Prediction of Residential Building Energy Consumption in Jilin Province, China

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Abstract
This research investigates and analyzes the current condition of urban and rural residential energy consumption of Jilin Province, China, by establishing a model of residential energy demand. The model can predict such energy demand based on the demand types and environmental load of Jilin Province until 2020. Compared with 2000, rural residential energy demand will reduce approximately 25% in 2020, because of the decrease of rural population per household, while the urban residential energy demand will grow about 2.5 times in 2020, because of the increased urban population and rising standard of living. At the same time, compared with 2000, CO₂ emissions resulting from rural residential energy consumption will grow approximately 10% in 2020. The basic reason for this is the increase of electricity consumption by rural residents. CO₂ emissions from urban residential energy consumption will grow about three times in 2020.

Keywords: China; Jilin Province; residential energy; environmental load; prediction model

1. Introduction
Energy consumption is the main cause of the environmental pollution arising from human activities. This is especially the case for atmospheric pollution, where the negative effects of energy consumption become more and more obvious. Development of human society and the economy increase the need for energy. However, energy consumption causes environmental pollution, while shortage of energy can also restrict socioeconomic development. In order to realize a strategy for sustainable development, we must take into account the environmental effects arising from energy consumption, and establish a proper system for socio-economic development which is environmentally-friendly and resource-economical. Asia, especially China is in the process of rapid industrialization. As the second highest in the world, next only to the United States, energy consumption in China is huge and leads to serious environmental pollution9). As the first step in decreasing energy consumption and protecting the environment, this research tries to investigate and analyze the current condition of residential energy consumption in urban (relating to or concerned with a city or densely populated area) and rural (relating to the countryside rather than the town) areas in Jilin Province. We then established a model of residential energy demand to predict residential energy demands by demand types and environmental load of Jilin Province, China until 2020.

2. Prediction Model of Energy Demand
In order to establish a prediction model of urban and rural residential energy consumption of Jilin Province, China, two aspects have been considered. The first is the possibility of data collection in China; the other is how to consider energy consumption in relation to economic increase, levels of living standard and technological development. To ensure the validity of the variable factors which affect the prediction model, the data for analysis is based on the careful examination of interrelated data published in a currently available statistical yearbook²).

Fig.1. demonstrates the analytical flow of energy demand of models for urban and rural residential houses in Jilin Province, China. Firstly, the energy demand per household by housing (demand) type has been estimated, and then multiplied by the number of households. According to an estimation of the environmental load, CO₂ emission from residential energy consumption can be predicted. The types of household use are divided into electricity, gas, coal, gasoline and heating. The model for predicting energy
demand for each fuel is as follows.

2.1 Electricity

Fig. 2. shows an analytical flow of urban residential electricity demand. In order to estimate the amount of electricity demand per household in an urban area, multiple regression analysis (Table 1.) was used to analyze its influence factor and then to formulate a model for predicting such demand by the number of electric appliances per household and overall consumer price index for urban residents.

Fig. 3. indicates the analytical flow of rural residential electricity demand, which has a higher relation with the number of electric appliances per household based on the multiple regression analysis.

The results of multiple regression analysis show a higher correlation in both areas. Details are shown in Note 1 at the end of the paper.

2.2 Gas

Fig. 4. shows the analytical flow of urban residential gas demand. The same method adopted for electricity has been used. Through the multiple regression analysis, we select the amount of electric cooking per household and the rate of urban residential gasified rate to predict gas demand. Urban residential gas demand can be calculated based on demand per household and the number of households, and then, according to the component of the gas, the demand for coal gas, natural gas and LPG can be calculated. The gas component is predicted from the urban gas supply connection rate.

Fig. 5. indicates the analytical flow of rural residential LPG demand. The result of multiple regression analysis has shown a higher correlation between the overall consumer price index of rural residents LPG consumption per household (Note 1).

2.3 Gasoline

The same analytical flow has been used to predict the urban and rural residential gasoline demand shown in Fig. 6. The result of multiple regression analysis has demonstrated a higher correlation with the number of automobiles and gasoline demand per household, as shown in Note 1.

2.4 Coal

Fig. 7. suggests the analytical flow of urban residential coal demand. To estimate the amount of coal demand per household, multiple regression analysis was used to analyze its influencing factor. From the results, we selected the number of households, the rate of increase of space heating area and the overall
consumer price index of urban residents to predict the coal demand.

Fig. 8. indicates analytical flow of rural residential coal demand. In this case, we selected the number of households and overall consumer price index of rural residents to estimate the amount of coal demand per household by multiple regression analysis.

### 2.5 Heating

The heating area is decided by the total number of urban households, popularization rate of district heating and per household living space. The consumption of urban households can be ascertained by multiplying heating area with the energy demand per floor space for district heating (Fig. 9.). Parameters, such as the popularization rate of district heating and per household heating space, can be obtained by using Table 1. From this table, we can predict heating consumption for future scenarios.

Table 1. Adjustment of Future Scenario Concerning External Variables and Estimate

| Urban and Rural | Total population | Calculated by assuming the same in Beijing | Prediction Formulas | Correlation Coefficient |
|-----------------|------------------|-------------------------------------------|--------------------|-------------------------|
| Urban population/Total population | Estimated by hyperbolic logarithm curve based on the 1996～2002 data | $1310.89\ln(Year) - 9914.68$ | 0.95 |
| GRP | Calculated by assuming the same in Beijing | | |
| No. of persons per household | Estimated by hyperbolic logarithm curve based on the 1996～2002 data | $-54.64\ln(Year) + 418.32$ | 0.71 |
| Overall consumer price index of urban residents | The average value of the 1996～2002 data | 470.13 | |
| No. of electric appliances per household | Estimated by the regression analysis with respect to GRP | $155.78\ln(GRP) - 929.64$ | 0.99 |
| No. of electric cooking per household | The average value of the 1996～2002 data | 125.63 | |
| Residential gasified rate | Estimated by the regression analysis with respect to GRP | $17.82\ln(GRP) - 106.10$ | 0.93 |
| Coal gas/Gas | The average value of the 1996～2002 data | 21.19% | |
| Natural gas/Gas | Estimated by hyperbolic logarithm curve based on the 1996～2002 data | $3015.78\ln(Year) - 22907.20$ | 0.87 |
| LPG/Gas | 100-coal gas/gas-natural gas/gas (%) | | |
| No. of automobiles per household | Estimated by the regression analysis with respect to GRP | $21.89\ln(GRP) - 169.29$ | 0.96 |
| Popularity rate of district heating | Estimated by the regression analysis with respect to GRP | $57.60/(1+324.06\exp(-0.0024GRP))$ | 0.87 |
| Per household living space | Estimated by the regression analysis with respect to GRP | $7.70\ln(GRP) - 38.53$ | 0.96 |

| Rural | Total population/Total population (%) | Calculated by assuming the same in Beijing | | |
|-----------------|------------------|-------------------------------------------|| | |
| Urban population/Total population | Estimated by hyperbolic logarithm curve based on the 1996～2002 data | $-66.40\ln(Year) + 508.57$ | 0.94 |
| GRP | Calculated by assuming the same in Beijing | | |
| No. of persons per household | Estimated by hyperbolic logarithm curve based on the 1996～2002 data | $16.13\ln(GRP) + 225.84$ | 0.99 |
| Overall consumer price index of rural residents | Estimated by hyperbolic logarithm curve based on the 1996～2002 data | $159.87\ln(GRP) - 1159.09$ | 0.98 |
| No. of electric appliances per household | Estimated by the regression analysis with respect to GRP | $44.26\ln(GRP) - 337.48$ | 0.99 |
3. Setting of Influence Factors

The influence factors for future scenario can be calculated in Table 1. The ratio of urban population, total population and number of persons per household is based upon the referenced data from 1996 to 2002. Total population and GRP are calculated by assuming the same values in Jilin as those for Beijing. The overall consumer price index of urban residents and the utilization of electric cooking per household refer to average values for the period 1996~2002. Higher correlation coefficients are shown for each factor in Table 1.

4. Prediction of Energy Demand and CO$_2$ Emission

According to the developed models, residential energy demand has been predicted by demand types and environmental load in Jilin Province, China until 2020. (For energy and CO$_2$ conversion rates refer to Notes 2-3)

Fig.10. shows the results of urban residential household energy consumption by fuel type in the future. It is clear that, while the use of coal is declining year by year, the amount of electricity and heating energy is increasing significantly. Compared with the year 2000, urban residential energy demand will grow
about 2.5 times in 2020. The primary reason is the increase of urban population and change of life style.

Fig.11. shows future rural residential household energy consumption by fuel type. Compared with 2000, rural residential energy demand will reduce by approximately 25% in 2020. The main reason is the decrease of rural population per household and the total number of households. Compared with urban residential energy demand, the change of rural residential energy consumption is relatively small.

Figs.12. and 13. respectively show the results of CO$_2$ emissions due to both urban and rural household energy consumption in the residential sector by fuel type. Compared with 2000, CO$_2$ emissions from rural residential energy consumption will grow approximately 10% in 2020. The primary reason is through an increase in rural residential electricity consumption. CO$_2$ emission from urban residential energy consumption will grow about three times in 2020, the primary reason being an increase in urban residential energy consumption.

Figs.14. and 15. respectively show the results of residential energy consumption per household and CO$_2$ emission per household. Rural residential sector energy consumption per household and its CO$_2$ emission is increasing greatly. Compared with 2000, urban residential sector energy consumption per household will increase by approximately 40%, while CO$_2$ emission from urban residential energy consumption per household will increase by approximately 65%, in 2020.

5. Conclusions

In this research, we investigated and analyzed the current condition of urban and rural residential energy consumption in Jilin Province, China and presented a method to predict the residential energy demand. By using the predicted model, we estimated the energy demand by fuel type and calculated its environmental load in Jilin Province, China until 2020. The main conclusions are as follows.

1) Compared with 2000, rural residential energy demand will reduce by approximately 25% in 2020. The primary reason is the decrease of rural population per household and the total number of households, while urban residential energy demand will grow about 2.5 times in 2020. The primary reason is an increase in the urban population and living standards.

2) At the same time, compared with 2000, CO$_2$ emissions from rural residential energy consumption will grow approximately 10% in 2020, the primary reason being an increase of rural residential electricity consumption. CO$_2$ emissions from urban residential energy consumption will grow about three times in 2020, the primary reason being an increase in urban residential energy consumption.

3) Residential energy consumption per rural household and its CO$_2$ emission are both decreasing a little, while that of the urban household and its CO$_2$ emission are both increasing greatly. Compared with 2000, urban residential energy consumption per household will increase by approximately 40%, while CO$_2$ emission from urban residential energy consumption per household will increase by approximately 65%, in 2020.

For future research, we need to establish a validation for the prediction model together with a field study. In addition, effects due to the rate of immigration from rural to urban areas should be analyzed. Meanwhile, the effects of energy saving policy and the consciousness of people regarding energy consumption should be analyzed.

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References

1) Toru Matsumoto, Jian Zuo, Xindong Wei Residential Energy Demand and CO$_2$ Emission in Asian Mega-cities: Estimation
Note 1. Multiple Regression Analysis Results

| Objective variable                  | Effective factors                              | Relevant coefficient | Relevant coefficient of effective factors | Inclined regression coefficient | Constant |
|-------------------------------------|------------------------------------------------|----------------------|------------------------------------------|--------------------------------|-----------|
| Urban                              | No. of electric appliances per household        | 0.96                 | 0.57                                     | 0.55                           | -0.7348   |
|                                    | Overall consumer price index of urban residents |                      |                                          | 0.0014                         |           |
| Gas demand per household           | No. of electric cooking per household           | 0.77                 | 0.12                                     | 0.0002                         | 0.0106    |
|                                    | Urban residential gasified rate                |                      |                                          | 0.0013                         |           |
| Gasoline demand per household      | No. of automobiles per household               | 0.99                 |                                          | 0.0001                         | 0.0043    |
| Coal demand per household          | No. of households                              | 0.94                 | 0.09,0.38,0.55                           | 0.2087                         | -2.1562   |
|                                    | Popularization rate of district heating         |                      |                                          | -0.0023                        |           |
|                                    | Overall consumer price index of urban residents |                      |                                          | 0.004                          |           |
| Rural                              | No. of electric appliances per household        | 0.76                 |                                          | 0.0001                         | 0.0494    |
| Gas demand per household (LPG)     | Overall consumer price index of rural residents | 0.85                 |                                          | 0.0001                         | -0.0415   |
| Gasoline demand per household      | No. of automobiles per household               | 0.88                 |                                          | 0.0001                         | -0.0005   |
| Coal demand per household          | No. of households                              | 0.89                 | 0.08                                     | 0.123                          | -0.3121   |
|                                    | Overall consumer price index of urban residents |                      |                                          |                                |           |

Note 2. Energy Conversion Rates

| 1 kWh  | 1 t Raw Coal | 1 t Coal Products | 1 t Coal Gas | 1 t Gasoline | 10⁶ m³ Natural Gas | 1 t Gasoline | 1 t Heating |
|--------|--------------|--------------------|--------------|--------------|--------------------|--------------|-------------|
| 0.0001 | 0.7143       | 0.7143             | 5.3229       | 1.7143       | 1.3300             | 1.4286       | 3.416-08 |

Note 3. CO₂ Gas Conversion Rates (tCO₂/TCEs)

| Energy Type | Electric | Coal | Gasoline | Coal Gas | LPG | Natural Gas | Heating |
|-------------|----------|------|----------|----------|-----|-------------|---------|
|             | 6.4810   | 1.8467 | 1.9745   | 1.5035   | 1.7174 | 1.4947      | 2.9065  |

412 JAABE vol.5 no.2 November 2006 Xindong Wei