Simulation Model of Electricity Demand Forecasting from End-user Based on LEAP

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Abstract. Under the background of China's power system reform, the electric power enterprise is required to upgrade its service and optimize the allocation of resources based on the electricity demand. Market competition requires electric power enterprises to pay more attention to the demand side, and predict the electricity demand, in order to provide timely feedback to the system. The electricity consumption of households is mainly predicted by household appliances. The electricity consumption of industrial, agricultural, and transportation industries is mainly predicted by the output and mileage of operation. This article uses LEAP (Low Emissions Analysis Platform) to set up a model to simulate the electricity demand in Beijing. This research can provide the significant support for improving the intelligent service of electric power enterprises, and provide a new perspective for electricity demand forecasting.

Keywords: Simulation; Electricity demand; LEAP; Forecasting.

1. Introduction
Electric power enterprises are required to upgrade their services and optimize the allocation of resources in China's power system reform. Thus, electricity demand is essential on the base of end-users. Some methodologies have been investigated regarding electricity demand. Hondroyiannis, G analyzes the Greek residential electricity demand based on multivariate and vector error-correction model[1]. Dilaver, Z. et al investigate Turkey’s industrial electricity consumption by using the structural time series technique [2]. Mori, H. et al apply data mining to electricity forecasting [3]. Kucukali, S et al research Turkey’s electricity demand based on fuzzy logic model [4]. LEAP model makes forecasting work more focus on the macro-economy, population, and social development. Bottom-up model realizes simulating the electricity demand from the end user. By energy efficiency indicators, it can clearly reflect the impact of increased technology level and technology diffusion on electricity demand. This article aims to build a bottom-up model to simulate the electricity demand forecasting. This paper will illustrate the demand module of LEAP model and Beijing as the study region. Firstly, main electrical appliances data and power use situation are collected and analyzed. Secondly, the technology diffusion of electrical appliances are analyzed and forecasted. Finally, electricity demands are obtained according to the electricity consumption of demand side and macroeconomic index. Electricity demands simulated from end-user is designed to provide a new perspective of energy demand forecast.

2. Model Structure Based on LEAP
Electricity demand is affected by many factors [5]. This article assumes that Beijing's electricity demand is mainly composed of agriculture in the primary industry, industry and construction in the
secondary industry, tertiary industry and household electricity consumption. The model structure is shown in Figure 1.

3. Equations and Mathematics
The calculation of electricity demand in household and three industries are investigated in this section. Growth rates of population, household appliances, GDP, production will be considered in the process of calculation. They can be represented as sustainability factors.

3.1. Electricity Demand in Household
Some selected household appliances will give examples of electricity demand calculation.

3.1.1. Air Conditioner.

\[ ECac = (NUhouse \times PUac + NRhouse \times PRac) \times ELac \]  

Where: \( ECac \) is annual electricity consumption of air conditioners (kWh) in urban and rural. \( NUhouse \) and \( NRhouse \) are urban and rural households (100 households). \( PUac \) and \( PRac \) are urban and rural households with airconditioner ownership (units/hundred household). \( ELac \) is Annual power consumption per air conditioner (Kwh/unit).

Electricity demands of refrigerators, washing machine and television can be calculated in the same method as well.

3.1.2. Lighting.

\[ EClight = \sum_{T} Npop \times (SUpop \times PCHu + SRpop \times PChr) \times Ltime \times Slight \times \frac{LB}{EF_{T}} \]
Where: $EC_{light}$ is the total electricity consumption of household lighting (kWh). $N_{pop}$ is the population of Beijing (100 million). $SU_{pop}$ and $SR_{pop}$ are the proportion of urban and rural population. $PCHu$ and $PChr$ are urban and rural. $Lt_{ime}$ is the annual lighting time (hours/year). $Sl_{ightT}$ is the proportion of the T-type lamps. $LR$ is the luminous flux per unit area (Lm/m²), and $EFT$ is the luminous efficiency of the T-type lamps (Lm/W).

### 3.2. Technology Diffusion of Household Appliances

The number of household appliances can be defined as the technology diffusion. Technology diffusions of refrigerators, washing machines, and televisions are calculated by the following equation[6].

$$\alpha$$

$$(\ln D_{\text{iff}} - 1) = \ln \gamma + \beta_{\text{dec}}\, I + \beta_{\text{elec}}\, E + \beta_{\text{urb}}\, U + \varepsilon$$

Where: $D_{\text{iff}}$ is the diffusion of the appliance for the country $c$. $\alpha$ is the saturation level. $I$ is the household income given by GDP divided by the number of households in the country. $U$ is the urbanization rate. $E$ is the electrification rate, and $\varepsilon$ is the error term.

The technology diffusion calculation of household computer, laptop, DVD and other household appliances is as follows.

$$P_{pc} \left( \text{unit / 100 household} \right) = CF_p \ast f_1 \ast e^{\left(-f_2 \ast e^{\left(-f_3 \ast \text{Income delay} \right)} \right)}$$

Where: $f_1=1.5$, $f_2=3$, $f_3=0.212$, $Y$ is the household per-capita income, $\text{Income delay}=700$. $CF_p$ is the correction factor, which are both 1.03 in urban and rural household.

The usage of air conditioner is closely related to air temperature. Therefore, the technology diffusion of air conditioner is closely related to the Cooling Degree Days (CDD). CDD is the cumulative number of daily average temperatures above a certain base temperature. The equation is as follows.

$$CDD_i = T_i - T_b$$

Where: $CDD_i$ is the daily value of cooling degree on day $i$. $T_i$ is the average temperature on day $i$, and $T_b$ is the base temperature. Add up the daily cooling degree day values of a year, then we can get CDD of that year. The base temperature $T_b$ of air conditioner cooling in summer is set to 26°C, and $CDD_{26}$ is used to reflect the hot degree in summer.

The correction method[6] is defined in equation 7 and 8.

$$Climate_{Maximum} = 1.0 - 0.949 \ast e^{(0.00187 \ast CDD)}$$

$$Diff = A(I) \times Climate_{Maximum}(CDD_{c})$$

$$A(I) = \frac{1}{1 + e^{4.152 \ast e^{(-0.2377 \ast I / 1000)}}}$$

Where: $A(I)$ is the affordability of each household’s air conditioner. $I$ is the average household income per year. CDD is cooling days.

### 3.3. Electricity Demand in Industry and Agriculture Industry

The electricity demand of industrial sub-sectors is calculated according to the following formula.

$$EC_{ind} = PROD_p \ast IEC_p$$
Where: $EC_{ind}$ is the annual industry’s electricity consumption (kWh), $PROD_p$ is the industry's annual production(ton), and $IEC$ is the unit electricity consumption (kWh/ton) of the product. The annual sector output in future years is calculated by elasticity coefficient method:

$$PROD_{p,t+1} = PROD_p \times (1 + GDPgrowth_t \times \varepsilon_p)$$  

(11)

Where: $PROD_p$ is the annual production(ton), and $GDPgrowth_t$ is the growth of industry value added in year $t$ (%), $\varepsilon_p$ is the production elasticity of product $p$.

Electricity demands of agriculture industry can be calculated in the same method as well. Electricity consumptions per unit of industry is in Table 1.

**Table 1. Electricity consumptions per unit of industry.**

| Product Type               | Electricity Consumption per Output (kWh/ton) | Elasticity | Note                             |
|----------------------------|---------------------------------------------|------------|-----------------------------------|
| Coal (10000 tons)          | 14.3 kWh/ton                                | -0.12      |                                  |
| Crude petroleum oil (10000 tons) | 83.4 kWh/ton                                | 0.17       |                                  |
| Ethylene (10000 tons)      | 138 kWh/ton                                 | 0.36       |                                  |
| Crude steel (10000 tons)   | 400 kWh/ton for Basic Oxygen Furnace         | 0.21       | Electric Arc Furnace accounts for 9.8% |
|                            | 730 kWh/ton for Electric Arc Furnace         |            |                                  |
| Rolled Steel (10000 tons)  | 140-150 kWh/ton for High speed wire rod      | 0.23       | Average 110 kWh/ton              |
|                            |                                             |            |                                  |
| Cement (10000 tons)        | 120 kWh/ton                                 | 0.40       |                                  |
| Machine-made Paper and Paperboard (10000 tons) | 1400 kWh/ton                                | -0.05      |                                  |
| Cloth (10000 m)            | 1200 kWh/ton                                | -1.01      |                                  |
| Alcoholic Drink (Million kiloliter) | 1.24 kWh/l                                  | 0.81       |                                  |
| Milk (10000 ton)           | 500 kWh/ton                                 | 1.79       |                                  |

Note: Data resources of electricity consumptions per unit of industry products. Crude steel, cement and ethylene[7]. Cement and crude steel[8]. Coal[9], crude petroleum oil[10], refined oil[11], machined-made paper[7][12][13][14], meat[15], cloth[16], textile[17].

### 3.4. Service and Transportation

**3.4.1. Service Industry.** Service industry includes wholesale and retail, hotels and restaurants, business, education and research, health and social welfare services, sport and entertainment, and street lighting. The calculation of electricity of service industry is as follows.

$$EC_{ser} = VAD_{ser} \times SEC_{ser}$$  

(12)

Where: $EC_{ser}$ is the annual service's electricity consumption (kWh), $VAD_{con}$ is the annual value added of service. $SEC_{ser}$ is the service’s electricity consumption of per value added (kWh/dollar).

**3.4.2. Transportation Industry.** At present, the transportation using electric power energy is public passenger transportation in Beijing transportation structure. Main public transportations are trolleybuses and subways. The calculation of electricity demand in transportation industry is as follows.

$$EC_{pt} = LT_{veh} \times INT_{veh} + LT_{sub} \times INT_{sub}$$  

(13)
Where: \( EC_{pt} \) is the annual electricity demand of public transport in Beijing (kWh), \( LT_{veh} \) is the operating length of the trolley bus in Beijing (km), and \( INT_{veh} \) is the electricity consumption (kWh / km) per mileage of trolley bus. \( LT_{sub} \) is operating length of rail transit (km), \( INT_{sub} \) is the subway electricity consumption (kWh / km) per mileage.

In the future, the length calculation of public transport lines will also be used in elasticity coefficient method.

\[
LT_{veh_t} = LT_{veh_{t-1}} \times (1 + Te GDP growth_t \times \epsilon_{veh})
\]

(14)

\[
LT_{sub_t} = LT_{sub_{t-1}} \times (1 + Te GDP growth_t \times \epsilon_{sub})
\]

(15)

Where: \( LT_{veh} \) and \( LT_{sub} \) are the transportation line length of trolley bus and subway in year \( t \). \( Te GDP growth \) is the growth rate of the value added in tertiary industry. \( \epsilon_{veh} \) and \( \epsilon_{sub} \) are the elasticity coefficient of the length of trolley bus and subway transportation line to the value added in tertiary industry.

4. Conclusions

Household electricity demands contribute a great share of total electricity demands. In particular, as the frequency of water heaters and air conditioners use in households increases gradually, the share of electricity demand of household sector will also show upward trend.

Electricity demand of the construction is on the rise, and the growth rate of electricity demand is larger, mainly because the change of industrial structure leads to the growth trend of the construction’s value-added proportion in the secondary industry. In addition, with the progress of technology, secondary energy input in the construction industry has increased, thus the demand for electricity in the construction industry is on the rise.

The proportion of electricity demand in the tertiary industry shows growth trend. Because industrialization is the dominant force of urbanization. With the acceleration of urbanization, the workforce will transfer from the primary industry to the secondary and tertiary industries. In the meanwhile, the development of tertiary industry will further promote urbanization.

This paper provides a new perspective of electricity or energy demand forecasting. LEAP model performs well in energy forecasting and has the practical value. The model can be used as a basic energy demand forecasting model, which will meet the requirement of actual energy forecasting research.

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