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Urban Energy Use in Asian Mega-Cities: Is Tokyo a Desirable Model?

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1. Introduction

The volume of Gross Domestic Product (GDP) and energy demand (or CO_2 emissions) have direct co-relation since economies heavily rely on the fossil fuels as sources of energy. Urban areas in particular, contribute significantly to total green house gas emissions, mainly Carbon Dioxide (CO_2), due to high energy demand in cities. The pattern of energy consumption in Japan shows that per capita energy consumption in urban area is lower than that of non-urban areas (Ichinose et al., 1993) and this phenomenon is common in developed countries. On contrary, in developing countries such as China and Thailand, opposite trend is reported (Ichinose et al., 1993). Mass transportation system, industrial structure, building floor space per household, urban growth structure and many other factors play complex role in shaping the energy footprint of a city. However, mega-cities are characterized by large population, increased travel demand and enhanced business and commercial activities, therefore the total volume of CO_2 emission or energy consumption contribution of mega-cities are very significant.

In this paper, authors have estimated the CO_2 emissions from energy use in selected cities and analyzed the performance of the cities in terms of the relation between per capita CO_2 emissions and per capita gross regional product (GRP). The results show that Tokyo's performance is outstanding. Based on this, authors have tried to raise the question whether Tokyo is a desirable model for urban energy use.

To understand the further intricacies of efficient energy use (in terms of CO_2 emissions), the past trends of CO_2 emission are studied and factor analysis was carried out to investigate contribution of factors such as energy intensity, per capita GRP, population in total and sectoral CO_2 emissions by Kaya's Factor Decomposition Method. Further, situational factors of Tokyo were analyzed based on industrial structure, travel pattern, motorization trend and household energy pattern.

This paper is a preliminary product of an ongoing study on urban energy use and environmental emissions in Asian mega-cities. The objective of this paper is to share the results of the preliminary analysis and to raise the relevant

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questions, rather then giving answers, for scoping the future research in this area. For this, the paper is rather ambitious in conveying the results of the preliminary analysis.

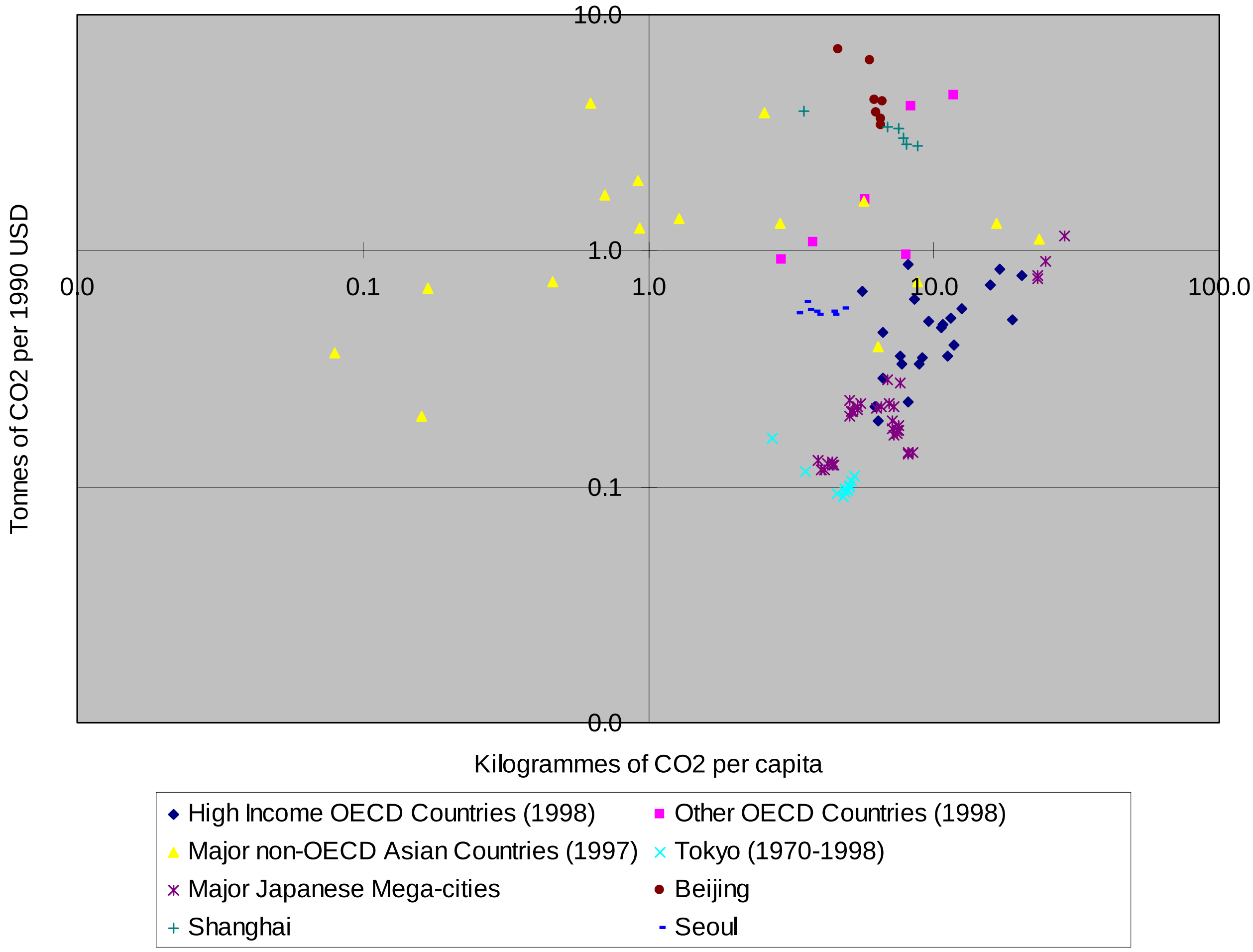

Figure 1. CO_2 emissions in per capita and per unit GRP/GDP (in log-log scale)

2. CO_2 emission performance of cities

A comparison of OECD countries, major non-OECD countries and cities in East Asia, in terms of CO_2 per unit GDP and CO_2 per capita, reveals that performance of Japanese cities is better in comparison to others, and, performance of Tokyo is outstanding. In recent years, after 1990, performance of Tokyo is seen to stagnate mainly due to the slowing down of economy. 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 while slightly increasing in per capita terms. Reducing CO_2 per capita seems to be a major difficulty for cities as all cities have failed in that aspect.

While deriving the per capita CO_2 emissions in Tokyo, the daytime population was used. However, studies have suggested that about 33% of Tokyo's workforce commute from outside Tokyo (TMG, 2000) and this makes the ratio of day-time to night-time population almost 1.25. If such commuting population were included in per capita CO_2 estimation, performance of Tokyo would improve further.

This suggests that Tokyo is already operating at a high performance state. In that sense, Tokyo might be able to serve as a desirable model to catch up with for rapidly developing cities, particularly cities in East Asia. However, Tokyo might not escape from needs to further cutting down of CO_2 emissions to contribute towards meeting Japan's commitments of 6% reduction in Kyoto Protocol. Therefore, Tokyo might have further scope of CO_2 reductions, mainly in buildings and transportation sectors by variety of technical and behavioral changes. Bottom-up modelers have demonstrated that such cut down is possible (Hanaki, 2002). If such measures could be implemented, it would further contribute towards making Tokyo a desirable model to catch up by other similar cities.

3. Trends of CO_2 emissions in Tokyo

In order to answer the question why Tokyo is performing better, CO_2 emissions by sector and fuel type have been investigated since 1970. The results suggested that in last three decades CO_2 emission has more than doubled with 2.5 % annual growth on average largely caused by economic growth or increased living standards. The contributions of transportation and commercial sectors are highest in total CO_2 emissions. Industry sector emissions has decreased significantly in last two or three decades. Basically, oil and electricity (converted to primary energy and CO_2 emissions based on average electricity generation mix) are responsible for majority of CO_2 emissions. Since the industrial sector contributed little, majority of these oil and electricity are used by transport, residential and commercial sectors.

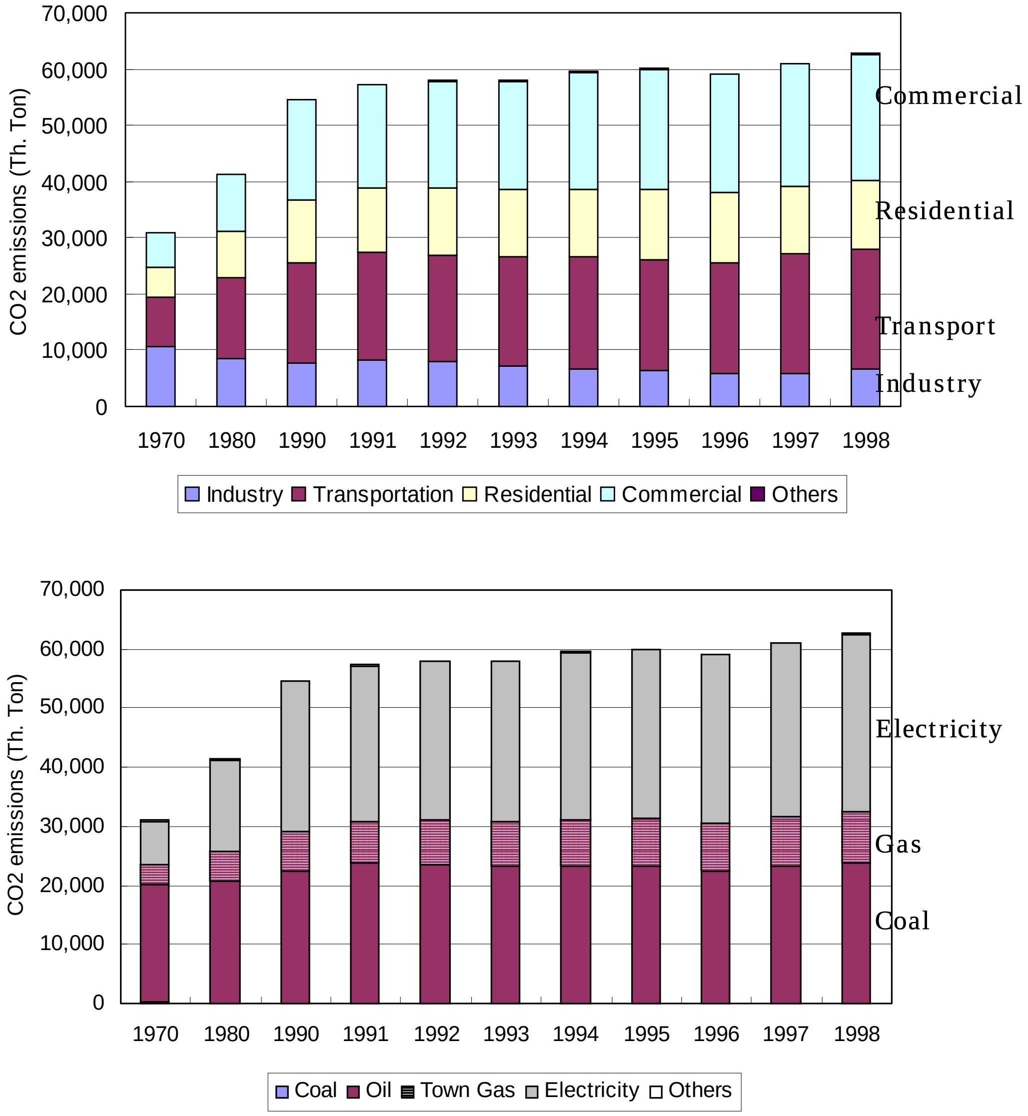

Figure 2. CO_2 emission trend by sector and fuel sources

4. Contributing factors of CO_2 emissions

4.1. Factor analysis for total CO_2 emissions

At macro level, the Kaya Identity is utilized to investigate the contribution of various factors in total CO_2 emission. This is explained by equation below.

CO_2 = CI * EI * GRPpc * Pop

Where:

CO_2 = Total carbon emissions

CI = Carbon Intensity, defined as the amount of carbon emissions per unit energy consumption which reflects the fuel mix of consumed energy in a city

EI = Energy intensity, defined as the amount of energy consumed per unit of GRP(Gross Regional Products) which reflects both energy efficiency and the macro structure of the economy

GRPpc = Per capita GRP, which is a measure of the living standard

Pop = Population.

Differentiating the equation yields:

dCO2/CO2 = dCI/CI + dEI/EI + dGRPpc/GRPpc + dPop/Pop

Change in CO_2 = Carbon intensity effect + Energy intensity effect + Per capita GRP effect + Population effect

Data for 1970, 1980, 1990 and 1998 are used for analysis. Figure 3 shows the results. While the structure of factors for increased CO_2 emission in 70's and 80's are similar, a different structure of factors are observed in 90's. This is due to the economic recession that started in early 90's after the economic "bubble burst" in late 80's. It is observed that the contribution of per capita GRP was highest in increasing CO_2 emission, that means the growth of the economic activities was the major driving force behind CO_2 emissions. Energy required to produce one unit of value added improved, thus, energy intensity played significant role in decreasing CO_2 emissions in 70's and 80's. The effect of population and carbon intensity was minimal. However, in 90's, due to slowing down of the economy, per capita GRP was found responsible for decreasing CO_2 emissions while energy intensity was worsened and was reponsible for increasing CO_2 emission.

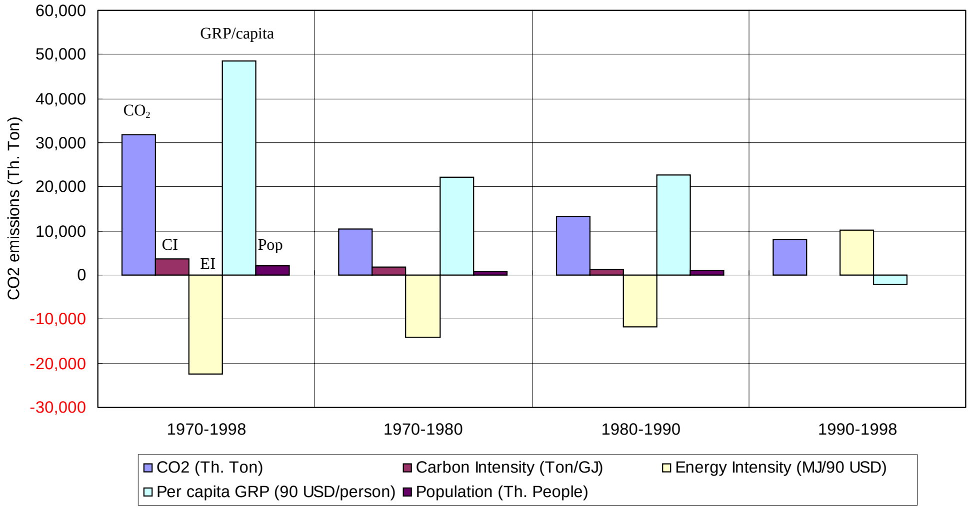

Figure 3. Factor analysis of CO_2 emissions in Tokyo for 1970-1998.

4.2. Factor analysis for CO_2 emissions from road passenger transportation

Factor analysis for road transportation sector was done with Kaya Identity as the followings:

$$CO_2 = CI * EI * VKTpv * V$$

Where:

CO_2 = Carbon emissions from transportation sector .

CI = Carbon Intensity, defined as the amount of carbon emissions per unit energy consumption which reflects the fuel mix of consumed energy in a city.

EI = Energy intensity, defined as the amount of energy consumed per unit of travel distance which reflects fuel economy of a vehicle.

VKTpv= Vehicle Kilometers Traveled per vehicle, which is an average travel distance.

V = Number of vehicle registered.

Factor analysis for transportation sector for 1970-98 was done. It is obvious that passenger vehicle population was responsible for most of the increase in CO_2 emissions from transportation sector. The effect of carbon intensity was found negligible while energy intensity (basically reflects fuel economy of fleet) contributed to decrease CO_2 emissions and travel distance per vehicle contributed to increase CO_2 emissions. The differences in structure of these factors are observed during high economic growth and recession periods. During high growth period in 80's, travel distance per vehicle contributed significantly in increasing CO_2 emissions while it contributed to decrease CO_2 emissions a little bit in 90's. The results also indicate that energy intensity was responsible for decreasing CO_2 emissions in huge amount in 80's. Between 1980 and 1990, road traffic volume (vehicle-km) had almost doubled in Tokyo. However, in 90's energy intensity was found to be the major cause behind increased CO_2 emissions. Further analysis is required to explain this phenomenon, however, urban traffic congestion and increasing share of big engine cars might be responsible. At national level, shares of car with 2000 cc or more has increased from 6% in 1990 to 27.5% in 1997, and national energy intensity is reported to increase from 885 Kcal/km in 1989 to 995 Kcal/km in 1997 while in late 80's energy intensity had decreasing trend (MITI, 1998).

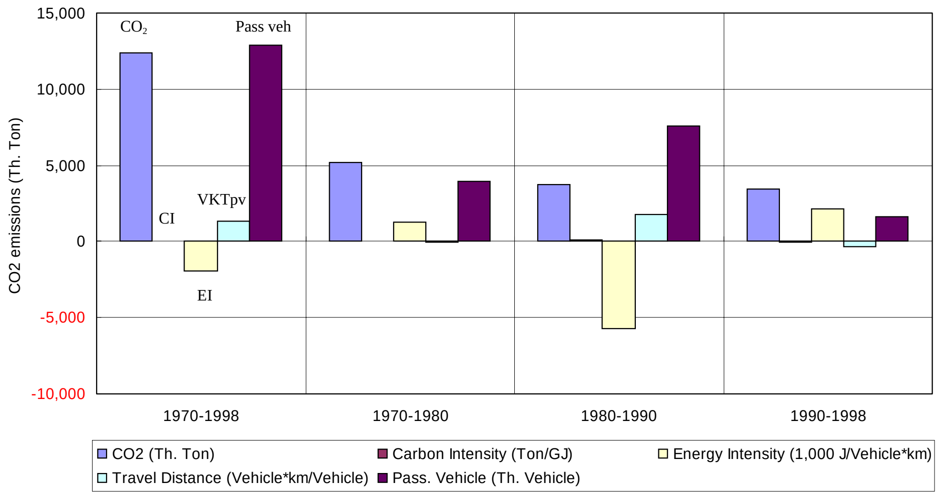

Figure 4. Factor analysis of CO_2 emissions of transportation sector in Tokyo.

4.3. Factor analysis for CO2 emissions from residential sector

For residential sector, the factors investigated are

- number of households
- carbon intensity (represents fuel mix)
- energy consumption per unit floor space (represents lifestyle and appliance efficiency), and

- building floor space per households (represents life style)

The Kaya Identity derives emissions as a product of these four factors. Figure 5 shows the contribution from each of these factors on CO_2 emissions of residential sector. Increasing number of households and increasing floor space per household have been identified as a major factors for CO_2 emissions from residential sectors. The effect of carbon intensity was small in comparison. Energy intensity however, played most important role in decreasing CO_2 emissions especially after 1980. In 90's, slowing economy, slowing household income growth and saturation of household appliances may have contributed in improving energy intensity and therefore played important role in decreasing CO_2 emissions. CO_2 emissions from energy use of residential sector seems to have saturated in recent years as demonstrated by figure 7.

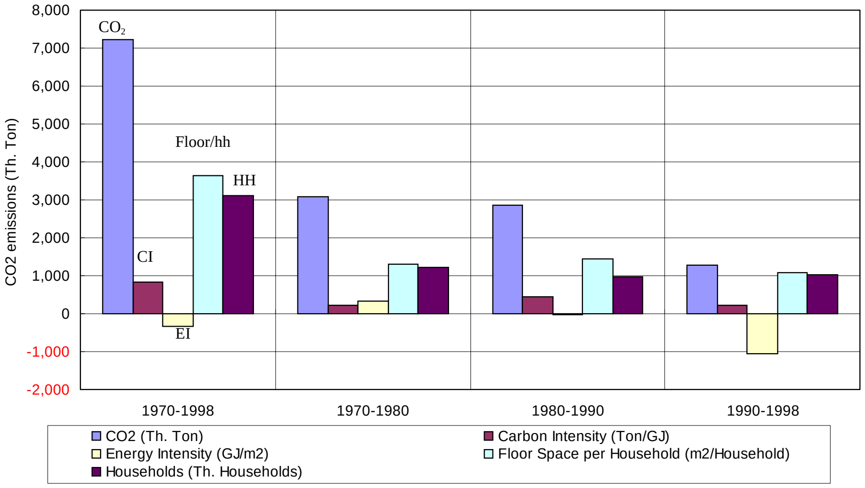

Figure 5. Factor analysis of residential sector, Tokyo.

4.4. Factor analysis for CO2 emissions from commercial sector

For commercial sector, similar to residential sectors, factors analyzed were carbon intensity (reflects fuel mix), energy intensity (energy consumption per unit service sector GRP), service sector GRP per unit floor space of office buildings (reflects productivity) and floor space of office buildings.

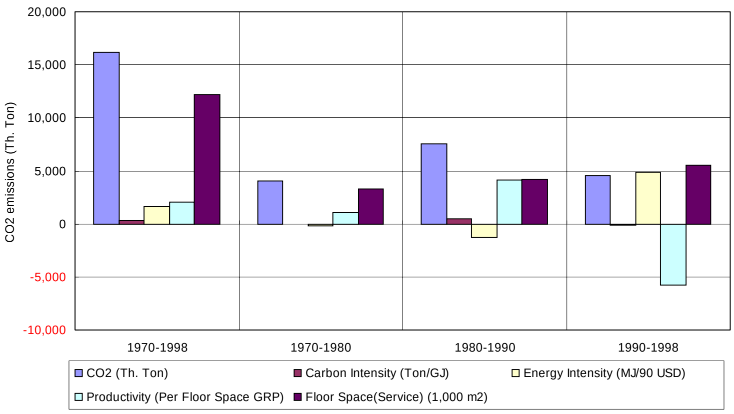

Figure 6. Factor analysis of commercial sector, Tokyo.

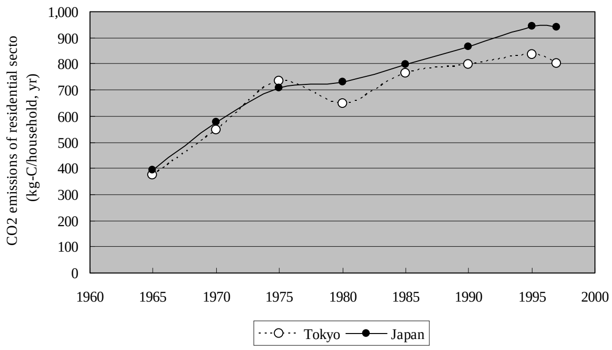

Figure 7. Residential CO_2 emissions

As in case of other sectors, the structure of factors in 90's was much different than 70's and 80's. During 1970-98 office floor space was responsible for more than 80% increase of CO_2 emissions. Contribution of carbon intensity was found minimal. During high growth period in 70's and 80's energy consumption per unit service sector GRP (value added) contributed to reduce CO_2 emissions, however in 90's it actually contributed most prominently in increasing CO_2 emissions due to sluggish economy. Similarly, during high growth period in 80's, GRP per unit floor area contributed significantly in increasing CO_2 emission, while in 90's it contributed most significantly in reducing CO_2 emissions due to sluggish economy.

4.5. Industrial structure

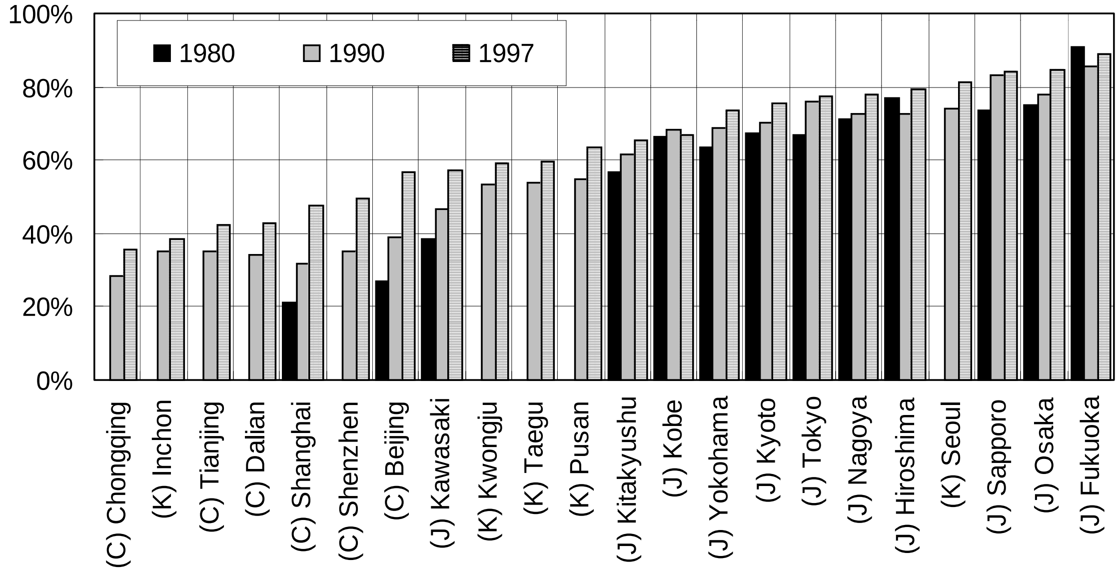

Figure 8. Share of tertiary industry of major cities in China, Korea and Japan.

Tokyo is dominated by service industries significantly. The share of tertiary industry in total value added from industrial products is continuously rising in Tokyo from 67% in 1980 to 78% in 1997. Figure 8 shows such share for different cities in Japan, Korea and China in 1980, 1990 and 1997. This is the primary reason why contribution of industrial sector in total CO_2 emissions is small in Tokyo.

5. Other factors contributing to transportation sector

Population of Tokyo has not changed significantly since 1960s. Population growth rate has been very small, yet positive, although population trend has shown it increasing (10.18 million in 1962, 11.82 million in 1997). It is interesting to note that population growth was nominal even in seventies and eighties when GRP of Tokyo grew rapidly. The huge workforce was mobilized by the developing massive mass transportation infrastructure. In 1999, about 33% of total workers did not live but commuted everyday to Tokyo (see Figure 9). The trip demand and generation pattern inside Tokyo has little changed in last 2 decades, however its interaction with outer areas such as Saitama, Ibaraki, Chiba, Kanagawa and Yamanashi increased significantly. Therefore, the distinction between day time and night time population is important for Tokyo. Figure 10 shows the day time and night time population in Tokyo and compares the shares of daytime to night time population in major Japanese cities and New York.

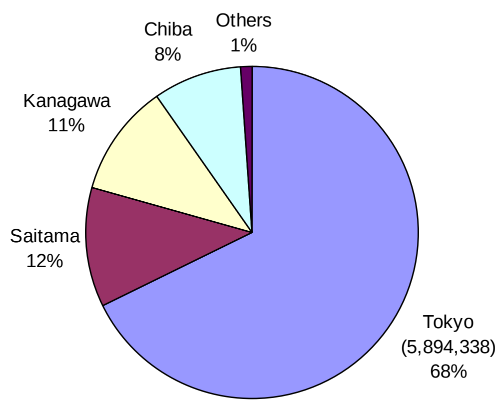

Figure 9. Workers commuting to Tokyo, 1999.
Source: Tokyo Metropolitan Government Data

It is important to note that mass transportation in Tokyo was already developed before motorization begun. In that sense, mass transportation such as railway and subway did not have to face competition from motorization which are being faced by rapidly developing cities now.

Analysis done by IPA (2000) compared the transportation system and its service quality in four cities in OECD, namely, London, New York, Paris and Tokyo. Figure 11 shows

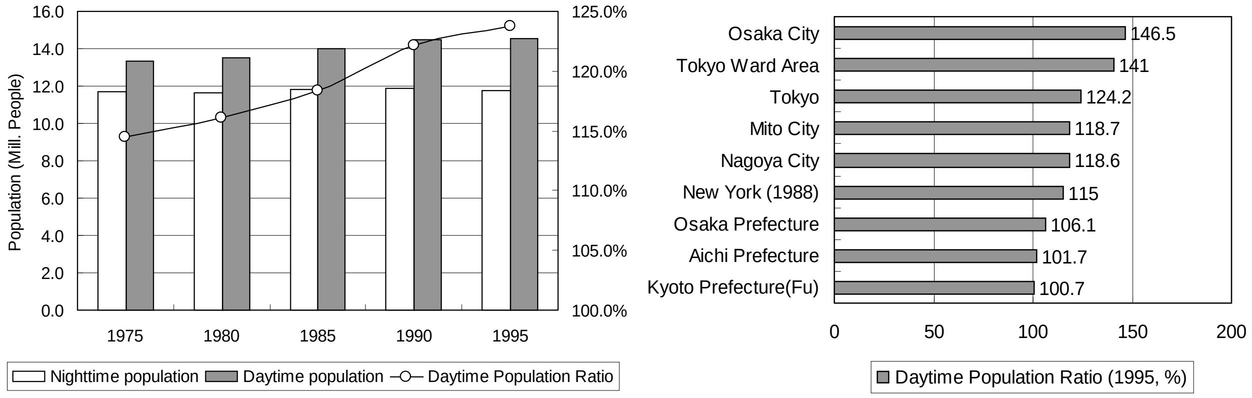

Figure 10. Day-time and night-time population for Tokyo and ratio for cities

such data. It is seen that Tokyo is the best city in terms of the mass public transportation. The use of private automobiles is smallest in Tokyo among these four cities. In contrast, London and Paris has poor performance. This is an important factor for better emission performance of Tokyo. Assessment on the quality of subway and regional rail network also ranks Tokyo as a best city. The details are illustrated in Table 1.

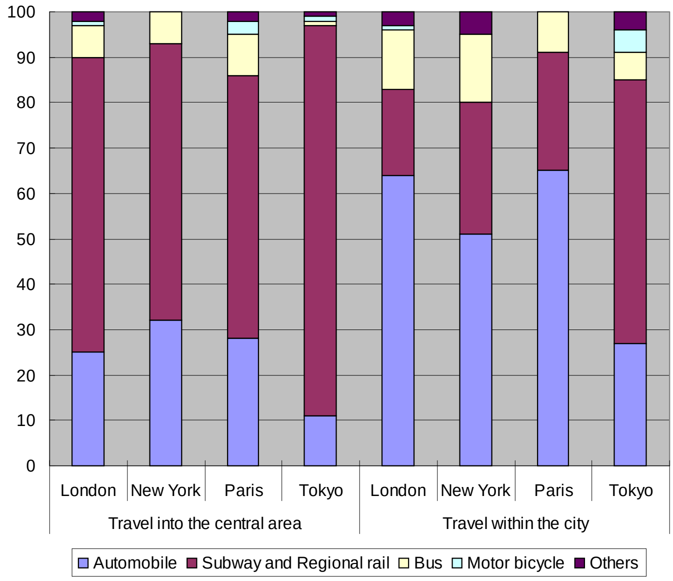

Figure 11. Transportation modes in four cities
Source: IPA, 2000

Table 1. Assessment of quality of service

	Subway network				Regional rail network			
	London	New York	Paris	Tokyo	London	New York	Paris	Tokyo
To be operated with less than 5 minutes waiting time at peak hours (%)	98	88	100	94	30	36	7	81
To be operated with less than 10 minutes waiting time at off peak hours (%)	100	97	100	99	53	13	8	94
The rate of the train which is not canceled (%)	97	97	91	100	99	100	99	100
To be operated with less than 5 minutes delay (%)	85	80	88	100	88	94	93	95
Total score of service	380/400	362/400	379/400	393/400	270/400	243/400	207/400	370/400

Source: IPA, 2000

6. Conclusion and future research

Above results suggest that the CO_2 emission performance of Tokyo is outstanding in comparison to selected cities and countries. We also analyzed the factors that contributed to Tokyo mainly by Kaya Identity by sector. The contributions of factors were seen to have distinctly different patterns during the bubble period of Japanese economy and economic recession thereafter. Tokyo had several advantages during their development of mass transportation such as rapidly growing economy (availability of surplus capita), less competition from motorized transportation and availability of huge labor forces from surrounding areas. High land price motivated people to live in a less floor space providing positive effect to energy demand. Based on these realities, we have raised several important questions to be answered in the future research.

- Does Tokyo serve as a desirable model for rapidly developing mega-cities?
- Is Tokyo actually efficient, what are the other factors for their efficient performance?
- Does it make sense for cities in rapidly industrializing countries such as Korea and China to follow Tokyo's footprint? Would it be a realistic target?
- How the technological factors assist or impede effort of other cities to catch up Tokyo?
- What other cities can learn from Tokyo's experience that how it would help them to set appropriate energy and environmental policies?

Some cities, such as Seoul, have developed in a similar way as Tokyo. However, economic structure, geography and many other factors influence the energy use and CO_2 emissions. Therefore, these questions and further detail analyses on the energy and CO_2 emissions of other cities in Asia would be addressed in the future research. In this preliminary study, limited data sets were available, mainly, for cities in China, Korea and Japan. Need for additional data from other mega-cities in Asia is evident. Similarly, this paper addresses CO_2 emissions from direct sources while indirect emissions (means the embedded CO_2 emissions is the good and services that are consumed in the city) are not addressed. This paper is rather ambitious in conveying the results of the preliminary findings.

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