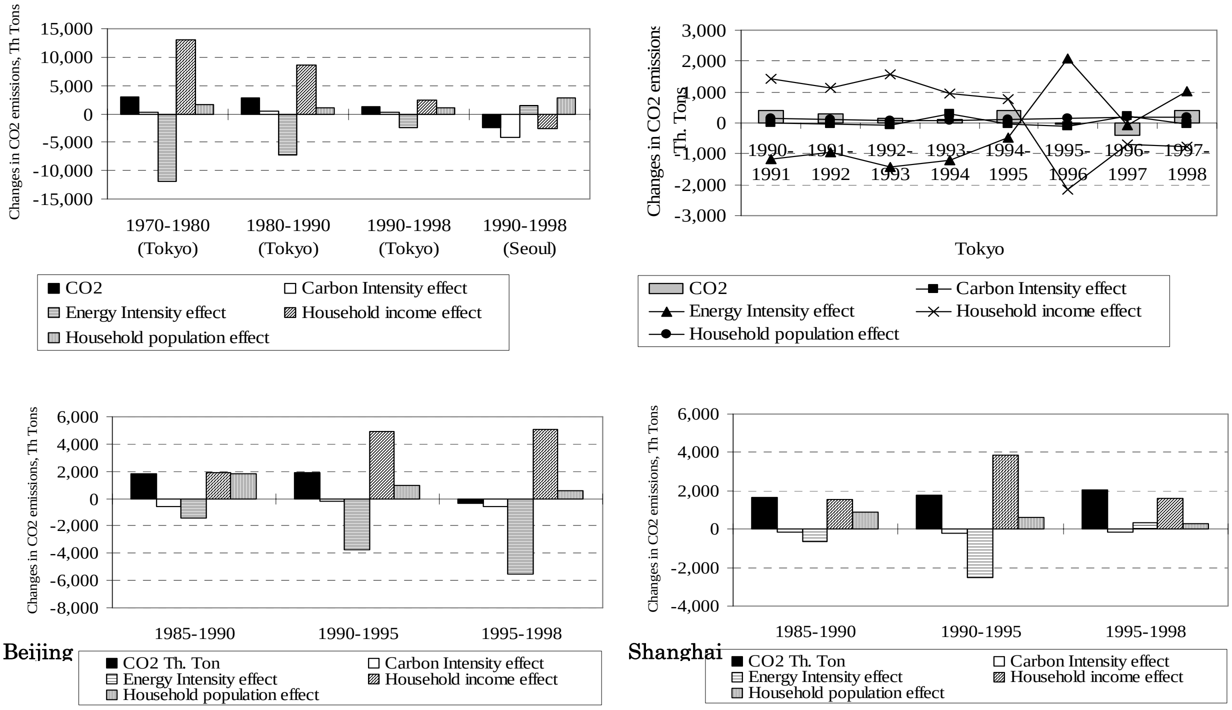

Figure 13. Factor decomposition for CO_2 emissions from residential sector

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 13. Such decreasing trend is also observed for Beijing in 1996-98 periods. Figure 13 shows the estimated contribution of each factor in the increase of CO_2 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_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.

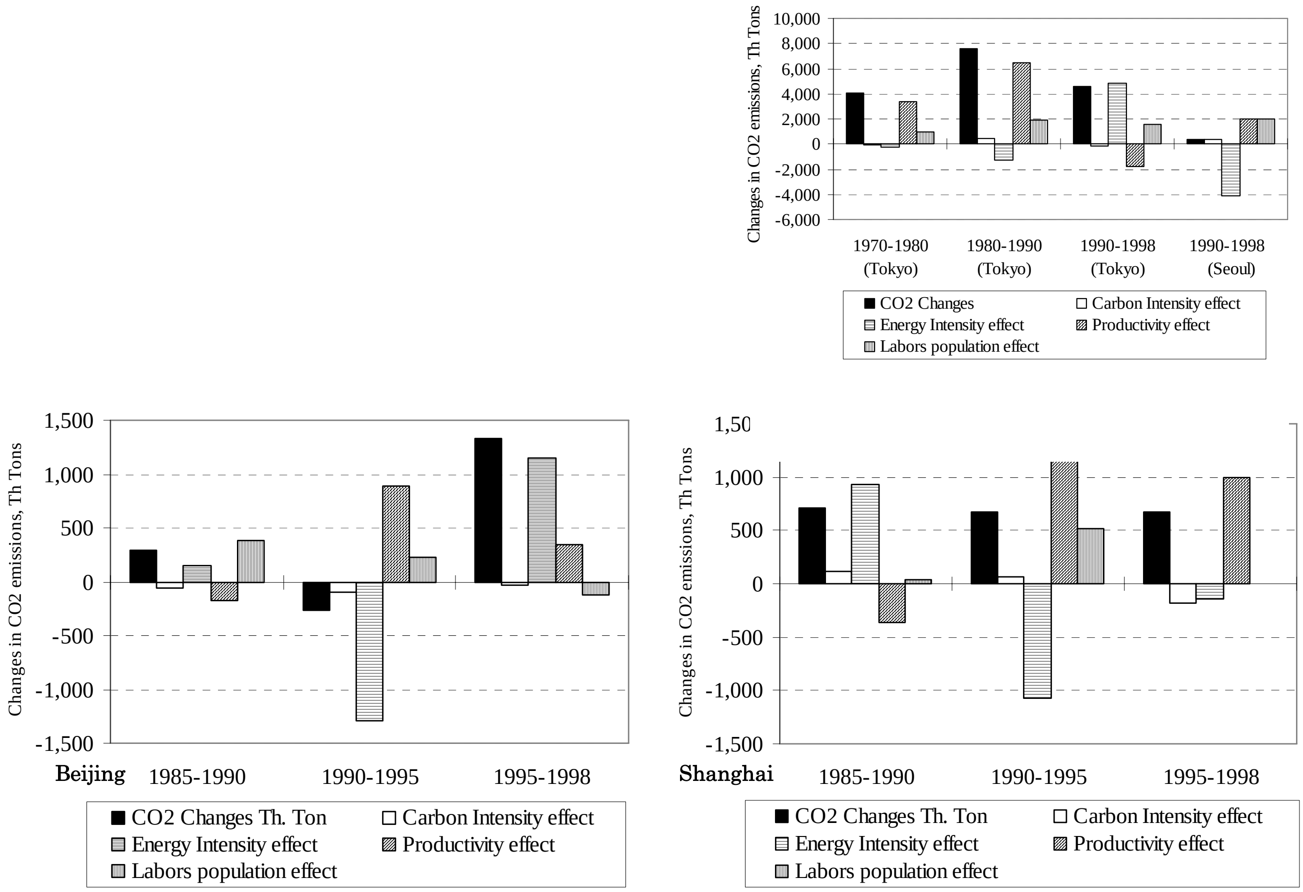

Figure 14. Factor decomposition for CO_2 emissions from residential sector

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 13, household income effect is also responsible for reducing emissions. Role of household number and energy intensity is quite 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 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 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 1995-98 unlike Beijing; energy intensity actually contributed to increase emissions.

4.3.3. Commercial sector

Commercial sector is the biggest contributor of CO_2 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_2 emissions in Tokyo and Seoul, except for the recession period of Tokyo (see Figure 14). 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 negative effects (increased emissions) 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.

In case of Beijing and Shanghai, the preliminary analyses showed that the factors are unstable as in figure 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.

4.4. 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_2 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_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 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_2 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_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. 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_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'.

However, 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 the future research such behavior of these factors should be co-related with actual policies.

5. Issues, challenges and countermeasures: Transport and Res/Com sectors

5.1. Direct energy consumption

In mega-cities, energy demand results from cooking, lighting, heating/cooling and electric appliances in households and commercial sectors, urban mobility and industries. These activities consume coal, oil, electricity, natural gas, etc., which are sources of GHG and local pollutants. Energy efficiency, frequency and use patterns, fuel choice, fuel quality, and industrial productivity are major factors that govern energy demand and GHG emissions. Usually, mega-cities have a limited scope to modify land-use patterns to achieve maximum efficiency. *The major issue is how to reduce energy demand and GHG emissions while maintaining the urban population's living standards.* Pressure is rising on countries such as Japan, China and Korea to reduce GHG emissions, and this has obvious impacts on cities.

Reducing energy demand and GHG emissions are also related to reducing local air pollution. In Tokyo, population growth is more or less stabilized, but per capita energy consumption is increasing. Therefore, major opportunities for policy interventions are in the road transportation and household sectors. Coal use is almost eliminated in Tokyo; fuel switching and enhancing industrial manufacturing processes play a minor role in reducing GHG emissions. *Key to these issues is a change in lifestyle and consumer behavior*. In Seoul, fuel switching in industries and buildings has contributed significantly to reducing GHG emissions in the last decade. Unlike Tokyo, Seoul uses central heating systems in buildings. The potentials for improving energy efficiency and fuel switching are high because in the past switches were mainly from coal to oil and, to some extent, from oil to gas. Road transportation and private cars are another area of concern in Seoul.

For Beijing and Shanghai, industry, buildings and urban transportation are sectors with a great potential for interventions to reduce GHG emissions. In both cities, fuel switching in industries is a viable option. Building insulation, efficiency improvement of electric appliances and fuel switching for central heating systems can also play an important role in reducing energy and GHG emissions. Fuel switching would contribute to significantly reducing local pollutants. In Shanghai, car-limiting policies have been some success; this city has adopted the Singapore style of auctioning registration permits for new vehicles.

GHG emissions from urban transportation may seem low at the moment for both Beijing and Shanghai. However, massive investments in the transport systems are planned for the coming years, which bring about the threat of greater energy use, air pollution and GHG emissions. Although, compared to other mega-cities, private cars are relatively little used now; Shanghai and Beijing are already suffering from serious air pollution from the transport sector.

Table 2. Air quality in selected cities, in micrograms per cubic meters

City	Total suspended particulates (1995)	Sulfur dioxide (1998)	Nitrogen dioxide (1998)
Beijing	377	90	122
Shanghai	246	53	73
Tokyo	49	18	68
Seoul	84	44	60

Source: World Development Indicators 2001, pp –75. Table 6

Further, China's growing economy and WTO membership is likely to increase incomes, reduce tariffs for automobiles (due to competition) and enhance credit facilitation mechanism. Thus, urban planners in Beijing and Shanghai are already projecting a 3-4-fold increase of cars and trucks by 2020. The transportation in these cities highly depends on road transportation infrastructure, and is following the trajectory of other cities such as Bangkok, which suffers from severe congestion and air pollution. Government see private vehicle growth (automobile industry[e]) and infrastructure development as a driving force for economic growth through stimulating personal consumption. Accordingly private vehicle stimulating policies such as purchase loans, reduced fee for vehicles use[f] and lengthening the useful life of passenger cars from 10 to 15 years are being implemented (Lin, 2003).

5.2. Material consumption related indirect emissions

For a sustainable development, both direct and indirect emissions are of importance. As mega-cities consume huge amounts of materials and goods, this has implications for manufacturing and resource-extraction sites outside cities. Therefore, cities should be judged by their *"total environmental load"*, taking also into account indirect emissions too. Analyses suggest that the indirect energy consumption of Tokyo (1995) and Shanghai (1992) is almost 3 times and 2 times higher than their direct energy consumption, respectively[g]. In Beijing, both direct and indirect energy consumption are estimated to be equal. Since energy consumption is the proxy to GHG emissions, the "environmental load" that Tokyo exerts to other places is significantly higher than its direct emissions.

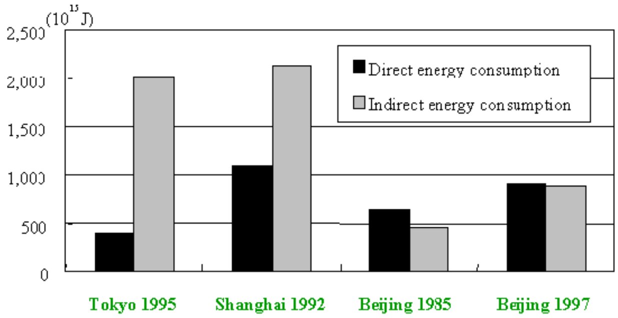

Figure 15. Direct and indirect energy consumption of targeted cities (primary energy base)
Source: Nakayama (2002)

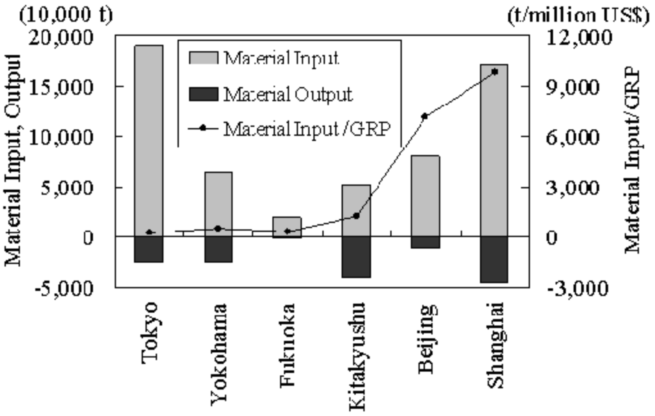

Figure 16. Material balance in selected cities

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[e] In 1998, China was ranked 10th in automobile production in the world. Produced 2 million vehicles in 2000.

[f] Chinese government stopped collecting 238 different fees related to vehicle use. See http://finance.sina.com.cn[34)]

[g] Nakayama (2002), Kyushu University

5.3. *Few Plausible Countermeasures in Transportation and Building Sectors*

Potential countermeasures in the transportation sector include a switch to alternative fuels (e.g. compressed natural gas - CNG); promoting electric and hybrid vehicles; increasing average vehicle speed through traffic management; increasing the fuel efficiency of cars and improving fuel quality; improved public mass transportation systems and limiting private cars; and appropriate land-use planning. These measures should contribute to reducing travel demand, trip length and frequency.

In Beijing, light duty gasoline trucks and cars are expected to become a key component in future reductions of energy demand and GHG emissions. However, car-limiting policies for new vehicles alone would not be sufficient in Beijing and Shanghai; greater efforts are needed to control vehicles in use and to reduce vehicle mileage. Efficient public mass transportation systems are inevitable for these cities. Car-limiting policies are difficult to be implemented in Tokyo and Seoul. In terms of fuel efficiency, fuel quality and the end-of-pipe technology at vehicle tailpipe, there is limited scope for further drastic improvement in Tokyo and Seoul, but the most promising way is to implement policies that motivate people to change their lifestyle (such as driving behavior), and to set up a system of economic instruments such as parking fees.

The prospects for implementing countermeasures in the building sector are also enormous in these cities. This includes improvements in building insulation, appliance efficiency, and efficient central heating systems. Government policies can aim at a building code, laws, and standards for promoting appliance efficiency. Simple measures such as changing from incandescent lamps to fluorescent lamps can save huge amounts of electricity. The scope for improvements in appliance efficiency may be much less in Seoul and Tokyo than in Beijing and Shanghai. The use of renewable energy such as solar panel for hot water production, appropriate temperature settings for heating and cooling systems, and avoiding waste of electricity are key to saving energy.

6. Summary: Overcoming the challenges to the path of sustainability

The objective of this paper is to discuss and explore the link between cities, sustainability, energy and green house gas emission with providing an overview of East Asian mega-cities. In particular, it estimated CO_2 emissions from energy use in four East Asian mega-cities; Tokyo, Seoul, Beijing and Shanghai and analyzed them and their few driving factors. Although national scale analyses of the CO_2 emissions from energy use are very common, similar analyses at city scale are not common yet in Asia and the results are hoped to be useful to subsequent research. The results have shown that the performance of Tokyo is outstanding in comparison to major Japanese large cities, Seoul, Beijing, Shanghai, major OECD and major non-OECD countries. 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 need to consider in future comparisons. CO_2 emissions from sectors show that transportation and commercial sectors dominate Tokyo, transportation and residential sectors dominate Seoul and industry sector dominates Beijing and Shanghai. Coal is majorly responsible CO_2 emissions in Beijing and Shanghai while oil and electricity in Tokyo and Seoul. Despite the large differences in the volumes of energy consumption, all four cities are approaching towards similar per capita energy consumption. Income effects are largely responsible for majority of emissions in all the four cities. Carbon intensity played big role in Seoul and some role in Beijing and Shanghai in reducing emissions but not in Tokyo. Energy intensity effect also contributed in reducing emissions in these cities. There are considerable differences in the ways driving factors contributed to sectoral emissions in each city. This paper also emphasizes the need to incorporate indirect energy (and thus emissions), as a result of consumption pressure, into the actual policy making agenda. Few final concluding observations are listed below.

6.1. Concluding Observations

- Mega-cities already pose significant *sustainability challenges* in the future, and managing them would become more complex and delicate. However *counter measures are available* through appropriate policies.
- Environmental Kuznet curve says that environmental degradation or energy use increases with rising income and after it reaches to a point, rise of income leads to the reduction of energy use or environmental degradation. In this regard, a developing country should not follow the model of developed countries and instead *"leap-frog"* i.e. reduction in energy consumption at the earlier stage of income growth is essential. Learning from the lessons of the developed countries and remodeling polices to avoid the mistakes that were done by developed countries are necessary.
- Asian mega-cities are rapidly developing and are in the process of constructing massive infrastructures. Once these infrastructures are constructed, they will be in no position to significantly alter or change these infrastructures. Therefore, policy makers should incorporate the concept of energy efficiency and should think of the environment while constructing these infrastructures in order to *avoid future problem* after *"lock-in"* to these *infrastructures*. It is not too late for policymakers to make a visionary policies to make energy-efficient-cities in terms of infrastructure. Mass transportation strategies such as rail network and others may look financially demanding for the time being, but worth pursuing in the long-term and in a number of stages. Construction of such efficient infrastructure is possible with the joint sharing of cost between private sector, citizens and the government, in the form of *innovative financial mechanisms*.
- Due to rapidly rising household disposable income in rapidly industrializing countries, *lifestyle* is becoming more energy intensive in mega-cities and people are indifferent towards energy use. A drastic campaign and rising of the awareness is necessary on the part of policymakers, non- governmental organisations (NGOs) and concerned organizations such as media.
- *Mega-cities in Asia are not "durable"* due to the low life cycle of buildings and other infrastructures. Drastic changes in building construction material and techniques are required to make a "durable" city. This helps to reduce the consumption of natural resources and thus reduces the impact of mega-cities to other places from where these resources are extracted or manufactured.
- Particularly in the building sector, *building insulation* is a very important issue, from the energy perspective, that is largely not taken seriously by policy makers in Asian mega-cities. Some of the mega-cities such as Shanghai saw rapid income rise in the last one decade, this has compounded the use of heating and cooling devices but building insulation could not keep pace. Good policies promoting energy efficiency in building through building code or others can contribute significantly in reducing energy demand.
- Yet, even those concerned policymakers are thinking in terms of direct energy demand and environmental emissions. If cities are to promote sustainability, understanding the interdependency of material use and energy is necessary. Policy makers should *think in-terms of "environmental load"* in mega-cities that not only accounts for direct energy demand and emissions places. Therefore, thinking in terms of "total" energy demand and emissions is necessary, including direct as well as embodied in materials used in the

mega-cities. Then only can the city move towards sustainability. Appropriate polices that promote efficient material use is key to sustainability.

- Although economically viable technologies are used in all mega-cities, *technology has a bigger role to play in the future* in all mega-cities. Promotion of alternative fuel, transportation technology, renewable energy technology and building technologies are necessary. Further, dissemination of existing high technology to developing mega-cities is a key.
- Technology improvement, management improvement and lifestyle changes are key to *avoid sustainability crisis*.

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