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 CO₂ 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 (CO₂), 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 CO₂ emission or energy consumption contribution of mega-cities are very significant.

In this paper, authors have estimated the CO₂ emissions from energy use in selected cities and analyzed the performance of the cities in terms of the relation between per capita CO₂ 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 CO₂ emissions), the past trends of CO₂ 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 CO₂ 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 than 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.

2. CO₂ emission performance of cities

A comparison of OECD countries, major non-OECD countries and cities in East Asia, in terms of CO₂ per unit GDP and CO₂ 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. CO₂ per unit GRP in Seoul is found to stagnate in 1990-1997 but CO₂ per capita is increasing. Beijing and Shanghai’s CO₂ performance in terms of GRP is improving rapidly while slightly increasing in per capita terms. Reducing CO₂ per capita seems to be a major difficulty for cities as all cities have failed in that aspect.

While deriving the per capita CO₂ 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 CO₂ 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 CO₂ 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](image-url)
4. Contributing factors of CO₂ emissions

4.1. Factor analysis for total CO₂ emissions

At macro level, the Kaya Identity is utilized to investigate the contribution of various factors in total CO₂ emission. This is explained by equation below.

\[
\text{CO}_2 = \text{CI} \times \text{EI} \times \text{GRPpc} \times \text{Pop}
\]

Where:

- \(\text{CO}_2\) = Total carbon emissions
- \(\text{CI}\) = Carbon Intensity, defined as the amount of carbon emissions per unit energy consumption which reflects the fuel mix of consumed energy in a city
- \(\text{EI}\) = 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
- \(\text{GRPpc}\) = Per capita GRP, which is a measure of the living standard
- \(\text{Pop}\) = Population.

Differentiating the equation yields:

\[
d\text{CO}_2 / \text{CO}_2 = d\text{CI} / \text{CI} + d\text{EI} / \text{EI} + d\text{GRPpc} / \text{GRPpc} + d\text{Pop} / \text{Pop}
\]

Change in \(\text{CO}_2\) = 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 \(\text{CO}_2\) 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 \(\text{CO}_2\) emission, that means the growth of the economic activities was the major driving force behind \(\text{CO}_2\) emissions. Energy required to produce one unit of value added improved, thus, energy intensity played significant role in decreasing \(\text{CO}_2\) 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 \(\text{CO}_2\) emissions while energy intensity was worsened and was responsible for increasing \(\text{CO}_2\) emission.
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:

$$\text{CO}_2 = \text{CI} \times \text{EI} \times \text{VKTpv} \times \text{V}$$

Where:

$\text{CO}_2$ = Carbon emissions from transportation sector.

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

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

$\text{VKTpv}$ = Vehicle Kilometers Traveled per vehicle, which is an average travel distance.

$\text{V}$ = 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).

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 CO₂ emissions of residential sector. Increasing number of households and increasing floor space per household have been identified as a major factors for CO₂ emissions from residential sectors. The effect of carbon intensity was small in comparison. Energy intensity however, played most important role in decreasing CO₂ 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 CO₂ emissions. CO₂ emissions from energy use of residential sector seems to have saturated in recent years as demonstrated by figure 7.

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.

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 CO₂ 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 CO₂ emissions, however in 90's it actually contributed most prominently in increasing CO₂ emissions due to sluggish economy. Similarly, during high growth period in 80's, GRP per unit floor area contributed significantly in increasing CO₂ emission, while in 90's it contributed most significantly in reducing CO₂ emissions due to sluggish economy.
4.5. Industrial structure

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 CO₂ 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.

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

![Figure 8. Share of tertiary industry of major cities in China, Korea and Japan.](image)

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Analysis done by IPA (2000) compared the transportation

![Figure 9. Workers commuting to Tokyo, 1999. Source: Tokyo Metropolitan Government Data](image)
system and its service quality in four cities in OECD, namely, London, New York, Paris and Tokyo. Figure 11 shows 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 10. Day-time and night-time population for Tokyo and ratio for cities](image)

**Table 1. Assessment of quality of service**

<table>
<thead>
<tr>
<th></th>
<th>Subway network</th>
<th>Regional rail network</th>
</tr>
</thead>
<tbody>
<tr>
<td>To be operated with less than 5 minutes waiting time at peak hours (%)</td>
<td>98</td>
<td>88</td>
</tr>
<tr>
<td>To be operated with less than 10 minutes waiting time at off peak hours (%)</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>The rate of the train which is not canceled (%)</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>To be operated with less than 5 minutes delay (%)</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>Total score of service</td>
<td>380/400</td>
<td>362/400</td>
</tr>
</tbody>
</table>

Source: IPA, 2000
6. Conclusion and future research

Above results suggest that the CO₂ 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 CO₂ emissions. Therefore, these questions and further detail analyses on the energy and CO₂ 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 CO₂ emissions from direct sources while indirect emissions (means the embedded CO₂ 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.

References


