APN

The Budgets of GHGs, Urban Air Pollutants and Their Future Emission Scenarios in Selected Mega-Cities in Asia (APN 2002-04)

Final Activity Report

February 28, 2003

Hidefumi IMURA

TABLE OF CONTENTS

Abstract

The budgets of GHGs, urban air pollutants and their future emission scenarios in selected mega-cities in Asia, Tokyo, Seoul, Beijing, Shanghai, Delhi, Calcutta and Manila was the focus of this project. The need for integrating global environmental concerns into local air pollution is evident in mega-cities to tap synergistic policy measures; present research contributes to this endeavor. It focuses on key urban sectors, namely urban transportation, residential, commercial, and waste sectors for energy use and resulting emissions. Consumption pressures, in the form of embodied emissions, are analyzed in this study, which partly represent sustainability implication arising from indirect energy consumption and emissions of Carbon dioxide. Modeling, situation analyses and future scenarios are the major parts of this study. A combination of button-up and top-down type of models are developed which are equipped to test the feasibility of various locally operational policy measures. This research is an ongoing activity far from completed. The integrated policy scenarios and their impacts are expected to complete by March 2004. APN support was crucial to this research in supporting various workshops and activities. The available outcomes have already added new knowledge in the areas of urban energy use and their GHG linkages in case study cities by quantifying and projecting them. These are described in the section of *Outcomes and Products*. The models and methodologies developed in this study have a great potential to apply to smaller cities; regional variation in data and methodologies needs to be clarified further in the future to stimulate future research in this area.

1. Project Information

1.1. Project Leaders:

H. Imura (Ph.D)
Professor, Nagoya University
Furo-Cho, Chikusa-ku
Nagoya, Japan.
Tel: +81-52-789-3347
Fax: +81-52-789-3837
E-mail: imura@genv.nagoya-u.ac.jp

A.P. Mitra (Ph.D)
National Physiscal Laboratory,
Dr. K.S. Krishnan Road
New Delhi -110 012 India
Tel: +91-11-5745298
Fax: +91-11-5852678
apmitra@csnpl.ren.nic.in

1.2. APN Funding (US$)

US$ 120,000 (FY2001 -2003)

Year 1	APN Funding
Budget	**70,000**
Expense	**70,000**
1) Shanghai Field Survey/ Meeting	11,162
2) Kitakyushu Workshop & Symposium	32,263
3) Fellowship (in Nagoya Univ.)	7,272
4) India Component	16,913
5) Printing	2,390

Year 2	APN Funding
Budget	**50,000**
Expense	**50,000**
1) Beijing Workshop	8,511
2) Hawaii Workshop	22,489
3) Fellowship (in Nagoya Univ.)	5,000
4) India Component	14,000

1.3. Duration of the project

2 Years (April 2001 to March 2003)

1.4. List of collaborating APN approved countries

China, Korea, Japan, India, Philippines

List of Collaborators

CHINA
- o Prof. Changhong CHEN (Shanghai Academy of Environmental Science)
- o Prof. Kebin HE (Tsinghua University, Institute of Environmental Science and Engineering)
- o Dr. Bin LIU (Tsinghua University, Energy Environment Economy Institute)
- o Prof. Shuyu LU (Shanghai Academy of Environmental Science)
- o Dr. Deliang TONG (Beijing Municipal Institute of City Planning and Design)
- o Prof. Zhihong WEI (Tsinghua University, Global Climate Change Institute)

KOREA
- o Prof. Sunghan JO (Andong National University, College of Social Sciences, Dept. of Economics)
- o Prof. Dong-kun LEE (Sangmyung University, Dept. of Environmental Science & Landscape Architecture)
- o Prof. Kwan-Jeh LEE (Dongguk University Dept. of Statistics)
- o Prof. Choon-Geol MOON (Hanyang University Dept. of Economics)
- o Prof. Eui-Yong YOON (Hyupsung University, Dept. of Urban Administration)

JAPAN
- o Mr. Kosuke ARAKI (Institute for Global Environmental Strategies (IGES), Urban Environmental Management Project)
- o Dr. Shobhakar DHAKAL (Institute for Global Environmental Strategies (IGES), Urban Environmental Management Project)
- o Prof. Hidefumi IMURA (Nagoya University, Graduate School of Environmental Studies)
- o Dr. Tae-Yong JUNG (Institute for Global Environmental Strategies (IGES), Climate Policy Project)
- o Dr. Shinji KANEKO (Hiroshima University, Graduate School for International Development and Cooperation/ Institute for Global Environmental Strategies (IGES))
- o Mr. Hiromitsu KAWAHARA (Fujitsu FIP Corporation, Environmental Systems Business Division)
- o Prof. Toru MATSUMOTO (University of Kitakyushu, Department of Environmental Space Design)
- o Mr. Toshihaya MINAMOTO (Fujitsu FIP Corporation, Environmental Systems Business Division)
- o Dr. Hirofumi NAKAYAMA (Kyushu University, Institute of Environmental Systems (IES))
- o Dr. So-Won YOON (Institute for Global Environmental Strategies (IGES), Climate Policy Project)

INDIA
- o Dr. Agnibha DASGUPTA (Institute of Radio Physics and Electronics)
- o Dr. A.P. MITRA (National Physical Laboratory)
- o Dr. Chhemedra SHARMA (National Physical Laboratory, Center on Global Change)

PHILIPPINES
- o Ms May AJERO (Manila Observatory Climate Studies Division)

2. Introduction

2.1. Background

The United Nations Framework Convention on Climate Change (UNFCC), which was adopted in May 1992, sets an ultimate objective of stabilizing greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous human-induced interference with the climate system. It urges the parties to protect the climate system in accordance with their common but differentiated responsibilities. The third Conference of the Parties (COP3), in particular, adopted the Kyoto Protocol in December 1997, which includes legally binding commitments for developed countries to reduce their greenhouse gas emissions an average of about 5% by the target year of 2008 to 2012. While industrialized countries are expected to meet their commitments, there are fewer such opportunities in developing nations. It is expected that the share of GHG emissions by developing countries will exceed that of industrialized countries in the mid 21st century, and a larger portion of the increase will be accounted for by the rapidly industrializing regions of Asia like China, South-east Asian countries, and India, which in total have more than 40 % of the world population. Energy use will be bound to rise as these countries increase their industrial production; provide better basic services such as electric lighting, refrigeration, air conditioning, and health care; use more vehicles for urban transport:, and build new cities that require large quantities of energy intensive construction materials such as iron, cement, bricks and plastics.
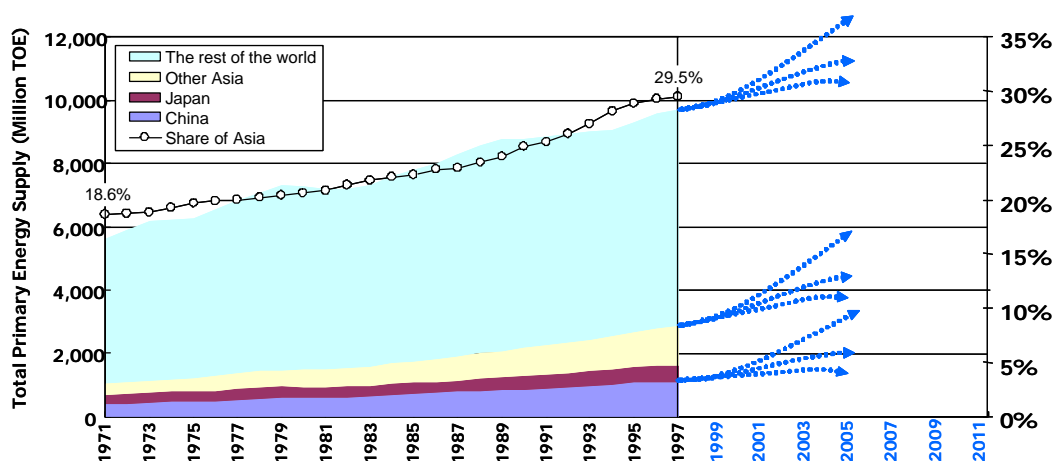

Figure 2-1: Trend and Scale of Energy Use in Asia

Within the region, the most significant increase of energy consumption and GHG emissions will take place in mega-cities which have rapidly expanding populations that enjoy higher living standards and material affluence than the people living in rural areas and smaller cities. Increasing demand for passenger mobility and freight transport will be reliant upon increases in the number of automobiles, which not only create problems such as traffic congestion, air pollution and noise (having serious health and quality of life implications), but that also will be a major cause of increasing energy consumption and CO2 emissions. However, the carbon sink within the mega-cities is primarily urban greenery of insufficient volume to absorb the emitted carbon. There are 15 mega-cities in the region that have a population exceeding five million. Many of them are playing important economic roles as industrial and commercial centers of their countries,

receiving larger investments by government and private sectors. These mega-cities also have a significant share in the overall national emissions of greenhouse gases, including CO_2 and CH_4, but they also emit gases such as CO, NOx, and SOx, and particulate matter. As a consequence of their comparative wealth, these cities are in a better position than the rest of the country to be able to adopt more advanced technological interventions and other measures to protect the global environment. The problems and difficulties the mega-cities are faced with today will be those which smaller cities will be following in the coming future, and actions of mega-cities will be a model for other cities. Thus the study on mega-cities will provide a good basis for countries to consider their comprehensive action strategies to promote sustainable development by employing efficient use of energy and resources to reduce environmental load. However, it is conceivable that emissions reductions strategies must differ from city to city (Delhi and Calcutta are likely to greatly differ), and thus that no single strategy will work for the entire country.
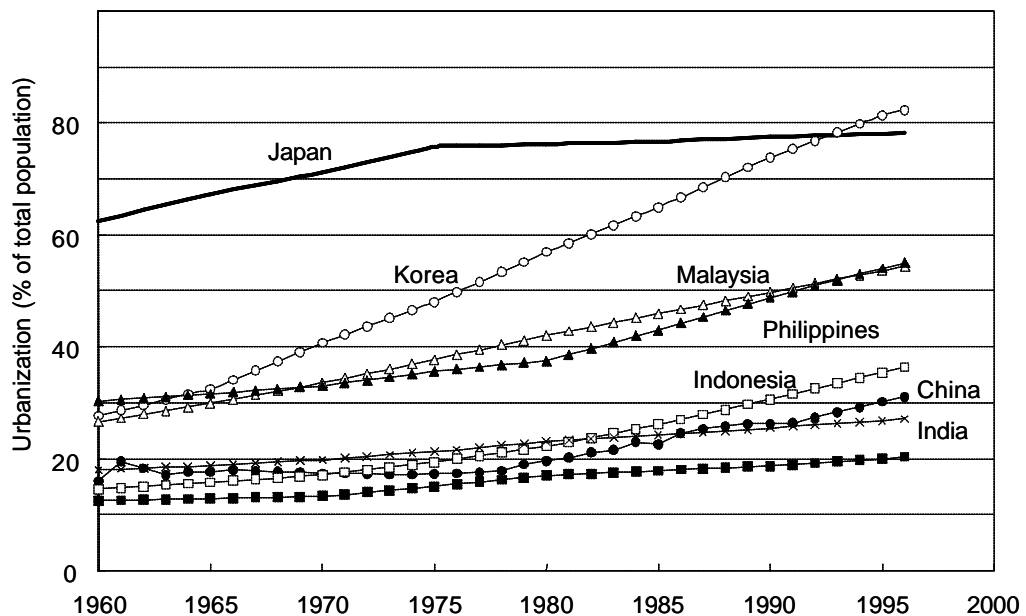

Figure 2-2: **Urbanization in Asia**

(Source: World Development Indicator 1998 CD-ROM, World Bank)

Cities in rapidly industrializing regions of Asia are confronted with multiple tasks for economic development and environmental protection. They tend to give their policy priorities to immediate, local issues and to regard global warming as a long term, distant issue. In fact, however, municipal policy to reduce energy consumption will bring multiple benefits to the community (Figure 3). It will help solve air pollution and traffic congestion problems, and will also facilitate the sustainable development of the city. Cities in Asia must pay more attention to the efficient use of energy and GHG emission reduction. The prerequisite for systematic actions for this is the scientific analysis of GHG emission budgets of cities. This will also generate information about emissions of related short lived gases (like CO, NOx, SOx) and particulate matter because the sources are the same. The short-lived gases have very significant environmental effects, including reductions in the solar energy available to agriculture and marine life, as well as immediate effects on human and ecosystem health.
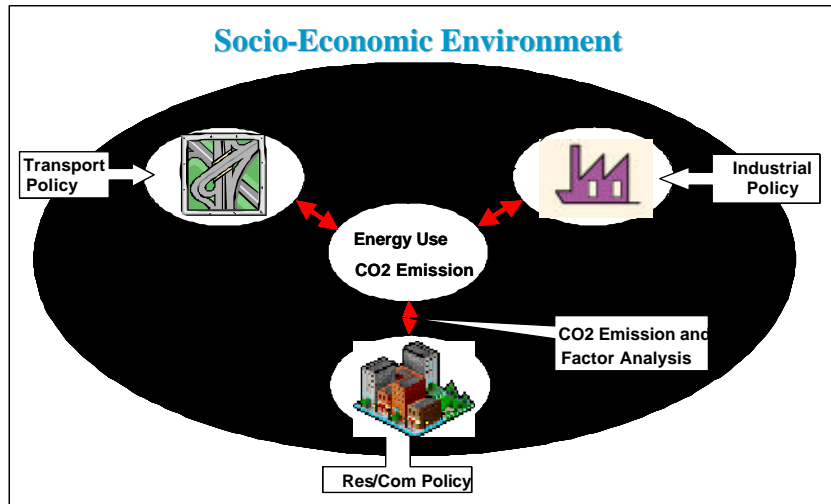
4

Figure 2-3: City and Urban Energy Related Policies

2.2. Project Framework

This project is multi-year project since year 2001 (APN 2001-18). The project was launched in April 2001 and was led by Prof. Hidefumi Imura and Dr. A. P. Mitra. The project focuses on the dynamics of industrial transformation taking place in Asian cities and analysis of the environmental implications, particularly with regard to energy consumption and GHG emissions. The study aims to collect GHG budget data of selected mega-cities in Asia, to present future scenarios for GHG emissions and carbon cycles of the cities to 2020, and to identify the drivers that cause such changes. The study focuses on sectors and activities of selected mega-cities to identify areas for potentially effective countermeasures through the adoption of locally operational policy instruments. Thus, the research is to provide special consideration and detailed analysis of transportation, residential and commercial sectors, buildings, urban infrastructure, and lifestyles of residents. This study also aims to generate discussion on the role of cities in achieving sustainable and cleaner utilization of resource and energy.
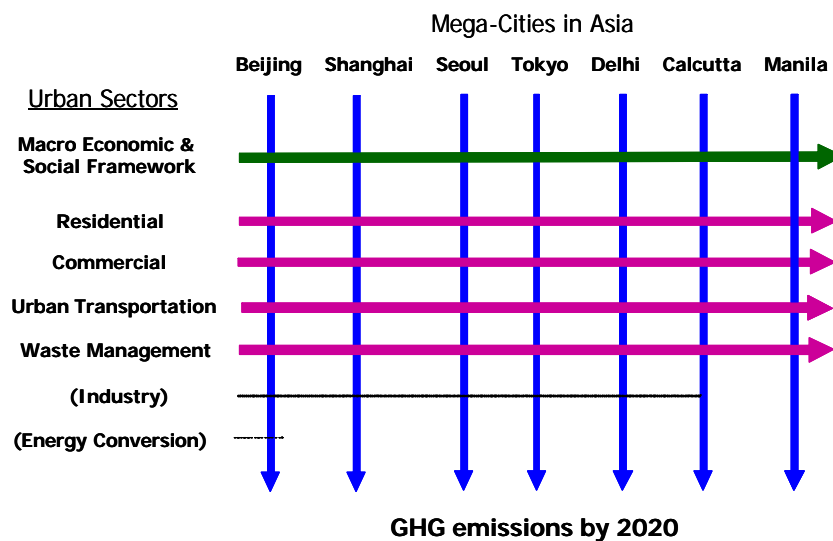

Figure 2-4: Outline of the Mega-City Project

2.3. Aim and Objectives

This study aims to collect GHG budget data of some mega-cities in Asia, and to present future scenarios of GHG emissions and carbon cycle of the cities up until 2020. It is also to generate inventory of various associated short-lived gases like CO, NOx, SOx and particulate matter. The study focuses on sectors and activities for which cities can manage to implement some effective countermeasures by adopting locally operational policy instruments. Thus it gives special consideration to transportation, residential and commercial sectors, buildings, urban infrastructures, and citizens' lifestyles where it needs detailed investigation and analysis. Key sectors are macro economic & social framework, residential & commercial sector, urban transportation sector, municipal solid waste management sector, indirect energy consumption by industry (Figure 2). The study also intends to account both for direct emissions and for embodied emissions, which is a new concept and needs formulation of suitable methodology.

The study includes:
- o Direct and Indirect Energy Consumption, Embodied Energy.
- o Future Scenarios is investigated in order to indicate the probable future trajectories for the year 2020 and also for longer time scale of energy consumption and GHG emissions caused by the entire activities of the cities, and to identify the major factors that might affect the trajectories.
- o Comparative Analysis.

In the first place, it is proposed to concentrate on some typical mega-cities in Asia for study. Candidate cities are Tokyo, Seoul, Beijing, Shanghai, Manila, Bangkok, Delhi, and Calcutta along with the surrounding urban areas depending upon the availability of data. These cities were selected based on the following considerations:

Tokyo	The most developed mega-city in Asia, which has modern urban infrastructures, well-organized mass transport systems, and a number of new energy saving technologies for buildings and products, and where people's awareness about global warming seems high.
Seoul	A modern city similar to Tokyo, with stricter land use regulation and planning but with a less developed mass-transport system, and larger energy demand for heating in wintertime.
Beijing	The capital city of China, undergoing rapid transformation, with increasing population, new buildings, and automobile traffic. Preliminary analysis has shown that both Beijing and Seoul are following Tokyo in sectors like transport but, with phase-lag.
Shanghai	The richest mega-city in China, undergoing rapid transformation, with a growing number of new business facilities, increasing automobile traffic and diffusion of affluent lifestyles.
Manila	A typical mega-city in Southeast Asia, with serious traffic pollution problems and slums dwelled in by poor people with limited access to electricity and gas.
Delhi	The capital city of India with the largest numbers of automobiles and highest traffic density among Indian cities, facing serious air pollution problems.
Calcutta	The most populated city in India with less affluent living conditions than Delhi.

2.4. Methodology

The first focus of the study is on CO2 generated by fossil fuel combustion and incineration of municipal wastes, and CH4 generated by municipal waste disposal, enteric fermentation etc. The activity data collected also lead to the generation of information about CO, NOx, SOx emissions from target cities. Methodologies are also developed for accounting for the embodied emissions. One of the major tasks is the quality assurance/quality control (QA/QC) of data and their inter-comparison and inter-calibration.

Embodied emissions are attributable to the use of energy for the extractive and industrial activities that produce building and paving materials, for the transportation of those goods to the cities, and for the expenditure of energy in construction. It may be the case that for some decades the embodied emissions of Asian cities will exceed the direct emissions, because of the rapid growth of those cities.

The GHG budgets are expressed in an inventory form using both top-down and bottom-up approaches. The format of the inventory is basically follow that of the national inventory of GHG emissions and removals as adopted for communication under the United Nations Framework Convention on Climate Change based on the IPCC methodology. However, an appropriate format that is simpler than the national inventory is worked out, considering the limited data available at the municipal level and the feasibility of data collection. The time horizons to be used is years 1970 (if possible), 1980, 1990, 1995 2000 (if possible), which permits understanding the growth patterns. In the case of household consumption, new studies such as surveys of the population may be necessary to collect relevant data. Effort will be made to get data about the various income-class of population within a mega-city.

In the course of developing database and sub-sector models, project review workshops have been held three times a year (Figure 5). Final workshop for each year (i.e. Kitakyushu for 2002 and Honolulu for 2003) is an international workshop which invited external researchers and experts working in the relevant field. The papers and comments made by those experts are utilized to supplement some of the research topics which project members did not cover such as LCA analysis and analysis on hydrological systems.
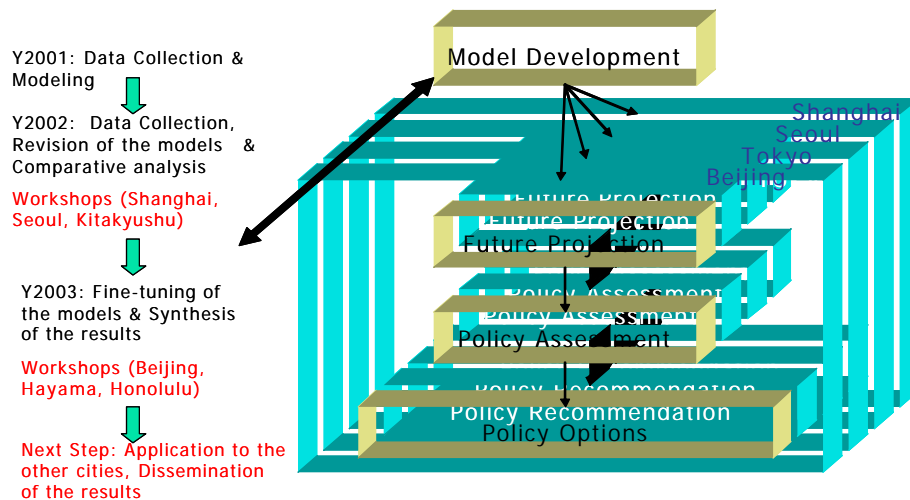

Figure 2-5: Methodological Framework

3. Activities Conducted

3.1. East Asian Group

Activity 1: Field Survey and Data Collection for Beijing
Date: June 6 to 11, 2001

The survey was conducted to collect necessary statistical data to complete the database for the study, and discuss with Chinese collaborators on technical issue associated with data inventory. Dr. Kaneko and Mr. Araki conducted field survey and data collection with the help of Prof. He and his students at Tsinghua University.

Activity 2: Field Survey in Shanghai
Date: June 12 to 13, 2001

The survey was conducted to investigate current state of urban environment and related policies in Shanghai. During the field survey, project members from Beijing , Korea and Japan visited Shanghai Academy of Environmental Science, Shanghai Environmental Protection Bureau, Shanghai Urban Transport Bureau and Shanghai Urban Planning Exhibition Centre, and were given lecture from each organisation.

Activity 3: 1st. Workshop on the Mega-City Project
Date: June 14 to 15, 2001
Venue: Shanghai Academy of Environmental Science
Objective:

The workshop was held from to discuss the issue associated with data collection, research method and schedule. The discussion was focused around the issue of a) data inventory, b) methodologies employed for each sub-module, c) how to integrate sub-modules.

Participants:
- Prof. IMURA, Hidefumi, Nagoya University
- Dr. KANEKO, Shinji, Institute for Global Environmental Strategies (IGES)
- Dr. JUNG, Tae-Yong, Institute for Global Environmental Strategies (IGES)
- Mr. ARAKI, Kosuke, Institute for Global Environmental Strategies (IGES)
- Prof. MATSUMOTO, Toru, University of Kitakyushu
- Dr. NAKAYAMA, Hirofumi, Kyushu University
- Mr. KAWAHARA, Hiromitsu, Fujitsu FIP Corporation
- Mr. MINAMOTO, Toshihaya, Fujitsu FIP Corporation
- Prof. YOON, Eui-Yong, Hyupsung University
- Prof. LEE, Dong-kun, Sangmyung University
- Prof. HE, Kebin, Tsinghua University
- Prof. WEI, Zhihong, Tsinghua University
- Dr. Deliang, TONG, Beijing Municipal Institute of City Planning and Design
- Prof. Mr. Shuyu, LU, Shanghai Academy of Environmental Science
- Prof. CHEN, Changhong, Shanghai Academy of Environmental Science
- Ms. Yang, Xiaoyan, Shanghai Academy of Environmental Science

Summary:

Based on the data requirements for each sub-sector model, discussion was focused on how to conduct the project, how to collect data and how to link sub-modules. It was agreed that macro economic & social scenario would provide the projection of basic variables for the other sectoral models, which are summarized below:

Overall Issues
- o The difference in the definition of statistical and technical terms in each country
- o How to get conversion factor of energy in China and Korea?
- o With regard to the floor space data for residential sector, Korea has only the data for annual increase and thus we need to calculate the stock data from available flow data.
- o Beijing and Tokyo has the floor space data.
- o Energy consumption per floor space of typical household is necessary for macro economic analysis, but difficult to obtain in China. Consumption patterns vary according to the income level of households which is so diverse and thus difficult to get the average.
- o Energy consumption patterns are different by types of buildings. But in Korea, building type is so rich in variation that it would be difficult to obtain the data for each type.
- o For the data we cannot get, we need an average and its elasticity. Then we have to make assumption and modeling.
- o We also have take geographical condition into consideration. It affects the energy consumption patterns (e.g. atmospheric temperature affects the energy consumption for room heating, etc.). Definition of the boundary is another important issue to consider. We may start with macro data for broader area, then disaggregate the data for smaller area.
- o In Shanghai, the data for vehicle emission is available only for taxi.
- o In 1986 and 1995 survey on vehicle emission were conducted and the detailed data is available for these two years.
- o Difficulty lies in the integration of the different models. The question is, how to modify it to global issue.
- o On Energy balance sheet, we have the data only for 1998. It would be difficult to get the time-series data.
- o How to calculate the emission data.
- o It is difficult to calculate the emission from different type of industry, but we can calculate some of the aggregated sector. Check the data for 1990 in Shanghai in the Environmental Statistical Yearbook.
- o Transportation sector is categorized under the tertiary industry, and it is difficult to disaggregate.

Data Issues
- o Need to build energy balance table for each city in a common format
- o Fuel type should be as disaggregated as possible, as detailed as possible
- o Sector classification of the energy balance table should be consistent with I/O table.
- o Set base year for future projection as 1995
- o Data base format will be designed and sent by IGES (Excel format with definition of the terms) to all participants by the end of June, 2001.
- o Completed table should be sent back to IGES within 2 weeks (Mid-July) upon receiving the template table.
- o Deadline for all the data requirements: Mid-July
- o All the data requirements should be submitted to IGES
- o Main contact (The person who will be in charge of information/data collection)
  Tokyo: Dr. Kaneko (IGES)
  Beijing: Prof. He
  Seoul: Prof. Yoon
  Shanghai: Prof. Lu, Prof. Chen

- o Transport sector: Prof. He will provide data requirement by the middle of July and will produce result of Beijing by the September meeting. Prof. He will also contact and discuss with Dr. Kaneko and Mr. Kawahara (Fujitsu FIP) for selection of more comprehensive transportation model.
- o Res/Com sector: Prof. Matsumoto will send data requirement by the middle of July and will produce the result of case study of Tokyo by September meeting.
- o Industrial sector/ Material flow: Dr. Nakayama will send data requirement (I/O table & Energy balance table) by the middle of July. I/O tables of Beijing for 1992 and 1997 will be provided by Dr. Kaneko. I/O tables of Shanghai for 1997 and those of Korea and Seoul should be sought for and prepared.
- o Waste management: Prof. Yoon will send data requirement by the middle of July and produce a result for Seoul by September meeting.
- o Top-down (Macro) Model: Dr. Jung will send data requirement by the middle of July and produce a result for Seoul by September meeting.

Linkage and integration of the models
- o Dr. Kaneko will deal with this task once he receives data requirements from everyone (after Mid-July).

How to develop scenario
- o Model experts are responsible for identifying the driving forces (external factors) & determining factors and will provide a list of those factors to Dr. Kaneko by the end of June.
- o Every participant is required to read the proposal of Prof. Lee and send comments and his/her own scenario description on that to Dr. Kaneko.
- o Selection of Base Scenario (trend with the policy adopted.)
  - • Issues:
  - • Relation with model (Model first or Scenario first?)
  - • Objectives of the model in concern
  - • Objectives of the study

Activity 4: 2nd. Workshop on the Mega-City Project
Date: September 4 to 5, 2001
Venue: Hanyang University, Seoul
Objective:
The meeting was held for each member to report their progress from the 1st. meeting. At the meeting, discussion was focused around the issues, difficulty and necessary adjustments for the research which had been found at this stage. Disaggregation of the data in country-original energy balance tables, data limitation of the transportation sector in particular were the central focus of the discussion. The structure of the project report was also discussed and the role of each collaborator was decided.

Participants
- o Prof. IMURA, Hidefumi, Nagoya University
- o Dr. KANEKO, Shinji, Institute for Global Environmental Strategies (IGES)
- o Dr. DHAKAL, Shobhakar, Institute for Global Environmental Strategies (IGES)
- o Mr. ARAKI, Kosuke, Institute for Global Environmental Strategies (IGES)
- o Dr. JUNG, Tae Yong, Institute for Global Environmental Strategies (IGES)
- o Dr. YOON, So-Won, Institute for Global Environmental Strategies (IGES)
- o Prof. MATSUMOTO, Toru, The University of Kitakyushu

- o Mr. KAWAHARA, Hiromitsu, Fujitsu FIP Corporation
- o Mr. MINAMOTO, Toshihaya, Fujitsu FIP Corporation
- o Prof. MOON, Choon-Geol, Hanyang University
- o Prof. YOON, Eui-Yong, Hyupsung University
- o Prof. LEE, Dong-kun, Sangmyung University
- o Dr. JO, Sunghan, Korea Energy Economics Institute
- o Prof. HE, Kebin, Tsinghua University
- o Ms. MITA, Maki, Sangmyung University

Summary
Discussion was focused around the following points.
1. Input
2. Methodology
3. Output

On methodological issues, it was agreed that Dr. Jung, based on the BeSeTo database, would generate the data (commonly used macro data) for the other teams' analysis.

Disaggregation of the data in country-original energy balance tables
- o Seoul: Energy-related survey data (e.g. for separating res/com. e.g. household energy consumption for residential sector.) will be made available.
- o China: Energy consumption for different building types.
- o Dr. Tong and Prof. Chen will provide background information for Chinese sector interpretation.
- o Tokyo: IGES will take care.

Review of urban policies which affect environment (Urban policy inventory):
- o Seoul (Dr. Yoon, IGES-CP)
- o China: Ms. Chan, Prof. He will collect the relevant material. (IGES will make the sample for Tokyo first, and send it to Prof. He and Dr. Yoon).
- o Tokyo (IGES-UE)

Transportation Analysis
Two levels for transportation analysis.
- o Prof. He (Macro-scope)
- o Fujitsu FIP (Micro-scope)
  - ➢ Definition of the city (admin. Boundary?)
  - ➢ Impact of the policy should be taken into account to adjust the data.
  - ➢ e.g. China: "West to East" Policy (promoting the use of natural gas transported through the pipeline from the western area)
  - ➢ Seoul: Road pricing policy.
  - ➢ List of exogenous information required
    - o OD survey (Tokyo data is already available. Optional for Seoul, Beijing, Shanghai)
    - o Prof. Lee and Yoon will check the availability of the data for Seoul.

Activity 5: Workshop of IGES/APN Mega-City Project, "Policy Integration for Energy Related Issues in Asian Mega-Cities"
Date: 23-24 January, 2002,
Venue: Rihga Royal Hotel, Kitakyushu City, Japan
Objective:
- o To present the outcomes of the researches conducted by two research groups under the APN funded Mega-City research project, namely, the North Asia Study Group coordinated by Prof. Imura and South Asia Study Group coordinated by Dr. Mitra.
- o To invite other researchers and experts in the field of urban sustainable development and urban energy related issues to exchange experiences of research activities and views on sustainable urban development in Asia.
- o To discuss what sorts of researches can contribute to actual urban policy and planning, in addition to identification of further research topics to be addressed.

Summary:
North Asia Group Report

The North Asia study group presented the energy and CO_2 emissions profiles by sectors and energy sources in Tokyo, Seoul, Beijing and Shanghai in 1990's in comparable form. Based on those data sets, the group conducted factor analyses of growing trends of CO_2 emissions at the macro level and found that the growth of GRP (Gross Regional Product) per capita primarily contributed to the increase of CO_2 emission in Tokyo and Seoul. An investigation into the emission performance of OECD countries, major non-OECD countries, and cities in North Asia including major Japanese large cities measured by CO_2 emissions per unit of GRP/GDP and per capita, revealed that Tokyo has an outstanding performance. The group has developed proto-type forecasting models by sectors of these cities, mainly transportation, residential and commercial and waste management sectors and presented preliminary results for GHG emission projections to the year 2020. According to the transportation study in Beijing, the contribution of Light Duty Gasoline Vehicle (LDGV) to the total fuel consumption and GHG and pollutant emission becomes larger, and LDGV is potentially the major contributor of all the fleets for deteriorating urban air quality. The study on waste management in Seoul has found that waste incineration generates more GHGs than LNG/Diesel boiler heating to supply the same amount of heat. The study also found that waste incineration reduces fossil fuel consumption, which in turn, leads to less GHG emission, and also brings economic benefits to local government. The comparative study of direct and indirect energy use in Tokyo, Beijing and Shanghai by using I/O (Input/Output) analysis techniques found that Tokyo and Shanghai depend largely on indirect energy use while direct and indirect energy uses in Beijing are almost similar in terms of scale. The studies done by this group have so far manifested the need for developing the database that contains more comparable data in various sectors among cities.

South and South East Asia Group Report

South and South East Asian study group reported the results of their CO_2 inventory and emissions analysis for Delhi, Calcutta and Manila. The South Asian group emphasized the need to account for particulate emissions in detail, due to prevailing particulate problems in South Asian cities. Particulate emissions from these cities are also believed to contribute to the potential for global warming. The research found substantial differences in emissions per capita among Delhi, Calcutta, and Manila, which are perhaps associated with life-style differences that are yet to the researched.

The detail workshop proceeding and summary are attached with this report.

Activity 6: 4th. Project Workshop
Date: July 5 to 6, 2002
Venue: Tsinghua University, Beijing, China
Objective:
   o   Progress report of the revised modelling analysis
   o   Discussion on the data issue, model and scenario development
   o   Discussion on fine-tuning the models

Summary:
Model construction

   Modellers have already completed the construction of tentative models, particularly in transportation (Prof. He and FIP group), residential and commercial sectors (Prof. Matsumoto). Similarly, Prof. Yoon already studied energy issues of waste sector for Tokyo and Seoul. In that sense, we have tentative framework already in place. Data is the crucial factor for extending sectoral modeling coverage to all remaining cities. Araki-san is coordinating data gathering effort for each modeler. Once data gathering will complete, carrying out analysis and future projection is to be done for all remaining cities. If there would be data problem, it is expected that modelers would scale down their models.

Scenario development:

   The purpose of scenario generation in this research has its own objective. The objective is to find locally operational options to reduce energy demand and local/regional/global emissions. Therefore, we should not follow hypothetical and philosophical scenarios as in the case of IPCC, GEO-2 or others, which put grater emphasis on development paths, too broad and too vague. The objective of scenarios in our case, should be to show the policy makers in respective cities what could be done in local context to reduce energy demand and emissions. This essentially means, implications of various policy alternatives set future scenario; "what if" kind of analysis would define future scenario. This should be followed by analysis on strategies to implement those chosen policy alternatives. The strategy formulation can be done in fiscal year 2003. However, the target for 2002 fiscal year should be to come up with potential policy alternatives and the quantification of implications (in terms of energy/emissions reductions). For scenarios, possibility of "rebound effect" should be carefully examined. "Rebound effect" means, when we affect one variable positively, there could be negative effect on another variable so that overall situation would degrade pollutant emissions. Such inter-dependency among the model control variable should be carefully examined. On example of this is; when fuel conversion is carried out on public bus (to CNG), bus fare may increase or due to short supply of CNG many buses would be out of operation; as a result people may prefer two-stroke two wheelers; and the overall effect on emission is negative.

Base case scenario

   This scenario is the business as usual scenario that is based on today's information, trends and what cities have already planned for future. For e.g., in case of Beijing, infrastructure development may have already been planned till Olympic, which is eminent. Similarly, Emissions standards may have been already planned for future. Similarly in case of Tokyo, household appliance penetration rate may have already been projected to saturate in the near future etc. However, sensitive analysis should be done on base case to account for the uncertainty that may exist in technology, market, and due to policy failures or institutional factors.

Alternative scenario

Alternative scenarios can be formulated based on local specific conditions. Following criteria can be made:

Generic scenarios
- o Urbanization and land use alteration scenario
- o Technology intervention scenario: This involves technology such as vehicles technology improvement, fuel efficiencies of vehicles, energy efficiency of appliances, fuel switching, electric/hybrid/CNG vehicles, building insulation improvement, solar energy use for hot water use etc.
- o Lifestyle change scenario: This is essentially the implementation of demand side management options at end-use that may exist in transportation, residential, commercial and waste sectors. Energy conscious societal development is of focus here. Activities such as lowering thermostat setting of air-conditioning equipment, driving behavior, avoiding electricity use at peak load period etc.
- o Management scenario: This involved many management options that can be implemented directly by local government such as traffic management, banning two stroke engine vehicles, command and control approach etc.
- o Other local specific scenarios

Activity 7: Data Collection and Processing
Date: August 20 to 23, 2002
Venue: Hanyang University, Seoul, Korea
Objective:
- o Calibration of the data to substitute unavailable data, with Prof. moon at Hanyang University

Activity 8: 5th Project Workshop
Date: December 2 to 3, 2002
Venue: Institute for Global Environmental Strategies, Hayama, Japan
Objective:
- o To review the study results of sub-sector models which were to be presented at Hawaii workshop
- o To discuss the form of final output

Summary:

Common agreements from the discussion:
- o Macro Model provides the projection of social & economic variables.
- o The policy & technical aspects should be covered by each model.
- o Basic variables required by each sector:
  - ➢ MSW: population: GRP; number of household
  - ➢ Transportation: GRP; population; number of vehicles; energy consumption.
  - ➢ Res/com: GRP (service sector), population, number of household, size of household, energy price, floor space
  - ➢ Embodied energy: how to set up the calculation of CO_2
  - ➢ CGE analysis: Labour force: pop growth rate
- o Technical variables required
  - ➢ MSW: the detailed data for selected incinerators
  - ➢ Transportation: ten parameters
  - ➢ Vehicle pop by type
  - ➢ Projection number of vehicle by type;

- ➢ Emission factor for the new vehicle in future;CO NOx SOx TSP PM10 CO2
- ➢ Deterioration rate of emission
- ➢ And deterioration rate of fuel oil??
- ➢ Average vehicle mile by type
- ➢ Average sulfur content
- ➢ Carbon content
  - o There is a need to set up the general scenario, and then do projection, and then take this scenario as the standards to do forecasting for each sector.
  - o Common scenario is necessary.
  - o Common economic and social scenarios are different.
  - o There is a need to identify the target readers of our report. Like the IPCC scenario for CO2 emission, the technical part should be separated from the other type.

Data and modelling issues
- o Urbanization issue maybe combined with the CGE model
- o Transportation:
  Tokyo the future predictive data is unavailable. The problem is the methodology is totally different from Shanghai and Beijing. They do not emphasize on the registered number of vehicles. For Seoul, the vehicle data is inaccessible. Check the IPCC national data report
- o Residential/ Commercial
  - ➢ Time and data limitation for shanghai.
  - ➢ Find some macro variables and then assume, the share of GDP in tertiary sector? Do some regression analysis for some cities and then assume something. If the data is unavailable, we can adopt this kind of regression analysis. Based on historical data, predict the energy consumption by sector Also I/O table can be used. How much energy can be used by each household? Not sure we can get this from regression analysis. The influencing factor maybe the income, energy price, the climate. But the other is cooking? Electricity? These two are directly related to income.
  - ➢ Need to report the consistent result for the four cities.
  - ➢ Need to provide the whole picture of this project.
  - ➢ Need to response to the sponsors;
  - ➢ Need to give some idea and story (scenario).
  - ➢ Industry sector should not be omitted, I/O table can be used.
  - ➢ To use macro estimation, to do projection by fuel type and by sector, those two numbers do not need to match, that is the issue of "share for each sector". Dr. Jung will investigate it. Macro model will give some prediction for the energy consumption by sector.

Activity 9: "International Workshop on Policy Integration Towards Sustainable Urban Energy Use for Cities in Asia"

Date: 4-5 February 2003

Venue: East West Center, Honolulu, USA

Objective:

This workshop is aimed at presenting and discussing the methodologies, results and policy implications of each sector analysis which have been carried out for the past two years under the APN funded project (APN 2001-18 & APN2002-04 (Mega-City Project)). It also aimed at exchanging the information and learning from the other similar ongoing research initiatives on methodology data and results as well as to discuss future research direction and collaboration. Throughout the workshop, the points of discussion are focused around the following key questions:

o   How to integrate energy dimension in urban environmental policy and planning?

o   How to promote capacity building of energy-related studies for cities in developing countries?

o   What kinds of methodologies are being used in such analyses, what kinds of data and information barriers exists?

o   How to interpret the research results and how to translate such results into policies?

Summary:

Workshop organization

The workshop was divided into six sessions including a panel discussion at the end of the workshop. Session 1 was dedicated to the presentation of Asian mega-cities and some reflection from Mexico city. Session 2 was focused on urban energy use and urban sustainability. Experience of Asian cities and European cities were discussed in this session and also emphasized the need to reach to research outcomes to policy makers in order to facilitate the urban sustainability. Session 3 was solely dedicated to urban transportation and energy issues since urban transportation remains a key sector where policy interventions are urgent and which also offers significant opportunities to integrate global environmental concerns into locally operational policies. Session 4 investigated the methodology, models and data issues as well as research outcomes in residential and commercial energy use sector, embodies energy and emissions and macro-scale analyses such as CGE modeling approach and optimum energy emission path through MARKAL modeling at urban context. Session 5 drew a bit more holistic view rather than sectoral approach which allowed a better understanding the cities, their environmental transition, their energy use, emissions and few broad but key observations. Session 6 comprised of an informal panel discussion on how to integrate global environmental concerns into the traditional sectoral policies.

The Present and Future of Economy, Energy and Environment in Mega-Cities

East Asia:

In this session One of the Project Leaders of the mega-city project, Prof. Hidefumi Imura addressed the opening of the workshop and summarized the background, issues, objectives and goals of this project in his presentation titled, "Economic development, energy and emission scenarios in rapidly growing cities in East Asia: A comparative study of Beijing, Shanghai, Seoul and Tokyo". The need to carry out research on magacities were mentioned due to the fact that they are:

o   Front-runners in the country and the region in terms of urban development, economic growth, industrial transformation, lifestyle change and policy implementation.

- o Intensive consumption in energy and materials.
- o Critical environmental experiences and pioneering approaches.
- o Good models to other small and medium-sized cities.

Prof. Imura highlighted the position of the mega-city project. Firstly, this project is the first attempt in Asia in international multi-sectoral comparative analysis using comparable data sets at city-level. Secondly, it is unique in terms of integrating sub-sector models of macro-economic framework, transportation, residential/commercial, and MSW management, and other supplementary analyses (embodied energy, CGE, etc.). Thirdly, it can also contribute to capacity development of participating researchers for development of a methodology and its application to cities. The research in this project is focusing on the following aspects:
- o The dynamics of industrial transformation taking place in Asian cities, particularly in terms of energy consumption and GHG emissions
- o Integration of global environmental considerations ("climatic change") into urban policies
- o Policy scenario: policy measures and actions on the local level

South Asia: The research result of the South Asian group are presented by Dr. A. P. Mitra and Dr. Chhemendra Sharma. They highlighted their activities such as: Primary data collection; Inventory of GHGs and other urban pollutants on direct and indirect sources; future Projections of emissions; data validation; socio-economic scenarios of Mega-cities, and revision of inventories. One of the interesting observations in their study is the estimated benefit of the metro rail construction in Delhi which is under development. Total track to be built in first and second phase is 51 km, total expected investment in first and second phase (= $ 10 billion), and expected completion date for first and second phase is March 2005. Expected benefits of metro railway development are: 2600 less buses on road (saving of 7.8 million litres of diesel); increase in average speed of road buses from 10.5 km/hr to 14 km/hr, saving 26 lakh man hours due to reduced journey time; saving in fuel cost worth Rs 500 crores; and improvement in air quality

The result of the case study of Manila is outlined some of the facts and current situation of the city, and their future scenarios: Vehicle registration for the entire country and for the Metro Manila region still continue to increase (1981 to 2000) at average annual growth rates of 7.8% for the Philippines and 6.9% for Metro Manila. Metro Manila's share in the country's vehicle count for the period is averaged at 41 (40.6%). The share however has been decreasing from 44% (44.35) to 35% (34.63%). Certain vehicle-fuel types however have greater shares. Gasoline-fueled cars in Metro Manila, for example, contribute to almost 70% of the gasoline cars' population in the country. The number of gasoline-fueled vehicles in the area has been decreasing, while the diesel-fueled vehicles continue to increase in number. Metro Manila's vehicle fleet is mostly composed of Cars (39% to 49%); Utility Vehicles (35% to 42%); Motorcycles/Tricycles (8% to 13%); Trucks (5% to 7%) and Buses (1%).

Decrease in electricity consumption for Metro Manila in the years 1984 to 1986 reflected the worsening economic and political (1983-assassination of a political icon - Ninoy Aquino and the 1986 People Power Revolution) conditions at that time. For most years in the 1981 to 2000 period, the commercial sector of Metro Manila consumed approximately 40% of the total electricity consumption while the remaining 60% is being shared by the residential and industrial sectors. Average annual growth rates for the sectors are as follows: total consumption 4.8%;

commercial 5.35%; residential 5.1%; industrial 3.73%; and streetlight 2.57%. Despite changes in the pattern or trend of emission factors (based on the power generation mix), CO2 emissions almost reflected the same trend as electricity consumption. The average annual growth rates of emissions for the sectors are as follows: total consumption 6.42%; residential 6.72%; commercial 6.96%; industrial 5.33%; and streetlight 4.15%.

Mexico City: Energy, Mobility and Sustainable Urban Development: The case study of the Mexico City is presented by Mr. Gabriel Quadri de la Torro. With regard to urban structure in Mexico City, urban sprawl grows faster than population, which results in a ever sparser city, lower densities and urban decay in downtowns. Urban decentralization and urban sprawl, low densities and land use specialization have three discernible impacts besides segregation and exclusion. Some of the pressing agenda which the city is facing now are:

o Low competitiveness of transit systems and further distortions of transport mode share. (Transit systems operate efficiently only when there exists a concentrated trip demand along urban corridors origin-destiny pairs.)

o The need of more freeways to allow for an enhanced mobility for private cars. (In this scenario, automobiles become virtually the only accessibility means. Those who lack a private car suffer more exclusion and are put in an accessibility and mobility disadvantage).

o Urban degradation and environmental impact (Brought by the new freeways as a consequence of higher emissions, noise, accidents, segregation, non accessibility, and visual and scenic despair.)

Energy and Urban Sustainability

MSW Management and Energy Recovery: This sub-sector analysis is done by Prof. Yoon and Prof. Jo in Korea. Tentative policy implications from their study are the following: to increase recycling/ reuse rate of MSW & to develop more effective policy strategies; and to reduce food waste generation & its utilization. In case of Beijing & Shanghai, need for new facilities, policy instruments, and citizen participation are emphasized. For Seoul, the suggestion are to increase the operation rate of incineration plants (current rates: 36%); and to benchmark the operation of Tokyo incineration plants. And, for Tokyo, to refer to LFG utilization in Seoul.

o In this session, Mr. James Yienger presented current status of the "Cities for Climate Protection Campaign" of ICLEI. ICLEI is an international association of local governments dedicated to a sustainable environment and advocates "grassroots" and on-the-ground action. ICLEI represents a collective voice for city government at national and international policy forums. It was organized in 1990 under the sponsorship of the UN Environment Program and the International Union of Local Authorities. Now it consists of 450+ local government members from 6 continents and 50+ countries. Some of the facts about "Cities for Climate Protection Campaign" are presented. Dr. Yienger also highlighted the need for reducing emission from the public sector infrastructure, as a corporate emissions reduction strategy for local government.

European Experience: Professor Peter Pearson from Imperial College London presented the collaborative project between Imperial College & GLA (former LRC), "The Reference Sustainability System (RSS) Project". RSS is a network model for investigating the environmental sustainability of cities and its purpose is to develop the RSS to represent urban energy, resource and material flows. It is also aimed at conducting systematic assessment of potential of technology & resource

management strategies to enhance sustainability. The methodology utilized the optimization as well as simulation approaches for energy, paper, water and solid wastes.

Urban Transportation and Energy

Case of East Asian mega-cities: In this session, firstly, the results of a comparative study on transportation, energy and environment in Beijing, Shanghai, Seoul and Tokyo is presented by Prof. Kebin He from Tsinghua University of China. In Beijing and Shanghai, traffic volume has been increasing rapidly and trend will continue, and thus creates greater pressure on the environment. The number of bus has been gradually declining. Beijing is now developing the subway network system, but its construction is lagged to accommodate the rapid increase in the travel demand. On the contrary, Tokyo has a good urban railway networks and the development of road transport seems to be stable in Seoul, though development trend is slowing down.

With regard to energy consumption and CO2 emission, with only 1/10 of Tokyo's fleet, Beijing and Shanghai's fleet tend to consume equivalent amount of oil and emit amount equivalent CO2 which implies the need for improving fuel economy in Beijing and Shanghai. There is also a need to develop urban transport, especially large-scale public transport and adjusting transport structure.

Regarding pollutants emission, smaller vehicle fleets produce much more emission amount in Beijing and Shanghai. The results proposed further reduction of the VMT of vehicles, stronger control of in-use vehicles, and need to address emission issue urgently in the cities before it gets out of hand. The largest contributors of pollutant emission in each city are: small bus and motorcycle in Shanghai, small truck in Tokyo, large truck in all the cities, especially for its PM emission. The need for innovative policies in those area are emphasized.

US and international experience: Mr. Roger Gorham from EPA, USA presented the initiative of energy use and emissions from urban transportation. The approach to understand and tackling the transportation-energy-environment problems through ASIF framework was presented. In this approach, the emissions are the functions of:
A – Activity in the sector (Passenger- or Ton-kilometers);
S – Modal structure of that activity (%);
I – Energy intensity of each mode (units of energy consumed per pkm/tkm occurring on mode) and
F – Carbon-equivalent content of fuel-mix used to produce a unit of energy by mode. AS focus on reducing the (unchecked) growth in transportation activity; and IF focus on reduce the emissions per unit of transportation activity. Behavior and technology interact to produce emissions therefore focusing on one or the other may be misleading. ASIF can help quantitatively assure this balance. Further improvement of this approach to solve the following issues is highlighted.
o Need to do a better job conceptualizing and communicating strategies that affect travel behavior, as well as technology
o Need to do a better job measuring all aspects of transportation, energy, and emissions from the bottom-up. Aggregate numbers tell us very little.
o Need to do a better job forecasting activity, structure, intensity, and fuel/technology mix. Any one alone gives a misleading picture.

Urbanization, transportation and Land Use: Based on his experience at the World Bank, Dr. James Ford from the World discussed the issue of urbanization, transportation and land use. According to Dr. Ford, countries or regions that develop

national or regional strategies have more instruments and more options in terms of managing the consequences of growth. Well-designed intergovernmental fiscal systems can create effective incentives for local and regional administrations to make prompt and appropriate choices for transportation, planning, land management and land use. Within limits, new communities and new towns can channel growth to particular locations. In addition, intercity transportation and communications alternatives can influence the location of growth, as well as the rates of growth at these locations. Naturally, these options vary with fiscal/financial capacities. China is at least one case that would be appropriate here. Given this situation, he goes on to suggest the list of possible actions which cities and developing countries can take as following:

o   Get ahead of the problem with policy reform and planning that is designed to:
o   Develop fiscal/financial capacities
o   Make land markets more efficient
o   Facilitate housing finance
o   Develop realistic transportation and land use plans
o   Facilitate accommodating growth rate and affordability of services to the projected population of users – from industry to informal sector worker.
o   Introduce congestion pricing and incentives for appropriate fuel technology choices

Modeling and Data Issues

Modeling of urban development, energy and environment: Based on the experience in modeling exercise in present Mega-City project, Prof. Shinji Kaneko from Hiroshima University presented the issue, complexities and difficulties of comparable modeling analysis at different cities. He stressed the issue of balancing the comparability of each city and the data availability of each city and explained how East Asian group has created the comparable set of data for Beijing, Seoul, Tokyo, and Shanghai. He identified the challenges of the project as following: Modeling technique, integration of sector models, integration of top-down and bottom-up approaches and explained each in detail. Prof. Kaneko also mentioned the complementary modeling method employed in this project such s CGE modeling, embodied energy analysis, and transportation analysis based on Origin-Destination survey data.

Lifestyles and energy consumption in households and commercialsectors:

Prof. Toru Matsumoto from Kitakyushu University presented the result of sub sector analysis on Residential and Commercial (Res/Com) sector in the Mega-City project of East Asian group. The results highlighted the rapid growth of energy consumption in Beijing and Shanghai in the next 20 years while Tokyo and Seoul will saturate their consumption level by the year 2020. Res/Com sector analysis has also had a difficulty in data collection and he suggested the future directions are as followings: improvements in data and model structures, two directions, more simplified model to deal with same structure as other mega-cities or complete, bottom-up model which model variables can be closely based on policy options; and scenario analysis. The present model can incorporate a number of policy interventions in the areas of household attributes, lifestyle factors, architectural characteristics, characteristics of energy devices, and carbon intensity in energy consumption.

<u>Experience in Shanghai:</u>

On behalf of Prof. Chen of Shanghai Academy of Environmental Science who could not attend the workshop, Dr. Tae Yong Jung introduced the results of the Prof. Chen's case study on Shanghai's energy consumption. The study was based on the MARKAL model. This was basically a reference energy system modeling with optimizing supply and end use demand side through intermediate energy carriers on cost minimization basis. A number of scenarios were introduced mainly on technology interventions. Results were overwhelming which highlighted the role of policies and quantified the emissions reduction under policy inteerventions.

<u>Integration of Urban and Global Policies:</u>

CO_2 emissions from energy use in East Asian mega-cities: Driving factors, challenges and strategies: Dr. Shobhakar Dhakal estimated the CO_2 emissions from energy use for Tokyo, Seoul, Beijing and Shanghai by sector and fuel type and compared the emission performance of these cities. The results showed that Tokyo was outstanding in terms of emission per unit economic activities and per capita emissions. Trends of these cities are studies over time and observations are drawn. The driving factors of CO_2 emission were decomposed by factor decomposition method and the relative contribution of each factors on CO_2 emission at total as well as sectoral levels are investigated.

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'.

Dr Dhakal observed that in Tokyo, use of technology is already stretched while change in lifestyle and consumer behavior is a key. In Seoul, fuel switching has contributed in past and transport sector in a key. In Beijing and Shanghai, there is a

low share of transport sector but emissions growth rate is very high. Managing energy and emissions while meeting needs of growing living standards in these cities were highlighted. The need for followings were discussed: developing energy efficient infrastructures: reducing automobile dependency and "lock-in" effect, promoting energy efficiency in buildings, such as building insulation, efficient central heating and cooling system, and energy efficient appliances , policies to encourage "durable" infrastructure to relieve construction material's consumption pressure, campaign and raising of awareness to less energy intensive lifestyle and energy saving, technology push: promotion of alternative fuel, efficient transportation technology, renewable energy, and utilization of efficient existing technologies, and promoting the culture of comprehensive and integrated planning

Panel Discussion

The topic for panel discussion center around "How to integrate energy dimension in urban environmental policy and planning, and how to promote capacity building of energy-related studies for developing country cities". The major panelists were: Dr. Shobhakar Dhakal, Roger Gorham, Dr. James Yienger, James Ford, Prof. Peter Pearson, Dr. A.P. Mitra, Gabriel Quadri de la Torro and Dr. Tae-Yong Jung. Prof Hidefumi Imura moderated the panel discussions. Prof. Imura highlighted the need for integration of local and global policies, especially transportation sector and buildings with due consideration to lifestyles, consumption pattern, prices and buildings. IF can emply technological options such as energy recovery from waste, photovoltaic cells, fuel cells, energy savings and others.

Conclusion, summary and outcomes

Prof. Imura summarized the discussion and outcomes. The followings were highlighted

o   The data and modeling are important but how much analyses is necessary and sufficient for policies are open question. So we must adopt strategic approach
o   Our research is for policies, so we need more bottom up approach to meet specific local policy needs
o   To make complex analyses accessible to others, our reports and books (possibly) deal wit care questions such as how to present results, how to interpret them and how to make them understandable to policy makers.
o   ASIF approach is useful. IF part is very much tech dependent, it is easier to achieve results from IF then AS. We need long term vision with AS
o   We need to address micro-economic aspects such as prices..
o   The unique features of each cities should be taken into account in policy measures or countermeasures
o   Though mega-cities are important, smaller cities are need attention.
o   Governance, institutional and legal frameworks questions are need to be addresses and included in the analyses.
o   We continue this research in future with support of all collaborators and supporters.

B. South and South East Asian Group:
Activity data related to demographic profiles, socio-economic parameters, vehicle population, consumption of energy & agriculture products, generation of waste for the cities of Delhi, Calcutta and Metro Manila have been collected. Dr Mitra had visited Calcutta several times to co-ordinate efforts in Calcutta while Mr Agnibha Dasgupta visited Delhi twice for discussions about methodology and calculation of

inventory estimates. In December 2001, Drs Mitra and Sharma visited Calcutta for discussions about the progress and preparation of project outputs. Ms Ajero had visited several organizations, government offices for the collection of activity data in Metro Manila. The coordination between Delhi and Manila was done through internet.

This work has been presented at:
1. Global Change- Open Science Conference at Amsterdam during 10-13 July 2001
2. SASCOM meeting at Kathmandu during 2001
3. START SSC meeting at Washington during 15-17 Oct 2001

During the Kathmandu meeting, the members of SASCOM strongly recommended the inclusion of at least two more highly polluted mega-cities of the South Asia namely Dhaka and Karachi in the present studies. During the next year, a meeting of Indian group is also being planned to be held at Delhi/ Calcutta.

Activity 1: Project Meeting at Kalcutta University, Kalcutta, February 2, 2002
Activity 2: Project Meeting at Jadavapu University, Kalcutta, January 3, 2003-02-07
Activity 3: Data collection from Delhi, Kalcutta, Manila to consolidate the existing data
Activity 4: Data validation exercise undertaken by checking with the primary data references
Activity 5: Refinement of the inventory of GHG and other urban air pollutants and their future projections
Activity 6: Socio-economic scenario are being developed for Delhi and Calcutta

4. Outcomes and Products
4.1. Introduction

In this chapter, summary of research outcome of the project will be presented according to the initial objectives. As stated in the section 2.3, "Aim and Objectives", the initial objectives of this project are specified as following:

- o To collect GHG budget data of some mega-cities in Asia,
- o To present future scenarios of GHG emissions and carbon cycle of the cities up until 2020.
- o To generate inventory of various associated short-lived gases like CO, NOx, SOx and particulate matter. (Key sectors: macro economic & social framework, residential & commercial sector, urban transportation sector, municipal solid waste management sector, indirect energy consumption by industry).
- o To account both for direct emissions and for embodied emissions.

The above objectives have been achieved and detailed account of research findings will be given in the following sections. However, due to the data constraints, in some sectors, detailed comparison of the cities and detailed analysis for some sectors were not possible. The reason for the modification (i.e. the issues on data collection and its influence on initial framework of modelling analysis(**Figure 4-1-1**)) will be explained below.
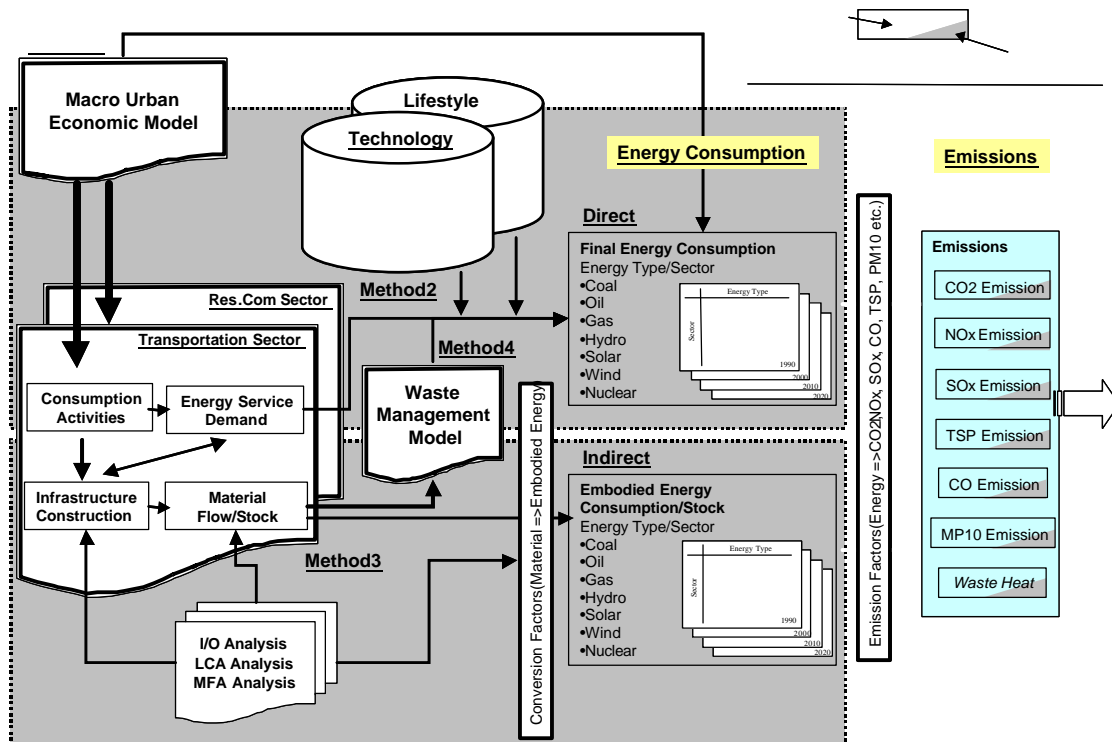
Figure 4-1-1: Initial Framework of Modelling Analysis

4.2. Data Issue

Since launching this project, data collection has been the central issue as the model structure and type of scenarios which can be analysed largely depends on the availability of data. IGES requested each modelers to make a list of required data and IGES distributed it to local collaborators to collect the required data for each sub-sector module. The following list is the summary of data requirements for comparative studies.

- o Macro socio-economic data
  - ➢ GRP by major sector
  - ➢ Demographic data
  - ➢ Labors by sector

- o Energy balance data
  - ➢ Sector (Primary energy supply, transformation, final consumption)
  - ➢ Energy type (Coal and coal products, Oil and oil products, LNG, Town gas (City gas), Electricity, Heat)

- o Sectoral data/ transportation, residential, commercial and waste management
  - ➢ Classification of registered vehicle
  - ➢ Travel demand by type of vehicle
  - ➢ Floor space by type of building
  - ➢ Appliances by energy service
  - ➢ Energy efficiencies by appliance
  - ➢ Waste generation and composition
  - ➢ Waste management facilities profiles

- o Emission factor
  - ➢ CO2
  - ➢ Air pollutants (CO, HC, NOx, PM) from transportation sector

Definition of the City
Cities can be defined in a number of ways such as central business district (CBD), densely inhabited district (DID), ward area, etc. Although the data for ward area or DID may be more appropriate indicator for socio-economic analysis of the city, due to the data constraints on technical variables, the data used this time refers to the city as defined by administrative boundary. Collecting the above listed data however, has been faced with several difficulties. Those are:

(1) Development of comparable dataset for the four cities.
Each country has different statistical system and different definition even though the same terminology is used, which created the difficulty in interpreting the data. This problem has mostly been solved with the help of local collaborators through consultation at workshops, field survey, as well as e-mail exchange.

(2) Effective collaboration in interdisciplinary and international joint research
Another difficulty lies in the fact that this project is interdisciplinary in nature. Experts of specific sector are not necessarily familiarized with the data of other sectors even for their own country, about which we were too much optimistic at project formulation stage. Since local collaborators are experts in a specific field and we asked them to collect local data for not only their specialized field, but also the other sectors, data collection cannot be done smoothly. Interpretation of the technical term especially in

waste management sector, with foreign language was also difficult. These difficulties, nonetheless, have been gradually cleared through a series of workshops and discussion among collaborators, which contributed to capacity building of the researchers involved.

The detailed account of the collected data is given below.

Energy Balance Data

In order to link macro socio-economic framework of the cities and their energy consumption and GHG emission profile, data on energy balance, especially energy balance table, is essential. Availability of such data differs from city to city, and situation of each city is summarized in the **Table 4-1-1**.

Table 4-1-1: Energy Balance Data

	Type	Source	Year	Sector	Energy type
Tokyo	Final energy consumption data	Internal report of TMG	70, 80, 90-98	31 final cons. sectors in total: Agriculture; manufacturing (22); residential; commercial; Transportation (4)/no Construction, energy for air craft is not included	17 energy types: Coal and coal products (3); Oil and oil products (11); Natural Gas; Town Gas; Electricity
Seoul	Energy balance	Internal database of KEEI	90-98	8 sectors in total; Production(1) Transformation(3) Final cons. (4)/ResCom aggregated	28 energy types: Coal and coal products (5); Oil and oil products (19); Natural Gas; Town Gas; Electricity; Heat
Beijing/ Shanghai	Energy balance	Commercial publication	85, 90, 95-99	17 sectors in total; Supply (4); Transportation(6); Final cons. (7). Partially available: mining (7); manufacturing (17)	18 energy types: Coal and coal products (7); Oil and oil products (8); Natural Gas; Electricity; Heat No Town gas

While energy balance table of Beijing and Shanghai are published, the ones of Seoul and Tokyo are not. In the case of Seoul, energy balance table is obtained with the help of Prof. Jo at Andong National University, Korea. In the case of Tokyo, the data is obtained from internal report of Tokyo Metropolitan Government (TMG). The data for Tokyo however, is not a balance table, but final energy consumption data estimated by using basic unit data of consumption of various fuels by sector. Estimation method is clarified in the report of TMG..

Looking at the data, while data of Tokyo is rich in the type of sectors, Seoul data is most detailed in terms of energy types though sector is aggregated compared to Tokyo. The detail of Chinese data is in between Tokyo and Seoul.

In order to enable the comparative study of energy consumption by sector, those energy balance data from each city are modified to the common format as shown below.

Table 4-1-2: Common Format of Energy Balance Data

UNIT:	Industry TOE	Residential TOE	Commercial TOE	Transportation TOE	Others TOE	Total TOE
Coal						
Crude Oil						
Diesel						
Gasoline						
Kerosene						
Heavy Oil (Fuel Oil, Bunkner)						
Other Petroleum Products						
LPG						
Natural Gas						
Town Gas						
Electricity						
Heat						
Others						
Total						

Sectoral Data

In addition to the basic macro socio-economic data which is relatively easy to collect, sectoral data for transportation, residential & commercial (Res/Com) and municipal solid waste (MSW) management have also collected with continuous effort. Those sectoral data are in most cases, technical and even though the terminology is same among the cities, the estimation method, concept, definition, etc. are different. Necessary modification is made where applicable, and the data which is not available but vital, are estimated using existing data. Collected and estimated data are summarized in the **Table 4-1-3**. This is the best we could get by now. With more time and resource, more detailed data may be obtained in the future.

Emission Factor

Having estimated the energy consumption by sector in each city, the next step was to estimate the GHG emission by fuel type by sector. IGES collected the basic emission factor by sector for each city and provided those data to the experts. Experts in transportation, Res/com and MSW management utilized those data and developed their own methodology to calculate the emission from respective sectors. Again, those data are normally not published and collected from reports of commissioned survey by local government of each city. Such survey was targeted to specific issues at each locality and thus the definition, sector classification of the data used to calculate emission factor is not common among each report. Such differences of the data among each city is summarized in the **Table 4-1-4**.

Table 4-1-3: Sectoral Data

	Transportation		Residential/Commercial		Waste management	
	Vehicle fleet	Travel demand	Floor space	Appliances	Waste volume	Facilities
Tokyo	Bus, Truck, Passenger vehicle, light car (<660cc) Truck (4), Bus (2), Sedan (2), Light motor (2), Special use (2), Heavy special kinds of vehicle ➔6 types, 3 types	Passenger-km, Ton-km vehicle-km (survey report)	Commercial (office, school, hospital, entertainment, etc), Residential (wooden and non-wooden (5))	No. of energy service devices (heating, cooling, lighting refrigerator, TVs, etc) Energy efficiency by type	Waste collected volume by treatment method and by type (10) Calorific value of waste by type	No. of facilities (incinerator, landfill site, composting) Capacity of facilities
Seoul	Bus, Truck, Passenger car, Special vehicle NA for further detail data ➔ 3 types	Vehicle number, Driving distance (national average) vehicle-km (pass. car, taxi, bus)	Total residential only No commercial	No	Waste collected volume by treatment method and by type (10) Calorific value of waste by type	No. of facilities (incinerator, landfill site, composting) Capacity of facilities
Beijing/ Shanghai	Passenger vehicle (including bus), Truck Car, Small bus, Large bus, Small truck, Large truck ➔6 types, 3 types	Working hour of passenger vehicle, speed, Ton-km, average freight capacity vehicle-km (survey report)	Total residential only No commercial	No. of major energy service devices for urban and rural No efficiency data	Waste collected volume by type Paper, plastic and textile are integrated No calorific value	No

Table 4-1-4: Emission Factor

	CO_2	CO	NOx	HC	PM-10
Tokyo	National emission factor (MoE, Japan) TEPCO	g/km by type of vehicle	Note1: Classification of vehicle type (Passenger vehicle, bus, light truck and ordinary truck) is based on transportation census which is not consistent with Tokyo statistical yearbook and vehicle registration data. Note2: Emission factors for each type of vehicle in use are estimated based on the existing vehicle fleet composition by vintage and their emission standards.		
Seoul	IPCC guideline (1996) Energy balance	g/km by type of vehicle	Note1: Private passenger car, tax, small bus (gas., diesel, LPG), medium bus (diesel), large bus (LNG), small truck (gas., LPG, diesel) medium truck, large truck Note2: Past emission factors are estimated based on the existing vehicle fleet composition by vintage and their emission standard. No information for future		
Beijing/ Shanghai	IPCC guideline (1996) Energy balance	g/km by type of vehicle	Note1: Light duty gasoline vehicle, Light duty diesel vehicle, Light duty gasoline truck 1 and 2, Light duty diesel truck, Heavy duty diesel truck, Heavy duty gasoline vehicle, Heavy duty diesel vehicle. Note2: Past emission factors are estimated based on the existing vehicle fleet composition by vintage and their emission standard.		

4.3. Modified Framework, Objectives and Outcome

Initial framework of modelling analysis was modified in the face if data limitation. Basic idea is that the macro socio-economic sector, using generalized maximum entropy (GME) method, makes a future projection of basic variables which can be input to the sub-sector model as an exogenous variable, and then each sub-sector model makes projection of future energy consumption and CO2 emission up to the year 2020. Projection of variables which macro socio-economic sector cannot cover, are estimated by supplementary estimation method such as computational general equilibrium (CGE) method, factor decomposition analysis etc (**Figure 4-1-2**).
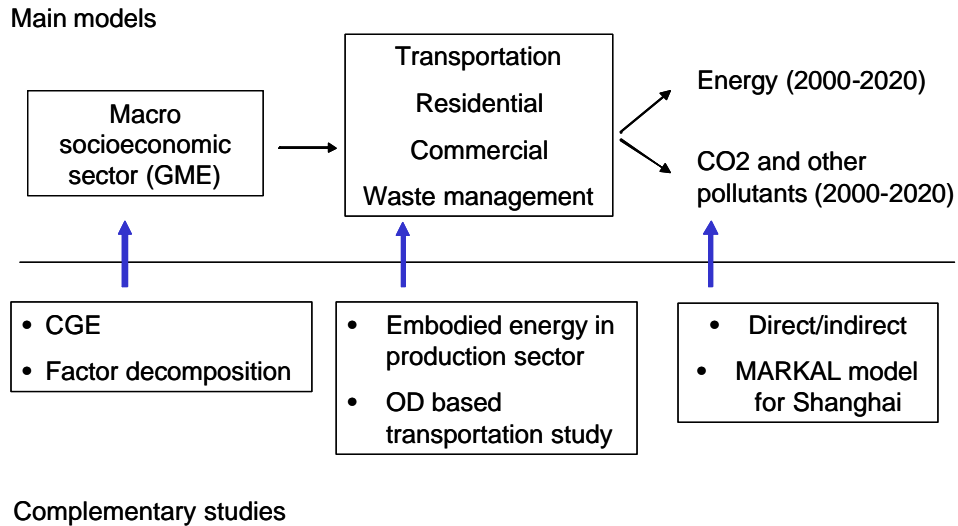
Figure 4-1-2: Modified Overall Study Framework

Such supplementary studies mainly deal with the following aspects.
- o Interaction with outside regions (**Figure 4-1-3**)
  - ➤ Energy dependency and trans-boundary environmental impacts
  - ➤ Traffic inflow and outflow with surrounding regions
- o Urban economic growth
  - ➤ CGE (Computational General Equilibrium) model
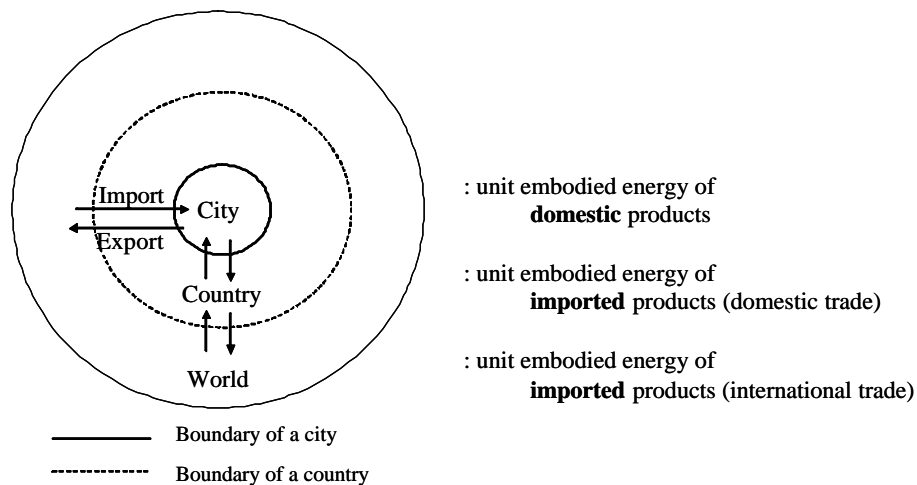
Figure 4-1-3: Boundary Setting of the City

Other aspects such as LCA assessment and water pollution are not covered by the main study, but such aspects are discussed through the presentation by invited speakers at workshops in Kitakyushu and Hawaii.

The degree of achievement of initial objectives are summarized in the **Table 4-1-5** below.

Table 4-1-5: Objectives and Achievements

Initial Objectives	Achievement
To collect GHG budget data of some mega-cities in Asia	Achieved. Completeness varies among the cities (see above tables)
To present future scenarios of GHG emissions and carbon cycle of the cities up until 2020.	Only CO2 has been calculated in Tokyo, Seoul, and Beijing
To generate inventory of various associated short-lived gases like CO, NOx, SOx and particulate matter. (Key sectors: macro economic & social framework, residential & commercial sector, urban transportation sector, municipal solid waste management sector, indirect energy consumption by industry).	Transportation sector covered CO, NOx and PM. SMW sector covered energy recovery from waste incineration.
To account both for direct emissions and for embodied emissions	Indirect energy consumption was calculated but not yet emissions which can be done after integration of all the sub-sector models.

Table 4-1-6: Selected Cities and Sectors Covered in the Report

	Basic Information	Transportation sector	Residential sector	Commercial sector	Waste management
Tokyo	v	v	v v	v	v v
Seoul	v	v	v	v v	v v
Beijing	v	v v	v v	v	v
Shanghai	v	v	v	v	v

Note: v: Brief introduction, vv: Detail information

4.4. Major Findings
4.4.1. Comparative Study of Beijing, Seoul, Tokyo and Shanghai

Scale of the City
The selected cities of this study can be referred to as mega-cities because of their large population. Prior to the research for these mega-cities, the spatial scale of urban agglomeration in terms of area or population density should be taken into account.
Concerning the administrative boundary, **Figure 4-4-1-1** shows the current urban scales of Tokyo, Tokyo ward area, Seoul, Beijing, Beijing ward area, Shanghai and Shanghai ward area in 1997. Except for Seoul, there are two kinds of administrative boundaries of the whole city and ward area (central part), and statistical data is available for either both or one of them. This figure allows us to comprehend accurate statistical values with regard to urban scale of these four cities. Furthermore, the figure provides the future perspectives on how the transportation systems as a whole should be formed in these cities, especially in Beijing and Shanghai. In addition, it enables us to avoid misunderstanding of the definition of built-up area among these cities. More specifically, the boundary of the core ward areas (build-up areas at the center of ward areas) in Beijing and Shanghai is more comparable with Tokyo and Seoul, although the boundary is consistently changed over period and the data availability is much lower.
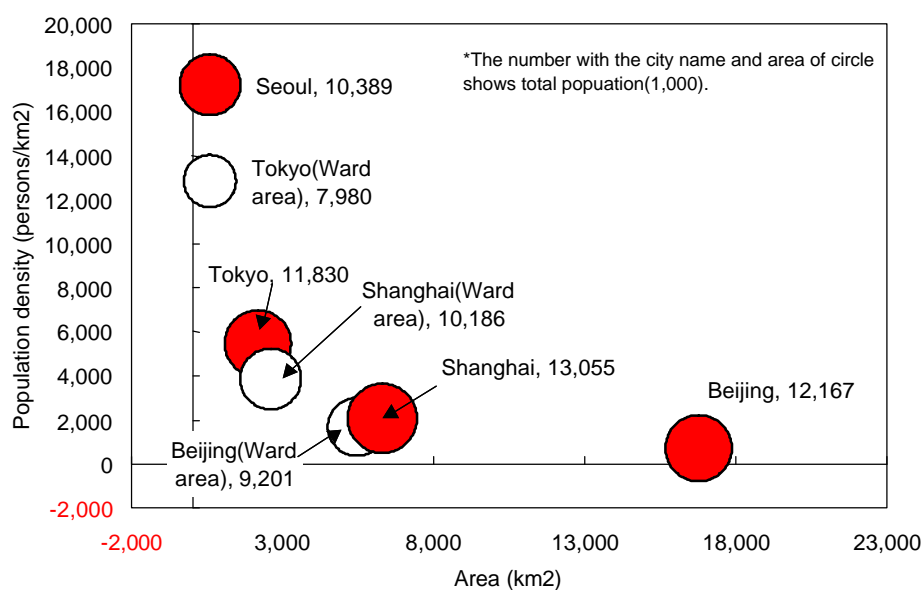
Figure 4-4-1-1: Population Size of the Four Cites

Ambient Air Quality
Among various urban environmental issues, air pollution is a major challenge for many cities in East Asia. Public concerns over air quality increases with the rising standard of living as it exhibits direct risks to human health. Major sources of air pollution in large cities are automobiles, although there are other diverse sources such as factories. Air pollution caused by traffic is most notable and serious in mega-cities in which the number of vehicles is increasing much faster than the pace of population growth. Therefore, this study conducts a comparative analysis of air pollution caused by automobiles in four mega-cities in East Asia, i.e., Tokyo, Seoul, Beijing and Shanghai. These four cities have a population of nearly ten million, and provide a good set of

comparative analysis of cities which have both similar and distinctive characteristics in terms of transportation mode, land use, legislation for air pollution control, etc.
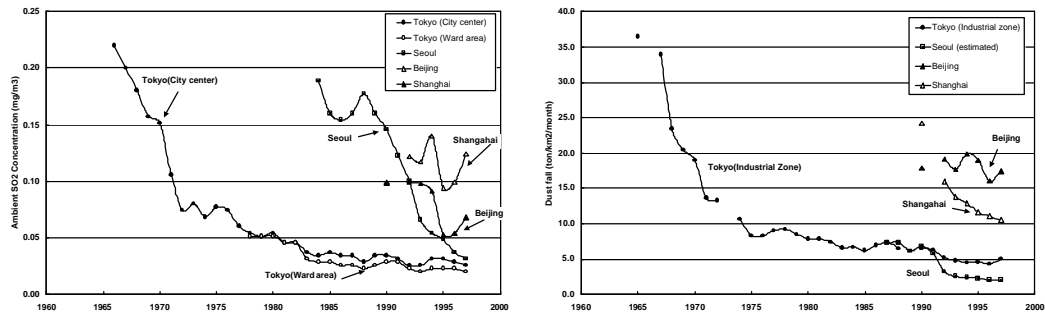
(A) Ambient SOx concentration (mg/m^3)

(B) Dust fall (ton/km^2/month)[1]
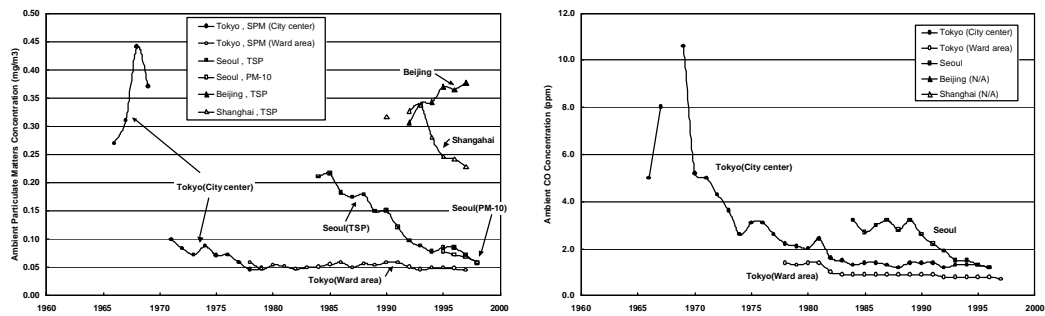
(C) Ambient PM concentration (mg/m^3)[2]

(D) Ambient CO concentration (mg/m^3)
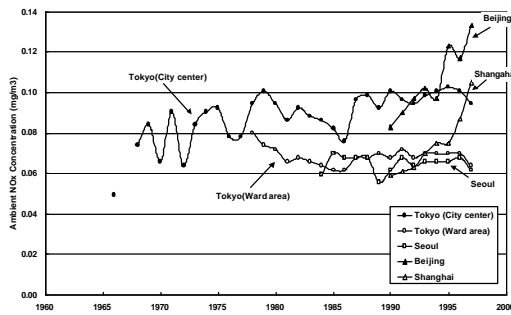
(E) Ambient NOx concentration (mg/m^3)[3]

Figure 4-4-1-2: Comparison of the trends in major air quality indicators in 4 mega-cities

Data Source: China State Statistical Bureau, 1990-1998; Ministry of Environment of Korea, 1990, 1998; The Tokyo Metropolitan Research Institute for Environmental Protection, 1996; Tokyo Metropolitan Government, 2000.

Note
1. Data on total emitted amount of TSP is used for the estimated dust fall of Seoul.

2. SPM for Tokyo and PM-10 for Seoul include by definition every particle 10 micrometers **and** smaller. TSP for Seoul and Chinese cities include by definition every particle 100 micrometers and smaller.

3. Data on NO2 is used for NO$_x$ of Tokyo and Seoul respectively.

In all of the four cities, despite the government's efforts against the degradation of air quality, the emission of air pollutants from mobile sources is one of the most urgent challenges. The comparison of the ambient concentration of major air pollutants in the cities shown in **Figure 4-4-1-2** confirms that the NOx concentration, largely discharged from automobile exhaust gases, still remains at a substantial level, while other air pollutants have to some extent decreased for the past several decades. As compared to the industrial air pollution that has recently been improved by various measures focusing on stationary source of air pollution, the future prospects on the improvement of mobile air pollution in these cities is not optimistic. The underlying reason is attributed to the existing situations in the case-study cities. Concerning urban transportation, it is expected that these mega-cities face the growing transportation demand from both freight and passengers that depends to a great extent on road transportation. Yet, considering the existing conditions in these Asian mega-cities, including rapid increase of automobiles and strong preference of private cars, the improvement of current road transportation system is so far very limited.

Indeed, the municipal governments made great efforts to reduce the use of private passenger cars, while they encouraged people to use public transportation modes. However, as seen in other regions, public transportation policy measures have a limited impact on the change of modal choice and trip behavior at individual level. Therefore, it is apparent that the changes of lifestyle and commuting behavior of individual citizens call for innovative policy measures. Furthermore, the governments in Japan, Korea and China, where the automobile industry plays a key role in their national economy, have to pay attention to the growth of the domestic automobile market. Given the situation, the improvement of the public transportation system towards sustainable urban environment poses new challenges on the issue of urban transportation in the selected East Asian mega-cities.

Transportation
(i)   Vehicle Population
Although the motor vehicle fleet is not exactly the same as the frequency of their use, it is one of the reliable indicators to explain motorization. **Figure 4-4-1-3** shows the trends of registered motor vehicles in Tokyo, Tokyo ward area, Seoul, Beijing and Shanghai, respectively. The registered vehicles are categorized into two groups, namely, passenger cars and trucks. While buses belong to the passenger car group in China, they belong to trucks in the other cities.
Concerning the number of passenger cars, motorization in Tokyo can be observed to have started since early the 1960s. Then rapid expansion occurred during the period between the mid1960s and the early 1970s. More specifically, between 1963 and 1973, the number of the passenger cars increased by 15.6 percent of the annual average growth rate and grew to 4.3 times as large as 1.7 million. In the 1990s, when Japan experienced the collapse of bubble economy, registered passenger cars did not show much growth in Tokyo. In particular, the number of registered passenger vehicles in the ward area of Tokyo has remained at the level of around 2 million since 1990. This is not simply because the economy has been facing a recession since 1990, but it should be perceived that the capacity of the introduction of new cars is saturated.
The rapid motorization in Seoul has occurred since the early 1980s. Without any discontinuity, the passenger vehicle fleet of Seoul has risen steadily and grew to 1.8 million in 1997. As a result, the past trend of passenger vehicle fleets in Seoul shows a logistic curve known as typical diffusion pattern of durable consumer goods in the market. Since 1995, there have been signs that the rapid increase of passenger vehicle ownership is approaching its limit. Considering that the scale of Seoul is quite similar to

Tokyo ward area, the upper limit of registered passenger vehicles in Seoul will be around 2 million, as large as the current level for the Tokyo ward area.

Compared with Tokyo and Seoul, on the other hand, the total number of passenger vehicles in Chinese cities is relatively small, where privately owned passenger vehicles have yet to be popularized among citizens. As of 1997, the number of passenger cars in Beijing was only 16.6%, 28.0% and 32.3% as many as those in Tokyo, the Tokyo ward area and Seoul, respectively. Similarly, Shanghai corresponds to 6.6%, 11.0% and 12.8%. The number of passenger cars in Beijing was twice as many as that in Shanghai in 1986. As a result of recent increases of passenger cars in Beijing, the number increased to more than 2.5 times that in Shanghai by 1997. So far Beijing is leading the motorization trend in China.

Though there are certain gaps in time and saturation levels that are still uncertain for Beijing and Shanghai, four mega-cities show similar growth patterns in terms of vehicle population. The booming periods and growth rate depends largely on the condition of the economy and income levels. In addition, saturation levels are closely associated with land use. In this regard, the availability of parking space is important.
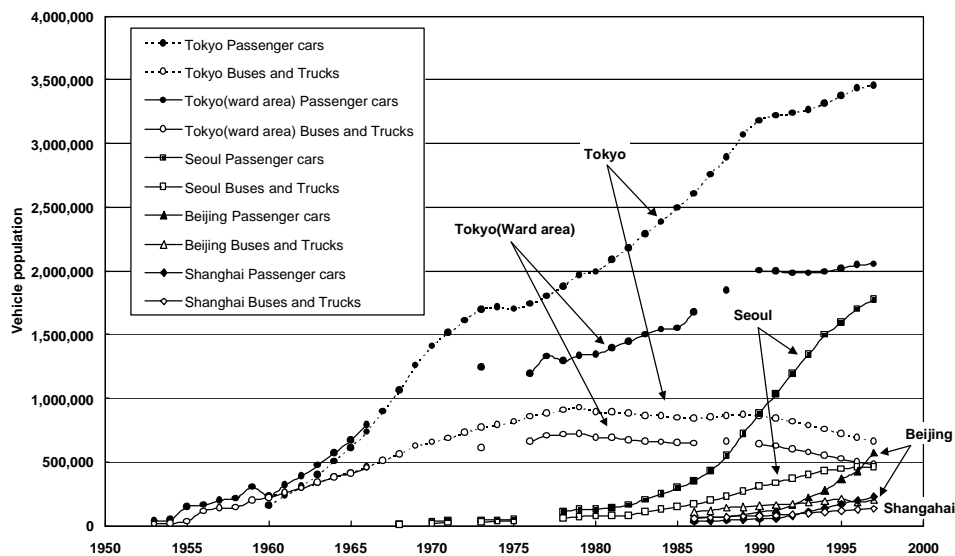
Figure 4-4-1-3: Vehicle Population

Data Source: China State Statistical Bureau, 1987-1998; Ministry of Home Affairs of Korea. 1969, 1971-1977, 1979-1997; Tokyo Metropolitan Government, 1962-2000; Council for Large City Statistics of Japan. 1952-2000.

(ii)   Public Transportation

Of generated trips and transportation demand, how much can be absorbed by public transit is very important for minimizing the use of private passengers. Whether public transit can provide attractive services or not is the key. **Figure 4-4-1-4** presents the total passengers of public transit and their modal splits. Among these four cities, there are apparent differences in characters of transit mode shares.

In Tokyo, total passengers have increased steadily since 1974 and peaked at 9 billion in 1992. Railway network systems including surface rails and subway lines in Tokyo are one of the most sophisticated one in the world. The surface rail networks in Tokyo developed before the motorization that came out behind the rail transportation system.

(A) Tokyo

(B) Seoul

(C) Beijing
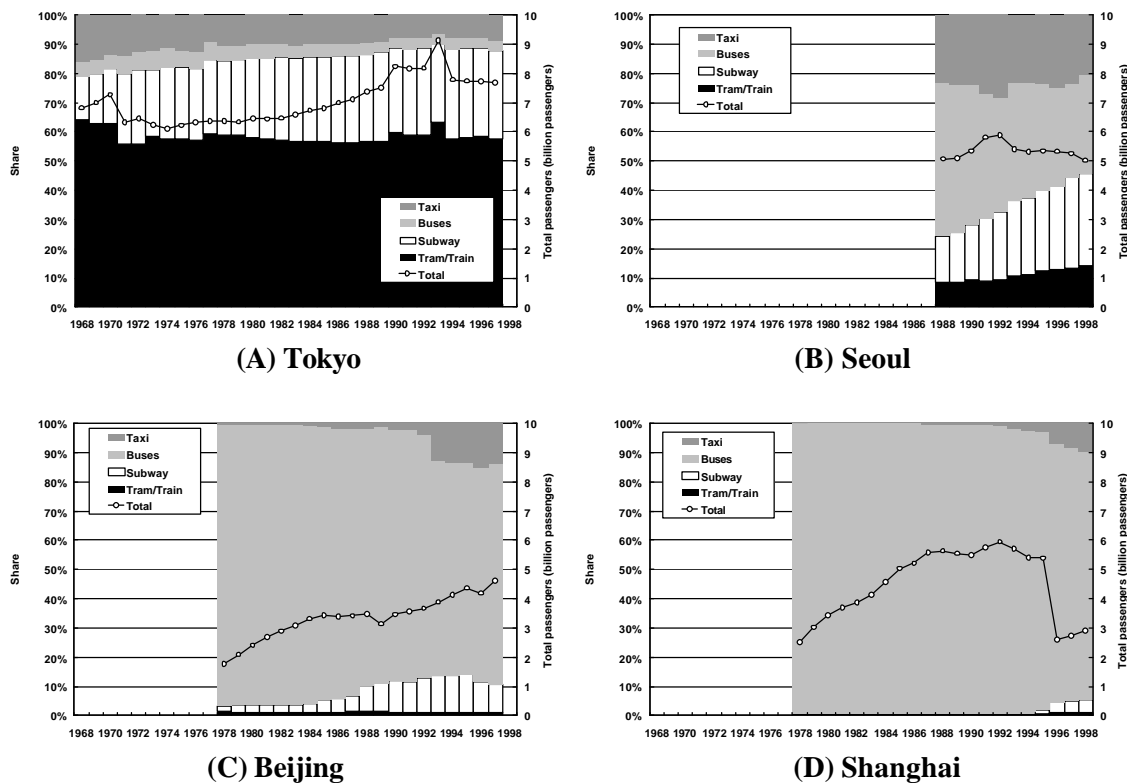
(D) Shanghai

Figure 4-4-1-4: Trends in Public Transit Modes

As a result, the shares of on road public transit such as buses and taxis have remained small from the beginning. The surface trains have been keeping more than 50% of total share throughout the periods from 1968 to 1997. This is the result of the private sector involvement. When Tokyo experienced urban sprawl, many private rail companies constructed railways from the city center to the peripheral area. Since the government allowed them to make profits on the sale of real estate in order to recover the huge initial investments of railway constructions, they usually formulated the corporate groups with construction and real estate agencies. They newly constructed shopping centers and residential areas around each station contributed to the development of satellite cities and suburb areas. This enables them to provide better services of railway transits with lower fares. Subways run by public organizations expanded their share in passengers of public transit from 15% in 1968 to 30% in 1997.

In Seoul, public transit is much more diversified as compared to the other three mega-cities. In addition, the share of public transit has significantly changed by the shift from buses to subway during recent decades, while total passengers have fluctuated between 5-6 billion. As for road transit, while taxis have kept a certain share of more than 20%, buses have continuously been losing their share from 53% to 34%. Instead, subways have rapidly increased from 16% to 32% during the same period.

People in Beijing utilize public transits more often every year. The total passenger of public transit in Beijing has increased 2.6 times from 1978 to 1997. Public

transportation in Beijing used to depend fully on bus transit including trolley buses with a share of 96% in 1978. In the 1990s, public transit started to diversify slightly. Since 1991, the number of taxi companies has increased dramatically from 354 in 1991 to 2,366 in 1997 – by 6.7 times. At the same time, the number of taxis has also rapidly increased from 14,000 in 1991 to 60,000 in 1997. As a result, taxi shares increased to 14% in 1997. Another important public transit method in Beijing is the subway that began operations in 1969. The subway gained shares every year and peaked at 13% in 1995. In order to address the deficit of subway operations, the Beijing government has doubled the fare since 1996. The rapid increase in subway fares caused a sudden drop in the number of passengers. The share of public transit in Shanghai shows a similar trend with Beijing, while substantial subway operations just started in 1994.

The differences of subway performance among these cities are compared specifically. **Figure 4-4-1-5** shows the passenger traffic by subway and the total length of subway lines. The total length of subway lines in the Tokyo ward area is 236 km in 1997 that is as long as 1.1, 5.7 and 11.5 times than those in Seoul, Beijing and Shanghai respectively. Moreover, annual subway passengers in Tokyo are 2.5 billion in 1997 that is 1.6, 5.7 and 22.7 times as many as those in Seoul, Beijing and Shanghai respectively. Since the late 1970s, Seoul has constructed subway lines intensively and took just 15 years to catch up to the Tokyo ward area in terms of total length. However, annual passenger traffic has not increased as rapidly as the extension of lines. This relation, that is, the passengers per unit length of subway line, is defined here as subway performance. Tokyo has been keeping at a constant level of subway performance for more than 25 years. This recent aggravation of subway performance in Seoul is caused by the result of rushed subway construction. On the other hand, the performances in Beijing and Shanghai have quickly improved while the subway in Seoul has worsened the performance gradually since 1991. It is found that Beijing uses its capacity of subway lines to the fullest.
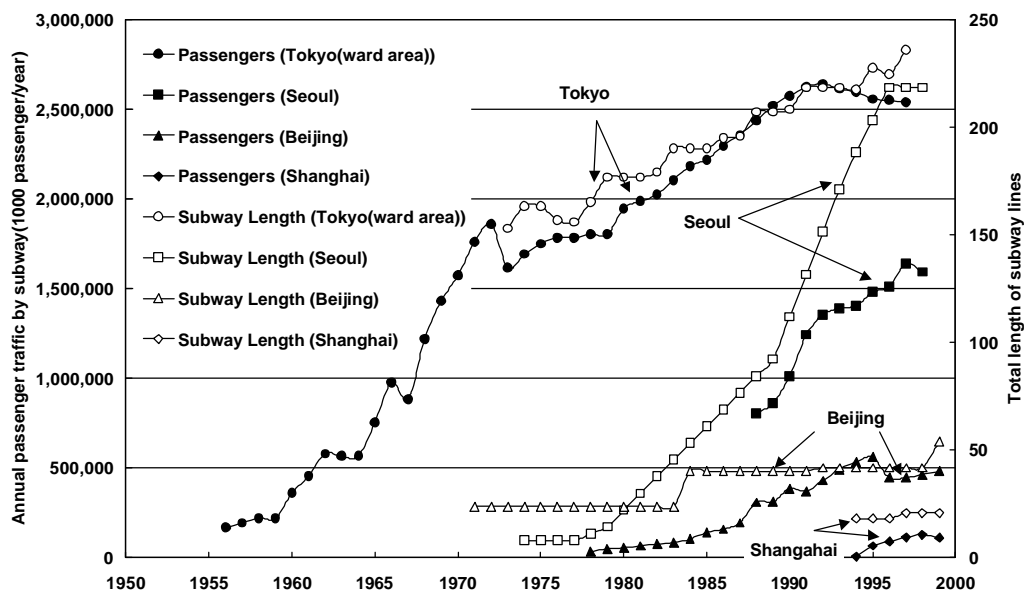
Figure 4-4-1-5: Subway System and Passengers

Hourly Load Curves of Buildings

In the total energy consumption profile in mega cities, the share of commercial building is quite important. Especially, the energy consumption patterns of commercial buildings in the cities like Tokyo and Seoul, which do not have many activities of manufacturing sector, rather have more service related activities. It is also worthwhile to note that the energy consumption patterns of commercial buildings are quite different from the activities of those buildings. **Table 4-4-1-1** below shows the results of actual survey conducted in specific buildings in Seoul in 1992. This table indicates the major specifications of buildings, which are related to energy consumption. This survey is the results of one-year measurement of actual electricity and heat consumption. There are four categories of commercial buildings; Hotel, Hospital, Department Store and Office. The first two types are more or less operating for 24 hours, while the last two types are used mainly for business hours. The energy consumption patterns are quite different, depending on the activities of buildings. Therefore, it is critical to consider the load patterns of energy consumption for the commercial buildings.

Table 4-4-1-1: Basic profiles for buildings to be surveyed in 1992

	Hotel	Hospital	Department Store	Office
Floor Space(m2)	176,786	129,273	64,440	299,753
Heating Space(m2)	105,443	102,702	26,411	196,695
Cooling Space(m2)	105,443	95,977	26,411	195,312
Floors	38	16	12	54
Heating/Cooling Method	Central	Central	Central	Central
Capacity of Heating(T/H)	24	40	15	36
Capacity of Cooling (R/T)	4,058	3,005	2,250	6,300

(i)   Electricity

The electricity consumption in commercial buildings shows common and distinct characteristics, depending on the types of buildings, as showed in the below figures. First of all, all types of buildings show the higher electricity demand in summer. The main reason is obviously that the demand for cooling energy (electricity) increases in summer. However, the seasonal ratios of peak and off peak are different from types of buildings. For example, in the case of hotel, this ratio is the largest, since the air conditioning depends on each individual guest in the room, which in general requires more electricity demand in summer, compared with that in other types of buildings.

If we compare the hourly load curves by seasons, we also observe that the hourly electricity load patterns are heavily related to the activities of buildings. For example, the buildings for office and department stores use more electricity during business hours, regardless of seasons. During the business hours, the electricity consumption of such types of buildings is more than five or six times larger than off business hours. This observation has strong implication on energy analysis in urban cities. For electricity in urban cities, the load management is also important as much as the electricity consumption pattern itself.

On the other hand, the impact of the seasonal factor on the buildings such as hotel and hospital is relatively smaller, since those types of buildings are operating for 24 hour-bases. Therefore, the hourly load patterns for those buildings are not quite different.
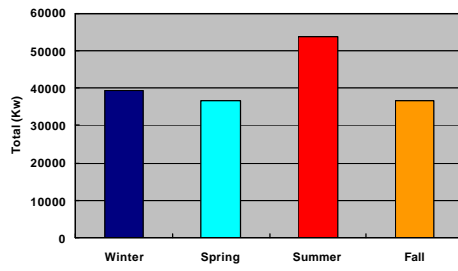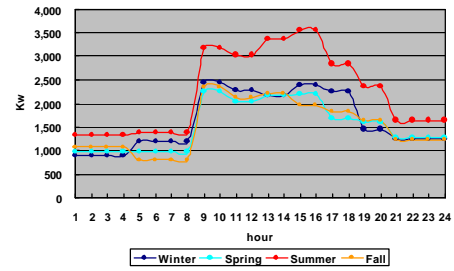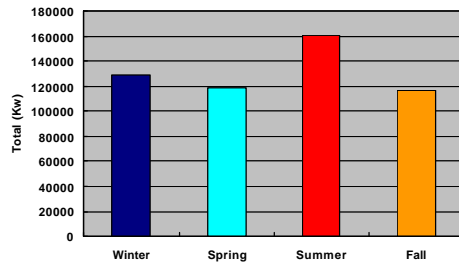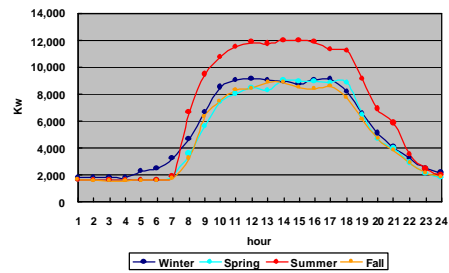
(A) Total per day by season   (B) Hourly load curves by season

Figure 4-4-1-6: Electricity use for hospitals in Seoul
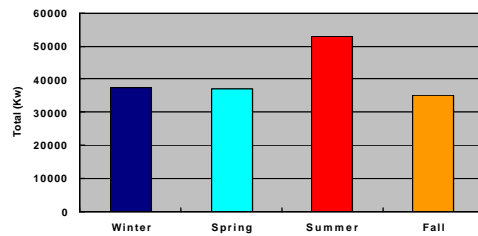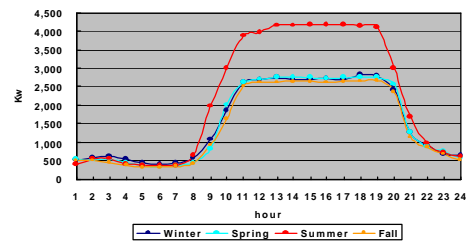**Data Source:** Roh, Dong S., KEEI

(A) Total per day by season   (B) Hourly load curves by season

Figure 4-4-1-7: Electricity use for offices in Seoul
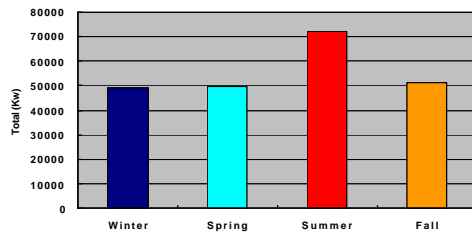**Data Source:** Roh, Dong S., KEEI
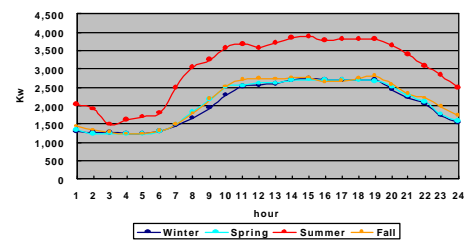

(A) Total per day by season   (B) Hourly load curves by season

Figure 4-4-8: Electricity use for department stores in Seoul
Data Source: Roh, Dong S., KEEI

(A) Total per day by season   (B) Hourly load curves by season

Figure 4-4-1-9: Electricity use for hotels in Seoul
Data Source: Roh, Dong S., KEEI

(ii)   Heating Energy

The heating energy demand in various types of commercial buildings also shows common and distinct characteristics, depending on the types of buildings, as showed in the below figures. First of all, all types of buildings show the higher heating demand in winter. The main reason is obviously that the demand for heating energy increases in winter. The weather condition in Seoul is quite cold in winter, which requires heating energy demand. On the other hand, the heat demand (cooling demand) in summer is also very high. Depending on the types of buildings, the heat demand in summer is higher than that in winter.

 However, the seasonal ratios of peak and off peak are different from types of buildings and this ratio is larger than that of electricity. Another common feature of heat demand in commercial buildings is that in summer during the daytime the peak for heat (cooling) is realized, while in winter this is realized in night time, if the building is used for 24 hours.

For example, in the case of hotel, this pattern is clearly observed. In the case of hospital, the demand for heat in winter and summer is relatively high and different hourly load patterns can be observed by seasons.

The buildings used during the business hours such as offices and the department store, show the similar hourly load patterns in heat demand as the case of electricity, which is to concentrate the energy demand during business hours.

(A) Total per day by season	(B) Hourly load curves by season
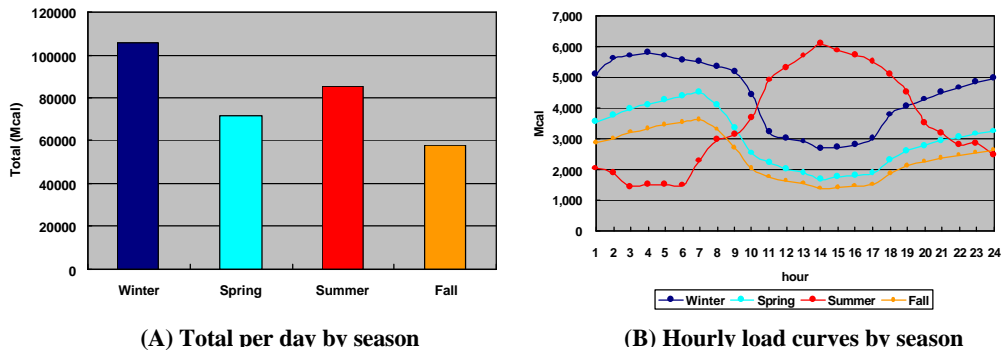
Figure 4-4-1-10: heating energy use for hotels in Seoul

Data Source: Roh, Dong S., KEEI

(A) Total per day by season	(B) Hourly load curves by season
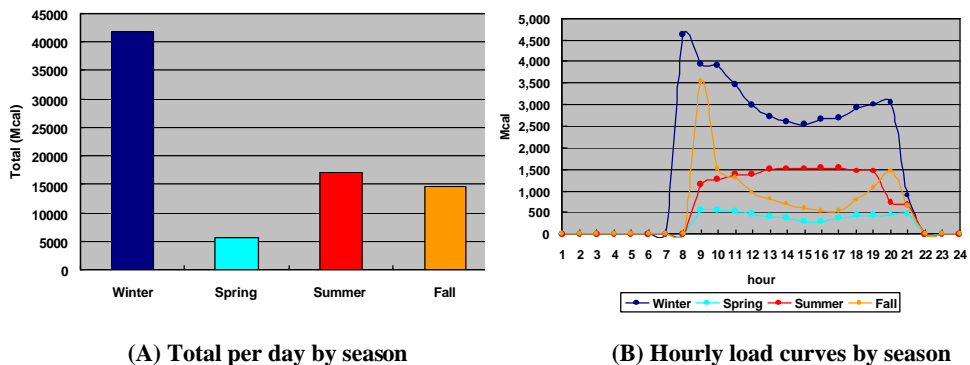
Figure 4-4-1-11: Heating energy use for department stores in Seoul

Data Source: Roh, Dong S., KEEI

| (A) Total per day by season | (B) Hourly load curves by season |
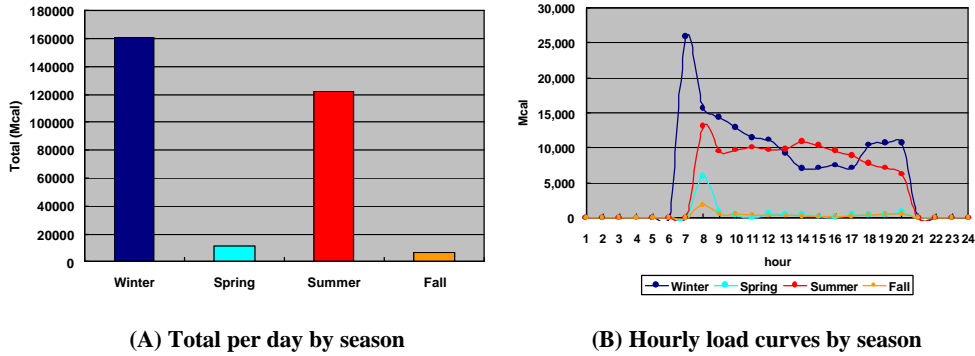
Figure 4-4-1-12: Heating energy use for offices in Seoul
Data Source: Roh, Dong S., KEEI

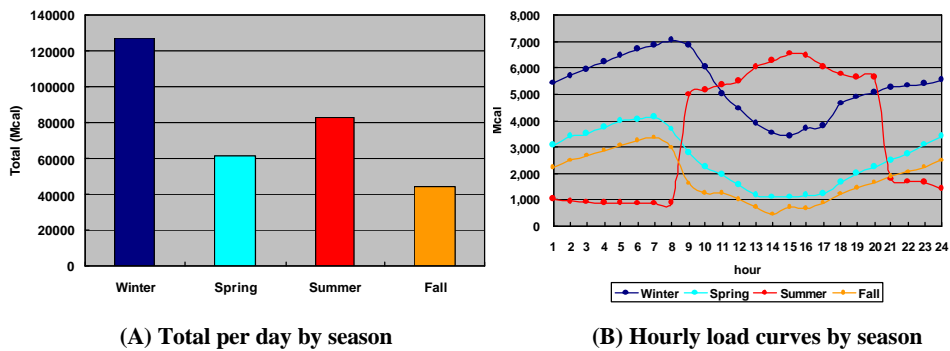| (A) Total per day by season | (B) Hourly load curves by season |

Figure 4-4-1-13: Electricity use for hospitals in Seoul
Data Source: Roh, Dong S., KEEI

Energy Consumption and Factor Analysis of CO2 Emission
(i)   Energy consumption
The final energy consumption of 4 mega-cities in East Asia is presented at the below figures. Due to the data limitation, we show trends for a few year in Chinese cities; Beijing and Shanghai. Here, it should be also noted that according to the definition of Chinese statistics, transportation sector does not cover the fuel use by transportation division of individual business and governmental bodies as well as private vehicle use. Therefore, the total gasoline consumption of all sectors is regarded as more reliable value for the total volume of vehicle energy consumption in China. Based on this consideration, the sectors in Chinese energy statistics are modified.

In terms of energy mixes, for Tokyo, oil has been the major energy source even in 1970's. The shares of town gas and electricity, both of which are considered as clean and convenient energy sources, have increased. The total energy consumption reached at almost 20,000 TOE in 1995.

On the other hand, the energy consumption trend for Seoul is to cover the period of 1990 – 1998. The first distinct feature is that during this period, the coal demand was almost disappeared, due to the tight environment regulation on air pollution in the metropolitan of Seoul. Like in Tokyo, the shares of town gas and electricity have been increased, mainly due to environmental consideration and income effect. However, in 1997, the energy demand in Seoul was peaked, reaching at the almost same level as in Tokyo. In 1998, it was sharply dropped, due to the financial crisis occurred in the late 1997.
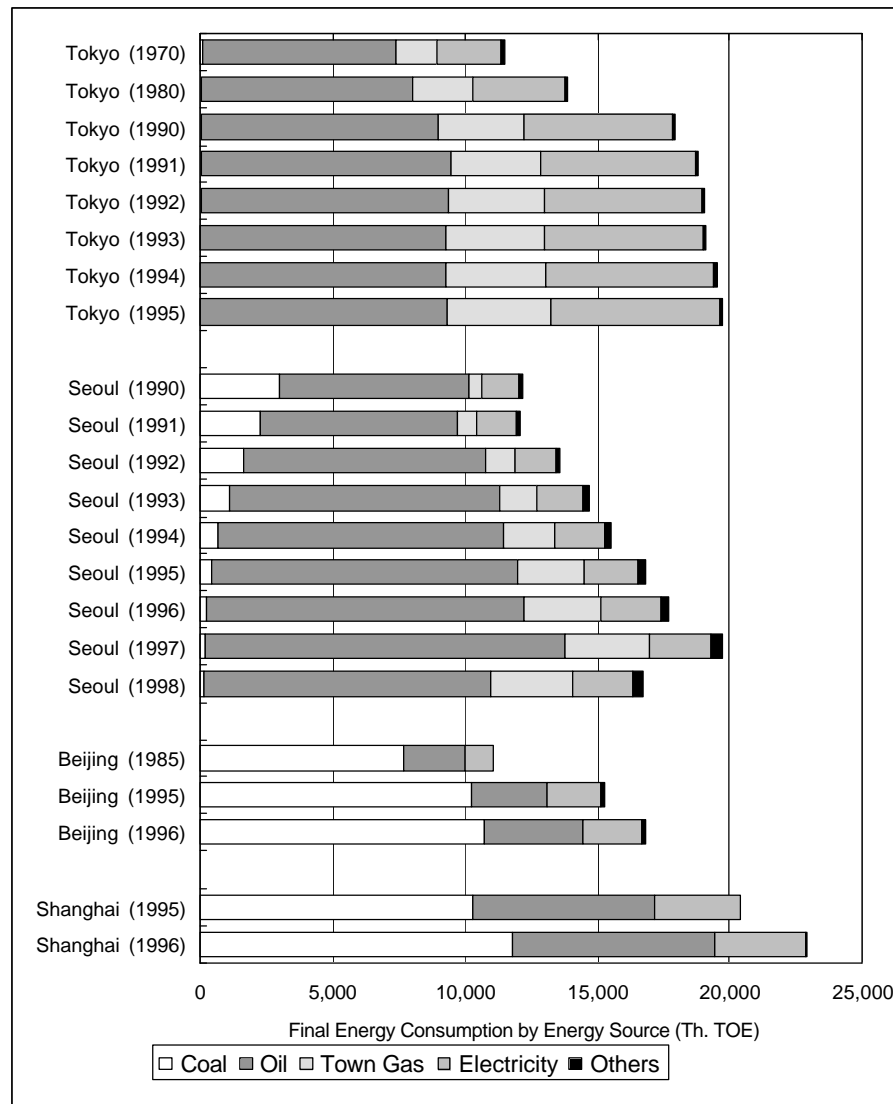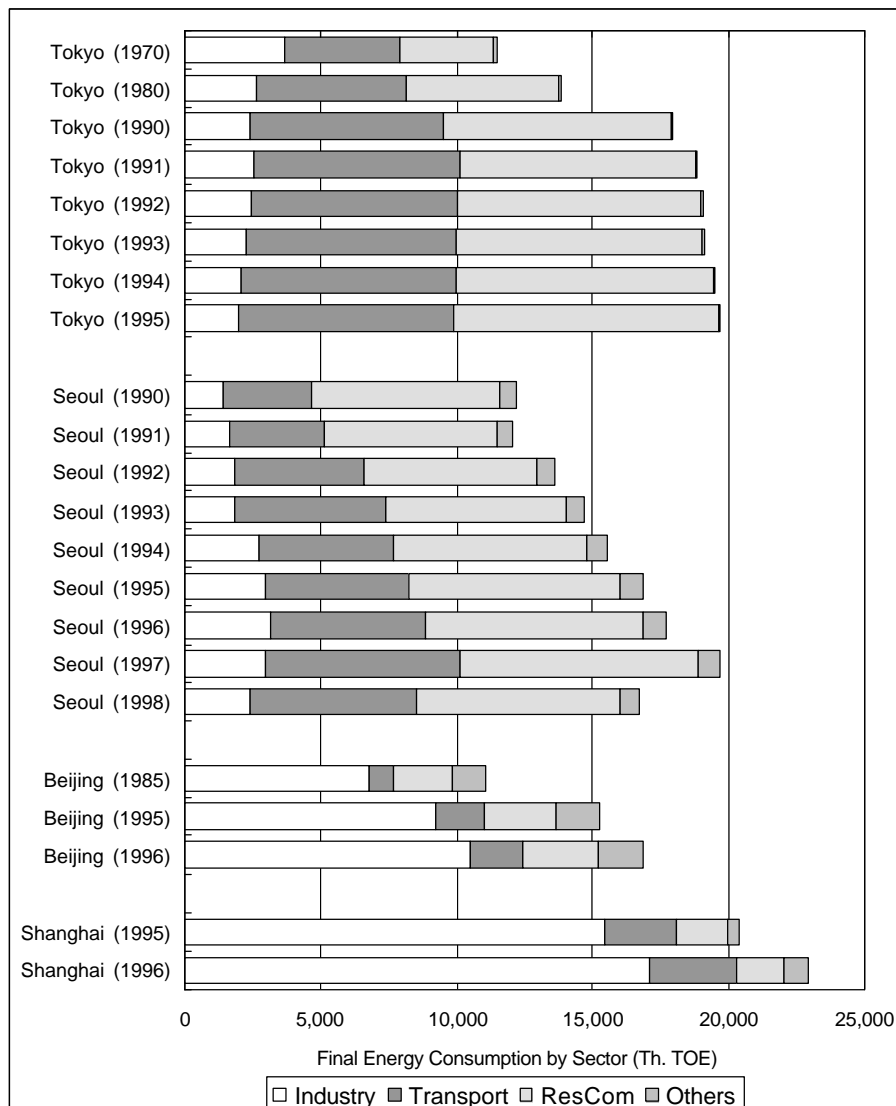
Figure 4-4-1-14: Final energy consumption by energy type

Data Source: Department of Industrial and Transportation Statistics of China State Statistical Bureau, 1998; Korea Energy Economics Institute, 1998; Korea Energy Economics Institute, 1999; KEEI Database; Bureau of Environmental Protection of Tokyo Metropolitan Government, 1998.

For Beijing, during one decade (1985 – 1996), the energy mixes remained more or less same, but the energy demand was increased. It is worth to note that the coal was the main energy source, which covered more than two third of total energy demand in 1996.

For Shanghai, the share of oil is much larger, since there are more industrial activities in this city, compared with Beijing. The total energy demand is much larger than that of Beijing. The total energy demand in Shanghai is the largest among those 4 mega-cities in this region.

Figure 4-4-1-15 shows the energy demand trend by sectors. In Tokyo, the absolute amount and shares of energy demand from transport sector has steadily increased. The share of residential and commercial sectors in energy demand has been the largest, as we expect this trend in major mega-cities. For Seoul, we observed the similar trend as in

Tokyo. The share of residential and commercial sectors is even larger. On the other hand, the share if industrial sector is larger in Chinese cities.

Figure 4-4-1-15: Final energy consumption by sector

(ii)   Factor Analysis

There is a method to analyze the factors to affect CO2 emissions in a specific economic unit, such as a country or a city. It is called 'factor analysis of CO2 emissions', which was first introduced by Professor Kaya, Y. (Sometimes, it is called 'Kaya Identity'.) This identity can be easily explained by the following equation. The CO2 emissions can be decomposed into four factors, which are shown in the right hand side of the equation.

In other words, The CO2 emissions can be explained by four factors such as the carbon intensity, energy intensity, per capita GRP (Gross Regional Product) and population. The carbon intensity implies that the content of carbon per unit energy consumption. The energy intensity is defined as the amount of energy to produce one unit of production. Per capita production implies the overall economic performance of a city or country. The trend of population is a kind of a scale variable, which explains the main underlying driving force of any economic activity.

$$CO2 = (CO2/E)*(E/GRP)*(GRP/Pop)*Pop$$
$$CO2 = (Carbon\ Intensity) * (Energy\ Intensity) * (Per\ capita\ GRP) * Pop,$$

where E is the energy consumption and Pop is the population.

If we differentiate the above equation, the change of CO2 emissions can be approximately decomposed into the change of those four factors.

$$\boldsymbol{D}\, CO_2 \gg \boldsymbol{D}\, (Carbon\ Intensity) + \boldsymbol{D}\, (Energy\ Intensity) + \boldsymbol{D}\, (Per\ capita\ GRP) + \boldsymbol{D}\, Pop$$

Hence, we identify the major factors to contribute the change of CO2 emissions within a specific period.

For the empirical study of factor analysis, we applied two cities; For Tokyo, we have data from 1970 – 1990 with 10 year span and 1990 – 1995 with every year span. For Seoul, we have data for 1990 – 1998 for every year.

The first set of figures in the following graphs shows the case of Tokyo for every decade from 1970 (**Figure 4-4-1-16**). As we expect, the economy of Tokyo (GRP) has been increased by three times for two decades. However, the increase of population has been trivial. The energy consumption and CO2 emissions have been increased with lower growth rates. The right-hand side graph shows the change of indicators in Kaya Identity. By this analysis, we identify which factor is the main contributor for the CO2 emission increase during the period. Obviously, the per capita GRP increase is the main reason for the increase of CO2 emission in Tokyo, which implies, in other words, that the expansion of economic activities in Tokyo is the main driver for the CO2 emission increase in this city. Also, it is worthwhile to note that during the same period, the energy intensity has improved more than 50%, which means that during the same period, to produce one unit of output, about half of energy was required. This is an important contribution from energy sector for slowing down the increase of CO2 emission. However, the contribution of carbon intensity was trivial, which means that the change of CO2 emission by fuel switching to less carbon intensive one was trivial, while the change of population was also marginal.

However, this situation is changed, if we applied the same method for the period of 1990 – 1995 in Tokyo (see **Figure 4-4-1-17**). During this period, Japanese economy has experienced the severe recessions. The GRP during this period has increased by 2 %, while the population in Tokyo somewhat decreased. On the other hand, energy consumption and CO2 emissions were increased by about 8%. As a result, during this period, the major contributor to the increase of CO2 was the increase of energy intensity, while per capita GRP affected in negative way. Still, it is important to note that carbon intensity has consistently improved during this period.
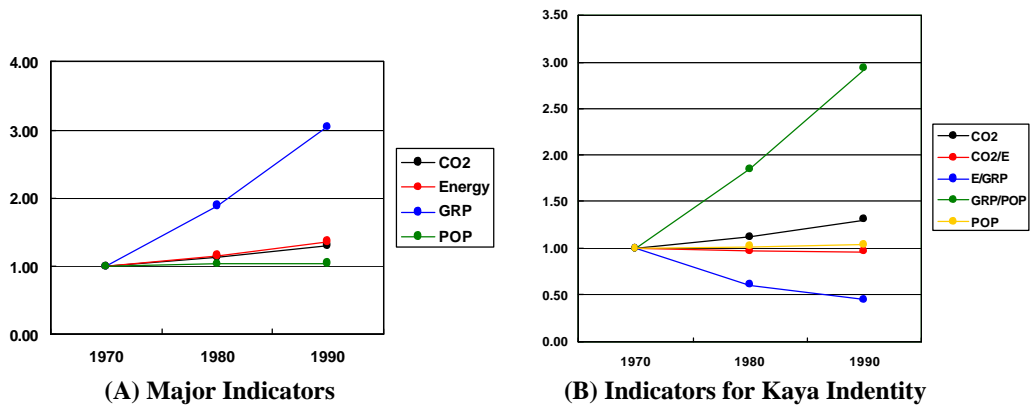
(A) Major Indicators   (B) Indicators for Kaya Indentity

Figure 4-4-1-16: Major indicators for Kaya identity in Tokyo (1970-1990)

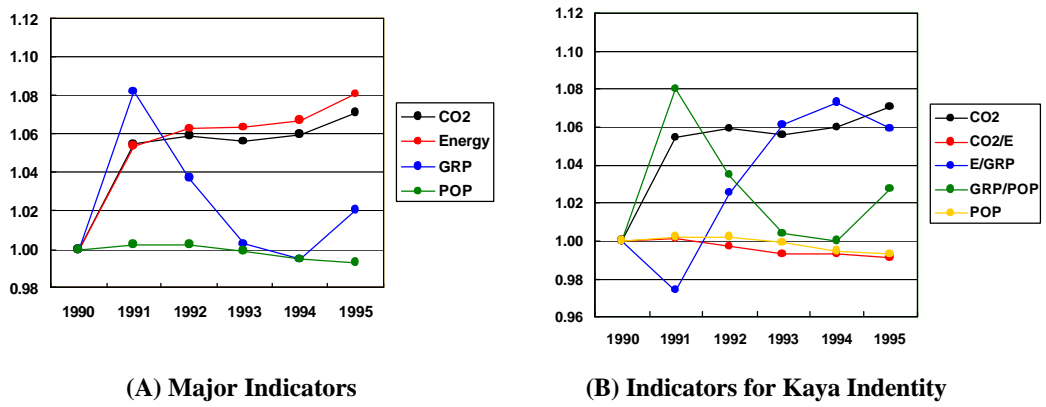(A) Major Indicators   (B) Indicators for Kaya Indentity

Figure 4-4-1-17: Major indicators for Kaya identity in Tokyo (1990-1995)

4.4.2. Comparative Analysis of CO$_2$ Emission in Beijing, Seoul, Tokyo and Shanghai

(1) Introduction

The volumes of Gross Domestic Product (GDP) and energy demand (or CO2 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[1]. On contrary, opposite trend is reported in developing countries, such as China and Thailand[2]. In volume basis, a large city contributes significantly to total national CO2 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 CO2 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 CO2 inventory[3][4][5][6][7][8][9]. 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 CO2 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 [10] . 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 CO2 emissions from energy use in Tokyo, Seoul, Beijing and Shanghai and compared their CO2 emissions in per capita and per unit gross regional product (GRP) basis. To understand the further intricacies of urban energy use in terms of CO2 emissions, past trends of CO2 emissions were analyzed for

---

[1] Literally means Beijing, Seoul and Tokyo.

[2] Ichinose, T., Hanaki, K and Matsuo, T. : International comparison of energy consumption in urban area. Proceedings of Environmental Engineering Research, Japan society of Civil Engineers, Vol. 30, pp. 371-381 (in Japanese), 1993.

[3] McEvoy, D. W., Gibbs, D. C. and Longhurst, J. W. S. : Assessing carbon flow at the local scale, Energy and Environment, Vol. 8, no. 4, pp. 297-311, 1997.

[4] McEvoy, D. W., Longhurst, K. W. S. and Gibbs, D. C. : A framekork for the construction of local CO2 inventories, in Air pollution V –modeling, monitoring and management, editied by Power, H., Tiranassi, T. and Brebbia, C. A., 3-13. Southampton, Computational Mechanics Publications, 1997.

[5] Kates, R. W., Mayfield, M. W., Torrie R. D. and Witcher. B.: Methods for estimating greenhouse gases from local places, Local Environment, Vol. 3, no. 3, pp. 278-298, 1998.

[6] Baldasano, J. M.,, Soriano, C. and Boada, L. : Emission inventory for greenhouse gases in the city of Barcelona, 1987-1996, Atmospheric Environment, Vol. 33, pp. 3765-3775, 1999.

[7] Bennett, M. and Newborough, M. : Auditing energy use in cities, Energy Policy, Vol. 29, pp. 125-134, 2001.

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

[9] ICLEI : Local government implementation of climate protection: case studies. http://www.iclei.org/co2/fact/cpcs97.htm (Aug. 1, 2002), 1997.

[10] Kenworthy, J. R. and Laube F.B. with Peter Newman, Paul Barter, Tamim Raad, Chamlong Poboon and Benedicto Guia (Jr): An International Sourcebook of Automobile Dependence in Cities, 1960-1990, University Press of Colorado, Boulder, 1999.

these cities and contributions of driving factors for total and sectoral CO2 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.

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 CO2 emissions per unit energy consumption by type, are obtained from locally available sources (such as Ministry of Environment of Japan) and IPCC[11]. BeSeTo Database, which is under continuous update and expansion at Institute for Global Environmental Strategies (IGES), is used to obtain most of the required data for case study cities. BeSeTo Database incorporates primary data from census and from local authority's publications. Energy and CO2 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[12]. 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[13 14 15 16 17 18 19 20 21] City definition of Tokyo in this paper is Tokyo-to or Tokyo Metropolitan Government administered area while that for Seoul is Seoul City. Seoul Metropolitan Area includes Seoul City and Kyongi Province. Definitions for Beijing and Shanghai are the areas administered by respective local governments.

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

[12] OECD/IEA : IEA energy statistics 2000, International Energy Agency, Paris, 2000.

[13] TMG : Tokyo Statistical Yearbook, Annually published (1970-2001) by Tokyo Metropolitan Government, Tokyo, Japan.

[14] TMG : Tokyo Vision 2000, Tokyo Metropolitan Government, Tokyo, 2000.

[15] TMG : TDM Tokyo Action Plan. Tokyo Metropolitan Government, Tokyo, 2000.

[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] Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1991-1996 Beijing, China Statistical Publishing House, 1998.

[19] Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1997-1999, Beijing, China Statistics Press, 2001.

[20] Korea National Statistical Office : Gross regional domestic product and expenditure -1998 edition, Daejeon, Korea, 2000.

[21] Korea National Statistical Office : Gross regional domestic product and expenditure –1999 edition, Daejeon, Korea, 2001.
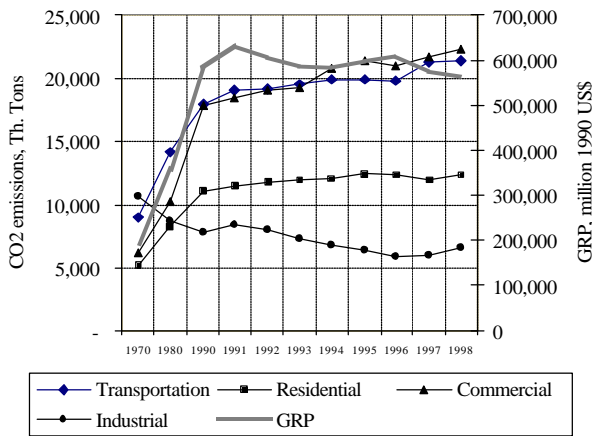
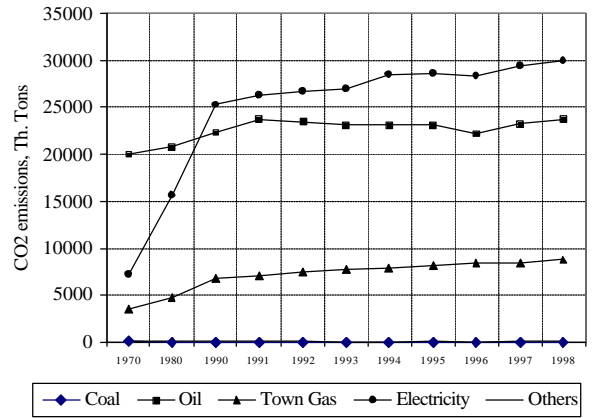**Fig. 4-4-2-1: Sectoral emissions profile of Tokyo**

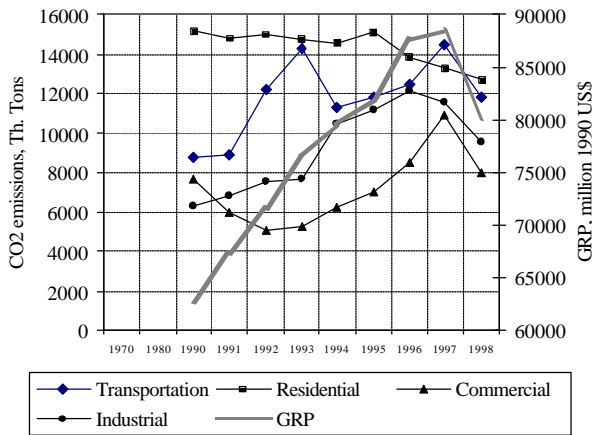**Fig.4-4-2-2: CO₂ emission of Tokyo by fuel type**

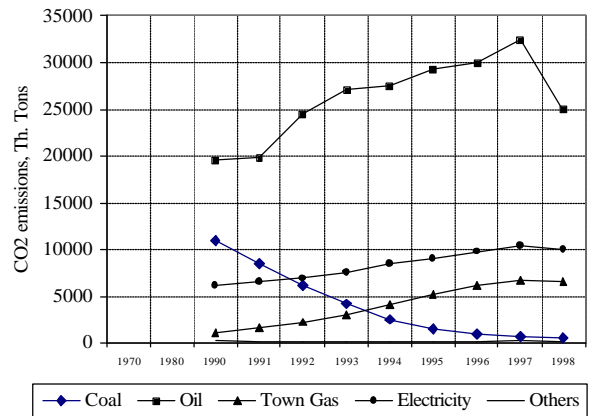**Fig.4-4-2-3: Sectoral emissions profile of Seoul**

Fig. 4-4-2-4: CO₂ emission of Seoul by fuel type

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

Emission trends

The estimation of CO2 emissions by sector and fuel type suggests that CO2 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 CO2 emissions for Tokyo and Seoul are estimated to 1.7% and 1.63%, respectively. **Figure 4-4-2-1** and **Figure 4-4-2-3** show the emission profile by sector for Tokyo and Seoul and **Figure 4-4-2-2** and **Figure 4-4-4-4** by fuel type. Beijing and Shanghai's emission growths are significantly higher than Tokyo and Seoul; the estimated annual emissions growths for 1985-1998 are 3.9% and 12.3% respectively while economic growth was about 15% for both cities. In 90's (1990-98) however, the annual growth of emissions are around 2% for Beijing and 5% for Shanghai despite the fact that economic growth rates are over 15%. This could be due to ongoing fuel switching, increasing productivity and improving energy efficiency.

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

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

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

In Tokyo, despite the slowing economy and negative economic growth in 1990's, emissions from only industrial sector has declined. The emissions from all other sectors, i.e. residential, transportation and commercial sectors, continue to grow. Industrial sector's contribution in CO_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 199821). 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 4-4-2-2**). Majority of these oil and electricity are used by transport, residential and commercial sectors.

In case of Seoul, emission from residential sector is the largest and that of commercial sector is the lowest. But, the share as well as emission volume of residential sector is gradually decreasing since early 90s while emissions from all other sectors continue to increase. Economic crisis, that gripped South Korea in 1997, has evident influence on emission profile of 1998 as demonstrated in the figures. Small contribution of industrial sector in total emissions can be partly explained by the dominance of tertiary sector. The share of tertiary sector in industrial valued added has increased from 74% in 1980 to 81% in 1997 (Korea National Statistical Office, 2000 and 2001). Similarly, oil contributes to over 70% of total CO_2 emissions due to its dominant use in buildings and transport sector (**Figure 4-4-2-2 and 4**) because most of the big buildings in Seoul use oil based centralized heating system unlike Tokyo.

Emissions in Beijing and Shanghai are mostly dominated by industry sector whose shares were at peak in 1996 (77% and 83% respectively). Since 1996, this sector has shown a declining trend in terms of shares as well as absolute volume of emissions while maintaining past trends of economic growth. Transport sector contributed around 4-6% of total emission in Beijing and about 6-10% in Shanghai (in 1985-98) unlike other mega-cities. However, since 1990 the shares of transport sector emissions have an increasing trend. As per capita car ownership in Beijing and Shanghai are much lower compared to Tokyo and Seoul, a low contribution of transport sector may be justified looking to the industry sector's dominance. Some inaccuracies may have resulted from accounting problems such as counting gasoline consumption by automobiles used in industries to industry sector and by households in household sector. Efforts have been made to limit such accounting problems. Coal is the major source of CO_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 4-4-2-5 to 8**)
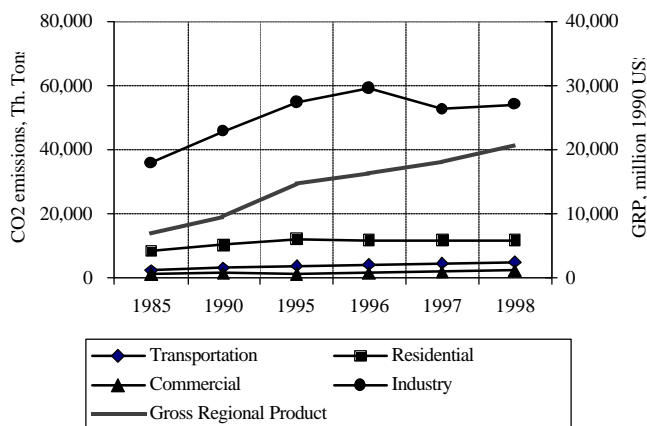
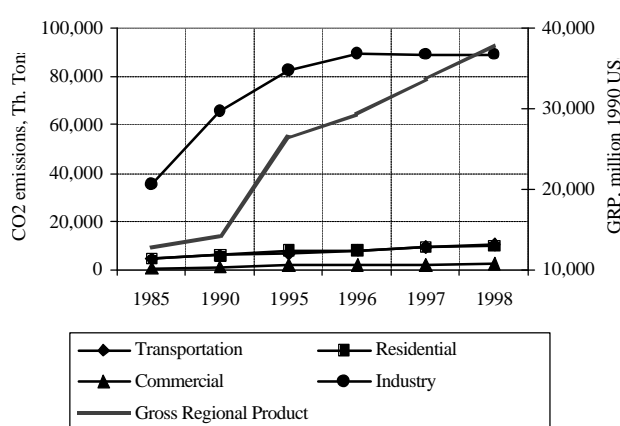**Fig.4-4-2-5: Sectoral CO₂ emissions in Beijing**   **Fig.4-4-2-6: Sectoral CO₂ emissions in Shanghai**
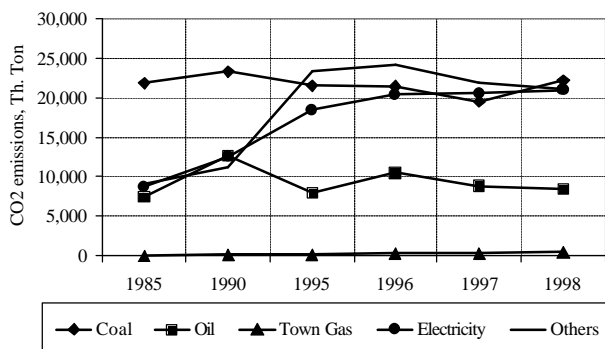Construction and agriculture sectors are included in Industry as their shares are very small.

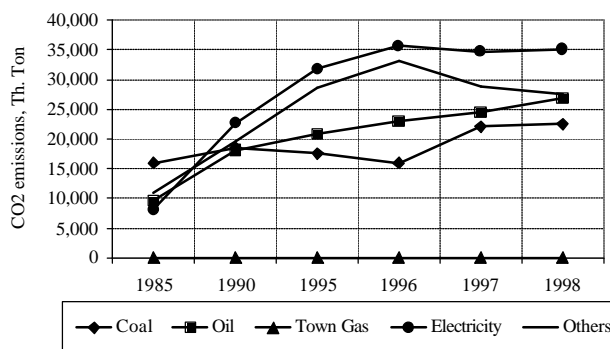**Fig.4-4-2-6: CO₂ emissions of Beijing by fuel type**   **Fig.4-4-2-7: CO₂ emissions of Shanghai by fuel type**
(Energy consumption calculations are made on primary energy basis. *Others* mean coking gas, coke, coking products and heat supply. Almost all energy sources for electricity, coking and heat supply are coal).

<u>CO2 emission performance of cities in per capita and per unit economic activities</u>

In this section we measured performance of the cities in terms of CO2 emissions per capita and CO2 emissions per unit GDP or GRP. CO2 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 CO2 emissions in electricity use in the cities are covered by the data. Due to data problems, CO2 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, CO2 emissions for Beijing and Shanghai are estimated by regional energy balance tables for respective cities [22] [23] and IPCC emission factors. Furthermore, GRP for Beijing and Shanghai are obtained from Beijing Statistical Yearbook and Shanghai Statistical Yearbooks, respectively. Estimated CO2 emission per unit 1990 GDP or GRP and per

---

[22] Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1991-1996 Beijing, China Statistical Publishing House, 1998

[23] Department of Industry and Transportation, National Bureau of Statistics China, China energy statistical yearbook 1997-1999, Beijing, China Statistics Press, 2001.
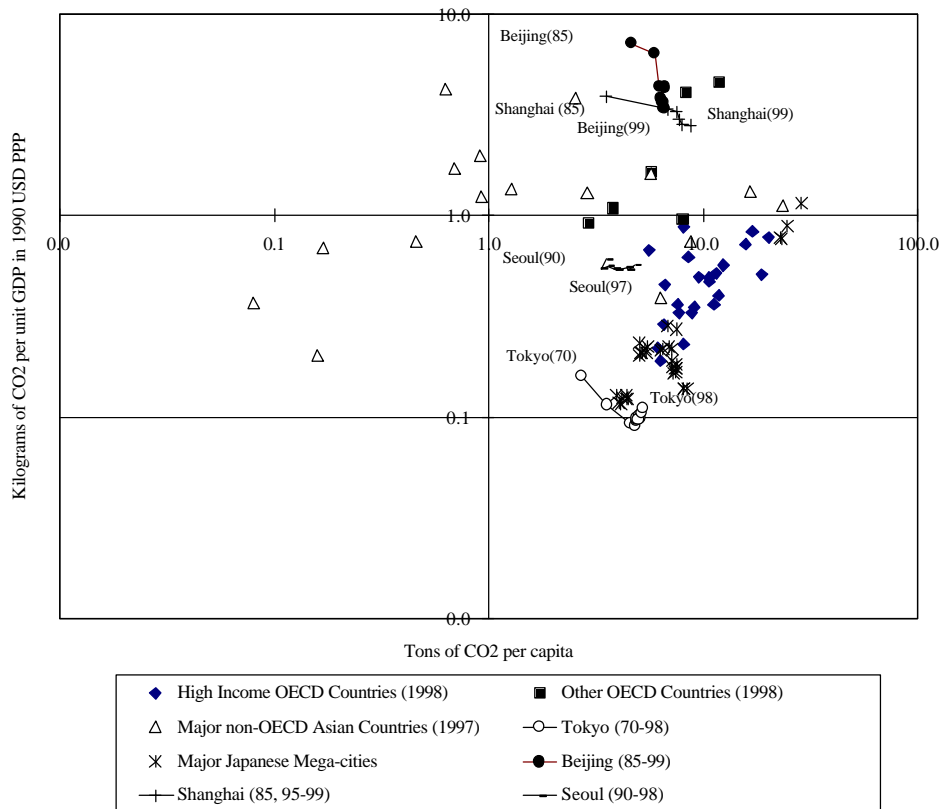
Figure. 4-4-2-9 CO₂ emissions in per capita and per unit GRP/GDP (in log-log scale).

capita CO2 emissions are plotted on logarithmic scale. Figure 9 shows the performance of cities. In **Figure 4-4-2-9**, the desired situation over time is the transition of the city towards the origin.

The comparison reveals that the performance of Japanese large cities is better, in general, than other cities and countries, and performance of Tokyo is outstanding. In recent years, especially after 1990, performance of Tokyo is seen to be slightly worsening mainly due to the slowing down of economy and inability to cut down CO2 volume. In Tokyo, slowing down of the economy is not cutting down lot of emissions because share of industrial sector is small in total CO2 emission. 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. This may be due to shift from traditional coal based technology. However, CO2 emissions are found to slightly increase in per capita terms. Reducing CO2 emissions in per capita seems major difficulty for cities and all cities have failed in that.

In deriving the per capita CO2 emissions for **Figure 4-4-2-9** the daytime population was used. However, studies have reported that 33% of workforces of Tokyo commute from outside Tokyo[24]. The ratio of daytime to nighttime population in Tokyo and Seoul is 1.25 and 1.04 in 1999, respectively[25] [26]. After, such commuting population is included

---

[24] TMG : TDM Tokyo Action Plan. Tokyo Metropolitan Government, Tokyo, 2000.

[25] TMG : TDM Tokyo Action Plan. Tokyo Metropolitan Government, Tokyo, 2000.

[26] Yoon, S. and Araki, K. : Scale of economy in urban energy use, Paper presented at IGES/APN Mega-city Project Workshop, January 23-24, Kitakyushu, Japan, 2002.

in per capita estimation, performance of Tokyo improved little while no noticeable effect is found in case of Seoul (not shown in figures).

This suggests that Tokyo is already operating at relatively better performance stage. In that sense, Tokyo might be able to serve as a desirable model to catch up with for rapidly developing mega-cities, particularly cities in North Asia. However, each city grows differently and, in reality, one city cannot serve as a complete model for another city, only suitable elements can be utilized. Future CO2 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[27]. If such technological measures could be implemented in the future, Tokyo's performance might improve further.

Factor Decomposition of CO2 Emissions

Determining factors for the changes in CO2 emissions from energy use are estimated for total as well as sectoral emissions. Due to data unavailability, contributions of factors were estimated for Tokyo since 1970 while that for Seoul from 1990. Beijing and Shanghai are analyzed for 1985-1998 period. The effects of changes in economic growth are highlighted where applicable.

a. Decomposition Method

Analyses on driving factors for CO2 emissions from energy use can be done by different methods. At macro-scale, Factor Decomposition, Vector Auto Regression (VAR), Correlation Analysis[28] 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 CO2 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[29]. In our study, we reviewed many literatures particularly by Shrestha and Timilsina[30][31], Ang and Liu[32], Greening et al.[33], Luukkanen & Kaivooja[34], Nag and Parikh[35], and Hamilton and Turton[36]. Our choice of

---

[27] Hanaki, K. : Integrated approach for best mix of technologies of reduction of carbon dioxide emissions - Tokyo Half Project (THP). Paper presented at IGES/APN Mega-city Project Workshop, January 23-24, Kitakyushu, Japan. 2002.

[28] 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.

[29] 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.

[30] Shrestha, R. M. and Timilsina, G. : A divisia decomposition analysis of NOx emission intensities for the power sector in Thailand and South Korea, Energy, Vol. 23, No. 6, pp. 433-438, 1998.

[31] Shrestha, R. M. and Timilsina, G. : Factors affecting CO2 intensities of power sector in Asia: A divisia decomposition analysis, Energy Economics, Vol. 18, pp. 265, 1996.

[32] 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.

[33] 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.

[34] Luukkanen, J. and Kaivooja, J. : ASEAN tigers and sustainability of energy use-decomposition analysis of energy and CO2 efficiency dynamics, Energy Policy, Vol. 30, pp. 281-292, 2002.

technique is subtractive decomposition that follows Sun and Luukkanen & Kaivooja[37]. 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 (EI) and GRP/P by per capita GRP (PC). I, EI, PC and P are explanatory variables. The increase in emissions in year t from year 0 is,

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

If we denote increment amount by D, then

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

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 CO2 emissions from different sectors. The choice of explanatory variables for each sector is different which reflects the sector in concern. The explanatory variables for sectoral analyses are described below.

For transport sector,

$$C_t = CI_t \times EI_t \times VKT_{pv} \times P_t$$

Where, Ct = CO2 emissions from transportation sector, in thousand Tons; CIt = Carbon Intensity, defined as the amount of CO2 emissions per unit energy consumption, in Tons/GJ; EIt = Energy intensity, defined as the amount of energy consumption per vehicle travel distance, in KJ/km; VKTpv = Vehicle Kilometers Traveled per vehicle, and Pt = Number of vehicle registered, in thousands.

---

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

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

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

Data used to estimate contributing factors in transportation sector was historical trend of CO_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.

(b) Contribution of factors for changes in total CO2 emissions

The decomposition results are presented in absolute terms where total change in emissions is the sum of carbon intensity effect, energy intensity effect, income effect and the population effect as in **Figure 4-4-2-10**. The results suggest that the economic activity, i.e. income effect, was the major driving force behind the changes in CO2 emissions in Seoul during economic growth as well as economic recession period. In case of Tokyo, economic activity was the major driving force behind majority of the emissions in high growth period, but its contribution to reduce emissions in economic recession period is found smaller. Tokyo experienced economic recession after so-called bubble-brust in late 80's while Seoul experienced economic recession after 1997 as shown in **Figure 4-4-2-10**.

In Tokyo, though carbon intensity effects and population effects were found responsible for slightly increasing emissions in 70's and 80's, their contribution was negligible in 90's. Unlike Tokyo, carbon intensity effect was found responsible for reducing a large amount of emissions in Seoul during high growth period (1990-97) but its contribution was negligible in recession of 1997-98. Energy intensity, which indicates the direction of technological changes and structural shift of activities, was responsible for the reduction of emissions by large amount in Tokyo during economic growth periods. However, it contributed in an opposite way during recession period. The role of energy intensity effect was found opposite in Seoul as compared to Tokyo. In Seoul, it
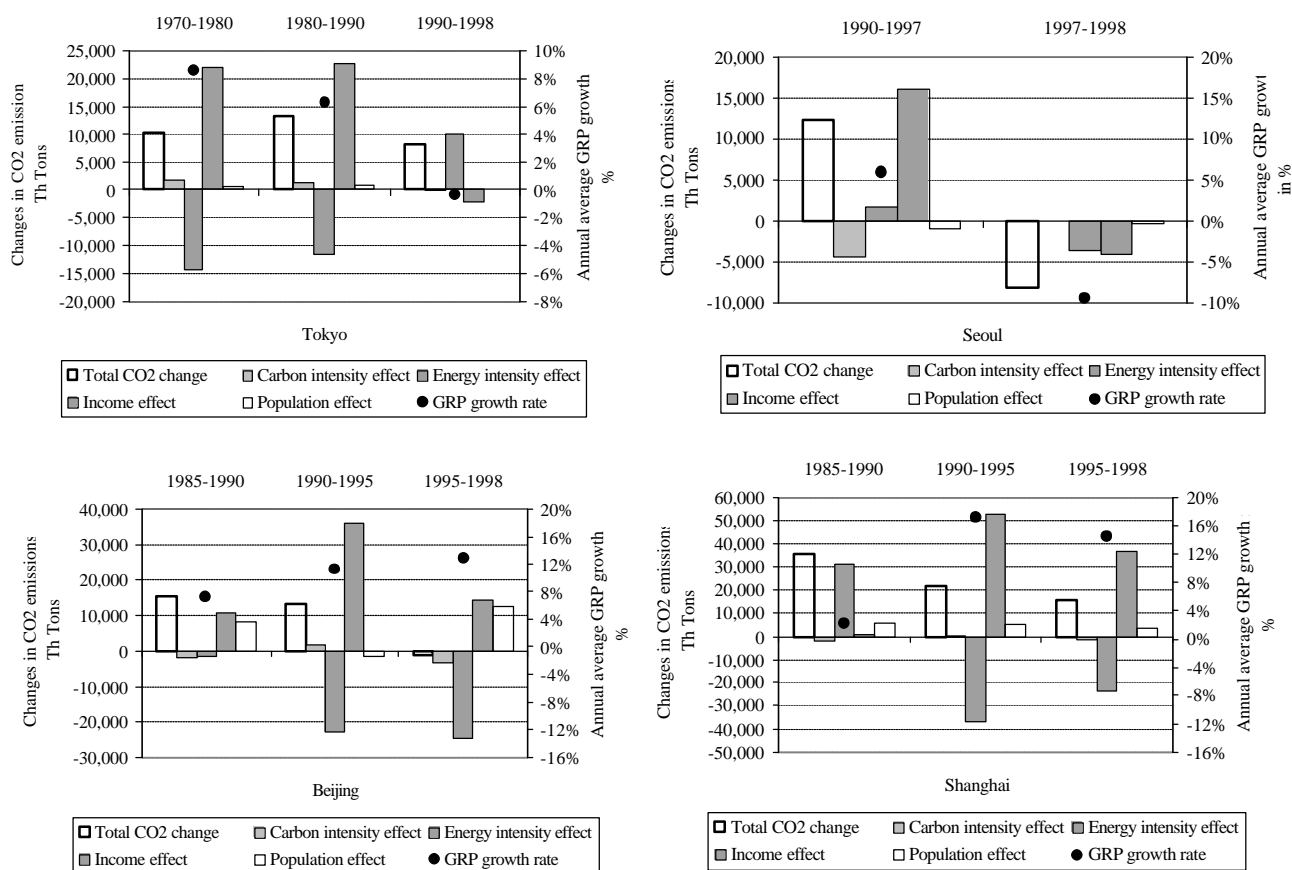
Figure 4-4-2-10: Factor decomposition of CO$_2$ emissions from energy uses

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

Income effect was responsible for reducing CO2 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 CO2 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[38] [39] 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 CO2 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.

---

[38] Korea Energy Economics Institute: Yearbook of Regional Energy Statistics 1998, Euiwang-Shi: Korea Energy Economics Institute, 1998.

[39] Korea Energy Economics Institute: Yearbook of Regional Energy Statistics 1999, Euiwang-Shi: Korea Energy Economics Institute, 1999.

Contribution of factors in sectoral emissions

(a) Transportation sector

Factor analyses for transportation sector show that passenger vehicle population was responsible for most of the increase in CO2 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 CO2 emissions during high growth period (80's) only. The results also indicate that energy intensity was responsible for decreasing CO2 emissions in large amount in 80's. However, in 90's energy intensity was found to be the major cause behind increased CO2 emissions. Further analysis is required to explain this phenomenon, however, urban traffic congestion[40], 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[41]. 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 CO2 emissions; the major contribution was from energy intensity effect, followed by vehicle utilization effect. Only vehicle population effect and carbon intensity effect is stable for both Tokyo and Seoul on yearly basis. Energy intensity effect is found to fluctuate significantly.

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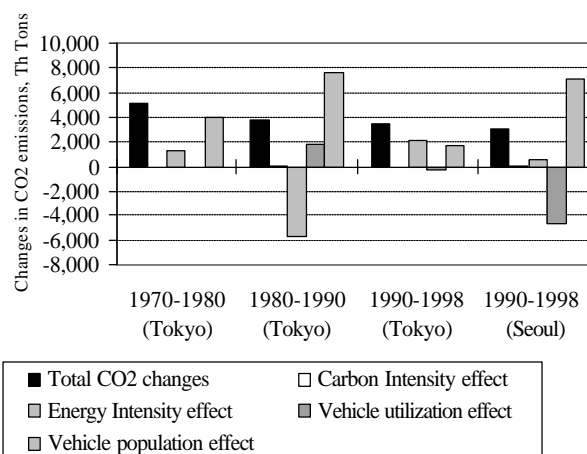

Figure 4-4-2-11: Factor decomposition for CO2 emissions from transportation sector

---

[40] TMG : Tokyo Vision 2000, Tokyo Metropolitan Government, Tokyo, 2000.

[41] MITI : Annual Automobile Transportation Statistics 1998, Ministry of International Trade and Industry, Japan., 1998.
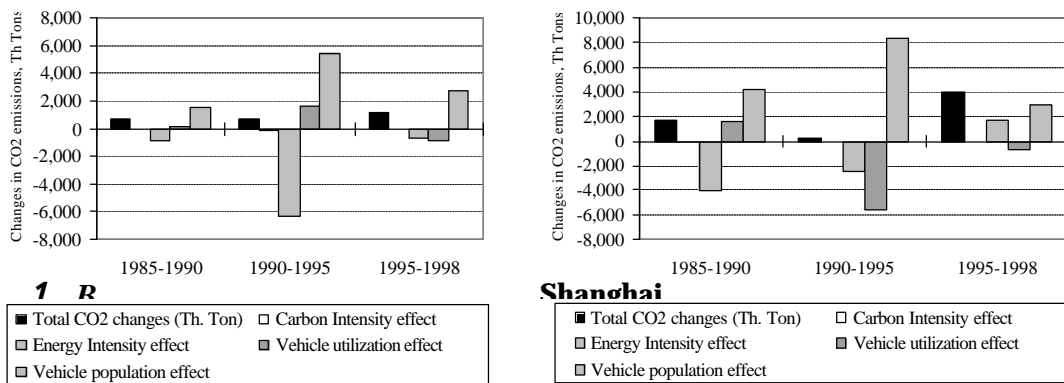
Figure 4-4-2-12: Factor decomposition for CO2 emissions from Beijing and Shanghai transportation sector in Beijing

(b) Residential Sector

CO2 emissions from energy use of residential sector seems to have saturated in recent years in Tokyo while, in Seoul, it has decreasing trend as demonstrated in **Figure 4-4-2-13**. Such decreasing trend is also observed for Beijing in 1996-98 periods. **Figure 4-4-2-13** shows the estimated contribution of each factor in the increase of CO2 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 CO2 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 CO2 emissions by large amount. The nature of factor's contribution (magnitude as well as positive or negative effect to CO2 emissions) is similar for high growth period of 70's and 80's as well as economic crisis of 90's for Tokyo.

In case of Seoul, for 1990-98, carbon intensity effect is most prominent and it contributed to reduce CO2 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 CO2 emissions in Seoul. Yearly variations of various effects for 1990-98 for Tokyo and Seoul are also analyzed; for Seoul only carbon intensity effect was found stable and all other effects could not be explained; for Tokyo, factors were relatively stable as shown in **Figure 4-4-2-13.**

The structure of factors for Beijing and Shanghai are similar for 1985-1990 periods. During this period, carbon intensity and energy intensity effects contributed to reduce emissions while income effect and household population effect were majorly responsible for increasing emissions. Fuel substitution from coal to gas, technological improvements of 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.
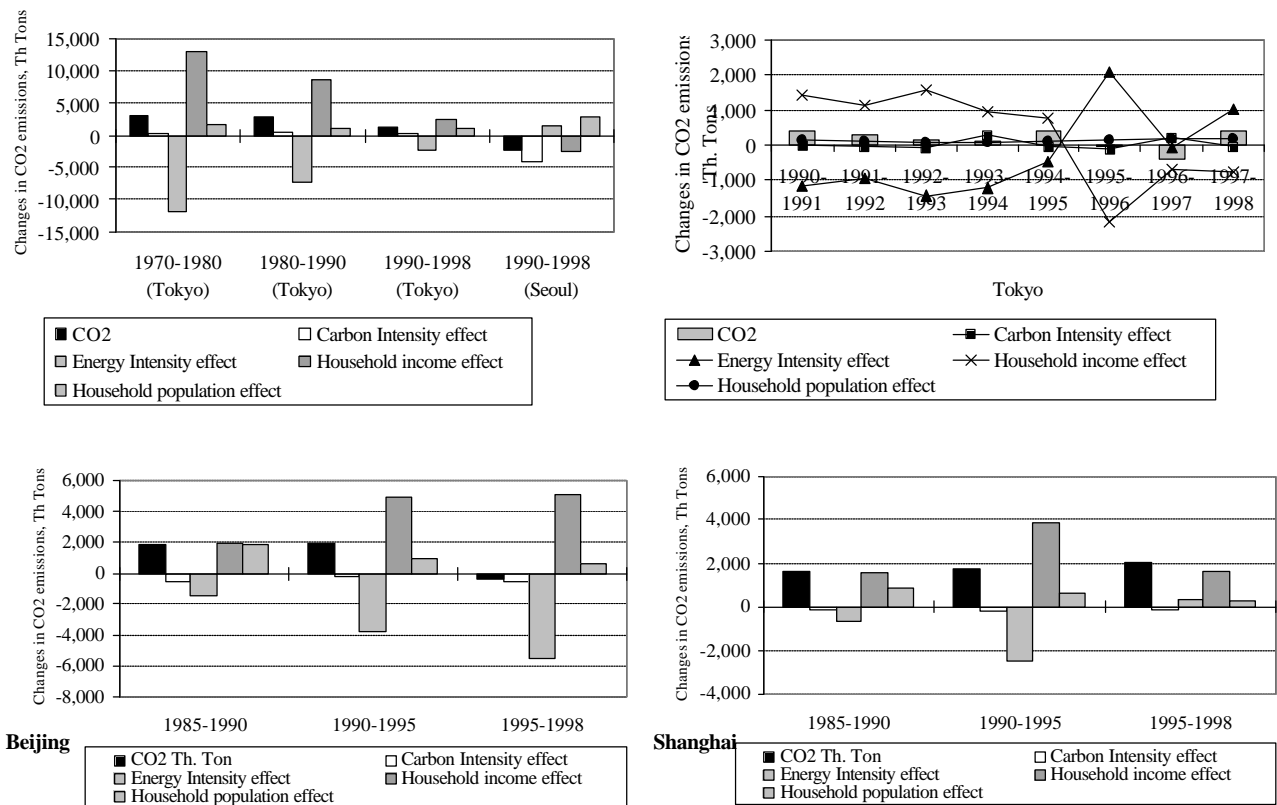
Changes in CO2 emissions, Th Tons

15,000
10,000
5,000
0
-5,000
-10,000
-15,000

1970-1980 (Tokyo)   1980-1990 (Tokyo)   1990-1998 (Tokyo)   1990-1998 (Seoul)

- CO2
- Carbon Intensity effect
- Energy Intensity effect
- Household income effect
- Household population effect

Changes in CO2 emissions, Th. Tons

3,000
2,000
1,000
0
-1,000
-2,000
-3,000

1990-1991 1991-1992 1992-1993 1993-1994 1994-1995 1995-1996 1996-1997 1997-1998

Tokyo

- CO2
- Carbon Intensity effect
- Energy Intensity effect
- Household income effect
- Household population effect

Changes in CO2 emissions, Th Tons

6,000
4,000
2,000
0
-2,000
-4,000
-6,000
-8,000

1985-1990   1990-1995   1995-1998

Beijing

- CO2 Th. Ton
- Carbon Intensity effect
- Energy Intensity effect
- Household income effect
- Household population effect

Changes in CO2 emissions, Th Tons

6,000
4,000
2,000
0
-2,000
-4,000

1985-1990   1990-1995   1995-1998

Shanghai

- CO2 Th. Ton
- Carbon Intensity effect
- Energy Intensity effect
- Household income effect
- Household population effect

Figure 4-4-2-13: Factor decomposition for CO$_2$ emissions from residential sector

(c) Commercial sector

Commercial sector is the biggest contributor of CO2 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 CO2 emissions in Tokyo and Seoul, except for the recession period of Tokyo (see **Figure 4-4-2-14**). Energy intensity effect was responsible for most of the reduction in CO2 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 CO2 emissions in all the analyzed periods. The large impact of energy intensity on CO2 emissions in Seoul may be due to the fuel switching in central heating and cooling plants from coal to oil, and increasing use of electricity.

In case of Beijing and Shanghai, the preliminary analyses showed that the factors are unstable as in **Figure 4-4-2-14**. Energy intensity effect contributed to reduce emissions only in 1990-95 periods. Labor productivity effect contributed to increase emissions in 90s'. Further analyses would be required to explain the behavior of these factors.
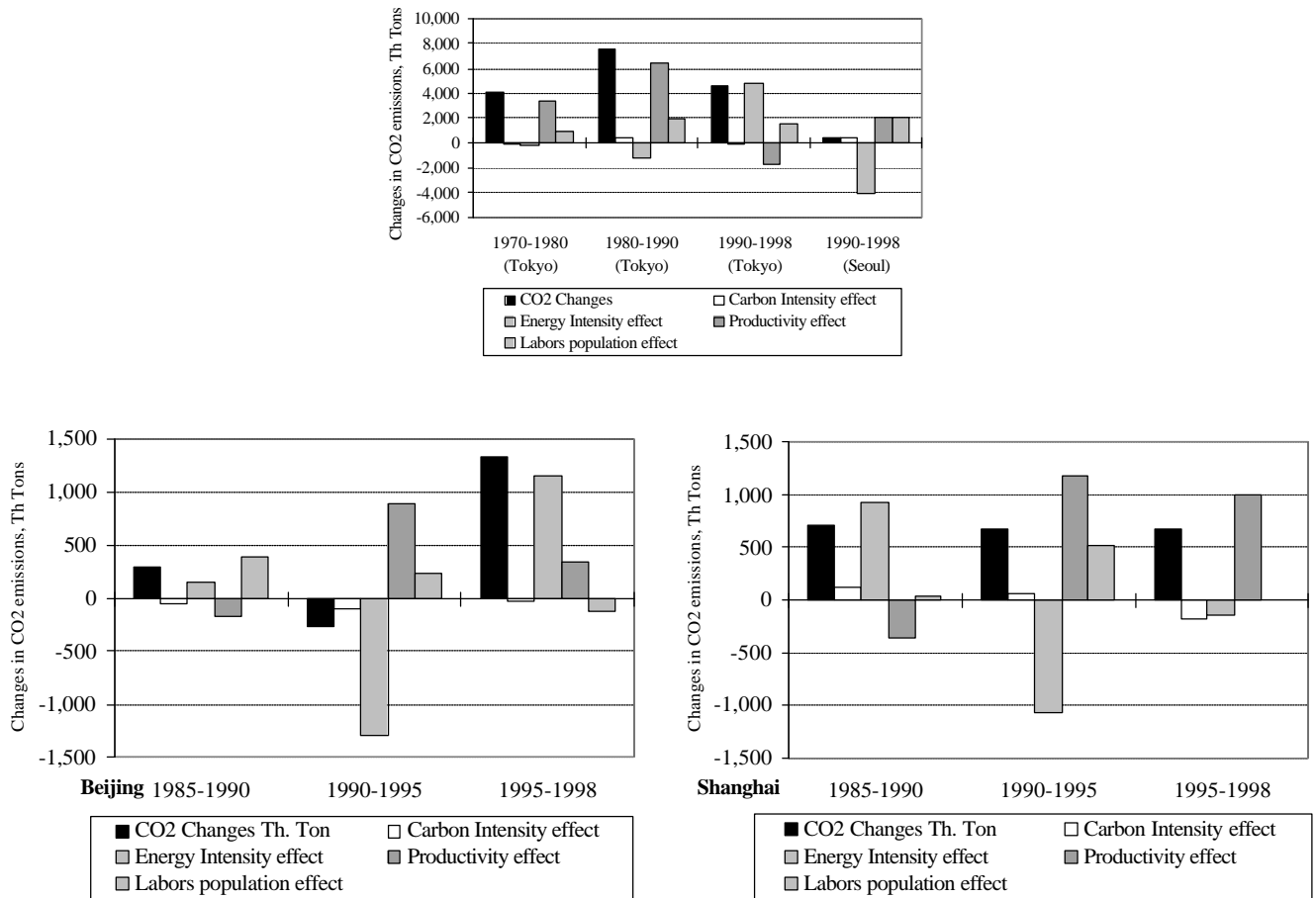
Fig. 4-4-2-14 Factor decomposition for CO₂ emissions from residential sector

(d) Summary of decomposition analyses

In this study, factor decomposition method was used to show the impacts of carbon intensity effect, energy intensity effect, income effect (or productivity effect in case of commercial sector) and scale effect on CO2 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 CO2 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 CO2 emissions in Seoul and Tokyo, respectively in that period. Despite economic recession, CO2 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 CO2 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 CO2 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.

4.4.3. Transportation Sector

(1)Characteristics of Urban Transportation System

(1)-1 Vehicle population

Figure 4-4-3-1 shows the vehicle population and vehicle ownership per 1000 persons in the four cities. Vehicle population increase most rapidly in Beijing with an annual growth rate of 17%. Because of the strict policy of private car development, the increase trend of vehicle population is much slower in Shanghai even with relative high GDP level. In Seoul, the increase rate of vehicle population began to slow down recently. While vehicle population in Tokyo seems to reach saturation point in 1990 and trended to be stable after 1990. The year in which the vehicle population reached to 1 million in Tokyo, Seoul, Beijing, and Shanghai is 1961, 1990, 1997, and 2010 (estimated), respectively. At present, the vehicle ownership in Tokyo is about 500 per 1000 persons, 2.5 times in Seoul, 5 times in Beijing, and 10 times in Shanghai.
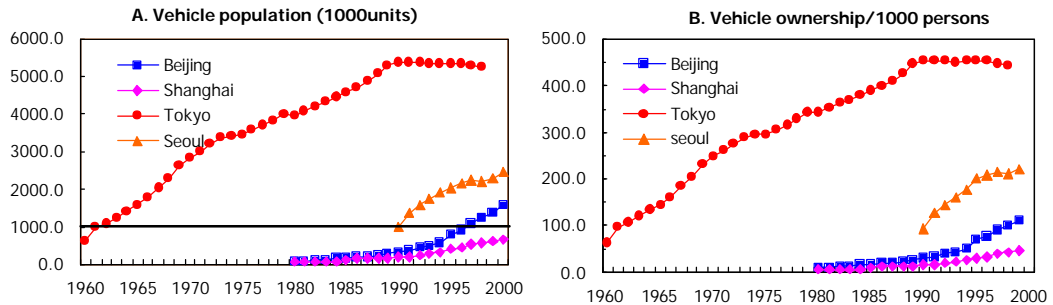
Figure 4-4-3-1 Vehicle population in the four cities

(1)-2 Urban transport infrastructure

Road

Urban roads play a critical role in forming the basic urban framework. In the cities, a lot of investment has been made to widen existing roads and to build new roads, including urban freeways. **Figure 4-4-3-2** compares the urban transport infrastructure in the four cities. The characteristics of urban transport infrastructure are quite different among the four megacities. The road area per capita is the largest in Tokyo, about 12 square meters, while is very low in Shanghai and Beijing. However, the road area per capita in Shanghai has increased rapidly since 1990. As Figure 3B shows, generally speaking, the vehicle population per km road length is increasing in all the cities. This increase trend is the extremely obvious in Beijing, indicating that transport
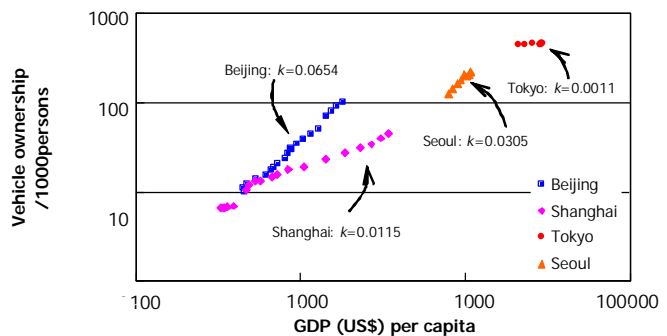
Figure 4-4-3-2 Vehicle ownership per 1000 person

Vs. GDP per capita

60

infrastructure has not been able to keep up with the significant growth in the number of vehicles in Beijing. Between 1979 and 1999, Beijing's road length increased nearly 100 , while Beijing's vehicles increased about 17-fold to 1.46 millions, and passenger travel volume by 4.4 times to 98.8 million person-times during the same period. Figure 4 shows the urban road net of Beijing and Seoul.
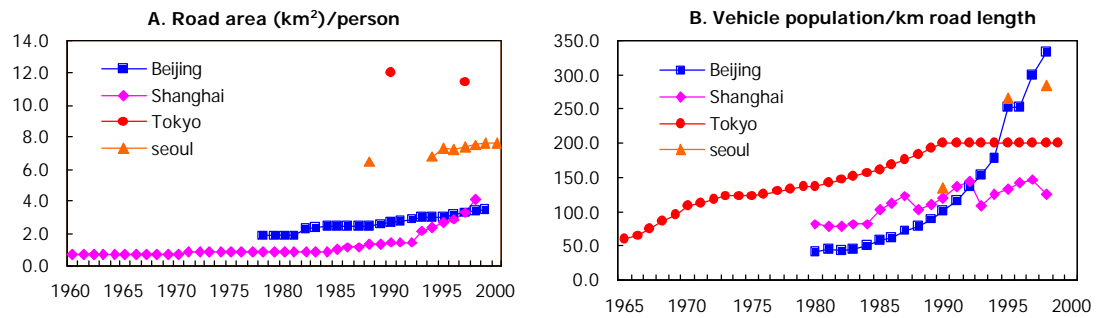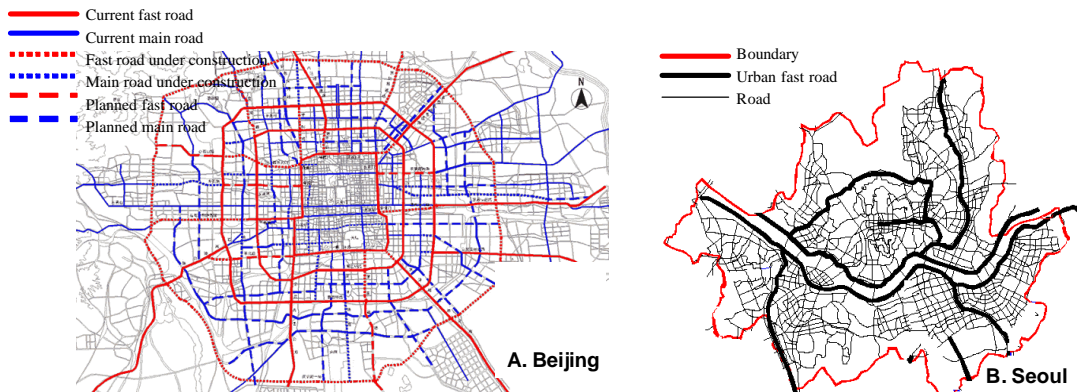

Figure 4-4-3-3 Comparison of road infrastructure

Figure 4-4-3-4: Urban road network

Urban railway
Table 4-4-3-1 compares the urban subway construction in the cities. In Beijing and Shanghai, the urban railway system is immature, with the sum of railway length only half of that of Tokyo. Figure 5 shows the urban railway net of Beijing, Tokyo, and Seoul. Beijing will make great effort to develop urban railway system. Besides the current 3 lines of urban rail, Beijing plan to construct 10 more lines by 2008, as shown in **Figure 4-4-3-5-A**. At that time, the total urban railway length will be 252 km. In Seoul, The total urban railway length in operation is 134km. At present, the Seoul government began new construction of four more lines. When completed, the whole subway length will be 280km. Tokyo has the most perfect urban railway system in Asia, even in the world. The Tokyo Metropolitan Region (TMR)'s rail network totals 2,143 km in route length, by far the world's largest.

Table 4-4-3-1: Information about urban rail construction

	Beijing	Shanghai	Tokyo	Seoul
Total length (km)	55.1	65.0	248.7	134
Number of station	45	48	235	115
Number of line	3	3	12	4
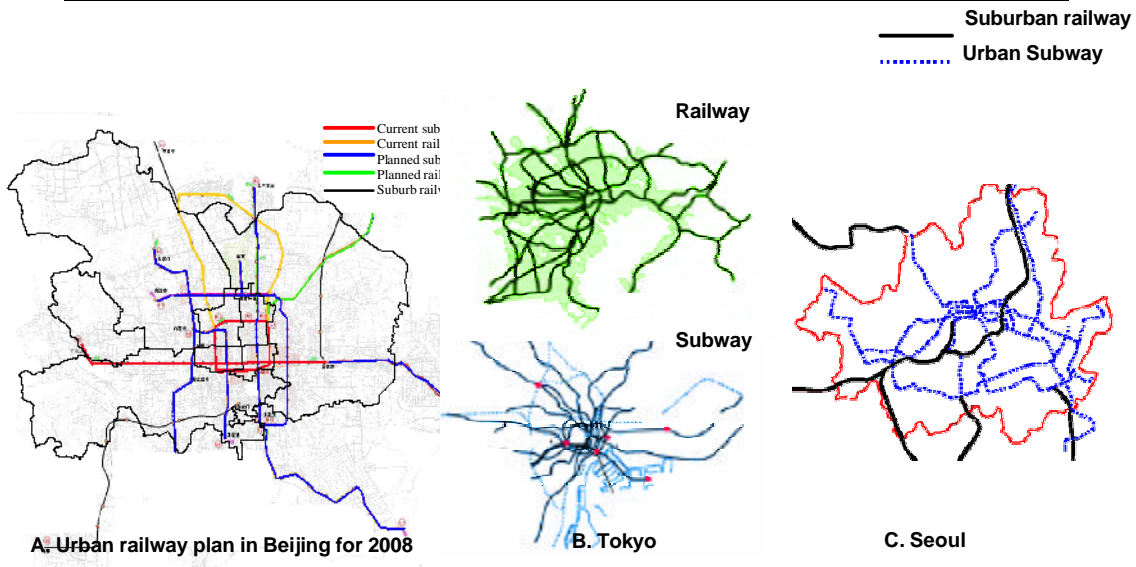
Figure 4-4-3-5: Urban railway network

(1)-3 Transport mode

Figure 4-4-3-6 compares the transport mode in the cities as measured in passenger-times. In Beijing and Shanghai, transport mode have been changed greatly during the 1990s, while in Tokyo and Seoul, it didn't change a lot. In Beijing and Shanghai, Non-motorized transport mode, such as by bicycle and by foot, was the main mode but was decreasing during the 1990s. Public transport, including bus and subway decreased greatly, while private transport mode, such as taxi and private car increases gradually, which inevitably pushed heavy pressure on the urban road transport system. A distinguishing feature of Tokyo's transportation system is its extremely high dependence on railways in comparison with other cities. In Tokyo rail transport accounts for about 45% of total passenger transportation, compared with a 70% dependence on road transport in Seoul and more than 95% in Beijing and Shanghai.
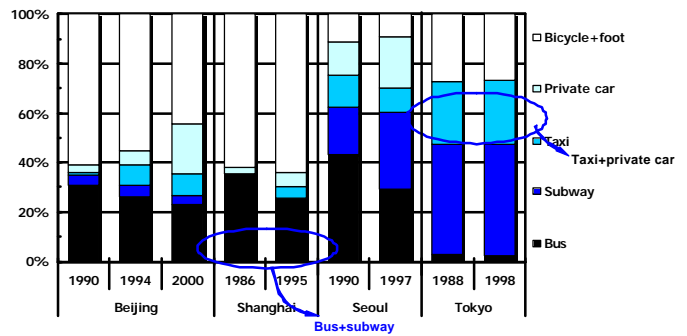
Figure 4-4-3-6: Variation of transport mode in the study cities

Figure 4-4-3-7 shows the variation of the passenger volume of the public transport system in Beijing and Shanghai during 1990 and 1998. Generally speaking, the passenger volume of the public transport in Beijing increased slightly every year, while decreased greatly in Shanghai. The percentage of buses was the largest, but it was decreasing

gradually even with the increasing number of buses during the same period. This imbalance of passenger vehicle number and traffic volume reveal the problems of construction and management in public traffic sector. On the other hand, the passenger volume of taxis increased greatly. For limited coverage of subway, the passenger volume of subway did not vary a lot. Increasing passenger volume of taxis reflect that taxi did satisfy the journey demand of persons with different incomes but also indicated that the lag of public traffic development in Beijing and Shanghai had resulted in the fact of large amount of taxis running on the road. The road area per passenger of taxis is very large, about 5 times that of buses. And, the fuel consumption and pollutant emission per passenger of taxis are also very large, about 10-50 times that of buses. This increase on taxi's passenger volume is adverse to smoothness and cleanness of the cities' transport. Therefore, development of highly efficient mass public transport system to attract passenger should be the orientation of the public transport system. This is the only way for solving the transport congestion issue in Beijing and Shanghai.
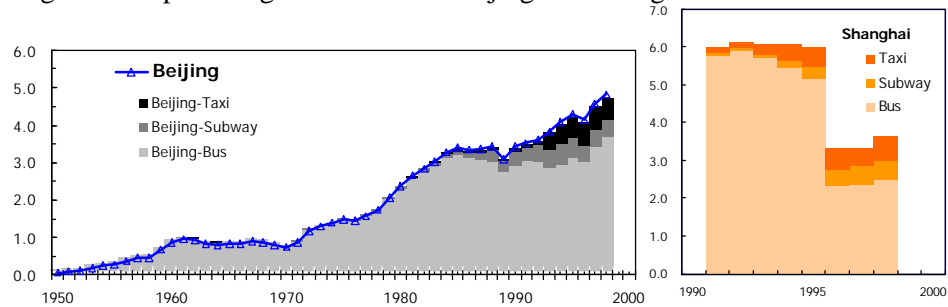
Figure 4-4-3-7 Public transport volume (billion person.times)

(2) Simulation of Environmental Impact of Urban transport

(2)-1 Methodology

The model is a multiple-page Excel spreadsheet with table-formatted inputs, calculations, and a graphical display for presenting results. The spreadsheet model requires the data of vehicle population, fuel efficiency and emission factors of new vehicles, and vehicle kilometers traveled. The model also need some related parameters about fuel specification. The model chooses 6 pollutants, CO, NO_x, HC, SO_2, PM_{10}, CO_2. The latter one reflects the influence on global climate.

A concept of *Fuel Economy Deterioration* (ratio of the fuel economy of in-use vehicles to the level when they are new ones) is introduced in this model to compute average fuel economy of the vehicle fleet. Base on the age distribution, the fuel economy of new vehicles and the fuel economy deterioration level, the average fuel economy can be computed as following expression:

$$AFE_n = \frac{\sum_{i=1}^{15}\left(VP_n^i \times NFE_{n-i+1} \times DFE_{n-i+1}^i\right)}{VP_n} \tag{A}$$

Where, *n*-year; *i*-vehicle age; AFE_n-average fuel economy in year *n*; VP_n-vehicle population in year *n*; VP_n^i-number of vehicles with age of *i* in year *n*; NFE_n-fuel economy of new vehicles in year *n*; DFE_n^i-fuel economy deterioration level of vehicles which are initially used in year *n* and have age of *i*.

There are a lot of factors that influence the emissions factors like the amount and quality of road infrastructure, age of vehicles, and speeds. Knowing the amount of new vehicles coming in to the fleet and the number that is being scrapped, their new vehicle emission standards and deterioration level for all the types of vehicles, the average vehicle emissions factors can be calculated for each year by a quick rollback method. The method is:

$$AEF_n = \frac{NVP_n \times NEF_n + [VP_{n-1} - NVP_{n-15}] \times AFE_{n-1} + \sum_{i=1}^{15}\left(VP_n^i \times DEF_{n-i+1}\right)}{VP_n} \tag{B}$$

Where, AEF_n-average emission factor in year n; NEF_n: emission factor of new vehicles in year n; DEF_n^i- emission deterioration level of vehicles which initially used in year n.

This formula is used to computed emission factors of NO_x, CO, HC, and PM_{10}. The emission factors of SO_2 and CO_2 is computed based on the fuel economy and fuel specification. The methods are:

$$SO_2 = S \times f \times \frac{64}{32} \tag{C}$$

$$CO_2 = \left[(f - EF_{HC}) \times C - EF_{CO} \times \frac{12}{28}\right] \div \frac{12}{44} \tag{D}$$

where: SO_2-emission factor of SO_2, g/km; S-sulfur content of the vehicular fuel; f-fuel efficiency, g/km; 64, 32-molecular weight of [SO_2] and [S] respectively. CO_2-emission factor of CO_2, g/km; C-carbon content of the vehicular fuel; EF_{HC}, EF_{CO}-emission factor of HC and CO respectively, g/km;12, 28, 44-molecular weight of [C], [CO] and [CO_2] respectively.

For a certain year j, the Vehicle mileage traveled (VMT) of trucks are calculated as:

$$VMT_{i,j}^F = 10 \times \frac{\gamma_{i,j} \times FTV_j}{\beta_{i,j} \times T_{i,j} \times VP_{i,j}} \tag{E}$$

where, i is truck type; $VMT_{i,j}^F$ presents the VMT of freight vehicle of type i (10000 km), FTV_j is freight traffic volume (billion ton-kms), $\gamma_{i,j}$ is the ton-km share of vehicle type i, $T_{i,j}$ is average load capacity (tons), and $b_{i,j}$ is actual load rate of trucks.

The VMT of buses and cars for urban transport in year j is calculated as:

$$VMT_{i,j}^{urbanP} = 10^4 \times 365 \times WH_{i,j} \times Speed_{i,j} \tag{F}$$

where, i presents vehicle types for urban passenger transport, VMT_i^{urbanP} is VMT of urban passenger vehicles (10000 kilometers); WH_i is work hour per day for vehicle type i (hour/day), for public buses, it is estimated based on public passenger traffic volume (person-times/day), carry capacity, average time for one passenger to finish one journey and number of public buses, $Speed_i$ is average speed (km/h) of vehicle type i.

(2)-2 Data preparation
Vehicle population
Figure 4-4-3-8 shows the estimation of vehicle population by type in the cities. In Tokyo, the vehicle population increase trend is very slow, and, with the construction of urban railway, the number of buss and trucks will decrease gradually. It is assumed that the percentage of car in Beijing and Shanghai increase most rapidly and the percentage of heavier vehicles decrease steadily. In 2020, the vehicle population in Tokyo, Seoul, Beijing and Shanghai will be 5.34, 3.06, 3.03, and 1.73 respectively. In Beijing and Shanghai, the number of car will be 71% and 69% respectively in 2020, increasing from 44% and 30% in 2020.

Fuel economy
At present, China hasn't any national vehicle fuel economy standards, but related researches are going on. The standards will be implemented in near future and car and small bus will be the target vehicles. For the vehicles fleets not being regulated by the standards, the labeled fuel consumption level will be used as its fuel economy of new vehicles. The fuel economy of cars and small bus in 2020 will be 70% and 60% improved from current level respectively. The years when the standards are going to be implemented are 2006, 2013 and 2018. For other types of vehicles, the fuel economy will be improved 1.5% per year during 2000 and 2005, and 1% during 2006 and 2020. The

Japanese government has established a set of fuel economy standards for gasoline and diesel-powered light duty passenger and freight vehicles, with fuel economy targets based on vehicle weight classes. These targets imply a 22.8% improvement in gasoline passenger vehicle fuel economy (15.1 km/l in 2010 vs. 1995 level of 12.3 km) and a 16.0% improvement in diesel passenger vehicle fuel economy (11.6 km/l vs. 10 km/l) compared to the 1995 fleet. **Figure 4-4-3-9** shows the variation of vehicle fuel economy in China and Japan.
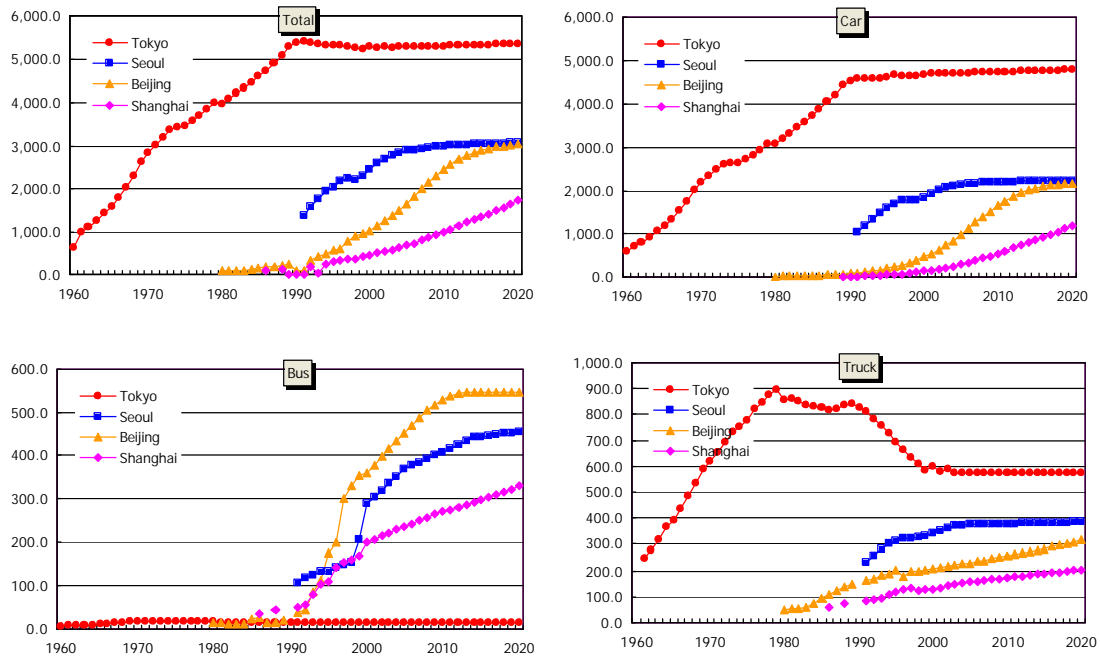
Figure 4-4-3-8 Vehicle population by type (Thousands)
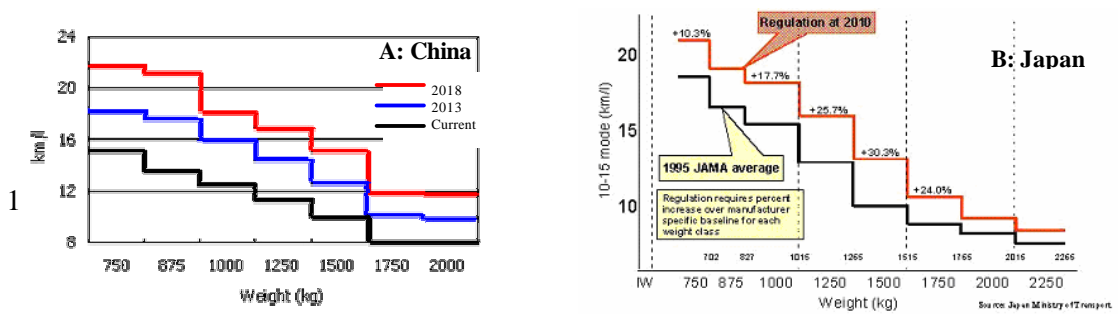
Figure 4-4-3-9 Fuel economy level of new cars

Vehicle emission control level

Table 4-4-3-3 shows the average emission factors in Beijing (1995), Shanghai (1995) and Tokyo (2000). The 29th Olympic Games will be held in Beijing in 2008 and the municipal government will implement a series of measures to improve the air quality. The methodology takes the national or municipal emission standards as the emission factors of

new vehicles. In the future, the government will implement the following measures for vehicle emission control. Table 4 is the vehicle control scenario for Beijing and Shanghai city.

Table 4-4-3-3 Average emission factors in Beijing (g/km)

	Beijing			Shanghai			Tokyo		
	NOx	CO	HC	NOx	CO	HC	NOx	CO	HC
Car	1.5	44.2	5.2	2.19	43.67	6.88	0.19	1.23	0.08
Large bus	17.3*	164.6*	29.6*	74.02	160.09	63.39	5.927	2.541	1.042
Small bus	3.2	34.5	5.5	3.2	34.5	5.5	0.19	1.23	0.08
Large truck	9.71	38.48	33.19	9.71	38.48	33.19	3.066	1.764	0.70
Small truck	1.29	1.5	0.1	1.29	1.5	0.1	0.70	4.31	0.343
Motorcycle	0.1	14.4	2.0	0.37	2.58	2.6	0.19	1.23	0.08

* Gasoline vehicles

Table 4-4-3-4 Vehicle control scenario in Beijing and Shanghai

New vehicle	EURO 2, EURO 3, EURO 4, and EURO 5, will be implemented in 2003, 2005, 2010, and 2015 respectively
In-use vehicle	Implementation of ASM inspection since 2001; Development of inspection operating condition suitable for China in 2002; Adoption of remote control inspection Realization of its supervision function in I/M system; Defected vehicle callback system; Establishment of bidding system; Special inspection companies taking in charge of vehicle I/M; Certification of maintenance station; Vehicle obligatory maintenance system; and Remote inspection supervision.
Other	25%, 50%, 75% and 100% of the public buses are refitted into CNGV in 2003, 2005, 2007 and 2010; In 2007, all local taxies are refitted CNGV, LPGV or reach stricter new vehicle standards; Completion of 200 km urban railway; Only vehicles with green label are allowed to ride within the 3nd Ring Road; Only vehicles with green environment protection label are allowed within the 4th Ring Road during air pollution forecast alert; Durability of 160,000km; Improving transportation and increase vehicle speed from 23km/h to 35km/h; Promotion of HEVs and FCVs and encouraging the application of zero-emission vehicles; and Defected vehicle callback system.

On the other hand, Japanese standards for passenger cars fueled by gasoline or LPG have been stable for many years. For gasoline trucks, new standards were implemented around 1994.

Vehicle mileage travel

According to the Formula (E) and (F), VMT is most relevant to total traffic volume (including passenger volume and freight volume) and its structure. Beijing and Shanghai are in the period of rapid development and rapid construction transport infrastructure, the VMT of vehicles will vary greatly in the future. While large variation will not occur in Tokyo. In Beijing and Shanghai, the journey frequency of residents will continue to increase, while development of the urban railway system can share larger part of total passenger traffic volume.

(3) Simulation results and analysis

(3)-1 Fuel consumption

Figure 4-4-3-10 shows the average fuel economy by type in the three cities. **Figure 4-4-3-11** compares the average fuel economy in 2000 and 2020. The fuel economy in Beijing and Shanghai is half that in Tokyo. **Figure 4-4-3-12** shows the total fuel consumption and annual oil consumed per vehicle. At present, the vehicle population in Beijing and Shanghai is about 1/10 of that in Tokyo, while their total fuel consumption is only 1/3-1/2

of Tokyo's, which is because of the lower fuel economy and larger VMT in China. In the future, fuel economy should be further improved, and urban transport should be well developed, especially large-scale public transport.
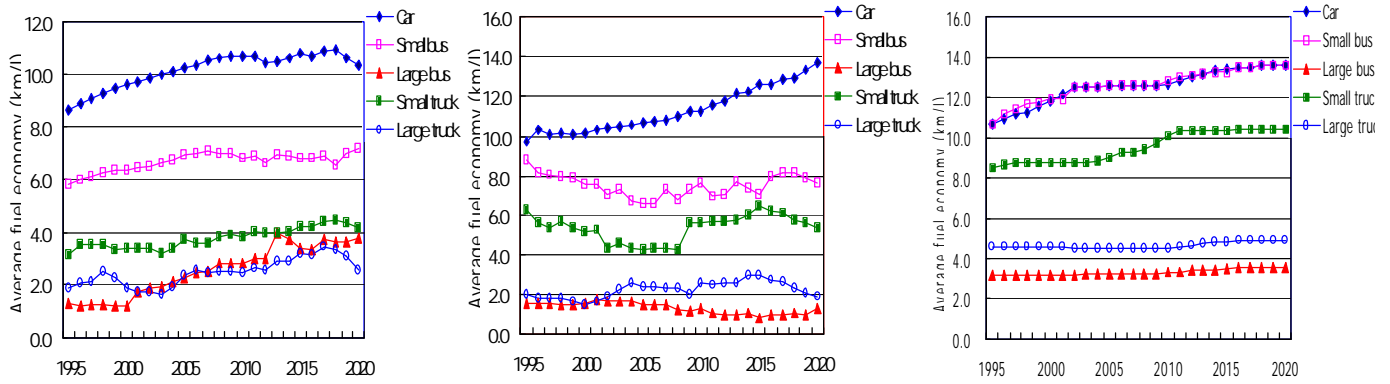

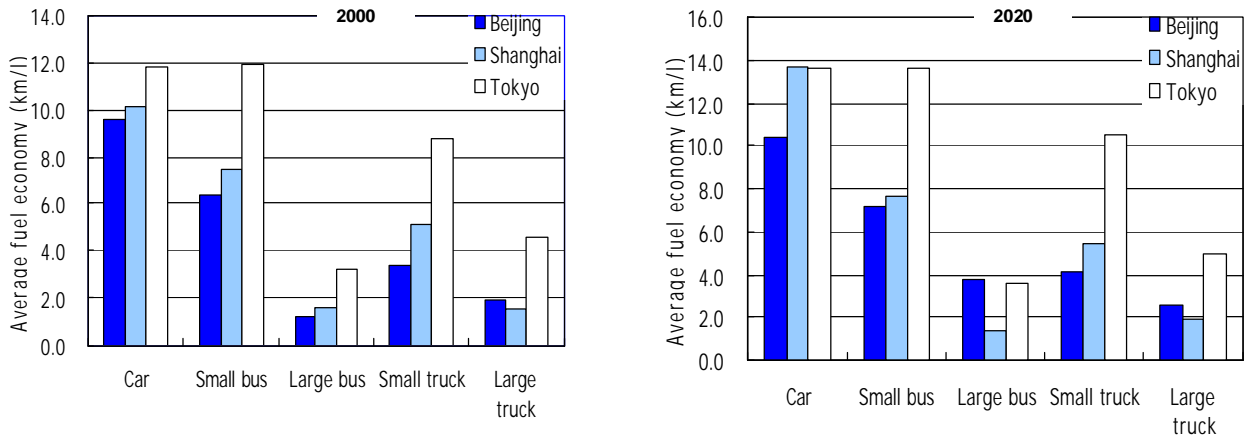**Figure 4-4-3-10: Variation of average fuel economy in Beijing, Shanghai, and Tokyo**

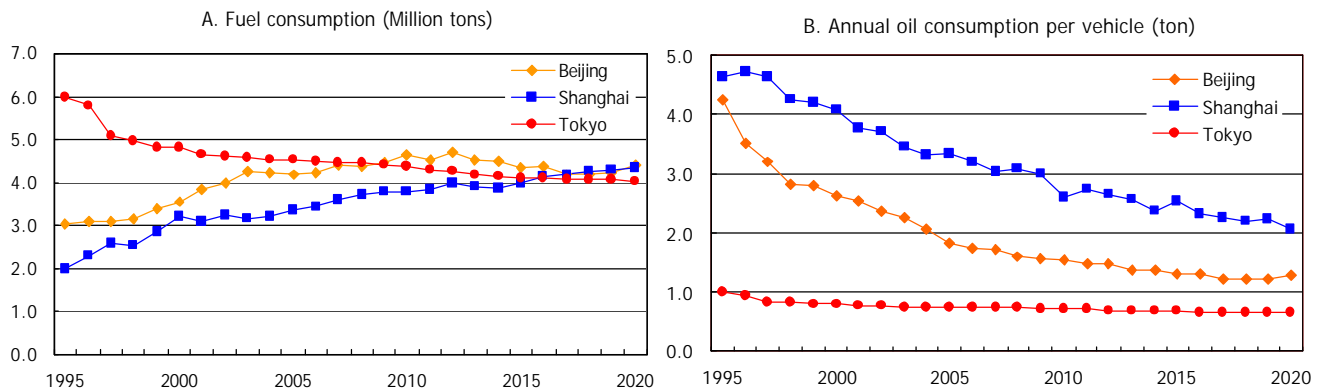**Figure 4-4-3-11: Comparison of average fuel economy in 2000 and 2020**

Figure 4-4-3-12: Fuel consumption in the cities

(3)-2 Pollutants emission

Figure 4-4-3-13 shows the simulation results of vehicular pollutant emission in the three cities. In Beijing and Shanghai, much smaller vehicle fleets emit more amount of pollutants. Therefore, Beijing and Shanghai should further reduce the VMT of vehicles and strengthen control of in-use vehicles, and the former will be depend on the development perfect urban transport system.
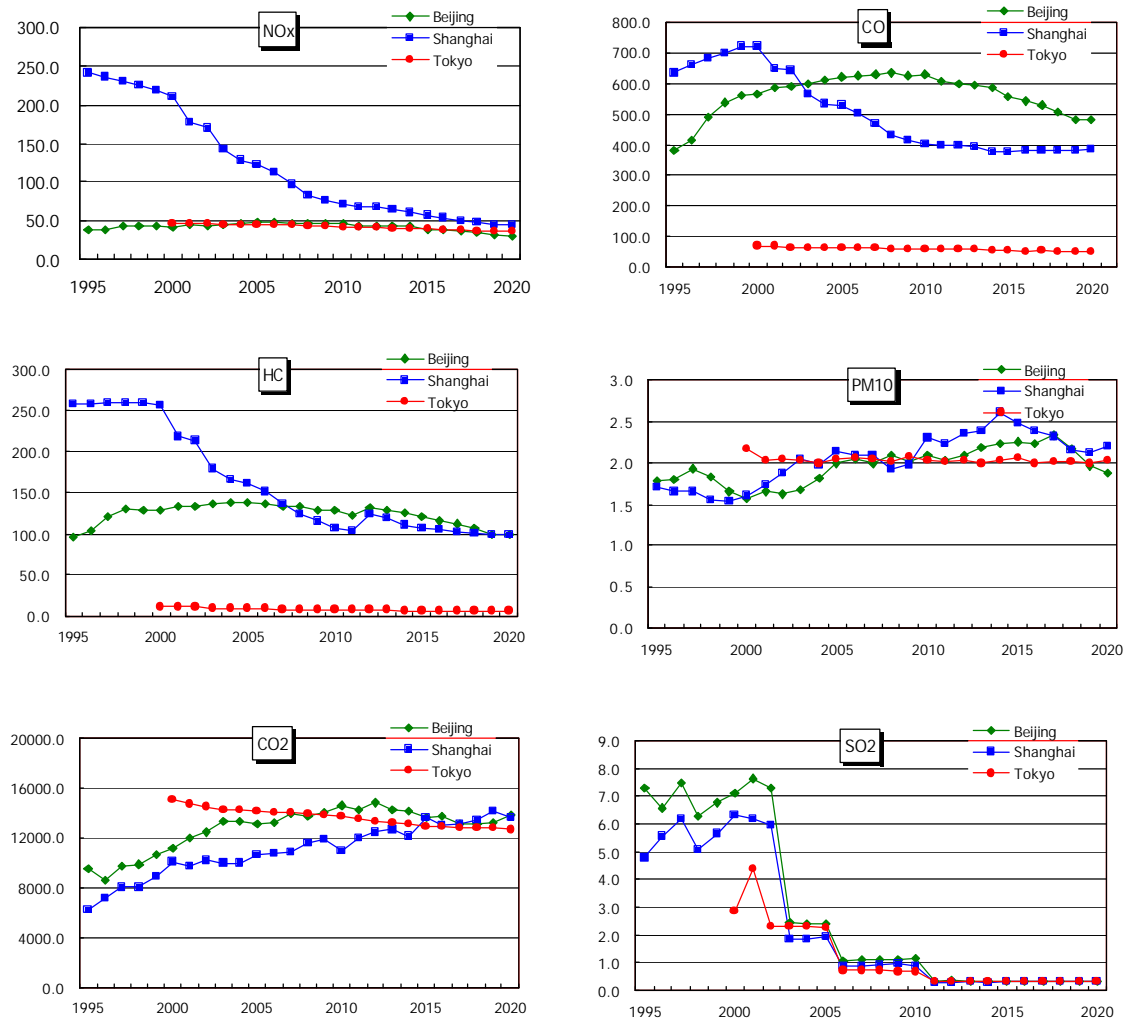
Figure 4-4-3-13 Pollutant emission in the three cities (1000 tons)

(4) Perspectives of the future work

The next phase of research work will be focused on the following items:
- Improve the data
- Improve the scenario
- Complete the Seoul case in the simulation
- Improve the methodology by integrating urban transport plan in the computation

4.4.4. Residential & Commercial (Res/Com) Sector

(1) Introduction

In 1996, approximately 46 of the world's population live in cities. According to economic levels, the urban population accounts for about 40% of the total population in developing countries, 30% in East Asia, and 76% in developed countries. Since rapid urbanization is anticipated especially in developing countries, urban activities will greatly affect the problem of global warming. Above all, energy consumption in the residential/commercial sector of Asian mega-cities will be the key because the synergistic effect of urbanization and economic growth is anticipated to significantly increase energy consumption.

The purpose of this study is to construct a model for the prediction of energy consumption in the residential/commercial sectors of Asian mega-cities. This paper reports on a prediction model of energy consumption in the residential/commercial sectors of metropolitan scales of Tokyo, Seoul, Beijing, and Shanghai (**Table 4-4-4-1**).

Table 4-4-4-1. Comparison of 4 Cities on Population, Area and Population Density

	Tokyo	Seoul	Beijing	Shanghai
Population (10^3)	12,059	10,373	12,780	13,216
Area sq.km	2,102	606	16,808	6,341
Population density (persons/sq.km)	5,737	17,132	760	2,084

Data Source: Tokyo Statistical Yearbook 2001, Statistical Yearbook Seoul 2001, Statistical Yearbook of Beijing 2001, Statistical Yearbook of Shanghai 2001.

(2) Lifestyles and energy consumption

Figure 4-4-4-1 shows floor space per household, and **Figure 4-4-4-2** shows the size of household. In all of the four urban areas, the floor space per household is becoming larger, and the number of persons per household is becoming smaller. Both trends are general factors of energy consumption increase per person.

Figures 4-4-4-3 to 6 indicate ownership rates of household electrical appliances in Tokyo, Shanghai, and Beijing. According to the figure 3, refrigerator ownership is almost 100% in urban areas and approximately 80% in rural areas in Beijing and Shanghai. Secondly, ownership rates of air conditioners are 160% in Tokyo, approximately 90% in urban areas of Shanghai, and approximately 60% in urban areas of Beijing (figure 4). Even in terms of color TVs and microwave ovens, ur ban areas in Shanghai and Beijing show numbers that are reaching very close to the standard of Tokyo (**Figures 4-4-4-5 and 6**).

 Figure 7,8 indicate transitions in total energy consumption, and energy consumption per unit of household in residential sector. Seoul has the highest number in both categories. Tokyo has a declining trend of total energy consumption and an almost unchanged trend of energy consumption per unit of household. On the other hand, in Beijing and Shanghai, energy consumption per unit of household increased slightly, but total energy consumption increased drastically.

Figure 9 indicates transitions in residential energy consumption ratios by fuel types in the four mega-cities during the period 1990-2000. Seoul shows a quite evident decline in coal and an increased diffusion of town gas. Even though coal use has been declining in both Beijing and Shanghai, Beijing has a drastically increased consumption rate of natural gas.
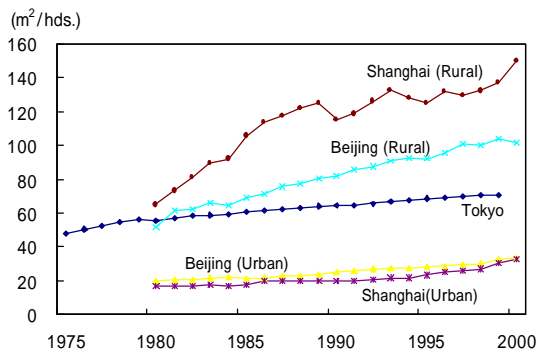
(m²/hds.)

Shanghai (Rural)

Beijing (Rural)

Tokyo

Beijing (Urban)

Shanghai(Urban)

Figure 4-4-4-1: trends of floor space for household

(persons/hds.)

Seoul

Beijing (Urban)

Shanghai

Tokyo

Beijing (Rural)
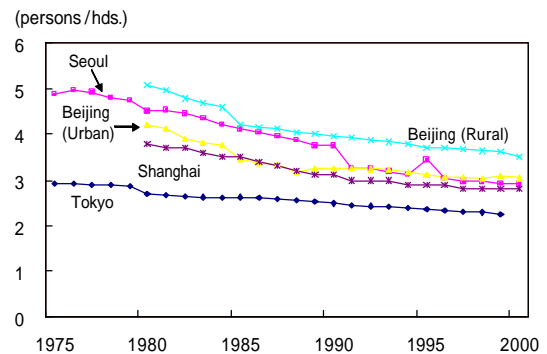
Figure 4-4-4-2: Trends of size of household

(/100 households)

Beijing (urban)

Beijing (rural)

Shanghai (urban)

Shanghai (rural)
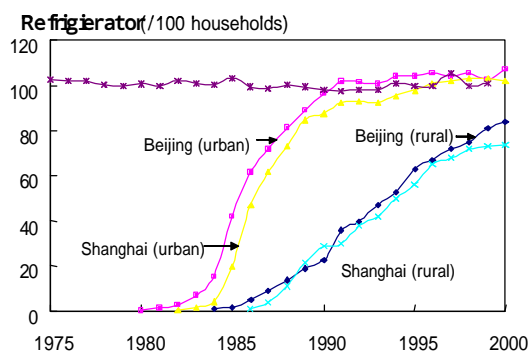
Figure 4-4-4-3: Refrigerator ownership

Air condition(/100 households)

Tokyo

Shanghai (urban)

Beijing (urban)
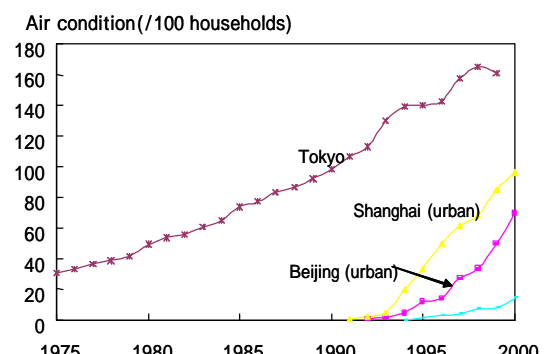
Figure 4-4-4-4: Air conditioner ownership

Color TV(/100 households)

Tokyo

Beijing (urban)

Shanghai (urban)

Beijing (rural)

Shanghai (rural)
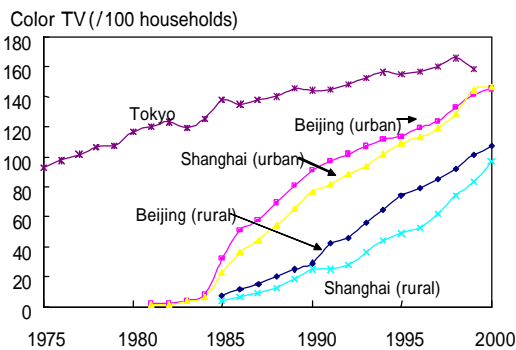
Figure 4-4-4-5: Color TV ownership

Microwave oven (/100 households)

Tokyo

Shanghai (urban)

Beijing (urban)
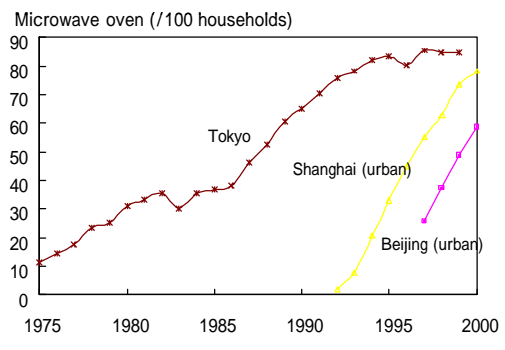
Figure 4-4-4-6: Microwave Oven ownership

(3) Basic concept and model structure
(3)-1 Basic concept
Asian cities should be studied with consideration of two points. One is data acquisition. Considering this, the refinement of the structure of a model appears limited. In particular, more data is available for Tokyo than for any other city, but model construction based on Tokyo is not permitted.

The other is to keep up with the varying rates of growth in the region. Economic growth and its accompanying change in living standards or enhancement of technical standards means that not many parameters can be handled as fixed values. This makes it necessary to ensure that the structural parameters of a model structure are variable. Therefore, the authors will develop a model satisfying these two points and predict the

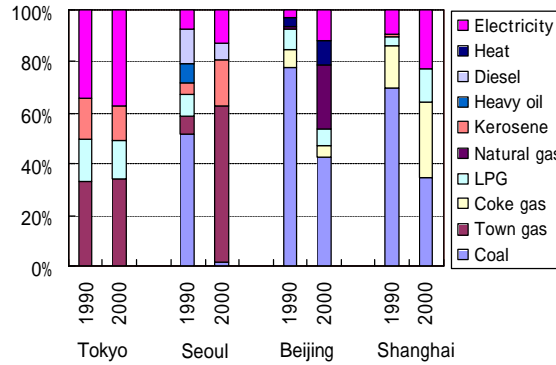energy consumption and carbon dioxide discharge in the residential/commercial sector in 2020.

Figure 4-4-4-7: Energy consumption in residential sectoer by fuel types

(3)-2 Model structure

Figures 4-4-4-8 and 11 demonstrate the estimated flows of energy demand in projection models for Tokyo and the other mega-cities, due mainly to the availability of energy consumption data by use types.

Since data regarding energy consumption by use type and fuel type in Tokyo was available, energy consumption per fixed floor space or household by use type has been estimated, and then this estimated value of energy consumption by use type was divided by fuel types. For estimating the amount of energy consumption by use type, multiple regression analysis with explanatory valuables was utilized.

For the other three mega-cities, since statistics for the amounts of energy consumption by use type and fuel type were unavailable, only the amounts by fuel types were estimated. Beijing has a widely diffused district heating system (DHS), thus heat is estimated separately. Further, the urban areas and rural areas have quite different energy consumption structures, which are estimated separately in Beijing.
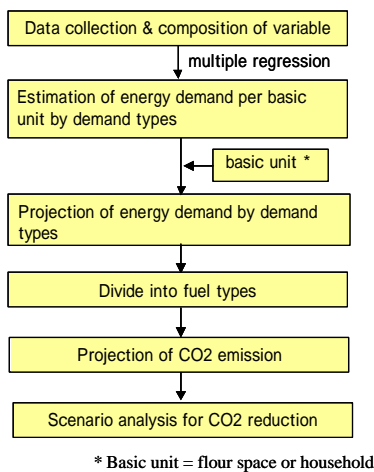
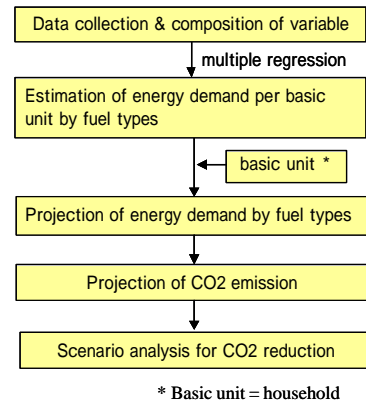**Figure 4-4-4-8: Analytical flow of residential sector for Tokyo**

Figure 4-4-4-9: Analytical flow of residential sector for other cities

(4) Development of energy demand model for residential sector
(4)-1 Analytical procedure
As the **Figures 4-4-4-10 and 11** show, the energy demand for each use is estimated and decomposed by usage and fuel types.

The uses of energy in each division were classified into heating, cooling, hot-water supply, and lighting, driving, and other uses. The energy demand for each use is expressed as the following identity with intermediate terms:

$$ENE.R = HS \times \frac{FL}{HS} \times \frac{ENE.R}{FL} \tag{1}$$

where ENE.R is energy consumption by demand type for residential sector, HS is number of household, FL is floor space. The second intermediate term represents the floor space per household and the third intermediate term represents the energy demand per unit floor space.

If floor space data is not available or the future floor space is directly available, the formula below is appropriate. The formula will also be used to predict the energy demand for heating not dependent on floor space.

$$ENE.R = HS \times \frac{ENE.R}{HS} \tag{2}$$

The second intermediate term represents the energy demand per household. The procedure up to the construction of the prediction model is outlined below.

STEP1
When necessary, synthesize the explanatory variables of energy demand per unit floor space, more specifically, energy price, equipment possession rate, and equipment energy efficiency. These variables are unique to the equipment or energy type. For use as explanatory variables of energy demand per unit floor space by uses, synthesize the variables into the average value for each use.

STEP2
To estimate the second and third intermediate terms of Formula (1), evaluate the variable factors by multiple regression analysis. From the results, formulate a model for predicting the floor space per household and the energy demand per unit floor space.

STEP3
Prepare predictive values for the explanatory variables of the model formulated in STEP2. Thus, the model is used to calculate predictive values of the energy demand by uses until 2020.

STEP4
Decompose the values estimated in STEP3 by fuel type (electricity, kerosene, city gas, and LPG). To do so, an energy demand matrix for each fuel type by use should be prepared. Estimate the matrices of electricity, kerosene, and gas (city gas + LPG) by use from the trends of the past 25 years. With regard to the breakdown of gases, city gas

consumption was predicted with the estimated future diffusion of city gas as an explanatory variable. The remainder is LPG.

STEP5
Estimate the energy demand by fuel type and multiply the energy demand by the unit requirement of carbon dioxide discharge to predict the carbon dioxide discharge until 2020.

(4)-2 Energy demand for heating
Figure 4-4-4-10 shows the method for estimating the energy demand for heating.
To estimate the requirement of energy consumption per unit area, variable factors were evaluated by multiple regression analysis. Consequently, the heating degree-day, the heating energy price, the house insulation factor, and the amount of heating equipment per unit floor space were adopted as four variables. The regression formula obtained this way was adopted as a prediction model.
As an explanatory variable, the amount of heating equipment differs greatly depending on the equipment type (air conditioner, kerosene stove, or fan forced heater) and also between single and multiple occupancy households. Therefore, the amounts of heating equipment by equipment and household type were synthesized from the energy efficiency of each model and the number of households by household type.
To estimate the floor space per household, an formula was created from the number of persons in a household and the compensation of employees per household. This also applies to the energy demands for cooling and hot-water supply.
The above explains the past energy consumption for heating but future parameter settings are necessary for prediction. As to the house insulation factor, the time series trend of the slowdown of growth was predicted by using an exponential curve . The equipment diffusion per unit floor space was predicted from the compensation of employees per household. The energy price and the heating degree-day were adopted from past averaged data. With regard to the number of households and the number of persons per household, values estimated by the National Institute of Population and Social Security Research were used.
By multiplying the energy consumption per unit floor space, the floor space per household, and the number of households estimated according to Formula (1), the predictive value of energy consumption was calculated for heating. The calculation method depends on the fuel type as explained in STEP4 of 4.1.
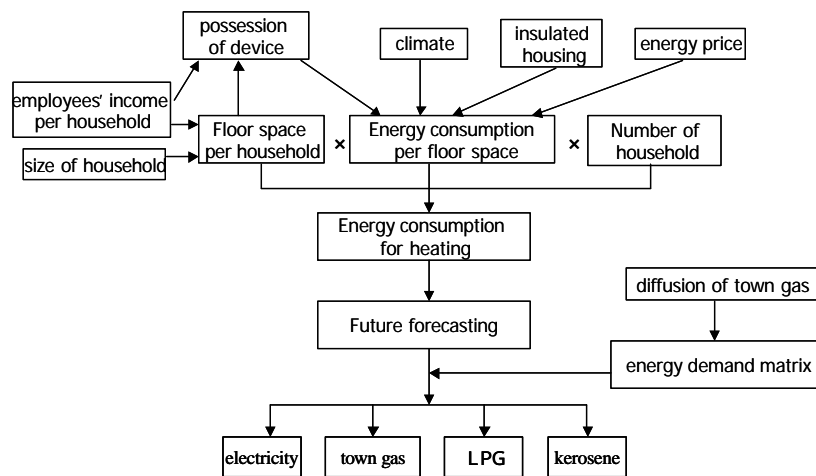

Figure 4-4-4-10: Estimation of energy consumption for heating

(4)-3 Energy demand for cooling

Figure 4-4-4-11 shows the method for estimating the energy demand for cooling.

To estimate the unit requirement of energy consumption per unit floor space, variable factors were evaluated by multiple regression analysis. Consequently, the heating degree-day, cooling coefficient of performance (COP), and the amount of cooling equipment per unit floor space were adopted as variables. As for heating, the cooling energy price, the cooling COP, and the amount of cooling equipment per unit floor space were weighted with energy consumptions by cooling equipment and averaged as synthesized variables. The regression formula obtained in this manner was adopted in the prediction model.

Future values of parameters were established for prediction. The cooling COP was evaluated using a time-dependent logistic function. The amount of cooling equipment per unit floor space was predicted by the floor space per household. For the cooling degree-day, the average value of past data was adopted as for heating.

By multiplying the energy consumption per unit floor space, the floor space per household, and the number of households estimated according to Formula (1), the predictive value of energy consumption for cooling was calculated. The energy for cooling is electricity only and needs not be decomposed by fuel type.
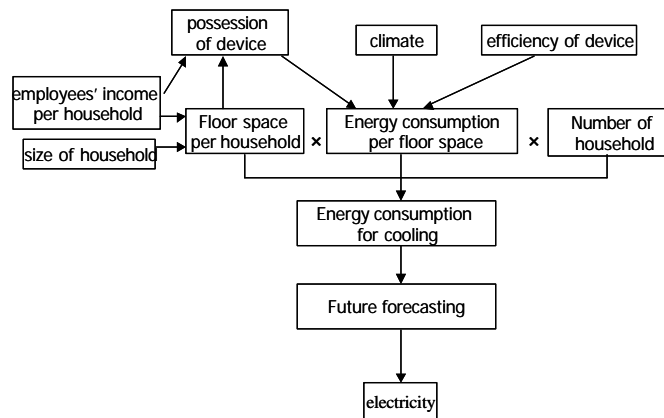

Figure 4-4-4-11: estimation of energy consumption for cooling

(4)-4 Energy demand for hot-water supply

Figure 4-4-4-12 shows the method for estimating the energy demand for hot-water. The energy demand for hot-water supply was calculated using Formula (2) because it does not depend significantly on the floor space.

To estimate the unit requirement of energy consumption per household, variable factors were evaluated by multiple regression analysis. Consequently, the hot-water supply energy price, the household insulation factor, and the water consumption per household were adopted as variables. The energy price is a synthesized variable. The house insulation factor was considered to average the performance of hot-water supply equipment as a proxy variable of new household diffusion. The regression formula obtained in this manner was adopted as a prediction model.

As to the future values of parameters, the water consumption per person was obtained by linear regression on the assumption that the tendency of a slight increase in the past 25 years would continue. From the energy consumption and the number of households estimated above, the predictive value of energy consumption for hot-water supply was calculated and decomposed by fuel type according to STEP4 of 4.1.
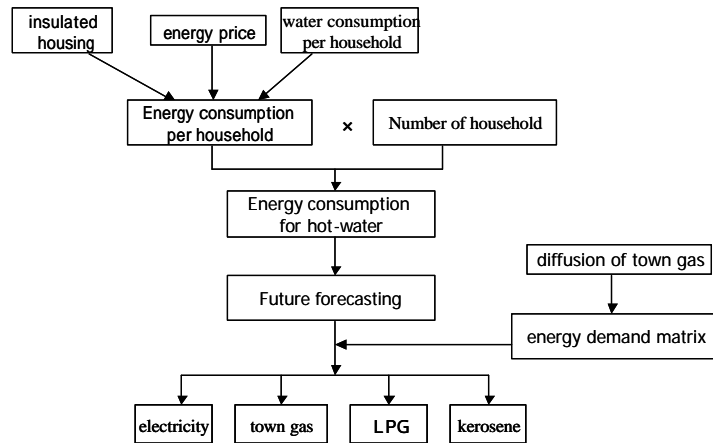
Figure 4-4-4-12: Estimation of energy consumption for hot water supply

(4)-5 Energy demand for lighting, driving, and other uses
Figure 4-4-4-13 shows the method for calculating the energy demand for lighting, driving, and other uses.

To estimate the unit requirement of energy consumption per unit floor space, variable factors were evaluated by multiple regression analysis. Consequently, the lighting, driving, energy price and the refrigerator equipment efficiency were adopted as variables. The energy price is a synthesized variable.

The future values of parameters were then established. With regard to equipment efficiency, the future value was estimated as a time-dependent logistic function.

By multiplying the energy consumption per unit floor space, the floor space per household, and the number of households estimated according to Formula (1), the predictive value of energy consumption for lighting, driving, and other uses was calculated and decomposed by fuel type according to STEP4 of 4.1.
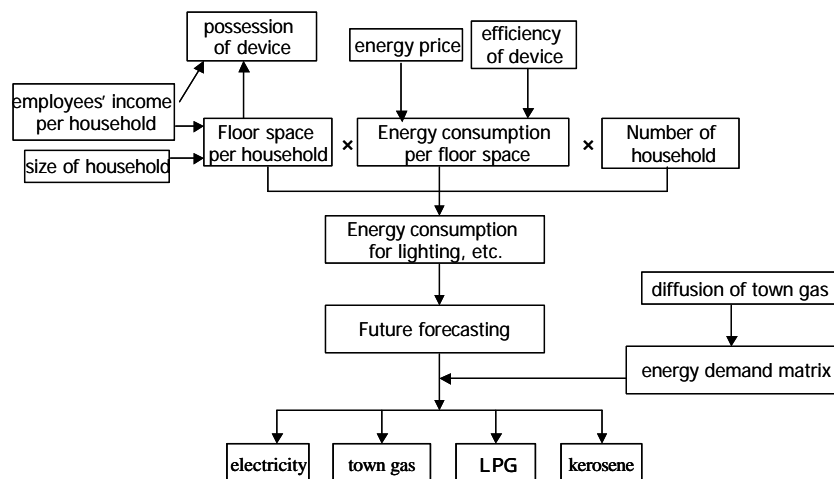

Figure 4-4-4-13: Estimation of energy consumption for lighting, etc.

(4)-6 Projection of energy consumption and CO2 emissions

Figure 4-4-4-14 shows the estimated results of future total household energy consumption and energy consumption per household in the four mega-cities by 2020. Beijing has a large percentage of increase, and will become the second largest energy consuming mega-cities after Seoul in 2020. In contrast, for both the total amount of energy consumption and energy consumption per household, the trend in Tokyo has changed from a sideways movement to a declining tendency since 2000.

Figure 4-4-4-15 shows the divided amounts of fuel types of future total household energy consumption in the four mega-cities by 2020. In Seoul, Beijing, and Shanghai, the amount of coal use is declining, and the amount of town gas and natural gas (LNG) use is increasing. Even though the percentage of electric energy consumption has not changed much, this is due to the fact that the results do not sufficiently express transitions to electric energy consumption for heating, hot water supply, and cooking.

Figure 4-4-4-16 shows future expected results of CO2 emissions from residential sector. One remarkable difference from the expected amount of energy consumption is that Beijing and Shanghai are positioned above Tokyo and Seoul.
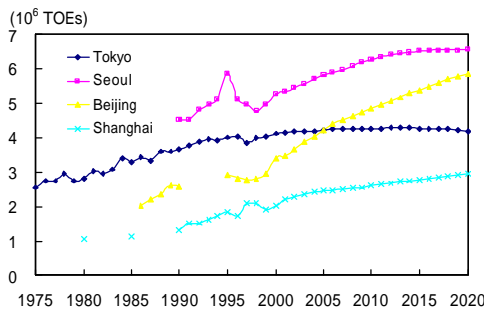

Figure 4-4-4-14(a): Projection of total energy consumption in residential sector
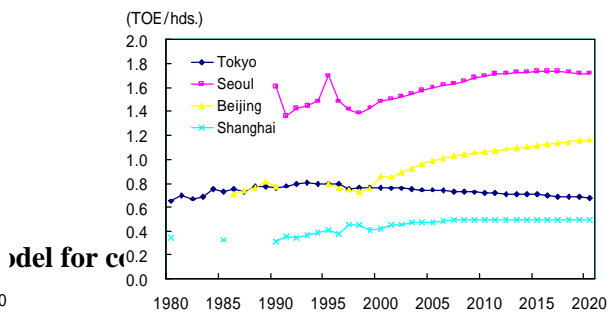

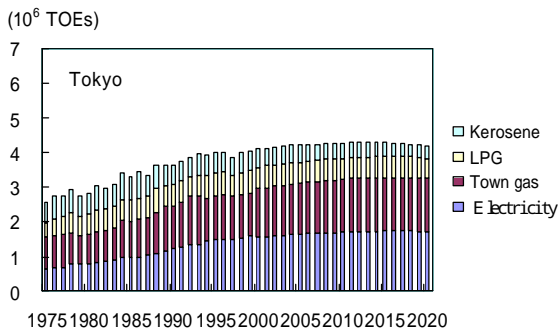**Figure 4-4-4-14(b): Projection of total energy consumption per household**

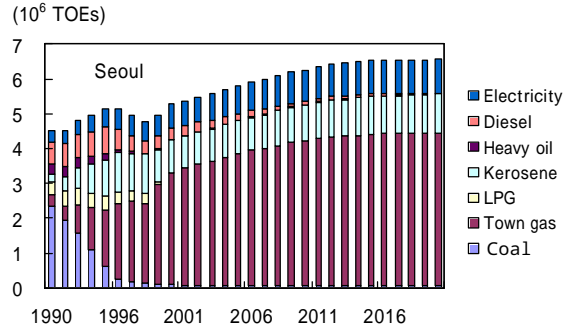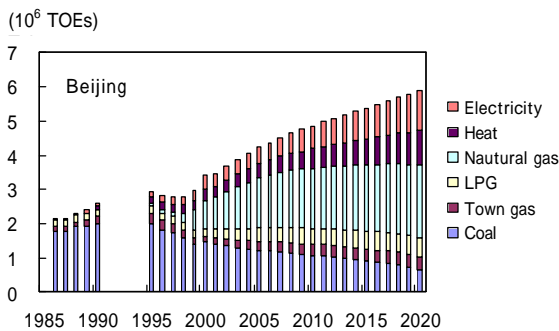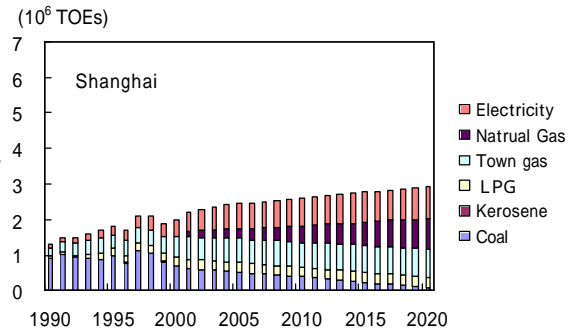**Figure 4-4-4-15: Projection of total energy consumption in residential sector by fuel types**
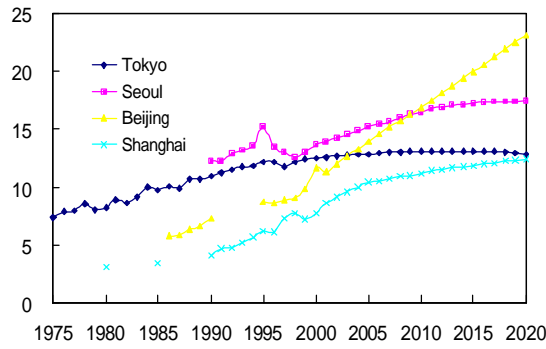
76

Figure 4-4-4-16: Projection of total CO2 emission in residential sector

(5) Analytical procedure

Figure 4-4-4-17 shows the model for predicting the business energy demand. For model development, commercial sector's data is generally more difficult to obtain than residential sector. The energy consumption by unit of GRP of tertiary industries is obtained and multiplied by the predicted GRP of tertiary industries. The identity can be expressed as shown below.

$$ENE.C = GRP3 \times \frac{ENE.C}{GRP3} \qquad (3)$$

where ENE.C is energy consumption for commercial sector. The second intermediate term denotes the energy demand per unit GRP of tertiary industries.

(6) Projection of energy consumption and CO2 emission

Figure 4-4-4-18 shows the future expected results of the amount of commercial energy consumption and the amount of energy consumption per GRP of tertiary industries in the four mega-cities by 2020. The amount of energy consumption per GRP of tertiary industries in Beijing and Shanghai tends to decrease; however, the results indicate that the amount of commercial energy consumption in those areas will exceed the amount in Tokyo by around 2010.

Figure 4-4-4-19 shows the divided amounts of fuel types for future commercial energy consumption in the four mega-cities by 2020. All of the mega-cities have a large percentage of electric energy consumption, and the increasing tendency will continue in the future.

Figure 4-4-4-20 shows future expected results of CO2 emissions from commercial sectors. One remarkable difference from the expected amount of energy consumption is that Beijing and Shanghai are positioned above Tokyo and Seoul as well as residential sector.
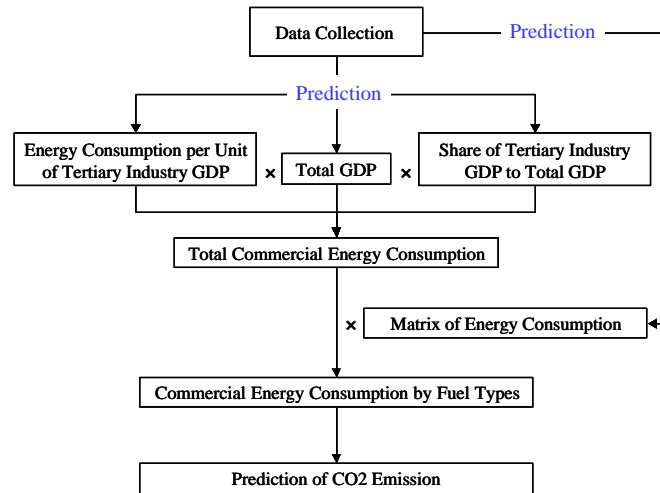
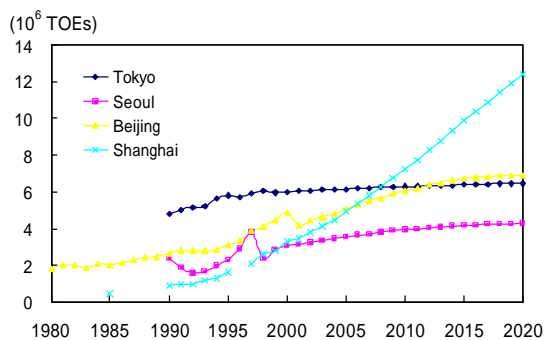**Figure 4-4-4-17: Analytical flow for commercial sector**

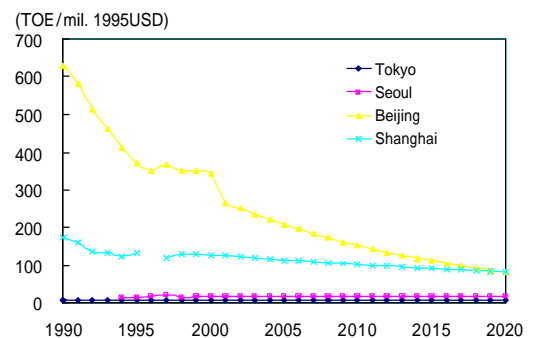**Figure 4-4-4-18(a): Projection for total energy consumption in commercial sector**

Figure 4-4-4-18(b): Projection for total energy consumption per GRP of tertiary industries

(7) Future directions

For application to Asian mega-cities, the authors developed a model for predicting the energy demand in the residential/commercial sectors of Tokyo. The analysis so far enabled for the prediction of a so-called trend case. The next step is to estimate the effects of various measures and the influence of social tre nd changes using the model.

The subjects in the home division can be classified mainly into   household and lifestyle factors,   household factors, and   energy equipment factor. For trial calculation, the influence of these scenarios on the unit requirements of energy consumption (per unit floor space and per household) calculated in section (4) was analyzed. As to   , the influence of household property changes can be experimentally calculated if the energy consumption characteristics by household can be gained through questionnaire surveys. The change in the time spent at home due to changes of work patterns may be another factor that can be experimentally calculated as a change from the assumed trend case in the same way.
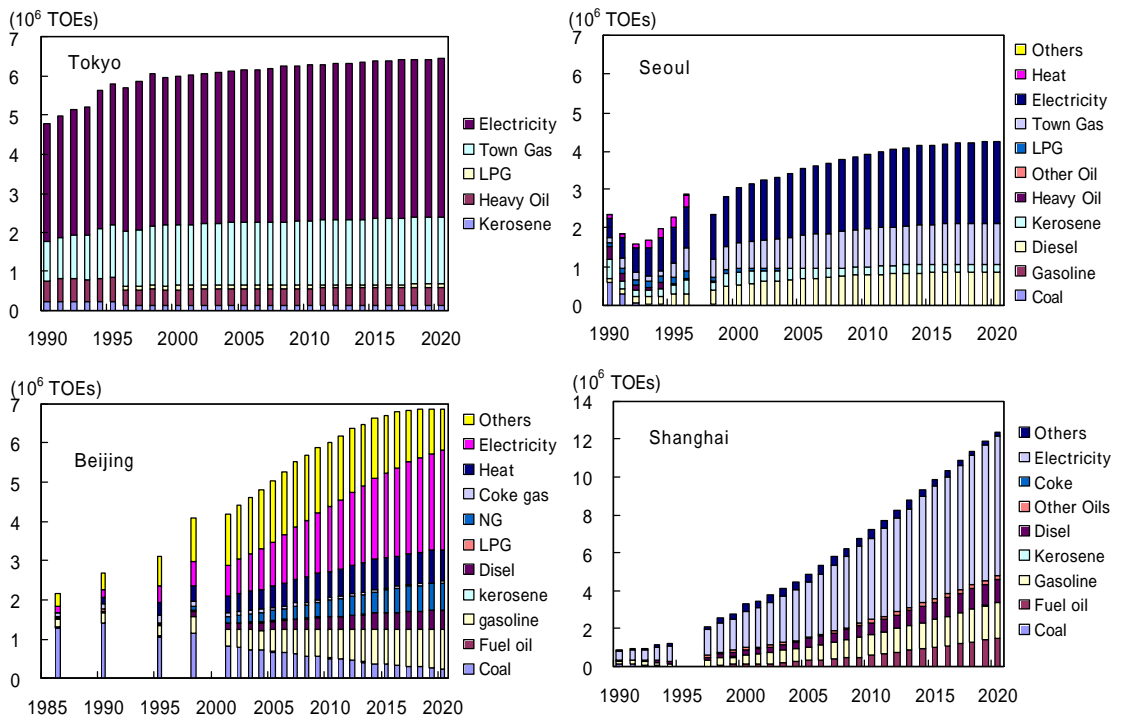
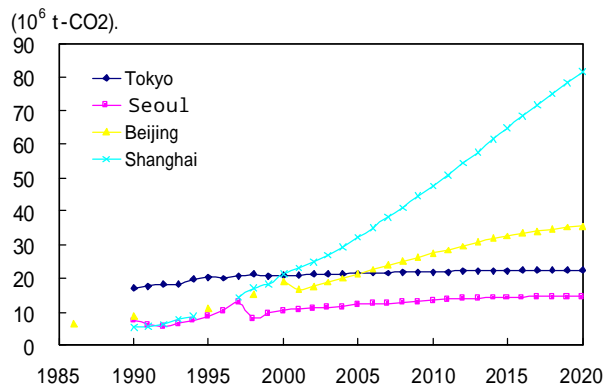**Figure 4-4-4-19: Projection of total energy consumption in commercial sector by fuel types**

Figure 4-4-4-20: Projection of total CO2 emission in commercial sector

4.4.5. Direct & Indirect Energy Consumption Analysis

(1) Introduction

It is note-worthy that all of the researches with focus on generating CO_2 emission inventories or projecting future emissions in this project have been done within the territory of each mega-city itself. In this approach emissions from manufacturing and transportation of commercial goods are assigned at the point where they are finally released to the atmosphere, no matter where the goods are consumed.

Generally speaking, as pointed out by Muradian (2002), the assessment of the environmental performance of any selected economic system requires us to specify the relevant spatial scales of analysis. How to design this kind of "spatial scale" may depend on assumptions mainly (1) the interrelationship between the different ecological systems transformed by economic activity; (2) the agents and institutions where environmental liability has to be assigned; (3) the economic driving forces of environmental transformation; and (4) the envisaged mechanisms of environmental policy. Dominating work in our Mega-city project has followed the traditional way of thinking in setting the boundaries of research object, which is to refer to the political boundaries but not the ecological ones.

However, we never intended to ignore the close relationship between the objective cities and the outside world, not only in terms of "international trade" or "internal trade", but also in terms of "trans-boundary environmental issues". Considering the hierarchy of dependency on outside world, city may be much more complicated than country. By analogy with country scale, city has similar boundary as country between itself and the world. However, additionally it has another boundary that can not be omitted: the boundary between the city and the country. Actually, tracing back to the boundary setting, we can easily find that the economic dependency on outside world makes the city an absolute open system and correspondingly extending beyond the political territory becomes necessary.

In addition to reconsidering the specification of territories in meaning of socioeconomic dependency, another point of view widely used in industrial ecology also attracts our concern. This is "metabolism", or specifically speaking, the "socioeconomic metabolism". In analogy to the biological notion of metabolism, the concept of socioeconomic metabolism describes physical exchange processes (i.e. material and energy flows) between human societies and their natural environment as well as the internal material and energy flows of human societies (Ayres and Simonis, 1994; Fischer-Kowalski, 1998). Robert Ayres (1976) firstly developed a kind of "industrial metabolism" analysis, which traces materials and energy flows from initial extraction of resources through industrial and consumer systems to the final disposal waste. Nowadays, the international standards to be used in accounting for socioeconomic metabolism are being developed. In the metabolism approach, socioeconomic systems are conceived as systems depending upon a continuous throughput of material and energy. Socioeconomic systems extract raw materials from their natural environment and subsequently transform these materials as part of the economic process. Materials are accumulated for a certain period of time (forming material stocks) or they are more or less readily released into the ecosystems as waste and emissions (Krausmann and Habert, 2002). So in virtue of the concept of "social metabolism", we can address two types of environmental problems: resources scarcity on the input side and the pollution or emission on the output side.

This action of boundary rethinking makes us treat the city as an ecological open system, which is located on an approximate close loop and interact with outside world through material and energy flows. Such kind of regional application of the concept of "social metabolism" can provide valuable insight into the sustainability of each sector in the

city scale. The information from this kind of study makes it possible to map the resources, to replay the process of transformation and to clarify the emission burden.

It is obvious that the metabolism of a city can only be clarified if both the energy and material flow are considered. Considering the ultimate objective of this project, here we will focus on analyzing the energy flow and correspondingly CO2 emission flow. One concept of "embodied energy" or "embodied emission" will be employed in our research. The term "embodied" or "indirect" energy use or emissions has been used by several authors to distinguish the indirect energy use for the production of goods in contrast to the direct energy uses (e.g. Van ENGELENBURG,1994; COLEY, 1997, SUBAK 1995). The indirect energy uses and emissions can imply the economic dependency of the city on the outside region and especially highlight the "environmental load displacement" of the highly developed mage-cities to the outside region. Additionally, the ratio of direct energy use or emission or indirect energy use or emission can also provide information about the economic structure change within the city. To simulate the energy flow emphasized in the socioeconomic metabolism, we try to make use of the IO technique to recur the energy related economic activities. In the late 1960s, some specialists brought IO analysis from economics to energy and environmental fields (Daly 1968; Leontief, 1970). The application of IO techniques to these fields allows one to trace, through an economy, the direct and indirect energy /environmental impacts of changes in the final demand.

Considering the characteristics of mega-cities itself, this research tries to highlight the exact role of mage-cities by extending the targeting scope from city itself to a broader space. To realize this objective, we developed the traditional concept of direct and indirect energy use and build up a set of indicators to serve for our ultimate goal. This will be discussed in detail in section 2.

(2) Basic model for " indirect energy consumption" and " indirect energy supply" basing on the concept of " embodied energy"

(2)-1 theoretical discussions about the concept of "indirect energy consumption" and "indirect energy supply"

No violating with the thermodynamic law, there should be an "energy balance" for each production sector or say system. This can be simply expressed as following.
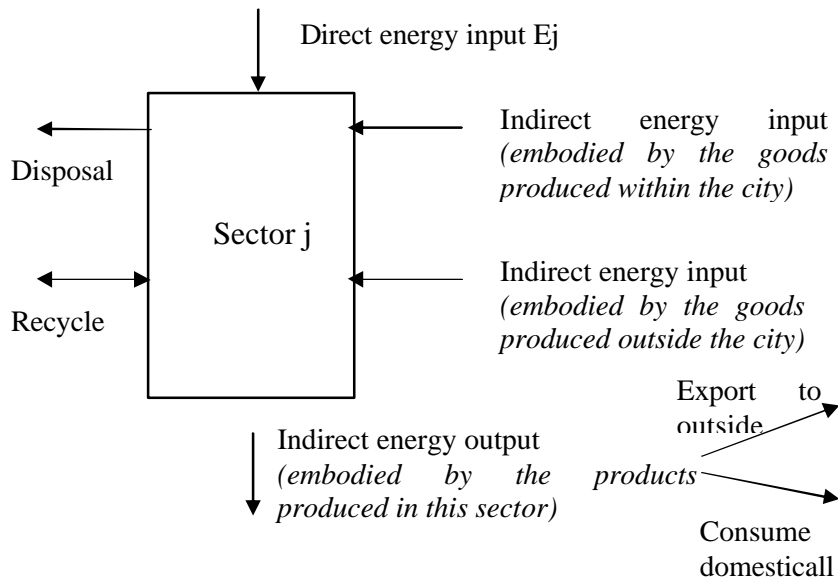

Figure 4-4-5-1: Energy balance for sector _j_ on a city scale

Due to data availability, this research will neglect the disposal part and recycle part and then the "energy balance" can be expressed in the following way

$$E_j + \sum_{i=1}^{n} e_i \mathbf{C}_{ij} + \sum_{i=1}^{n} x_i \overline{\mathbf{C}}_{ij} = e_j Q_j \qquad (1)$$

Where Ej is the direct energy input into sector j, ej is the embodied energy per unit production of industry j within the city; ?j is the embodied energy per unit production of imported goods; ? ij is the goods and services flow from industry i to industry j within that city, is the flow of imported goods and services from industry i to industry j.

Actually, goods and services consumed in a city can be clarified as 1. Local goods produced in the city, 2. Goods imported from other areas in the country, and 3. Goods imported from other countries. This makes it necessary to establish a model with not only boundaries between the city and the country but also between the country and the world. Data restriction, however, make it difficult to calculate the embodied energy of goods imported from other countries. So in this study, we assume that embodied energy of goods imported from other areas in the country were equal with those imported from other countries if they were in the same industry, but different between local and imported goods.

The essence of the "embodied energy" is a kind of indirect reflection on the behavior followed after the energy direct consumption. We try to emphasize the following two points: a). "indirect energy consumption" or say "indirect energy demand". That means that where the good is finally consumed, where the energy embodied in that good should be accounted as a kind of "indirect energy consumption" or "indirect energy demand". So in terms of "indirect energy consumption", the end-user should somehow take some responsibility for the energy consumption, and correspondingly the CO_2 emission. b). "indirect energy supply". Goods produced within the city can be divided into two parts: consumed domestically or exported to the outside, correspondingly, energy embodied in those goods which are exported to the outside should be a "indirect energy supply" to outside and also correspondingly the CO_2 emission from this part should not be simply accounted to the city itself, even though city really consumed this part of energy (directly or indirectly).

To highlight the contribution of "indirect energy consumption or demand" and "indirect energy supply", we can make clear how city "rely on outside" or "is relied on by outside". Of course, the direct energy consumption can be taken as an indicator on how city "rely on outside" beyond all doubts (assume that the energy extraction is outside the city). However, as kinds of proxy indicators, "indirect energy consumption" and "indirect energy supply" may provide some very interesting information which we can not easily draw from the "direct energy consumption" in the city", like:

1) Generally speaking, they are material-related indicator. To clarify the dependency on outside, the direct energy consumption of each sector, as a pure energy-related indicator, can give us little information about the material reliance on outside of the city. But these two indicators can contribute to this query in some sense, even though our ultimate objective is to show the energy embodied by the material but not the material itself.

2).They are directly related to the characteristics of the sectors themselves. So we can easily clarify the sectoral difference and characteristics in terms of energy or material reliance on outside, and consequently, easily draw some implications about the industry structure transition.

3) Since they are the mirror of the industry structure of the city itself, comparison among cities in different development stages can indicate how the evolution of industry influence the energy reliance of the city. And

4) To show how city rely on outside or is relied on by outside, is to clarify the role of city in the sense of energy consumption and CO_2 emission beyond the geographical

scope of the city itself. This may shed some light on the "urban sustainable development", since one objective of it is to "reduce the city's use of natural resources and energy". In addition to the dominating way of aiming at controlling the direct energy consumption, our point of view may highlight the real role the city played beyond the scope of city itself and broaden the view of any urban development planner. This may be very significant for planning sustainable development on national scale or even on global scale.

(2)-2 Model specification

The proposed model can be applied to a competitive-imports type input-output table that clearly distinguishes between local and imported goods but not to a noncompetitive-imports type input-output table that does not distinguish between local and imported goods. City-level input-output tables in China as well as in Japan are usually of the competitive-imports type and rarely of the noncompetitive-imports type. Therefore, the degree of self - sufficiency of each industry is used in this study to distinguish between local and imported products. In this case, the formula for the energy balance is as follows:

$$E_j + \sum_{i=1}^{n} e_i g_i C_{ij} + \sum_{i=1}^{n} x_i (1 - g_i) C_{ij} = e_j Q_j \qquad (2)$$

Where g_i is the degree of self-sufficiency of product i, which can be expressed as follows:

$$g_i = \frac{Q_i}{Q_i + M_i}$$

In the above formula, M_i indexes the imports of product i. Q_i indexes the local amount of product i.

(3) Data specification

Featuring with great data-intensiveness, basic model discussed above needs material flow and energy flow information of each detailed industry sector. The material flow data, as we discussed above, will be extracted from the input-output table of targeted cities. In our research, we employed the input-output tables of Tokyo 1990, 1995, Beijing 1992, 1997 and Shanghai 1992, 1997. The national input-output table is also employed if necessary. Comparing with the material flow data, the energy consumption data for each detailed industry is much more difficult to obtain, which are not always available for each specific industry sector, especially on city level. So if the detailed energy data is not available on city level, we will turn to the national data and assume that the marginal transaction price cost may remain constant within the whole country for all industry sectors. Detailed information for each city are summarized in **Table 4-4-5-1**

Basing on energy data, CO_2 emission will be obtained by multiplying the energy consumption of each fuel type with the corresponding carbon emission factors. Special attention should be paid to the electricity and heat since the consumption of which has no CO_2 emission.

Table 4-4-5-1: Data specification

	year	Sector aggregation of Input-output table	Energy consumption data
Tokyo	1990		Detailed data on city level
	1995	484 599	Detailed data on city level
Beijing	1992		Detailed data on national level
	1997	124 128	Detailed data on city level
Shanghai	1992	128 128	Detailed data on national level
	1997		Detailed data on city level

(4) Analysis result and discussion
(4)-1 direct energy demand and indirect energy demand- "how city rely on outside"

(4)-1-1 Direct and indirect energy demand in the targeted cities
Figure 4-4-5-2 shows the direct and indirect energy demand of targeted cities. For Tokyo and Shanghai, indirect energy demand is more significant than direct energy demand, though the ratio of indirect to direct energy demand decreases during the period of 1990-1995 in Tokyo and also of 1992-1997 in Shanghai. During 1990-1995, total amount of energy demand in Tokyo decreased by 6.34%, among which, indirect energy demand decreased by 10.74% and direct energy demand increased by 9.36%. During 1992-1997, total amount of energy demand of Shanghai increased about 1.66%, among which, the direct energy demand increased by 25.37% and indirect energy demand decreased by 11.94%. For Beijing case, direct energy demand is more significant. During the period of 1992-1995, total amount of energy demand increased about 25.77%, among which, the direct energy demand increased by 33.57% and simultaneously the indirect energy demand increased by 14.89%.
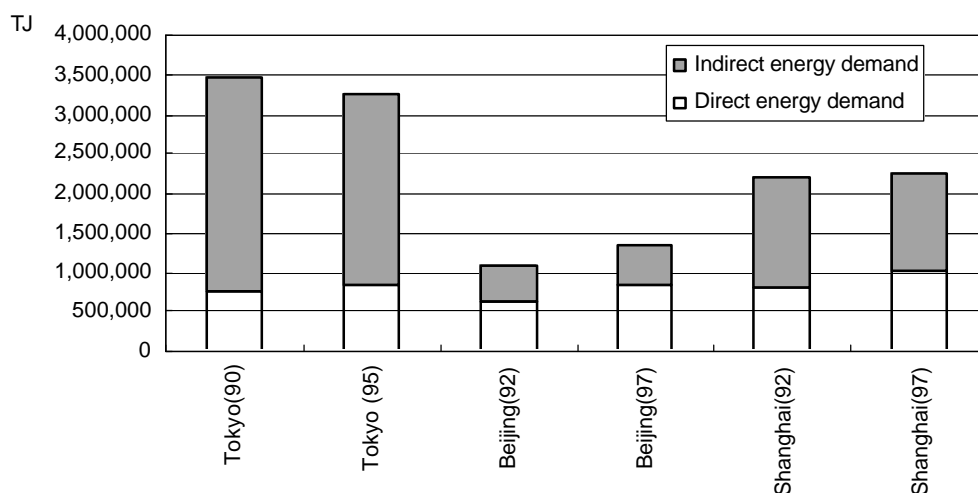

Figure 4-4-5-2: Direct and indirect energy demand of the targeted cities

(4)-1-2 Sectoral distribution of the direct and indirect energy demand
Taking a glance at the industrial structure transition of each targeted cities (**Figure 4-4-5-3**), we can easily find that for each city, during the shooting period the proportion of economic output of secondary industry decreased and at the same time the proportion of tertiary industry increased.
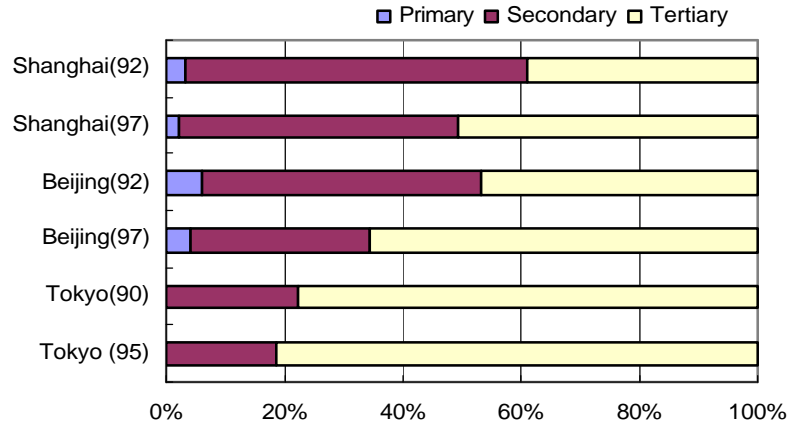

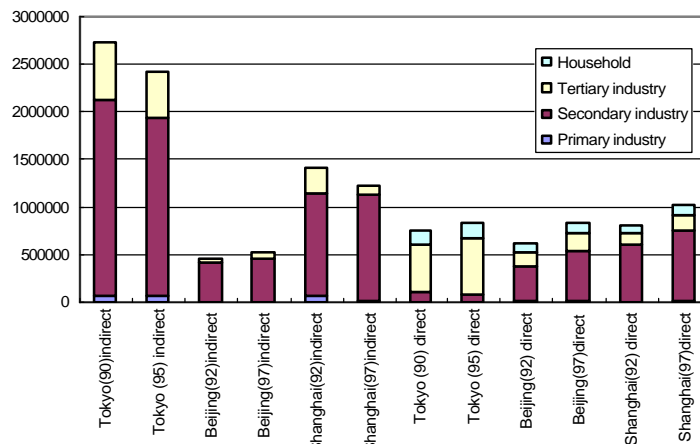**Figure 4-4-5-3: Industry structure transition of the targeted cities**

Figure 4-4-5-4: Sectoral contribution for direct and indirect energy demand of targeted cities

How these kinds of industrial structure transition contribute to the change of direct and indirect energy demand can be showed in **Figure 4-4-5-4**. For Tokyo case, during the period of 1990-1995, direct energy demand increased about 9.36 %, which should be mainly attributed to the increase of tertiary industry (increased by 14.5%) and household (increased by 9.7%). On the other hand the absolute amount of direct energy demand in primary and secondary industry has decreased (primary industry: -19.6%, secondary industry -15.5%). For Shanghai case, during the period of 1992-1997, each sector's direct energy demand increased greatly (primary industry: 267%, secondary industry: 19.0%, tertiary industry 50.1% and household 20.4%). As for Beijing case, during the same period, except primary industry, all of the other three sectors' absolute contribution also increased greatly, which lead to the increase of total direct energy demand.

As for indirect energy demand, as we discussed before, the total amount in Tokyo and Shanghai decreased during the targeting period. For Tokyo case, each sector's indirect energy demand decreased during 1990-1995, among which, primary industry decreased by 22.1%, secondary industry decreased by 8.9% and tertiary industry decreased by 16.0%. For Shanghai case, the drop of total indirect energy demand should be mainly due to the contribution of tertiary industry (-53.2%) and of primary industry (-58.8%). Differing from other cities, Beijing shows an increase in indirect energy demand during 1992-1997, which should be attributed to the great increase of indirect energy demand of tertiary industry (increased by 53 %.).

Basing on the discussion of the absolute level in each sector, we ulteriorly summarize the fluctuation of the proportion of each sector in total direct and indirect energy demand in the targeted cities (see **Figure 4-4-5-5** and **4-4-5-6**).
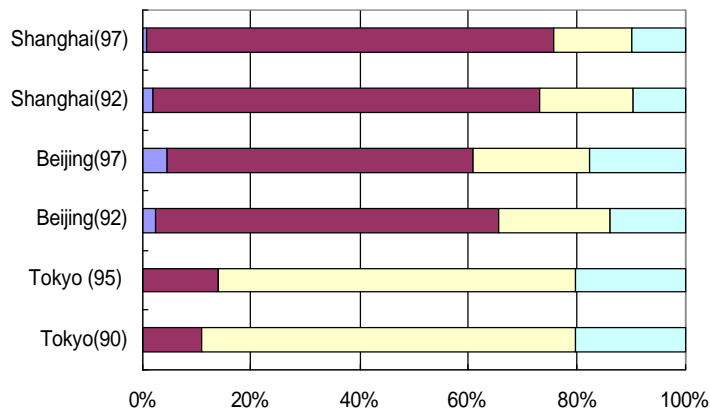

Figure 4-4-5-5: Promotion of each sector in the total direct energy demand in the targeted cities

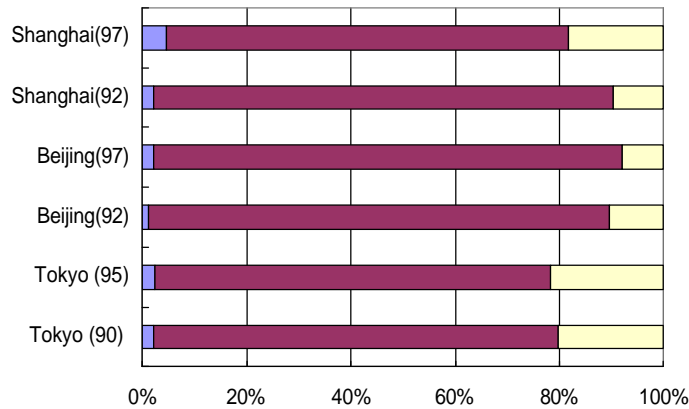□ Primary ■ Secondary □ Tertiary □ Household

Figure 4-4-5-6: Promotion of each sector in the total indirect energy demand in the targeted cities

□ Primary ■ Secondary □ Tertiary □ Household

Tertiary industry plays a dominating role in direct energy demand in Tokyo, since which accounts for almost 70% of the total amount. On the other hand, the secondary industry is most significant in indirect energy demand, which also occupy above 75% of the total amount. For Beijing and Shanghai case, same as Tokyo, the secondary industry plays dominating role in the indirect energy demand but greatly different from Tokyo, the secondary industry is most important for direct energy demand.

(4)-2 Direct energy supply and indirect energy supply-how the city is relied on by outside

As we discussed in previous section, in addition to direct and indirect energy demand, we try to define the other two concepts "direct energy supply" and "indirect energy supply" to indicate the to what extent city meet the local demand or contribute to the outside demand. The analysis is showed in **Figure 4-4-5-7**.

It is noticing that the proportion of indirect energy supply of Shanghai is highest among these three cities. Though this proportion has decreased from 58% to 42% from 1992 to 1997 in Shanghai, it still reflect that shanghai is strongly relied by outside and in terms of embodied energy, half of it has been transferred to outside world. Remaining at a level of around 30%, the outside reliance on Tokyo is very stable. For Beijing case, the proportion increased greatly during the period 1992-1997, indicating an ascending tendency of Beijing in terms of material export.
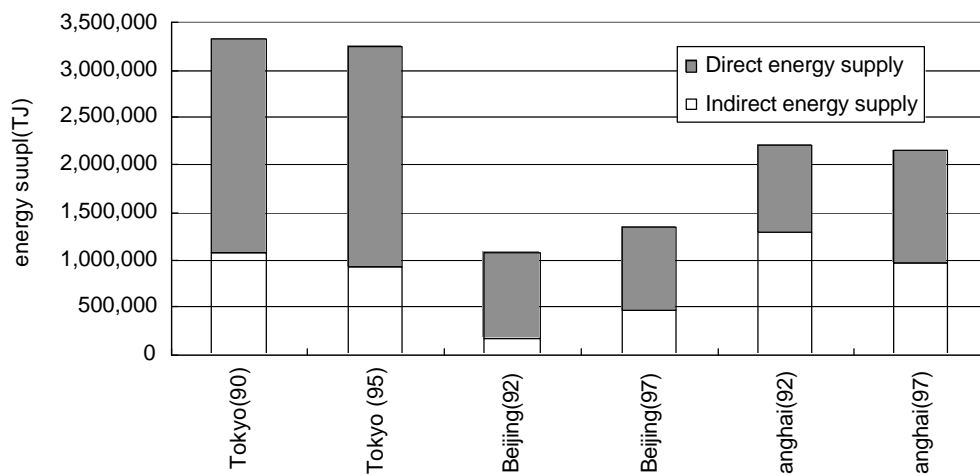

Figure 4-4-5-7: Direct and indirect energy supply of the targeted cities

(4)-3 CO2 emission: trace back the origin and clarify the responsibility

Basing on the discussion of "indirect energy demand" and "indirect energy supply", we try to trace back to the sources of CO2 emissions and re-define the role who should take responsibility for the CO2 emission, no matter embodied or direct.

Here we define the "direct CO2 emission" and "indirect CO2 emission" as the counter-parts of "direct energy demand" and "indirect energy demand". To distinguish the embodied CO2 emission coming from the materials consumed for local demand from the embodied CO2 emission coming from materials exported to outside, we define the "internal CO2 supply" and "external CO2 supply" correspondingly. **Figure 4-4-5-8** indicates the performance of "direct CO2 emission" and "indirect CO2 emission". **Figure 4-4-5-9 and 10** is the share of each sector in total amount. **Figure 4-4-5-11** shows the "internal CO2 supply" and "external CO2 supply". Why here we give up the

terminologies of "direct CO2 supply" and "indirect CO2 supply" but to emphasize the "internal indirect CO2 supply" and "external indirect CO2 supply" is to clarify the following point. All of CO2 here talked is basing on the concept of embodied CO2 emission, that means it is from the product side. So some proportion of this part of CO2 was emitted directly, but some part is embodied by other materials. So to avoid some misunderstanding, we use "internal CO2 supply" and "external CO2 supply" under this situation.

Figure 4-4-5-8 clearly show that indirect CO2 emission in Tokyo is much lager than direct CO2 emission (above 2.5 times), which indicate that in terms of indirect CO2 emission, Tokyo may take much more responsibility in addition to the apparent direct CO2 emission. As to say Shanghai and Beijing, we find that the indirect CO2 emission decreased during the period of 1992-1997.Especially for Shanghai case, the indirect CO2 emission decreased from 1.9 times of direct CO2 emission to 0.9 times of it. Which means that the transferring of indirect CO2 emission in Shanghai and Beijing is not so great as Tokyo. Sectoral contribution figure (**Figure 4-4-5-9 and 10**) shows that secondary industry should take major responsibility for indirect CO2 emission for all of the cities. As for direct CO2 emission, Tokyo case show that tertiary industry plays the dominating role and Shanghai and Beijing cases indicate a more important or at least equal role for secondary industry.

Considering the CO2 emission embodied in the products, we can find from **Figure 4-4-5-11** that mega-city should take major responsibility for the embodied CO2 emission since the dominating part of which is consumed to meet the domestic demand.

Combining with the analysis of the "direct CO2 emission" and "indirect CO2 emission", we can safely say that mega-city should take much more responsibility than it is assigned by the direct energy consumption and correspondingly direct CO2 emission. In the meaning of "indirect CO2 emission" mega-cities show great reliance on outside and should be responsible for the part consumed within its territory. On the other hand, in terms of "external CO2 supply", mega-cities transfer little to outside to relief its own burden. These two aspects beyond all doubts highlight the role of mega-city in CO2 mitigation.

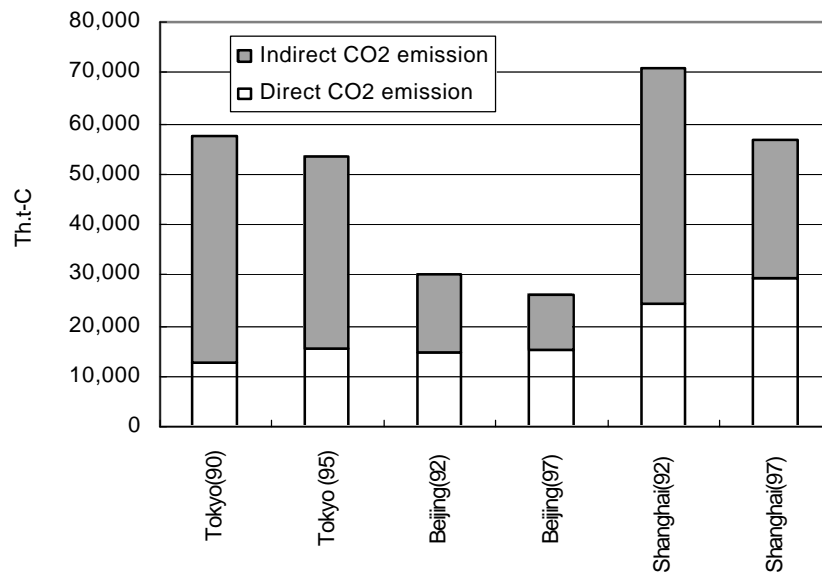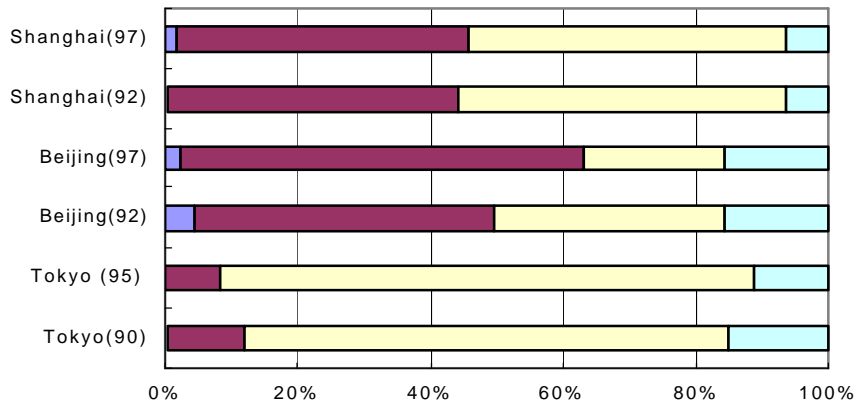**Figure 4-4-5-8: Direct and indirect CO2 emsission**

Figure 4-4-5-9: Share of each sector in the total direct CO2 emission in the targeted cities

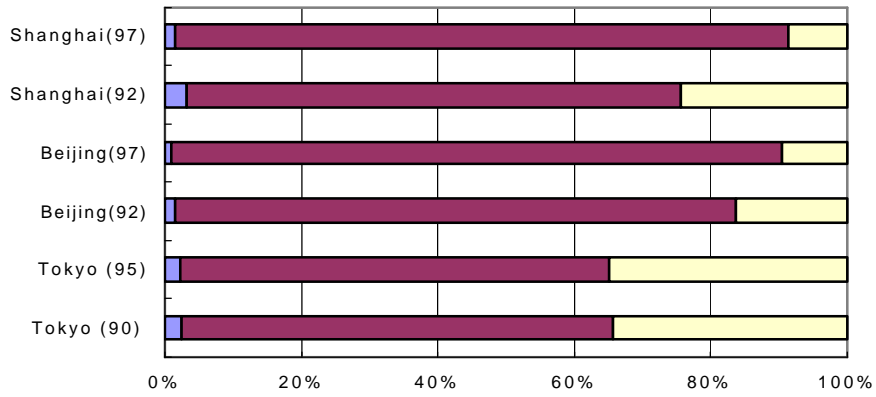■ Primary ■ Secondary □ Tertiary □ Household

Figure 4-4-5-10: Share of each sector in the total indirect CO2 emission in the targeted cities

■ Primary ■ Secondary □ Tertiary □ Household
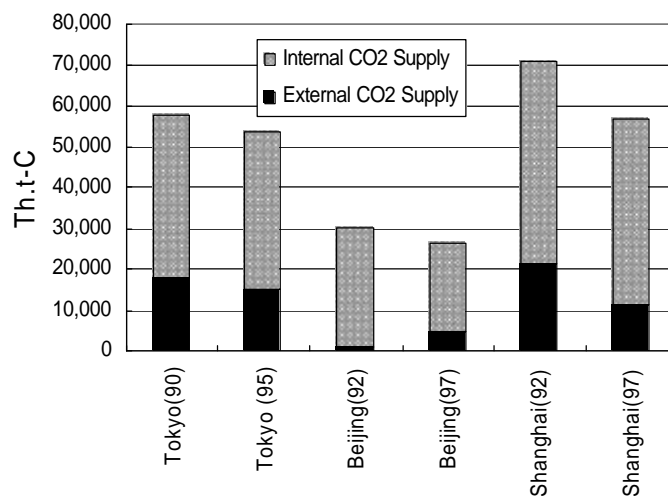
Figure 4-4-5-11: Internal and external indirect CO2 supply
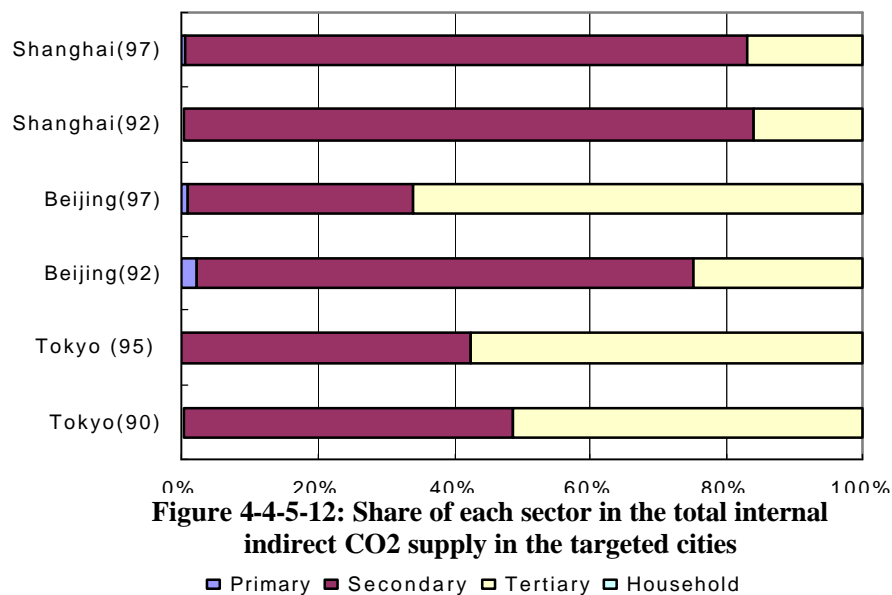
Figure 4-4-5-12: Share of each sector in the total internal indirect CO2 supply in the targeted cities

☐ Primary ■ Secondary ☐ Tertiary ☐ Household
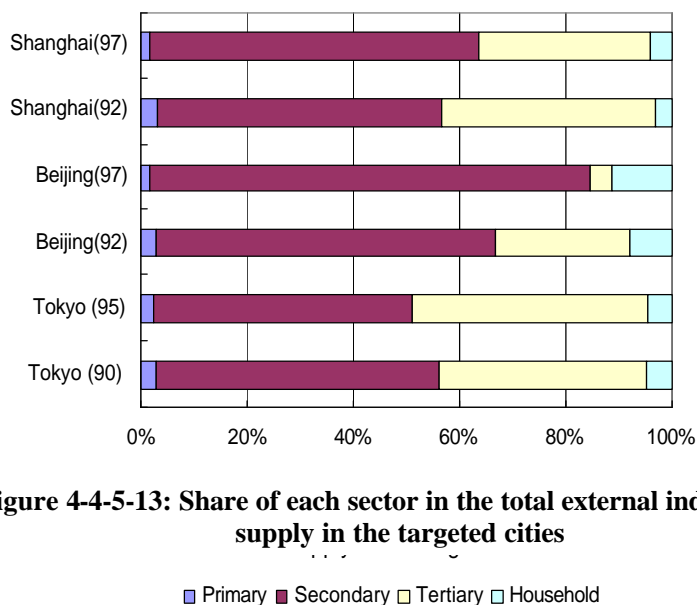
Figure 4-4-5-13: Share of each sector in the total external indirect CO2 supply in the targeted cities

☐ Primary ■ Secondary ☐ Tertiary ☐ Household

(5) Conclusion and implications

Considering that major attention has been paid to the direct energy consumption and CO2 emission in mega-cities, this research try to highlight the exact role of mage-cities by extending the targeting scope: from the city itself to the city and outside together. In virtue of the concept of "embodied energy", this research clarifies four types of indicators for the performance of energy and CO2 emission.

" Direct and indirect energy demand "emphasize the reliance of the mega-cities on outside. Our research show that indirect energy demand in Tokyo and Shanghai is much more significant than direct energy demand, which indicates that these two cities have great reliance on outside in terms of energy demand. Contrarily, direct energy demand in Beijing plays a more important role.

Tertiary industry plays a dominating role in direct energy demand in Tokyo, since which accounts for almost 70% of the total amount. On the other hand, the secondary industry is most significant in indirect energy demand, which also occupy above 75% of the total amount. For Beijing and Shanghai case, same as Tokyo, the secondary industry plays dominating role in the indirect energy demand but greatly different from Tokyo, the secondary industry is most important for direct energy demand.

It is noticing that the proportion of indirect energy supply of Shanghai is highest among these three cities. Though this proportion has decreased from 58% to 42% from 1992 to 1997 in Shanghai, it still reflect that shanghai is strongly relied by outside and in terms of embodied energy, half of it has been transferred to outside world. Remaining at a level of around 30%, the outside reliance on Tokyo is very stable. For Beijing case, the proportion increased greatly during the period 1992-1997, indicating an ascending tendency of Beijing in terms of material export.

indirect CO_2 emission in Tokyo is much lager than direct CO_2 emission (above 2.5 times), which indicate that, in terms of indirect CO_2 emission Tokyo may take much more responsibility in addition to the apparent direct CO_2 emission. As to say Shanghai and Beijing, we find that the indirect CO_2 emission decreased during the period of 1992-1997.Especially for Shanghai case, the indirect CO_2 emission decreased from 1.9 times of direct CO_2 emission to 0.9 times of it. Which means that the transferring of indirect CO_2 emission in Shanghai and Beijing is not so great as Tokyo. Sectoral contribution shows that secondary industry should take major responsibility for indirect CO_2 emission for all of the cities. As for direct CO_2 emission, Tokyo case show that tertiary industry plays the dominating role and Shanghai and Beijing cases indicate a more important or at least equal role for secondary industry.

All in all, we may tentatively draw a conclusion that mega-city should take much more responsibility than it is assigned by the direct energy consumption and correspondingly direct CO_2 emission. In the meaning of "indirect CO_2 emission" mega-cities show great reliance on outside and should be responsible for the part consumed within its territory. On the other hand, in terms of "external CO_2 supply", mega-cities transfer little to outside to relief its own burden. These two aspects beyond all doubts highlight the role of mega-city in CO_2 mitigation.

Reference

Murandian R., O'Connor M., Martinez-Alier J.,2002, Embodied pollution in trade: estimation the "environmental load displacement" of industrialized countries, Ecological Economics, 41, 51-67.

Ayres R.U., Simonis U.E., 1994, Industrial Metabolism, resucturing for sustainable development. United Nations University Press, Tokyo, New York, Paris.

Fischer-Kowalski M., Huttler W., 1998, society's metabolism, the intellectual history of material flow analysis, part II, 1970-1998, Journal of Industrial Ecology, 2, 107-137.

Krausmann F., Haberl H., 2002, the Process of industrialization from the perspective of energetic metabolism: socioeconomic energy flows in Austria 1830-1995, Ecological Economics, 41,177-201.

VANENGELENBURG B., VANROSSUM T.F.M., BLOK K., et al., 1994, calculating the energy requirements of household purchases, Energy Policy, 22, 648-656

COLEY, D.A., GOODLIFFE E.,, 1997, the Embodied energy of food: the role of diet, Energy Policy, 26, 455-459.

SUBAK S., 1995, Methane embodied in the international trade of commodities: implications for global emissions, Global Environmental Change, 5, 433-446.

Daly H., 1968, On economics as a life science, Journal of Political Economics,76, 392-406.

Leontief R., 1970, Environmental repercussions and the economic structure: an input-output approach. Review of Economic Statistics, 52, 262-271.

Costanza, R. 1980. Embodied Energy and Economic Valuation, Science, Vol.210, pp.1219-1224

Kanagawa, T., Imura, H. 1993. Study on the Accounting of Urban Energy Consumption Based on the Input-Output Model (InJapanese), Environmental Systems Research, Vol.21, pp.186-191

Park, S-H., 1982. An input-output framework for analysing energy consumption, Energy Economics Vol4.2, pp.105-110

Miller, R.E.,Blair P.D. 1985. Input-Output Analysis Foundations and Extensions, Prentice-Hall, Inc., Englewood Cliffs, New

Jersey

Moriguchi, Y. 1997: Material Flow Analysis for Interlinking Human Activities and Environmental Burdens(InJapanese),Environmental Systems Research, Vol.25, pp.557-568

A. Adriaanse et al. 1997. The Material Basis of Industrial Economies, World Resources Institute(WRI)

Emily Matthews et al. 2000. The Weight of Nations –material outflows from industrial economy-, World Resources Institute(WRI)

4.4.6. Municipal Solid Waste (MSW) Management Sector

This study highlighted the lack of incineration facilities in Beijing and Shanghai in spite of increasing waste generation.

Tentative policy implications from this sub-sector study are following: to increase recycling/ reuse rate of MSW & to develop more effective policy strategies; and to reduce food waste generation & its utilization. In case of Beijing & Shanghai, need for new facilities, policy instruments, and citizen participation are emphasized. For Seoul, the suggestion are to increase the operation rate of incineration plants (current rates: 36%); and to benchmark the operation of Tokyo incineration plants.
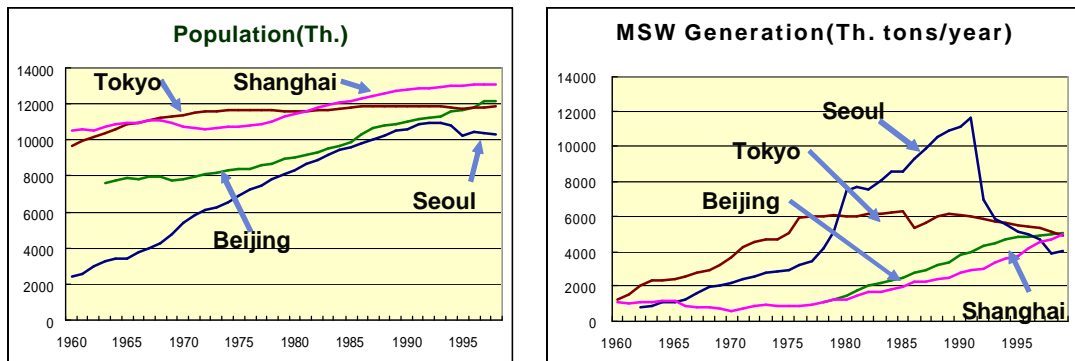
Shanghai ('99) : 13.1 mil.
Beijing ('00)   : 12.7 mil.
Tokyo ('00)   : 12 mil.
Seoul ('00)   : 10.3 mil.

Figure 1: Population & MSW Generation
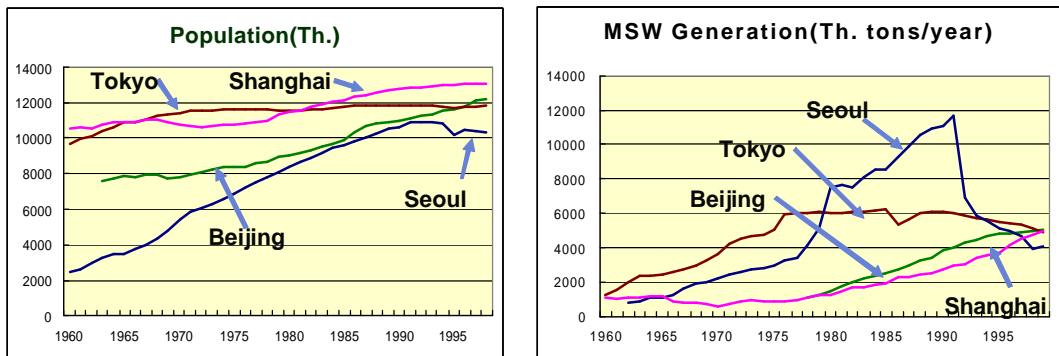
Shanghai ('99) : 13.1 mil.
Beijing ('00)   : 12.7 mil.
Tokyo ('00)   : 12 mil.
Seoul ('00)   : 10.3 mil.

Figure 2: MSW Generation per Capita

93
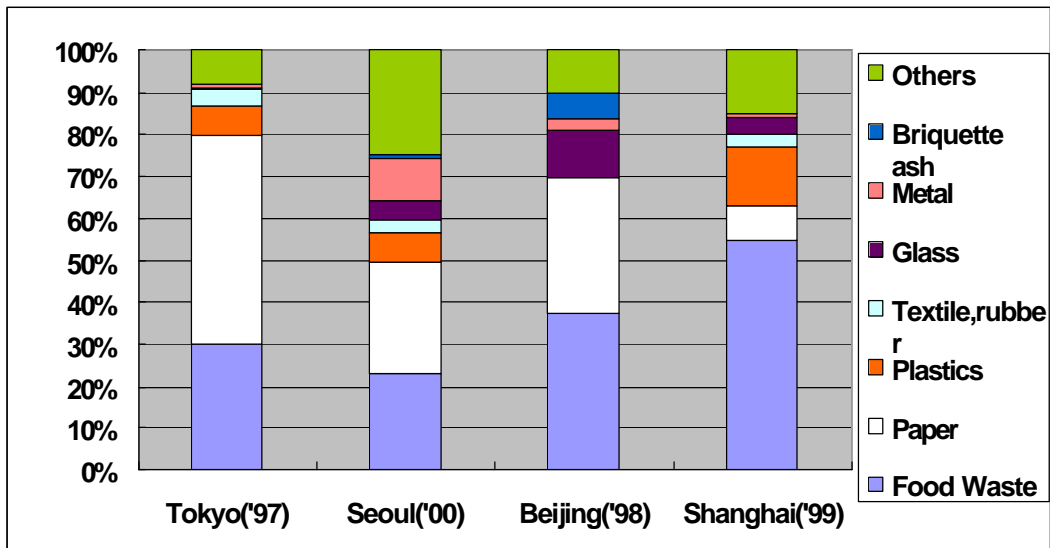
Figure 3: Comparison of MSW Composition
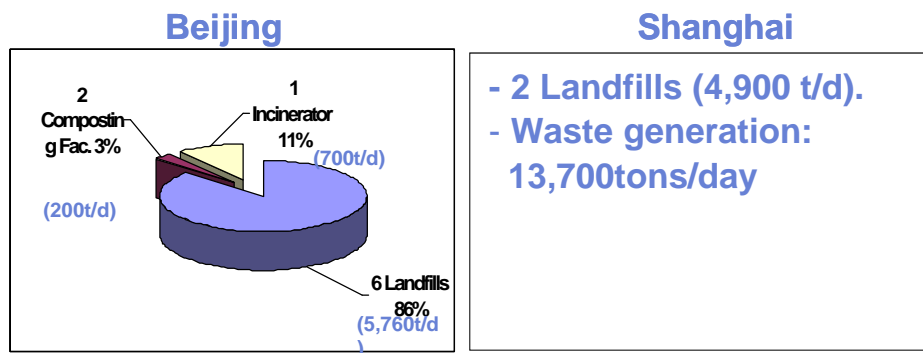
Beijing

Shanghai

- 2 Landfills (4,900 t/d).
- Waste generation:
  13,700tons/day

Both cities need more facilities & effective waste mgt. strategies to avoid waste problems faced by Tokyo & Seoul.

Figure 4: Waste Treatment Capacity: Beijing & Shanghai

Table 1: Characteristics and Effective Policy Initiatives

Tokyo: "Tokyo Act for Waste Treatment and Recycling (1992) "

"The TMG Basic Plan for Urban Waste Treatment: Tokyo Slim Plan 21" etc.

Seoul: "Waste Management Act to Promote Recycling (1991)"

"Volume-based Waste Collection Fee System (1995)" etc.

Beijing: Still increasing in MSW generation.

Shanghai: Growth in population and income level will make the increasing trend of MSW generation keep going.

Policy Recommendation

Due to the delay in data collection, the final report of the analysis of this sector has not been available at the time of writing this report. The data has already been obtained and the result of analysis using that data will be included in the final project report which will be published in FY2003.

Tentative policy recommendation from this sectors analysis are the following:

All mega-cities:
- o To increase recycling/ reuse rate of MSW & to develop more effective policy strategies.
- o To reduce food waste generation & its utilization.

Beijing & Shanghai:
- o Need new facilities, policy instruments, & citizen participation.

Seoul:
- o To increase the operation rate of incineration plants (current rates: 36%).
- o To benchmark the operation of Tokyo incineration plants.

Tokyo:
- o To refer to LFG utilization in Seoul.

4.4.7. Energy and Emissions in South Asian Mega-cities: Study on Kolkata, Delhi and Manila

(1) Introduction

The urbanization is a part and parcel of the human development process and, therefore, has witnessed a sharp increase in the last few decades of industrial era. In 1900, only 160 million people (one tenth of the then population) were living in the urban areas but by 2006, almost 3.2 billion people are expected to inhabit the urban areas1. This will be about half of the total world's population. Most of this projected growth will occur in the developing countries due to reasons like aspiration for economic prosperity, better social and civic amenities, degradation of rural areas and population increase. The industrialization has totally changed the human settlement pattern. During the period up to about 1950, most of the jobs were in the agriculture fields only, confining the population to rural areas, but now most of the jobs are in service sector which is an out growth of industrialization1 propelling the people towards urban centers.

Cities take up only about 2% of the world's available surface area but consume bulk of the key resources. It has been estimated that roughly 78% of carbon emissions from fossil fuel combustion and cement manufacturing, and 76% of industrial wood use occur in urban areas. Almost 60% of the total water tapped in the world for human consumption is consumed by the cities. Almost half of this water is used for irrigating the food crops consumed by city dwellers, roughly a third is used by city industries and the remainder is used to meet the requirement of sanitation and drinking water1.

The cities represent a massive concentration of all human activities. But there has been a difference of opinion in regarding cities as eco-hazards or eco–devices. On one hand such a massive concentrations of human activities can be considered naturally unviable due to extraction of huge resources but on the other hand, can also provide an opportunity to use these as eco-devices offering an opportunity for better and sustainable management of natural and human resources in geographically smaller and manageable area. Considerable efforts are underway to understand the various effects of urbanization to resolve this issue. One such effort is APN/IGES sponsored Asian Mega-city Programme which has been underway since last two years. In India, under this program, study of two of India's mega-cities, namely Delhi and Kolkata and Manila city of Philippines have been under taken to find out environmental consequences of the developmental process in these mega-cities. A number of trace atmospheric gases from different sources in these cities have been estimated, which include both direct emissions sources (e.g. emissions of carbon dioxide from fossil fuel consumption, methane emission from waste sectors etc.) as well as indirect emissions sources (i.e. embodied emission e.g. methane emission from rice paddy fields catering the need of rice consumed by city population or methane emission from animals providing milk to city population). The significance of these emissions in the national context is also being examined.

At present as per 2001 Indian census, there are more than thirty million plus cities in India with rapid developmental and industrial activities. Delhi and Kolkata (earlier known as Calcutta) are the two important mega-cities in India with different techno-socio-economic settings. The total population of the cities together was about 20 millions in 1990 but has increased to about 29 millions in 2000 as a result of rapid urbanization. The future population has been projected to be about 20 millions for Delhi and 25 millions for Kolkata in 2015. **Table 4-4-7-1** shows some interesting indicators reflecting different socio-economic and cultural features of India's four mega-cities namely Kolkata, Delhi, Bangalore and Mumbai2 for the year 2001-2002. Delhi is the

most affluent city in India having highest per-capita income, highest number of cars per thousand population, highest number of cell phones, highest number of expensive cars sold, and also highest amount of personal income tax collected. Kolkata, on the other hand, is almost at the bottom of this ladder among these mega-cities. Traditionally, Kolkata inhabitants are of different cultural habit than that of inhabitants of Delhi, which are more consuming society. But now in Kolkata too, change in trend is felt and it is also changing to a more consuming society. Due to these interesting differences, Delhi and Kolkata provides two different scenarios to study the environmental consequences of urbanization.

Table -4-4-7-1: Indicators in Indian Mega-cities

Cities	1983	1995	% Increase
Bangalore	0.2	0.8	300
Kolkata	0.26	0.56	115
Chennai	0.13	0.77	533
Delhi	0.67	2.43	242
Hyderabad	0.13	0.56	300
Mumbai	0.37	0.67	81

Metro Manila or the National Capital Region has a land area of 636 square kilometers, accounting for approximately 0.21 percent of the Philippines' total land area of 300,000 square kilometers. It is composed of four (4) districts with twelve (12) cities and five (5) municipalities. It is geographically located at 140 20' to 140 50' latitude and 1200 54' to 121010' longitude. Its climate is characterized by two pronounced seasons. It is normally dry from January to May, with April and May as the hottest months, and rainy during the rest of the year. Temperatures in Metro Manila measures as much as 31.2oC and as low as 24.8oC. In terms of tropical cyclone, the National Capital Region has been visited by a total of 39 tropical cyclones for the 1970 to 2000 period or approximately a frequency of 5 cyclones in 4 years. Despite being the smallest in terms of land area, Metro Manila has the biggest contribution to the country's Gross Domestic Product (GDP). At an average, it comprises 30 % of the Philippines' GDP. And with the premier airports and ports located in it, Metro Manila serves as the distribution center for exports and capital goods. It also provides almost half of the total national output in manufacturing, commerce and services.According to the latest census conducted on May 2000, Metro Manila has a population of almost 10 Million (9,932,560), making it a megacity by definition. NCR is also the most densely populated region with 15,617 persons occupying a square km of land, 61 times the national figure of 255 persons per square km.

(2) Emissions of trace gases and particulate matter from direct and indirect (embodied) sources

In order to study the impacts of developmental processes on the environment in the mega-cities, for the first time, an attempt has been made to calculate embodied emissions in the material and energy that flow in the mega-cities. Besides, emissions of both long lived greenhouse gases like carbon dioxide (CO_2) and methane (CH_4) as well as short-lived gases like carbon monoxide (CO), Oxides of nitrogen (NO_x), black carbon (BC), organic carbon (OC) and particulate matter (PM) have also been estimated. These numbers, although still associated with large uncertainties due to involved complexities,

nevertheless give some idea of the magnitude of emissions associated with the development and maintenance of mega-cities. Here we are presenting our work on emissions from energy sector. For the calculation of inventory values, in most of the cases IPCC-1996 methodologies3 have been followed. However, wherever country specific values of emission factors are available, the same has been utilized.

Emissions from energy sector:

Energy is the key driver of most of the world's economies, which is also primarily responsible for the emissions of greenhouse gases into the environment, considered to be responsible for the global warming. In India, more than 85% of the total CO_2 emissions have been estimated to be coming out of the energy related activities like consumption of fossil and bio fuels in total CO_2 emissions during 19904. Unlike the developed economies, traditional fuels like fuel-wood, crop residues, and animal waste etc. have significant contribution, which are estimated to account for about 40% of the total energy consumption in India4.

The energy consumed in the metropolitan area consists of coal, petroleum, diesel and bio-fuel. The consumption of biomass fuel mainly in the form of wood and dung-cake has been found much more in Kolkata than in Delhi. There is also a noticeable change in the consumption pattern in Kolkata from 192-92 to 1997-98. The industrial consumption was less in 1997 – 98 compared to that in 1992 – 93 periods, perhaps due to a decline in the industrial activity in the area. On the contrary, the coal consumption increased significantly during this period mainly for generation of thermal power. Consumption of energy is always associated with the pollution of the environment with increased emissions of suspended particulates, carbon dioxide, carbon monoxide, sulphur dioxide, nitrogen oxides, and other hydrocarbons. Both the suspended particulate matter as well as other form of pollutants in the metropolitan area is dominated by emissions from thermal power plants. Figure-1 shows the estimated carbon dioxide emissions from Delhi and Kolkata for different sources. This figure reveals that the major contributor of CO_2 emission in both Delhi and Kolkata is electricity consumption (including both direct and embodied). The embodied CO_2 emissions associated with steel and cement consumption also have significant contributions in the city totals.

For the assessment of source strength of materials consumed in Delhi and Kolkata like coal, gasoline (petrol), diesel, fuel wood and dung cakes for the emissions of greenhouse gases, we have used IPCC 1996 top-down approach3 using the consumption figures. The bio-fuel consumption in Delhi has been reported to be negligible but in Kolkata, it is one of the important sources for meeting household energy requirements. The consumption of bio-fuels also emits methane, which has also been estimated as per IPCC-1996 guidelines for different years. The consumption of bio-fuels like fuel-wood and dung cakes in Kolkata has recorded an increase during the period 1990-91 to 1997-98 and consequently methane emission also shows an increasing trend of emission during this period. The results show that the contribution of methane emission from fuel-wood consumption is almost five times higher than the methane emission from dung-cake consumption in Kolkata.

In Delhi, the direct emission of CO_2 has been found to be highest from the consumption of diesel followed by gasoline. The coal consumption in the thermal power stations in Delhi has been reduced, as these are now being operated upon natural gas. More over most of the electricity supplied to Delhi city is being drawn from the national grid as local electricity production is very small. However, when we take into the account of

embodied emission in the consumption of electricity assuming most of the grid power is generated by the thermal power stations elsewhere in the country, the resultant net CO2 emission estimates from electricity sector are almost same as that of the Kolkata where most of the power is generated by the thermal power stations situated in-side the city's area. The direct CO2 emissions are more in Delhi because of the higher consumption of petroleum products in Delhi. The emission related to steel and cement consumptions are found to be more in Kolkata than Delhi because the calculations are based on the per-capita consumption of these materials.

Transport sector is one of the major consuming sectors of petroleum and thus is a contributor of greenhouse gases. This sector has even more importance for the emission of polluted gases like NOx, SO2, CO, particulate matter etc. into the atmosphere. It has been estimated that motor vehicles contribute to about 64% of the pollution in Delhi while other sources (e.g. domestic-8%, industries 12%, power plants – 16%) are of much lesser contributions. These gases play active role in the atmospheric chemistry and are responsible for climate change, adverse effects on human and plant health, atmospheric corrosion etc. The growth of the vehicle population in India has been extremely fast especially in the post economic liberalization era and the number of vehicles has nearly doubled during the 1991-98 period from about 21 millions to about 41 millions5. The Indian mega-cities have also reported large growth rates in the increase in vehicle population as reflected in **Table 4-4-7-2**.

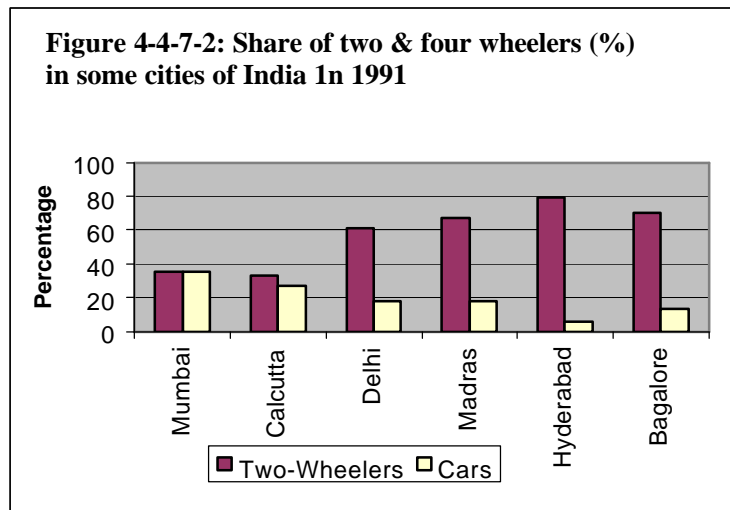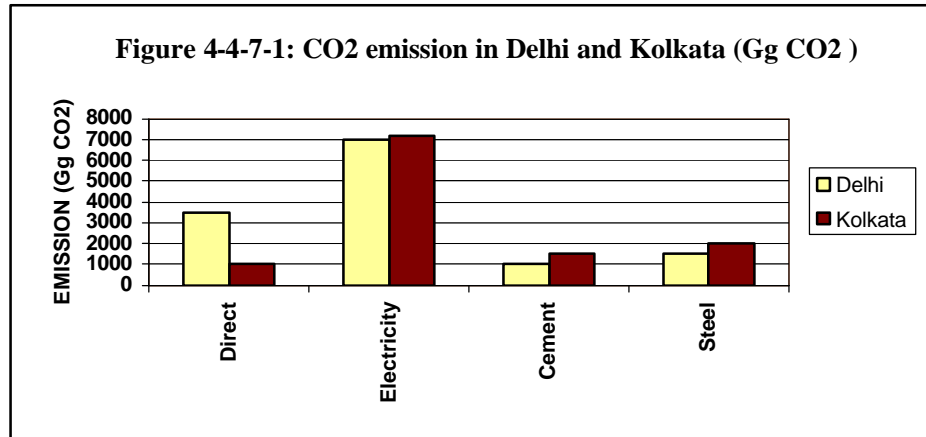**Table 4-4-7-2: Growth of vehicle population (in millions) in Indian mega-cities**

Cities	1983	1995	% Increase
Bangalore	**0.2**	**0.8**	**300**
Kolkata	**0.26**	**0.56**	**115**
Chennai	**0.13**	**0.77**	**533**
Delhi	**0.67**	**2.43**	**242**
Hyderabad	**0.13**	**0.56**	**300**
Mumbai	**0.37**	**0.67**	**81**

Delhi stands out with the largest number of vehicle population compared to any other Indian cities. The vehicle population in Delhi is more than the combined vehicle population of other Indian mega-cities like Chennai, Mumbai, and Kolkata. One of the important features of vehicle population in Delhi is the large proportion of two-wheelers (**Figure 4-4-7-2**), which indicates the preference of personal mode over public mode of transportation in Delhi. As per the estimates, the share of personalized mode is 37% while the share of buses and railways are 62% and 1% respectively in Delhi. In Kolkata, the share of bus in total transport mode is about 72%.

During 1980-81 to 1997-98 periods, the consumption of diesel in Delhi has gone up quite significantly, which has caused concern for human health related and ecological problems in Delhi. This consumption is not only by the commercial luggage vehicles but also by diesel driven cars, which users are tempted to purchase due to cheaper diesel prices. In Kolkata also, the consumption of diesel is more compared to gasoline, a trend normally observed in all the India cities. The diesel consumption in transport sector is one of the major sources of particulate matter emission.

Using the consumption of gasoline and diesel in the transport sector in Delhi and Kolkata, emissions of different greenhouse gases, other urban gases and particulate
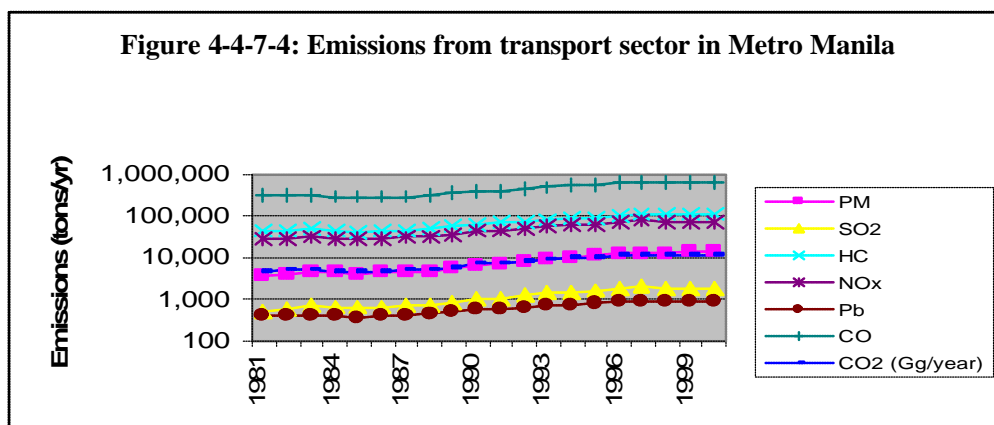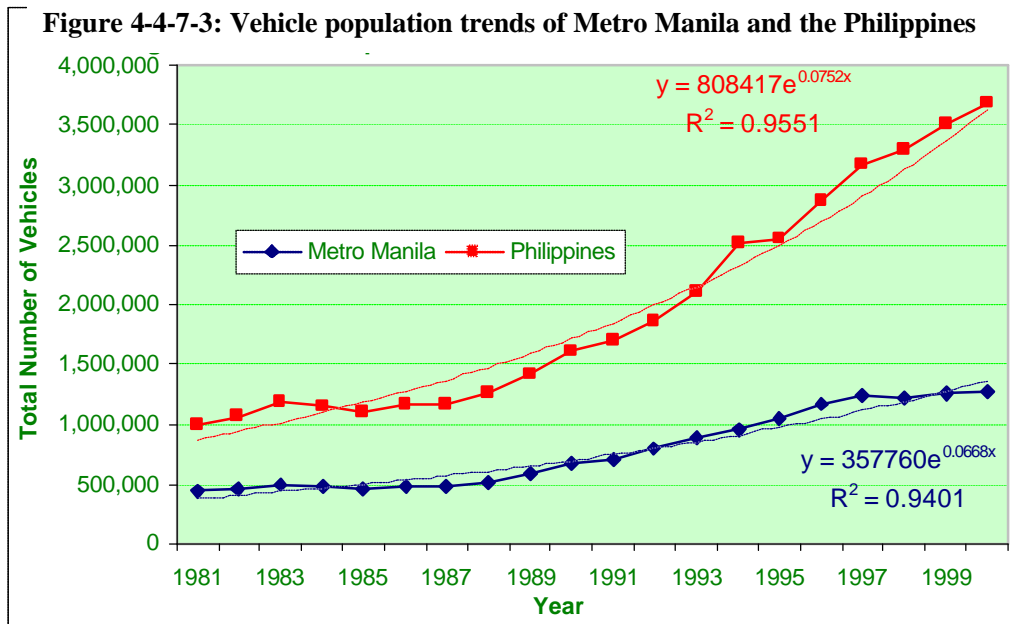
matter have been estimated using the IPCC-96 methodologies. For the estimation of CO, NOx, HC and particulate matter from diesel and gasoline, emission factors prescribed by Indian Institute of Petroleum, Dehradun6 have been utilized.

Figure 4-4-7-1: CO2 emission in Delhi and Kolkata (Gg CO2)

Figure 4-4-7-2: Share of two & four wheelers (%) in some cities of India 1n 1991

It has been estimated that the CO emissions from gasoline consumption has increased from 130 Gg (Giga gram which is equal to thousand tons) in 1990-91 to 164 Gg in 1995-96 while from diesel it has increased from 22 Gg in 1990-91 to 35 Gg in 1995-96. The NOx has increased from 3.5 to 4.5 Gg, hydrocarbon from 4.9 to 6.3 Gg, particulate from 0.7 to 0.9 Gg, black carbon from 0.05 to 0.06 Gg and organic carbon from 0.25 to 0.3 Gg from 1990-91 to 1995-96 period in Delhi from Gasoline consumption. From diesel consumption, CO has increased from 22 to 35Gg, NOx from 8 to 12.8Gg, hydrocarbon from 2 to 3Gg, particulate matter from 1.8 to 2.8Gg, black carbon from 7.3 to 11.5Gg and organic carbon from 3.7 to 5.8 Gg during the above-mentioned period in Delhi. In Kolkata, the gasoline consumption's contribution in CO has increased from 12 Gg in 1990-91 to 16Gg in 1995-96, in NOx from 0.3 to 0.4, in hydrocarbon from 0.5 to 0.6, in particulate matter from 0.06 to 0.08, in black carbon 0.005 to 0.006, in organic carbon from 0.02 to 0.03 Gg respectively during this period. The diesel consumption in Kolkata has contributed in CO from 7 to 9Gg, in NOx from 2.6 to 3.2, in hydrocarbon from 0.6 to 0.8, in particulate matter from 0.6 to 0.7, in black carbon 2.36 to 3, and in organic

carbon from 1.2 to 1.5 Gg respectively during this period. The transport sector in India is witnessing a rapid transition phase due to several policy interventions related to emission norms for vehicles and quality of fuel supplied. One of the interesting aspects is that most of these interventions have been conceived due to the deteriorated status of ambient air quality caused by pollutants in Delhi due to transport sector.

The vehicle fleet in Metro manila is also increasing very fast due to increased demand. It has increased from about 0.4 millions in 1981 to about 1.2 millions in 2002 while the vehicle population in Philippines has increased from about 0.9 millions to about 3.6 millions during this time (**Figure 4-4-7-3**). The average annual growth rate in the vehicle registration in Metro Manila has been recorded as 6.9% while for Philippines it is 7.8%. The total share of the Metro manila's vehicle in the country total is about 41% during this period although it has decreased from about 44% to 35%. However, certain type of vehicles have larger share in the country total, e.g. gasoline fueled cars in Metro Manila are almost 70% of the cars in the country. But the number of gasoline fueled vehicles in the region is decreasing while those of diesel fueled are increasing. The consequent estimated emissions of particulate matter (PM), SO2, HC, NOx, Pb, CO and CO2 from the transport sector in Metro Manila is given in **Figure 4-4-7-4**.

Figure 4-4-7-3: Vehicle population trends of Metro Manila and the Philippines

$y = 808417e^{0.0752x}$

$R^2 = 0.9551$

$y = 357760e^{0.0668x}$

$R^2 = 0.9401$

Figure 4-4-7-4: Emissions from transport sector in Metro Manila

The CO_2 emission from the consumption of electricity in the Metro Manila has also been estimated. The total consumption of electricity has gone up from 6,825 GWh in 1981 to 14,924 GWh in 2000 in Metro Manila (**Figure 4-4-7-5**). The average growth rate in overall consumption has been recorded to be about 4.8% but different sectors have witnessed different average growth rate, e.g. it is 5.35% for commercial, 5.1% for residential, 3.7% for industrial and 2.5% for street lighting. The CO_2 emissions also show the similar pattern (**Figure 4-4-7-6**) from electricity consumption in Metro Manila. The average annual growth rates for CO_2 emission from total consumption is 6.4% while from consumption in residential sector, it is 6.7%, 6.9% for commercial sector, 5.3% for industrial sector and 4.1 % for consumption in street lighting. Total CO_2 emission has been estimated to have increased from 3.5 Tg/yr in 1981 to about 9 Tg/yr in 2000 from electricity consumption in Metro Manila.

Figure 4-4-7-5: Metro manila electricity consumption, by consumer type, in GWh

Figure 4-4-7-6: 1981 to 2000 CO2 emissions from electricity consumption, by consumer type in Metro Manila
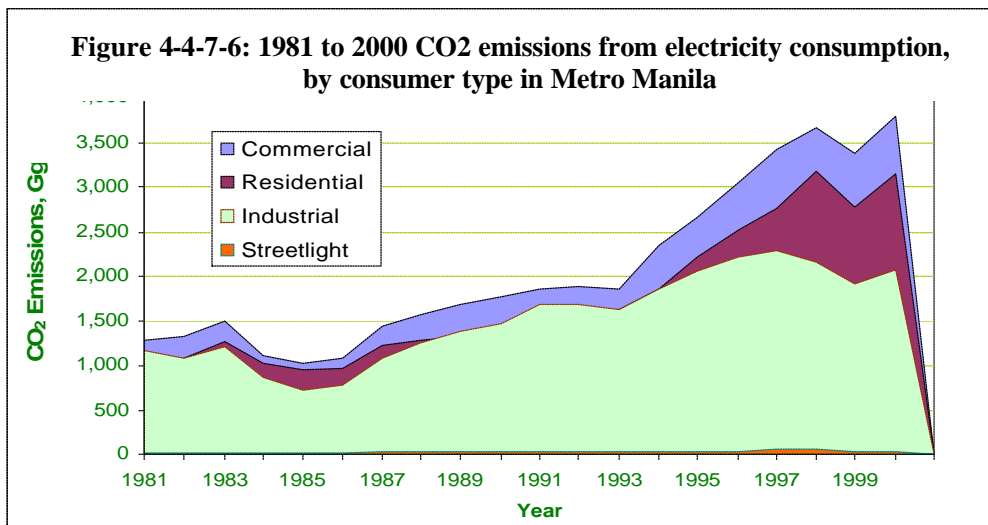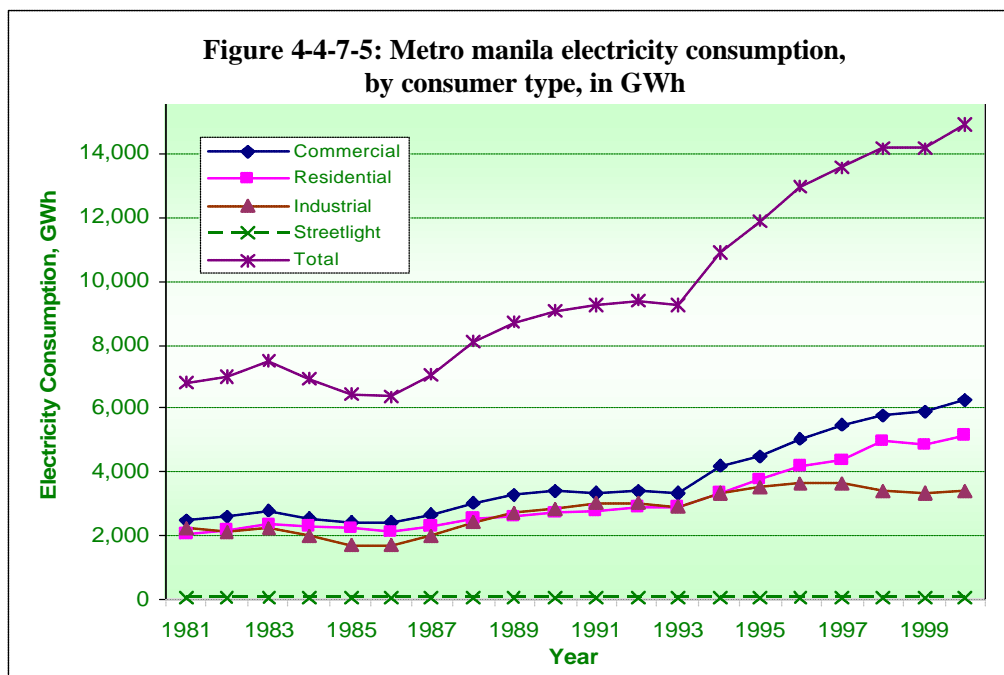
(3) Emission Status in Indian Mega-cities

The per-capita emissions as calculated from the estimates based on direct as well as embodied sectors are given in **Table 4-4-7-3**. The CO2 and CH4 estimation have been made for both direct and embodied emissions for Delhi and Kolkata while for other species like CO, NOx, hydrocarbons (HC), particulate matter (PM), black carbon (BC) and organic carbon (OC), mostly transport sector has been taken into consideration. The per capita emissions for most of the species calculated here are found to be higher in Delhi compared to Kolkata's average per-capita emissions. However, the comparison of percentage increases in emissions of short lived gases and particulate matter during 1990-95 periods reveals that percentage increase in per capita emissions of these gases and particulate matter have lower values for Delhi and Kolkata compared to percentage increase in national per capita emissions. The higher population density of these mega-cities compared to the nation is probably responsible for this observation. Interestingly, the percentage increase in emissions of few of the species like particulate, BC and OC in Delhi are almost as high as that of percentage increase in national emission which shows that the fuels like diesel has been consumed in Delhi in larger proportions. A comparison of per-capita CO2 emissions from Delhi, Kolkata and India are given in **Table 4-4-7-4** with population . Delhi and Kolkata having 2.4% of Indian population in 1990 have been estimated to have contributed about 5% to the national total CO2 emissions for 1990, 5.2% in 1995 (population share 2.7%) and 4.7% in 2000 (population share 2.9%). For methane, these cities together contributed to about 2.5% of the national total for methane emission in 1990. The ratio of per capita emissions to per capita income, which is a masure of carbon intensity, in Delhi and Kolkata with respect to India shows that while Kolkata's trend is almost similar to that of Indian trend, Delhi has slight difference during 1990-95 period (figure 7). The value decreases from 124.4 in 1990 to 75.1 for India in 1995 and from 124.3 to 77.8 for Kolkata, it decreases from 137.2 to 75.8 for Delhi .

Table 4-4-7-3: Per capita emissions of GHGs and other urban pollutants in Delhi, Kolkata and India

	Year	CO_2 (tons)	CH_4 (Kg)	CO (Kg)	NOx (Kg)	HC (Kg)	Particulate (Kg)	BC (Kg)	OC (Kg)
Delhi	**1990**	**1.5**	**23**	17.3	1.3	0.87	0.28	0.83	0.44
	1995			18.14	1.56	0.85	0.33	1.05	0.55
	% Increase			5.01	18.49	8.19	19.08	25.84	24.43
Kolkata	**1990**	**1.1**	**24.5**	1.63	0.25	0.09	0.05	0.20	0.10
	1995			1.83	0.27	0.10	0.05	0.21	0.10
	% Increase			11.90	7.79	10.33	7.70	6.90	7.04
India	**1990**	**0.62**	**21.2**	2.31	0.32	0.12	0.07	0.25	0.13
	1995	**0.78**		2.96	0.43	0.16	0.09	0.35	0.18
	% Increase	**25%**		27.64	37.71	31.21	37.96	40.20	39.80

Table 4-4-7-4: Comparison of CO2 emissions from Delhi, Kolkata and India

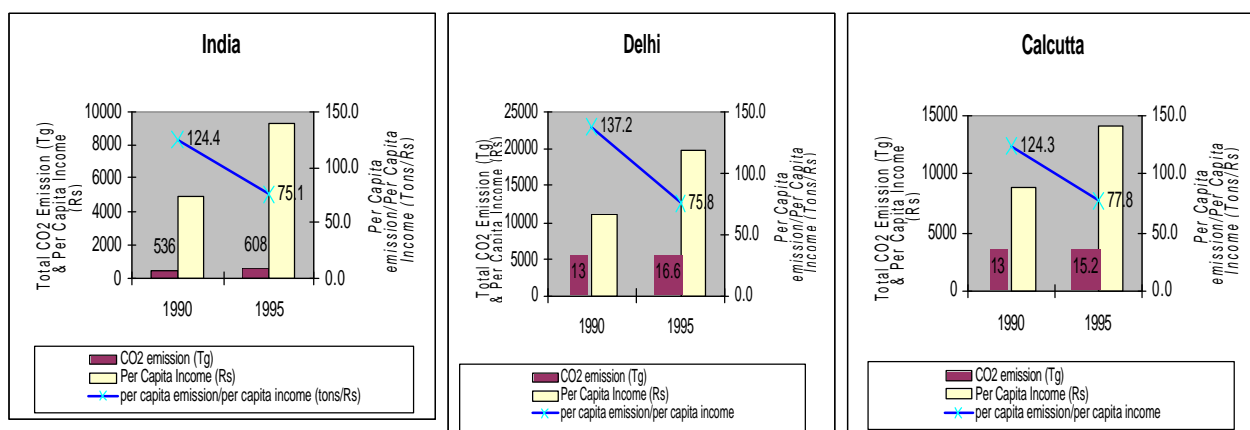|		Delhi	Kolkata	India
1990	Emission	13 Tg	13 Tg	536 Tg
	Population	8.8 million	11.8 million	855 million
	Per-capita	1.5	1.1	0.62
Delhi+Kolkata=5% Emission; 2.4% population				
1995	Emission	16.6 Tg	15.2 Tg	608Tg
	Population	11 million	13.8 million	930 million
	Per-capita	1.5	1.1	0.7
Delhi+Kolkata=5.2% Emission; 2.7% population				
2000	Emission	19.8 Tg	17.27 Tg	780 Tg
	Population	13.2 million	15.7 million	1000 million
	Per-capita	1.5	1.1	0.78
Delhi+Kolkata=4.7% Emission; 2.9% population				

Figure4-4-7-7: Carbon intensity in India, Delhi and Kolkata

(4) Future Projections for emissions in Delhi & Kolkata

Based on the growth rates of per-capita emissions and population, future projections for emissions of CO2, CO, CH4, NOx, hydrocarbon, Particulate matter, black carbon and organic carbon have been made for Delhi and Kolkata assuming the same growth rate as observed during 1990-1995 period and shown in **Figures-4-4-7-8a, 8b and 9**.
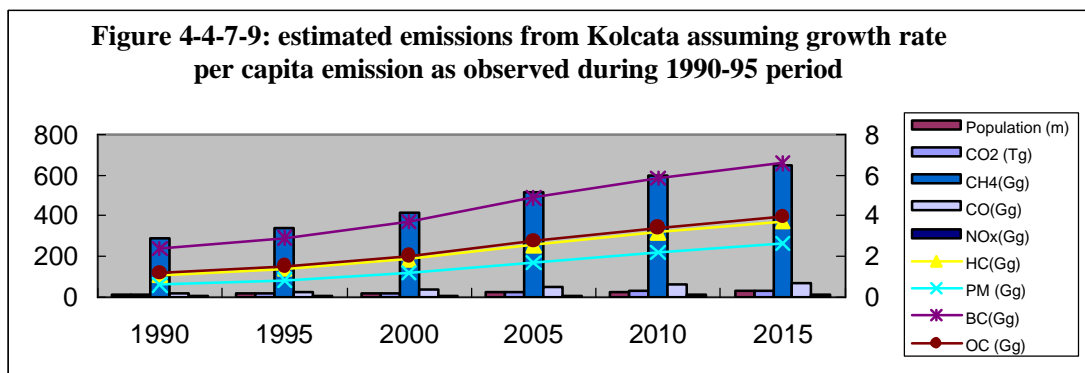
Loulou et al.7 have considered three scenarios in macro-economic growth in India for their projections by MARKEL model. These three scenarios are high, medium and low growth scenarios, which were based on observed GDP trends and the future scenarios constructed by some other studies8,,9. The base assumptions for these scenarios are as follows:

(i)   High Growth Scenario assumed 5% average compound annual growth rate for the period 1995-2035. The growth starts at the rate of 6.25% in 1995 and saturates at 2.1% by the year 2100.

(ii)　　Medium Growth Scenario assumed 4.5% average compound annual growth rate for the period 1995-2035. The growth starts at the rate of 5.5% in 1995 and saturates at 2% by the year 2100.

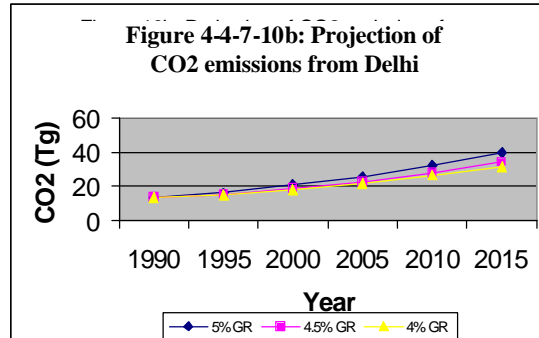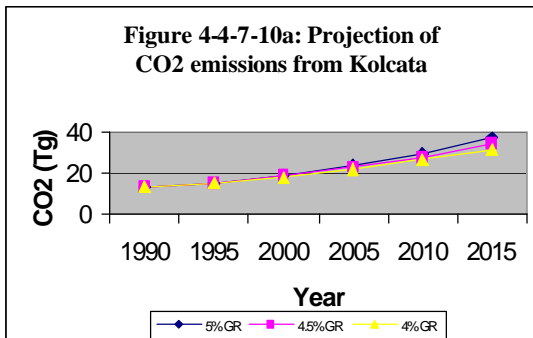(iii)　　Low Growth Scenario assumed 4% average compound annual growth rate for the period 1995-2035. The growth starts at the rate of 4.75% in 1995 and saturates at 1.9% by the year 2100.

Assuming these three growth rates as the likely emission growth rates in the two mega-cities too, the projected emission trend for 4% (low), 4.5 % (Medium) and 5% (high) per annum increase have been estimated for total CO_2 emissions from these cities. These estimations have been shown in **Figures 4-4-7-10a** and **10b** for CO_2 for Delhi and Kolkata respectively. These extrapolations reveal that the CO_2 emission from Kolkata and Delhi could be in the range of 31 to 37 TG/year and 34 to 40 Tg/year in 2015 respectively.

Figure 4-4-7-8a: Projected emissions from Delhi assuming same growth rate of per capita emission as observed during 1990-95 period

Figure 4-4-7-8b: Projected emissions from Kolcata assuming same growth rate of per capita emission as observed during 1990-95 period

Figure 4-4-7-9: estimated emissions from Kolcata assuming growth rate per capita emission as observed during 1990-95 period

Figure 4-4-7-10a: Projection of CO2 emissions from Kolcata

Figure 4-4-7-10b: Projection of CO2 emissions from Delhi

(5) Policy interventions

It is evident that the mega-cities have significant contribution in the national emission for most of the gases. Mega-cities also provide a platform to launch concentric targeted efforts to mitigate emissions of pollutants and greenhouse gases which would not only result in the reduction of national emissions but also would bring benefits at local scale like improvement in human health. Increasing awareness about the impact of pollutants on health as made this issue an urgent public agenda putting pressure on the policy makers to devise appropriate policies. In India, a road map has been devised for transport sector to control vehicular emissions which envisaged gradual tightening of emission norms forcing vehicle manufacturer to use latest technologies and improvement of fuel. In addition, program has also launched to have improved road network for better traffic management. In India, the lead (Pb) was totally eliminated from gasoline in 2000 but in Delhi, unleaded gasoline was introduced in 1994. The ambient measurements in Delhi have confirmed the reduction of lead in ambient air in Delhi (**Figure 4-4-7-11**) but the concentrations of benzene in ambient air (**Figure 4-4-7-12**) is going up (source: Central Pollution Control Board News Letter, 2002) since then due to various additives added to gasoline as anti-knocking agents in gasoline in place of lead tetra acetate, which should now be tackled properly.
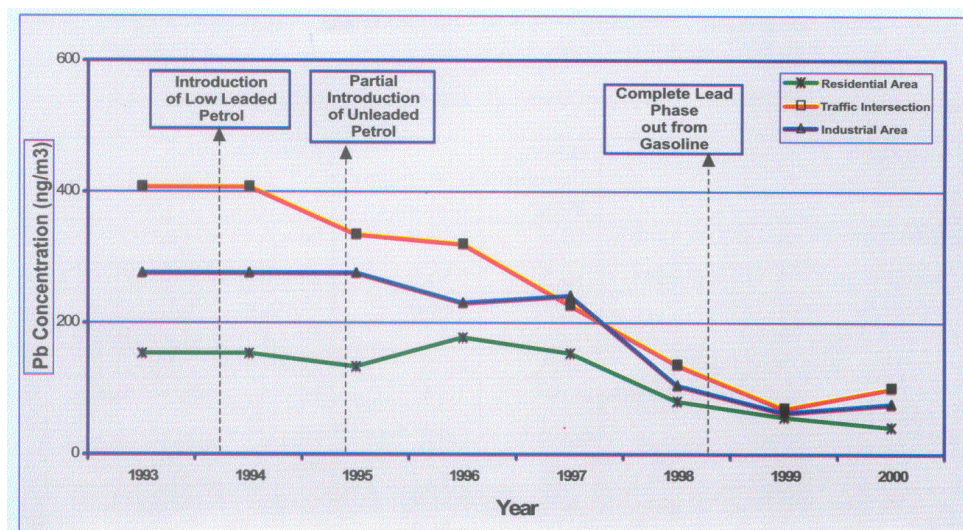

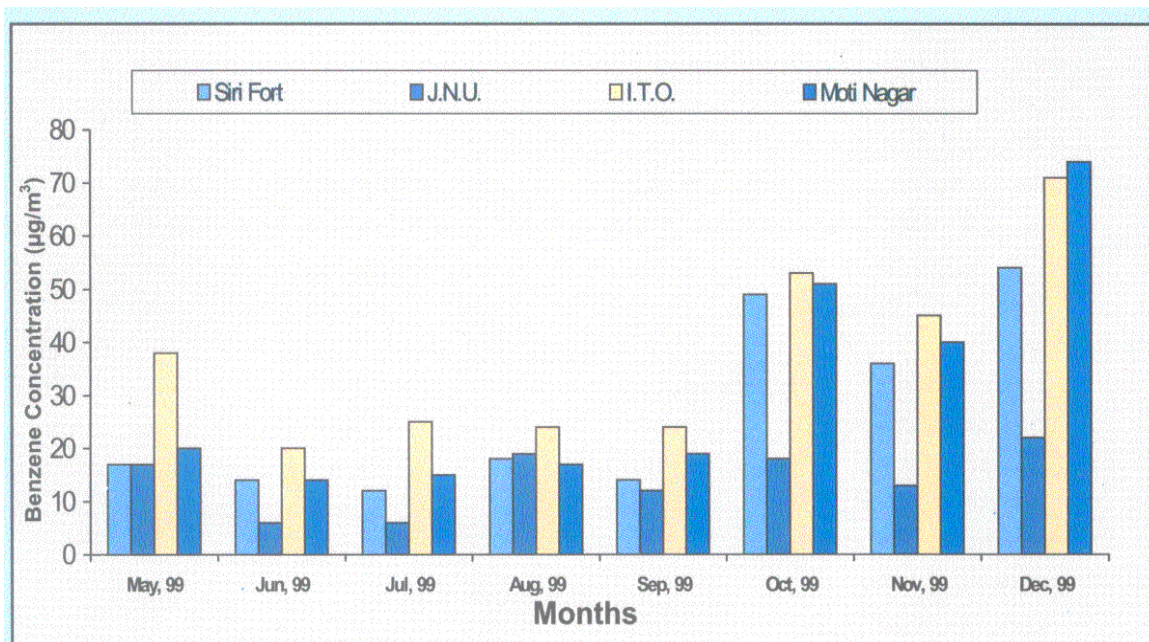**Figure 4-4-7-11: Lead in Delhi's ambient air**

Figure 4-4-7-12: Benzene in Delhi's ambient air

A number of measures have already been implemented in Delhi in transport sector. For example, The entire bus fleet for public transport in Delhi is now running on compressed natural gas (CNG) to improve the city's ambient air. In general most of the Indian cities have shown high suspended particulate matter (SPM) concentrations in ambient air. Recently (since December 2002), Metro train has also been introduced in Delhi and as per our estimates after the completion of its first and second phase in 2005 when it will run on 51 km track, it could result in the annual saving of 124 million tons of CO_2, 7 million tons of CO and 7 million tons of particulate matter. Kolkata is the first city in India where Metro train is already in operation. In 1998, it was covering a distance of 16 km which, on the basis of similar assumptions as that of Delhi, shows an annual saving of 41 million tons of CO_2, 2 million tons of CO and 2 million tons of particulate matter.

References:

- O'Meara M. 1999. Reinventing cities for people and the planet. World Watch Paper 147, Worldwatch Institute, 1999.
- Business Today, vol. 11, No.8, August 18, 2002. pp 68-71 (http://www.business-today.com).
- International Panel on Climate Change (IPCC 1996) Climate Change 1996: The Science of Climate Change. Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A & Maskell K (eds.) Cambridge University Press, Cambridge.
- Asian Least Cost Greenhouse Gas Abatement Strategy (ALGAS), Asian Development Bank, Manila, 1998, Publication Stock No. 971-561-186-9.

- The Citizens's Fifth Report, Edited by Anil Agrawal and Sunita Narain, Published by Centre for Science & Environment, New Delhi-110062, 1999.
- Global Change: Greenhouse Gas Emissions in India – 1992 Update. Edited by A.P. Mitra, Published by National Physical Laboratory, New Delhi –110012, 1992.
- Loulou R., Shukla, P.R. and Kanodia, A., (1997) Energy and Environmental Policies for a sustainable future. Allied Publishers Limited, Delhi.
- Government of India. (1991). A technical note to the eight plan of India, Planning commission.
- Sengupta R. (1993) Energy modelling for India: Towards a policy for commercial energy, planning commission, Government of India, New Delhi.

4.5. Other Outcomes & Products

1. Data base on urban indicator for Beijing, Seoul, Tokyo and Shanghai

2. Computer model for future projection of energy consumption and CO_2 emission
   - Macro socio-economic
   - Transportation, Residential & Commercial (Res/Com)
   - Municipal solid waste management,
   - Direct and indirect energy demand and supply
   - Computational general equilibrium (CGE) model for GRP, industrial structure, and urbanization ratio

3. Inventory of CO_2 emission

4. Proceedings of the workshops:
   - "Policy Integration & Industrial Transformation towards Sustainable Urban Energy Use for Cities in Asia", Proceedings of the APN/IGES Mega-City Workshop and International Symposium in Kitakyushu, Japan (January 23-25, 2002)
   - "Proceedings of International Workshop on Policy Integration towards Sustainable Urban Energy Use for Cities in Asia" (Honolulu, February 4-5, 2003)

5. Scientific papers and articles
   - "An analysis on driving factors for CO_2 emissions from energy use in Tokyo and Seoul by Factor Decomposition Method..", (Authors: Shobhakar DHAKAL, Shinji KANEKO, Hidefumi IMURA), Environmental Systems Research, Volume 30, pp 295-303. Japan Society of Civil Engineers (JSCE).
   - "Energy Demand Model of Residential and Commercial Sectors for Asian Mega-cities", (Authors: Toru Matsumoto, Miyoko Ishizaki, Jian Zuo, and Hirofumi Nakayama), Accepted for publication to Proceedings of 30th Annual Meeting of Environmental Systems Research 2002, Japan Society of Civil Engineers
   - "Mega-cities: Are these eco-hazards or eco-devices?" (Authors: A.P. Mitra and C. Sharma) Science and Culture - Special Issue on Climate Change and Society: An Indian Perspective, vol. 68, Number 9-12, September-December, 2002 pp. 285-291.

6. Network building among researchers and experts
   APN, IGES, START, UNEP, ESCAP, UNU, East West Center (Hawaii University), IHDP, World Bank, US-EPA, Kitakyushu City, Ministry of Environment of Japan

7. Capacity building of young researchers through internship at Nagoya University, data collection and processing. (Three students /year)

8. CD-ROMs for the proceedings at Kitakyushu and Honolulu

4.6. Conclusion & Future Projection

This study has constructed inventory of CO2 and local pollutants from selected cities and their key urban sectors, and embodied emissions as a result of consumption pressure.

The estimation of CO2 emissions by sector and fuel type suggests that CO2 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 CO2 emissions for Tokyo and Seoul are estimated to 1.7% and 1.63%, respectively. 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%. However in terms of emission volume, Beijing and Shanghai emits 1.3 times and 1.7 times of Tokyo respectively while Seoul emits 0.7 times that of Tokyo. The results have suggested that income effect was primarily responsible for majority of CO2 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 CO2 emissions in Seoul and Tokyo, respectively in that period. Despite economic recession, CO2 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.

At present, the vehicle population in Beijing and Shanghai is about 1/10 of that in Tokyo, while their total fuel consumption is only 1/3-1/2 of Tokyo's, which is because of the lower fuel economy and larger VMT in China. In the future, fuel economy should be further improved, and urban transport should be well-developed, especially large-scale public transport. In Beijing and Shanghai, much smaller vehicle fleets emit more amounts of pollutants. Therefore, Beijing and Shanghai should further reduce the VMT of vehicles and strengthen control of in-use vehicles, and the former will be depend on the development perfect urban transport system. The future forecasting of emissions is done in this research. The next phase of research work will be focused on improving the data, scenario and complete other cities while improving the methodology by integrating urban transport plan in the computation

The amount of energy consumption per GRP of tertiary industries in Beijing and Shanghai tends to decrease; however, the results indicate that the amount of commercial energy consumption in those areas will exceed the amount in Tokyo by around 2010. All of the mega-cities have a large percentage of electric energy consumption, and the increasing tendency will continue in the future. Estimations on future expected CO2 emissions from commercial sectors show remarkable difference from the expected amount of energy consumption in that Beijing and Shanghai are positioned above Tokyo and Seoul, this is true for residential sector as well.

"Direct and indirect energy demand "emphasize the reliance of the mega-cities on outside. Our research show that indirect energy demand in Tokyo and Shanghai is much more significant than direct energy demand, which indicates that these two cities have great reliance on outside in terms of energy demand. Contrarily, direct energy demand in Beijing plays a more important role. indirect CO2 emission in Tokyo is much lager than direct CO2 emission (above 2.5 times), which indicate that, in terms of indirect

CO_2 emission Tokyo may take much more responsibility in addition to the apparent direct CO_2 emission. As to say Shanghai and Beijing, we find that the indirect CO_2 emission decreased during the period of 1992-1997.Especially for Shanghai case, the indirect CO_2 emission decreased from 1.9 times of direct CO_2 emission to 0.9 times of it. Which means that the transferring of indirect CO_2 emission in Shanghai and Beijing is not so great as Tokyo. Sectoral contribution shows that secondary industry should take major responsibility for indirect CO_2 emission for all of the cities. As for direct CO_2 emission, Tokyo case show that tertiary industry plays the dominating role and Shanghai and Beijing cases indicate a more important or at least equal role for secondary industry.

In case of waste and energy relation, it is concluded that there is a need to increase recycling/ reuse rate of MSW & to develop more effective policy strategies, especially to reduce food waste generation & its utilization. In case of Beijing & Shanghai, need for new new facilities, policy instruments, & citizen participation is crucial. Seoul needs to increase the operation rate of incineration plants (current rates: 36%) and to benchmark the operation of Tokyo incineration plants. Tokyo perhaps can learn from landfill gas utilization of Seoul.

However, the conclusions drawn from this study are yet tentative need further refinement. This is because APN support duration for two years was basically directed towards making GHG inventory, and fine tuning methodology and facilitating data collection and to some extent making future forecasting. The scenario analyses and implications of the various policy instruments would be next target in 2003/4.
Some observation and future directions are summarized below as:

- The mega-cities being studied under the project seem to differ in both direction and magnitude of development. In terms of emissions, these cities have significant bearing on the national emissions scenarios. These cities also provide an opportunity for implementation of policies to improve the local air quality and health of its citizens. This study also shows the fact that cities provide a viable platforms for application of appropriate policy measures to reduce the national emissions effectively. Energy, transport and waste sectors are the potential target sectors in the mega-cities for this purpose.
- Socio-economic parameters should be taken care of as these have strong bearings in the implementation of any policy decisions in future.
- The data and modelling are important but how much analyses is necessary and sufficient for policies are open question. So we must adopt strategic approach on finding solution
- To make complex analyses accessible to others, our reports and books (possibly) deal with care for questions such as how to present results, how to interpret them and how to make them understandable to policy makers.
- We need to address micro-economic aspects such as price implications.
- The unique features of each cities should be taken into account in policy measures or countermeasures
- Though mega-cities are important, smaller cities are need attention.
- Governance, institutional and legal frameworks questions are need to be addresses and included in the analyses.
- We continue this research in future with support of all collaborators and supporters.

One of the key issues faced by this research was data availability and slow pace of methodological developments for integrated analyses. The case study cities in this research are relatively in a better position for data and information availability compared to other cities in South East Asia and South Asia. The delicate balance of methodology and data availability is a key issue that deserves a careful further look in the Asian region. Since Asia would be the home to majority of mega-cities in the world and it has tremendous potentials for medium and small size cities, role of cities in global climate change debate would be important in the future. In that sense, the capacity building of doing research in this areas is needed to be further enhanced with due consideration to methodological enhancement, data availability and capacity building of researchers to carry our urban energy and emissions research. The project would wish to open a dialogue in scientific circle reflecting regional consideration to these issues, and go one step ahead by expanding such analyses covering all major mega- and medium scale cities.

Appendix : Funding sources

<u>Funding Sources outwith APN</u>

AEON Foundatin	2,000,000JPN
Asahi Glass Foundatin	250,000JPN
Centre de Estudis del Sector Privad para el Desarrll Sustentable (CESPEDES), Mexico	In-kind support
Climate Policy Project. IGES	In-kind support
East West Center, Hawaii University	In-kind support
Imperial College London	In-kind support
U.S. Environmental Protection Agency (EPA)	In-kind support
United Nations University (UNU)	In-kind support
World Bank	In-kind support
Institute for Global Environmental Strategies (IGES)	9,500,000JPN
National Physical Laboratory, India	In-kind support
Manila Observatory, Philippines	In-kind support