1.1.1. 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.

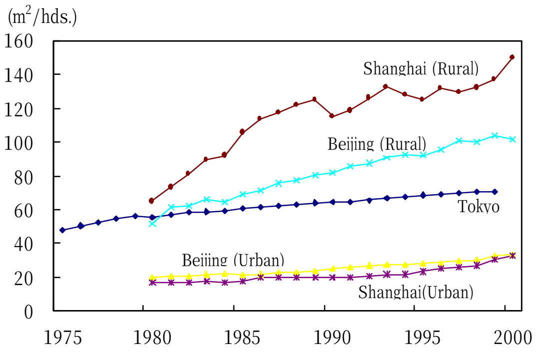

Figure 4-4-4-1: trends of floor space for household

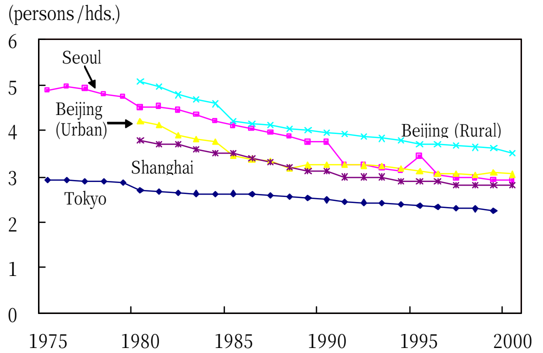

Figure 4-4-4-2: Trends of size of household

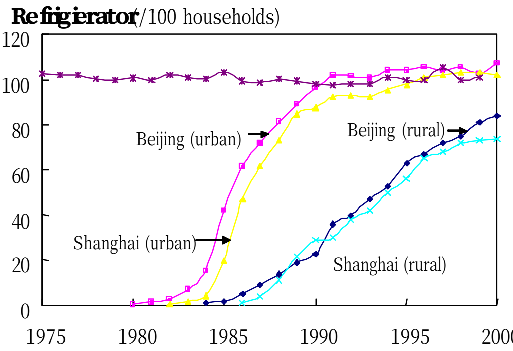

Figure 4-4-4-3: Refrigerator ownership

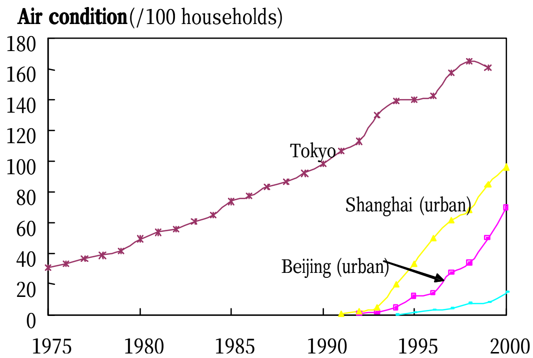

Figure 4-4-4-4: Air conditioner ownership

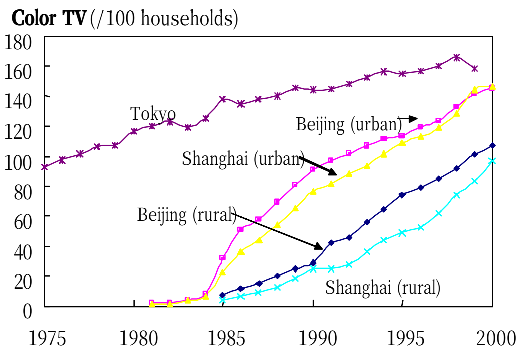

Figure 4-4-4-5: Color TV ownership

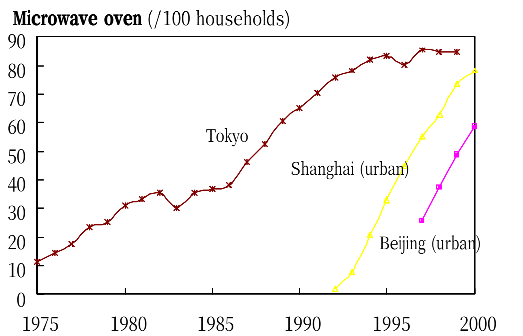

Figure 4-4-4-6: Microwave Oven ownership

(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.

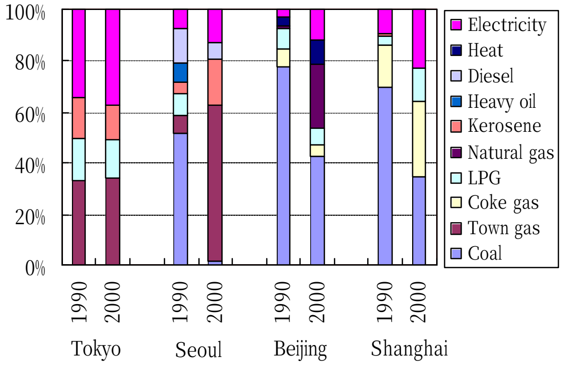

Figure 4-4-4-7: Energy consumption in residential sectoer by fuel types

(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.

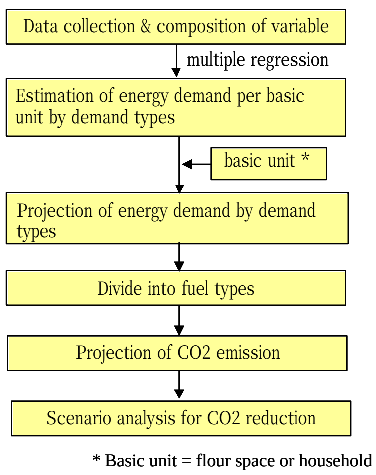

Figure 4-4-4-8: Analytical flow of residential sector for Tokyo

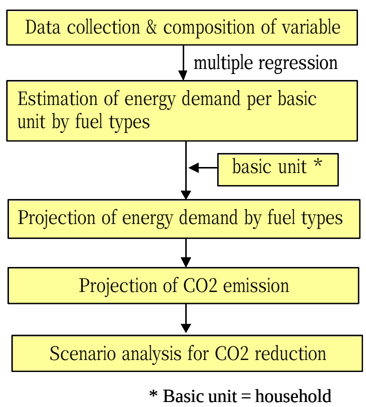

Figure 4-4-4-9: Analytical flow of residential sector for other cities

(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 ①heating, ②cooling, ③hot-water supply, and ④lighting, driving, and other uses. The energy demand for each use is expressed as the following identity with intermediate terms:

$$ENE.R = HS \times \frac{FL}{HS} \times \frac{ENE.R}{FL} \qquad (1)$$

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.

$$ENE.R = HS \times \frac{ENE.R}{HS} \qquad (2)$$

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.

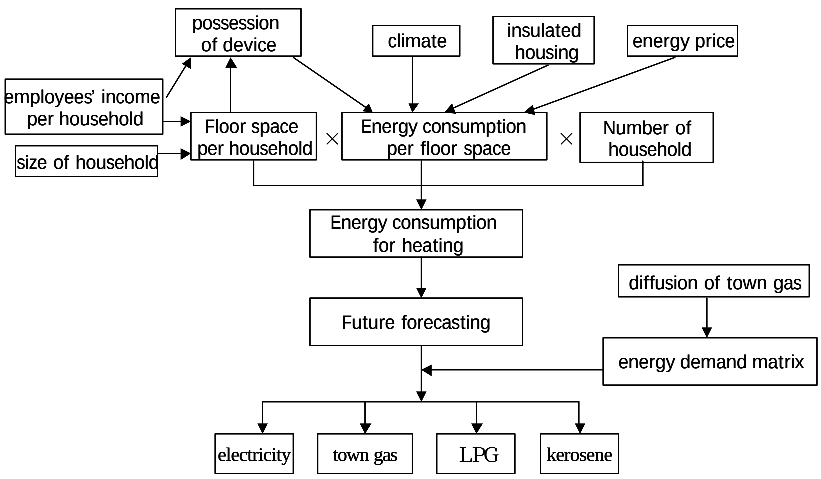

Figure 4-4-4-10: Estimation of energy consumption for heating

(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.

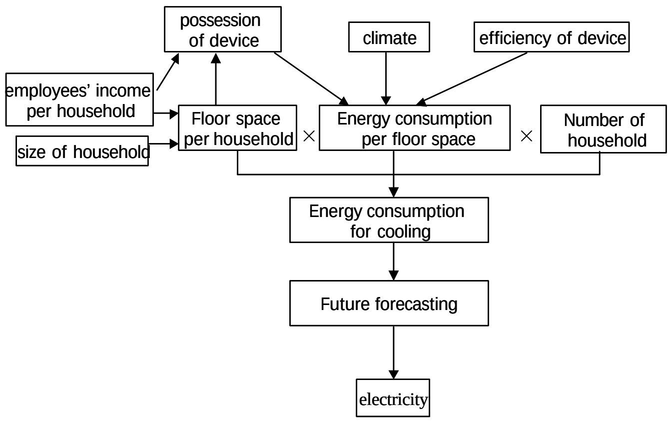

Figure 4-4-4-11: estimation of energy consumption for cooling

(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.

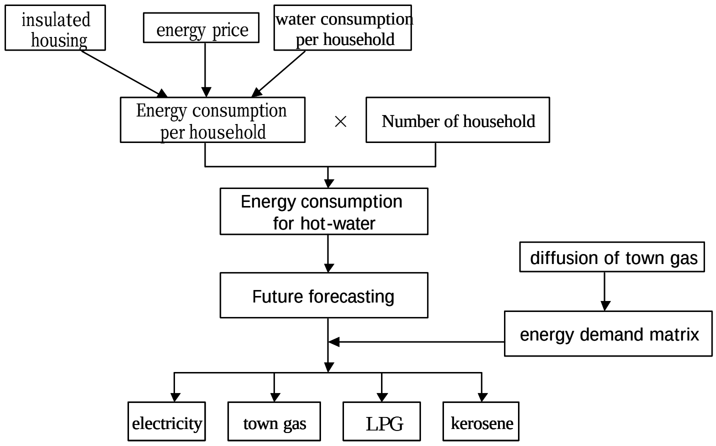

Figure 4-4-4-12: Estimation of energy consumption for hot water supply

(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.

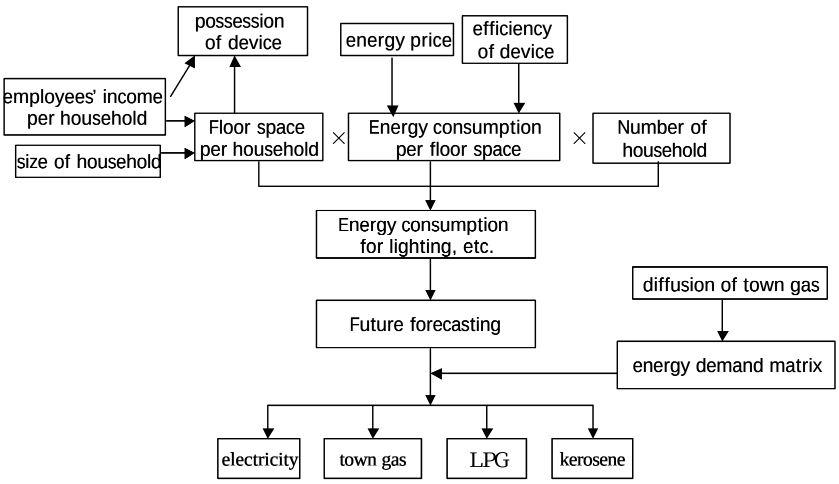

Figure 4-4-4-13: Estimation of energy consumption for lighting, etc.

(4)-6 Projection of energy consumption and CO_2 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 CO_2 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.

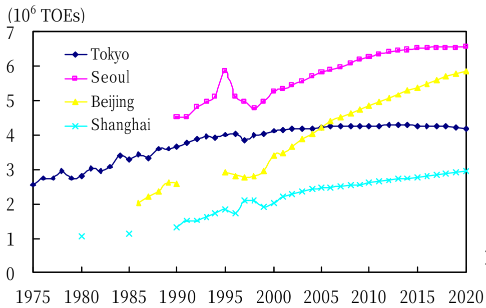

Figure 4-4-4-14(a): Projection of total energy consumption in residential sector

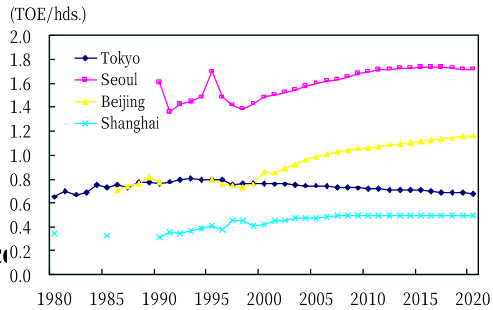

Figure 4-4-4-14(b): Projection of total energy consumption per household

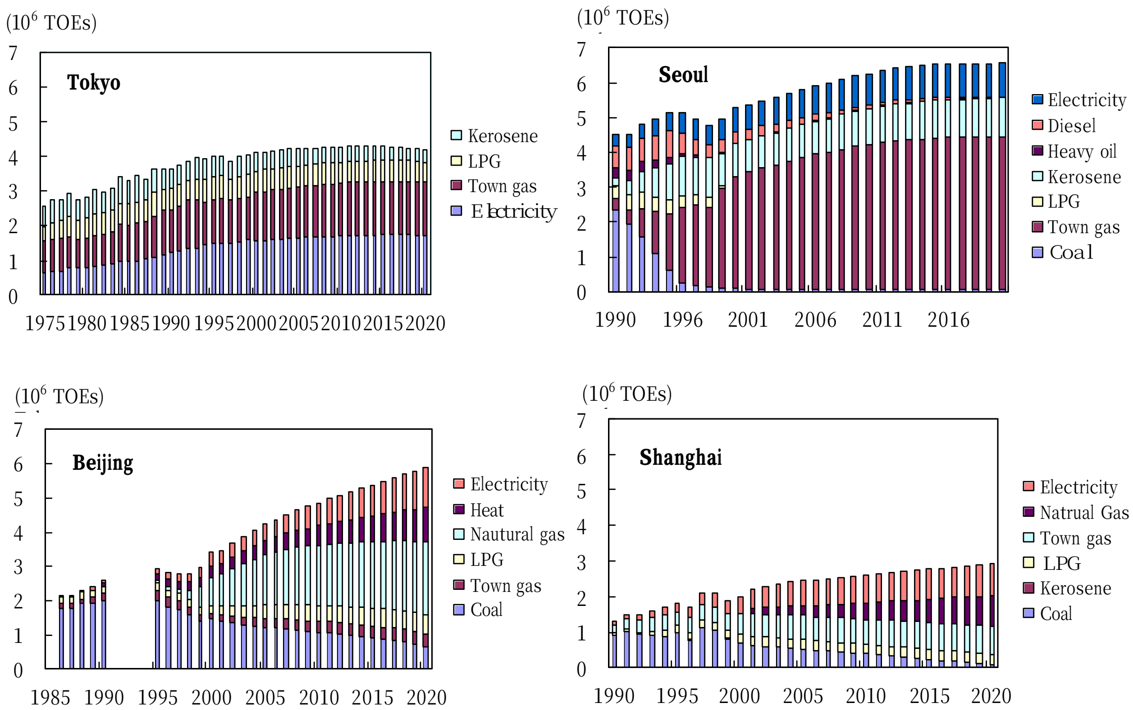

Figure 4-4-4-15: Projection of total energy consumption in residential sector by fuel types

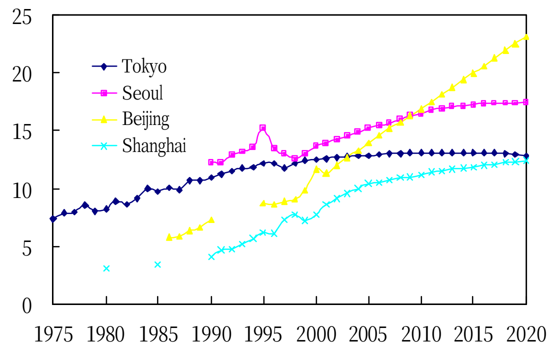

Figure 4-4-4-16: Projection of total CO_2 emission in residential sector

(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.

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

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 CO_2 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 CO_2 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.

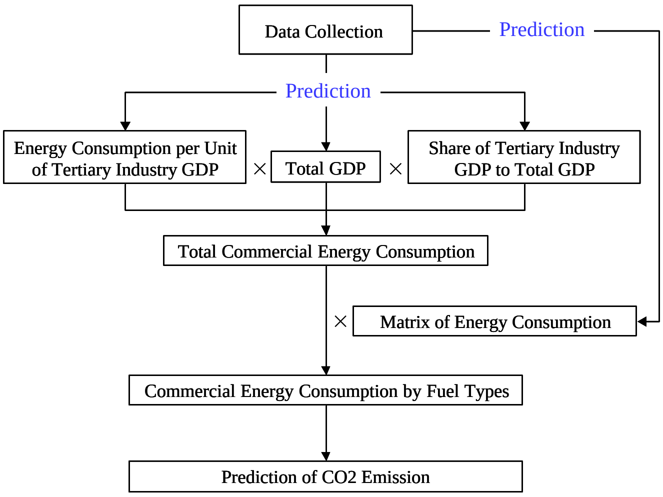

Figure 4-4-4-17: Analytical flow for commercial sector

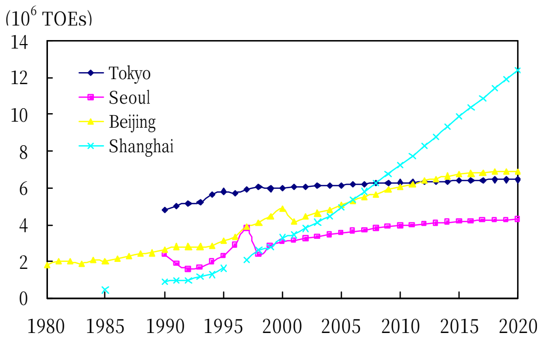

Figure 4-4-4-18(a): Projection for total energy consumption in commercial sector

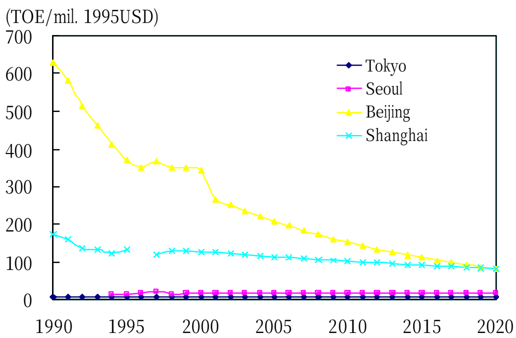

Figure 4-4-4-18(b): Projection for total energy consumption per GRP of tertiary industries

(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 ①household and lifestyle factors, ②household factors, and ③energy 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 ①, 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.

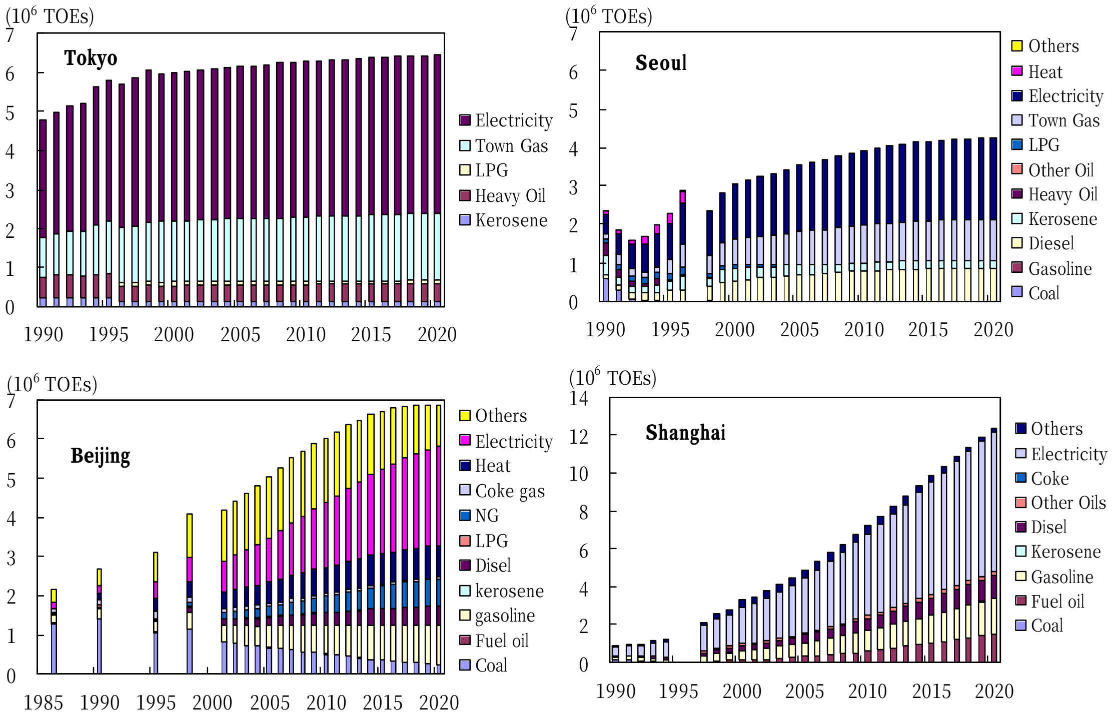

Figure 4-4-4-19: Projection of total energy consumption in commercial sector by fuel types

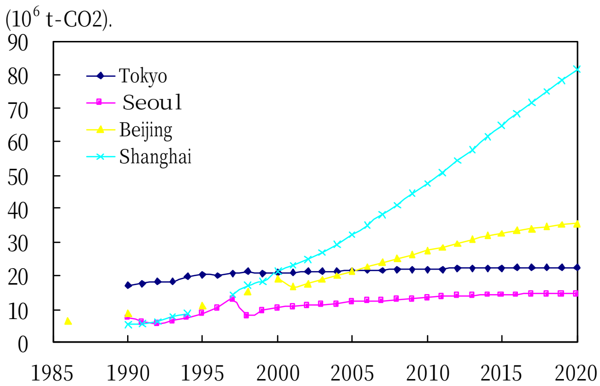

Figure 4-4-4-20: Projection of total CO_2 emission in commercial sector