Journal of Applied Science and Engineering Innovation, Vol.6, No.3, 2019, pp. 143-146
ISSN (Print): 2331-9062
ISSN (Online): 2331-9070

Research on Power Demand Forecast and Energy-saving Technology Impact in Hebei Province Based on System Dynamics

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Abstract: As the main energy supply, electricity interweaves with economy, policy, environment, industry and policy to form a complex system. Based on the analysis of the factors affecting power demand, this paper proposes a system dynamics power demand forecasting model including the first, second and third industries and household electricity consumption. The least square algorithm optimized by Drosophila is used to determine the weight of the factors. In this paper, the validity of the model is validated by the data of Hebei Province from 2002 to 2018. The electricity consumption from 2019 to 2030 is forecasted and the policy analysis of energy-saving technical variables is carried out.

Keywords System dynamics , Electricity consumption, Demand forecasting.

INTRODUCTION

Predicting electricity demand reasonably is an important basis to ensure the rationality of power grid planning and industrial development (Dong, *et. al.* 2012). The theoretical study of electricity demand forecasting began in the mid-20th century, and then introduced mathematical methods such as econometric models. (Amini, *et. al.* 2016) adjusted the parameters of ARIMA model. (Boroojeni, *et. al.* 2016) used autoregressive (AR) and moving average (MA) components to model. In recent years, modern forecasting technology based on emerging theory has begun to develop. (Wei, *et. al.* 2019) proposed an improved ELM model based on GA. (Miranda, *et. al.* 2018) developed an artificial neural network and fuzzy logic for load forecasting. System dynamics model had the characteristics of non-linearity, high order and multi-variable, which provides a more systematic and dynamic solution for medium- and long-term load forecasting, and a clearer causal feedback relationship (Wei, *et. al.* 2000). Based on system dynamics, a long-term electricity demand forecasting model suitable for the normal state of the new economy is proposed (He, *et. al.* 2017). (Liu 2016) constructed a system dynamics model for electricity demand forecasting in Guangdong Province. (Yu 2015) used system dynamics to analyze social electricity demand. (Yan, *et. al.* 2018) predicted the electricity consumption in Guangdong from 2016 to 2020 under different scenarios using system dynamics model. The advantages of development planning are gradually emerging, but the application of this method in medium and long-term power demand forecasting is not much at present. In this paper, the power demand of Hebei Province is systematically analyzed by using system dynamics. Considering the main factors affecting the power demand, a system dynamics model of power demand forecasting is established, which is used to forecast the power demand of Hebei Province and to guide the government to formulate relevant policies.

ANALYSIS OF INFLUENCING FACTORS OF ELECTRIC POWER DEMAND

The influencing factors of power demand in Hebei Province mainly include the following aspects.

Economic factors. It mainly includes the level of regional economic development, industrial unit consumption, product price, urbanization process, income of residence, consumption level and so on.

Electric structure. The electricity consumption structure includes the first, second and third industries and the domestic electricity consumption of urban and rural residents.

Energy consumption. Optimizing the energy structure will inevitably lead to the consumption of electric energy.

Technological innovation. Vigorously develop energy-saving technology to improve the efficiency of power transmission.

Policy orientation. The price of electricity affects the regional distribution of high-power consumption industry and the level of industrial and agricultural electricity consumption in varying degrees.

Natural factors. Electric load varies with season and day and night fluctuations.

MODEL CONSTRUCTION

Based on the statistical yearbook of Hebei Province and the historical data of power industry, the dynamic flow chart of power demand in Hebei Province is established by Vensim PLE software. On the basis of subjective and objective weights obtained by sequential relation method and Gini coefficient weighting method, the weights of influencing factors are obtained by Drosophila optimal least squares algorithm (Table 1). This study used the data particle swarm optimization (DPSO) neural network algorithm to predict the data of each influencing factor from 2019 to 2030 and then, all influencing factors are normalized.

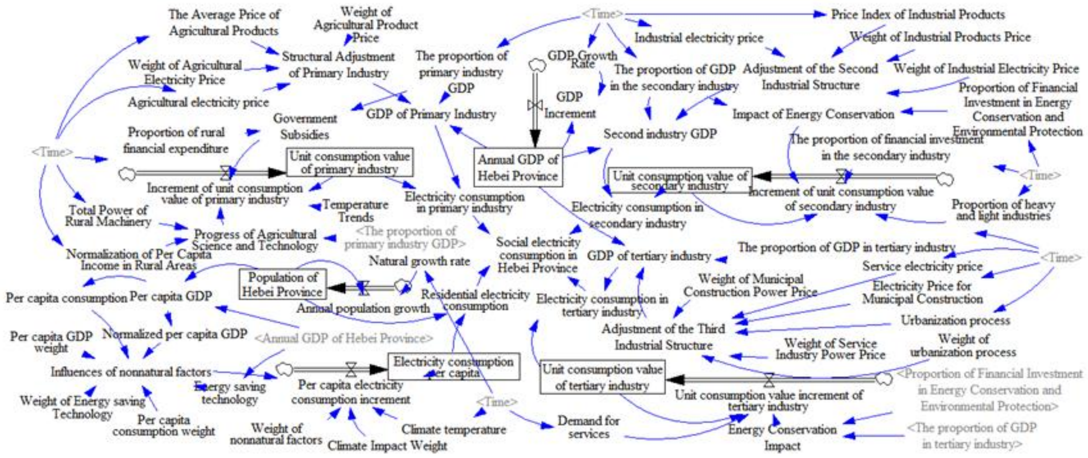

Fig. 1. Flow chart of power demand dynamics in Hebei Province.

Figure 1 shows the flow chart of power demand dynamics in Hebei Province.

Table 1. Weight of influence factor.

Classification	Influence factor	Weight
Primary industry	Agricultural electricity price	0.243
	Agricultural Products Price Impact	0.757
	Government Subsidies Degree	0.358
	Temperature Trends	0.289
	Agricultural Technology Progress	0.353
	Rural Per capita income	0.211
	Agricultural Machinery Power	0.359
	Primary Industry GDP	0.43
Secondary industry	Industrial electricity price	0.425
	Industrial Products Price Index	0.575
	Energy Conservation Impact	0.479
	Investment in Secondary Industry	0.521
Tertiary industry	Service electricity price	0.219
	Municipal Electricity Price	0.087
	Urbanization Process	0.694
	Energy Conservation Impact	0.381
	Service Industry Demand	0.619
Resident Life	Per capita consumption	0.258
	Energy saving technology	0.105
	Per capita GDP	0.637
	non-natural factors Impact	0.583
	Climate temperature	0.417

The functional relationship of electricity consumption in the primary industry is as follows.

$$W_1=GDP_1\times P_1 \quad (1)$$

$$GDP_1=GDP_S\times\omega_{GDP1}+STEP(GDP_S\times\omega_{GDP1}\times SA_1) \quad (2)$$

$$\Delta P_1=P_1\times(S+C-AS) \quad (3)$$

$$SA_{1=}(-AG\times\omega_{AG}+AP\times\omega_{AP}) \quad (4)$$

In the above formulas, W_1 is the primary industry electricity consumption, the unit is 100 million kWh. GDP_1 is the primary industry GDP,100 million yuan. P_1 is the unit consumption of the primary industry, kWh/yuan. GDP_S is Hebei Province's annual GDP,100 million yuan. ω_{GDP1} is the proportion of primary industry output value. SA_1 is the first industrial restructuring; P_1 is the increment of unit consumption value of primary industry, kWh/yuan; C is the trend of temperature; S is the government's subsidy coefficient for agriculture; AS is the coefficient of progress in agricultural science and technology; AG is agricultural electricity price, yuan/kWh.ω_{AG} is the weight of agricultural electricity price. AP is the average price of agricultural products. ω_{AP} is the weight of average price of agricultural products.

The functional relationship of electricity consumption in the secondary industry is as follows.

$$W_2=GDP_2\times P_2 \quad (5)$$

$$GDP_2=GDP_S\times\omega_{GDP2}+STEP(GDP_S\times\omega_{GDP2}\times SA_2) \quad (6)$$

$$\Delta P_2=P_2\times(I_2\times\omega_{I2}-ES) \quad (7)$$

$$SA_{2=}(-g\times\omega_g+P_2\times\omega_{P2}) \quad (8)$$

In the above formulas, W_2 is the power consumption of the second industry, 100 million kWh. GDP_2 is the GDP of the second industry, 100 million yuan. P_2 is the unit consumption of the second industry, kWh/yuan. ω_{GDP2} is the proportion of second industry output value.SA_2 is the adjustment of the second industrial structure. ΔP_2 is the increment of the unit consumption of the second industry, kWh/yuan. *ES* is the energy-saving impact coefficient. g is the industrial electricity price, yuan/kWh. ω_g is the weight of industrial electricity price. I_2 is the influence coefficient of government on the input of secondary industry. ω_{I2} is the proportion of light industry. P_2 and ω_{P2} are the influence and weight of the price of secondary industry products.

The functional relationship of electricity consumption in the tertiary industry is as follows.

$$W_3=GDP_3\times P_3 \quad (9)$$

$$GDP_3=GDP_S\times\omega_{GDP3}+STEP(GDP_S\times\omega_{GDP3}\times SA_3) \quad (10)$$

$$\Delta P_3=P_3\times(SN-E_3) \quad (11)$$

$$SA_3=(U\times\omega_U-CE\times\omega_{CE}-SE\times\omega_{SE}) \quad (12)$$

In the above formulas, W_3 is the electricity consumption of the tertiary industry, 100 million kWh. GDP_3 is the tertiary industry GDP, 100 million yuan. P_3 is the unit consumption of the tertiary industry, kWh/yuan. ω_{GDP3} is the proportion of tertiary industry output value. P_3 is the unit consumption increment of the tertiary industry, kWh/yuan. SA_3 is the adjustment of the tertiary industry. *SN* is the social demand coefficient of the service industry. E_3 is the social demand factor. *U* and ω_U are the process of urbanization and its impact weight. *CE* is the municipal construction price, yuan/kWh. ω_{CE} is the impact weight of municipal construction price. SE is the service price, yuan/kWh. ω_{SE} is the impact weight of service price.

The function of resident power consumption is as follows.

$$W_H=Q_H\times P_{HV} \quad (13)$$

$$GDP_{HV}=GDP_S/Q_H \quad (14)$$

$$\Delta H=H_S\times R \quad (15)$$

$$\Delta P_{HV}=P_{HV}\times(CT\times\omega_{CT}+N\times\omega_N) \quad (16)$$

$$N=(GDP_{HV}\times\omega_{GDPHV}+EX\times\omega_{EX}-ET\times\omega_{ET})/(\omega_{GDPHV}+\omega_{EX}+\omega_{ET}) \quad (17)$$

In the above formulas, W_H is the residential electricity consumption, kWh. Q_H is the population of Hebei Province, 10,000 people. P_{HV} is the per capita electricity consumption, kWh/person. GDP_{HV} is the per capita GDP, yuan; ω_{GDPHV} is the weight of per capita GDP. ΔH is the annual population growth, H_S is the population of Hebei Province, 10,000 people. R is the natural population growth rate. ΔP_{HV} is the increment of electricity consumption per capita, kWh. N and ω_N are non-natural factors and influence weights. *CT* and ω_{CT} are climate temperature and influence weight. *EX* is per capita consumption, yuan. ω_{EX} is per capita consumption weight. ET and ω_{ET} are energy-saving technologies and its weight.

Figure 1 shows the flow chart of power demand dynamics in Hebei Province.

ANALYSIS OF RESULTS

After completing the model construction, the simulation values of 2000-2030 are obtained. The comparison between simulated and real values from 2000 to 2018 (see figure 2) shows that the error is less than 7% which proves the validity of the model.

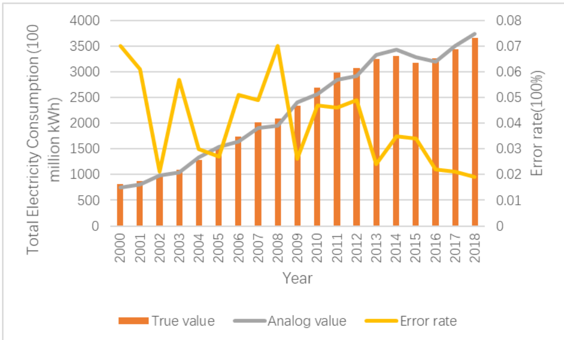

Fig. 2. Simulated and Real Values of Total Social Electricity Consumption from 2000 to 2018.

In 2008, the model forecast error is the highest, which may be affected by the economic crisis of that year. The error in 2013-2018 is less than 4% and has a downward trend, which is related to the stable development of society and economy in Hebei Province.

The electricity consumption forecast data for 2019-2030 are shown in Figure 3.

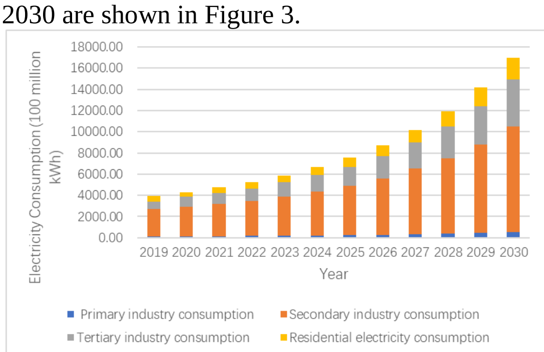

Fig. 3. Forecast Data of Electricity Consumption in Hebei Province from 2019 to 2030.

It is predicted that the electricity consumption in Hebei Province will increase steadily from 2019 to 2030, which is in line with the power planning which asks overall planning of power supply, construction of transmission channel and market absorption, promotion the coordinated development of network source, load and storage. Among them, the steady improvement of primary industry electricity consumption, to a certain extent, illustrates the improvement of agricultural mechanization level in the future. The proportion of electricity consumption in the secondary industry has steadily declined, and the power consumption in the tertiary industry has increased rapidly, which reflects the efforts made by Hebei Province in the transformation of industrial structure.

POLICY ANALYSIS

The "energy-saving technology" variable under residential electricity consumption is selected to analyze its impact on the power demand of Hebei Province. Scenario division is realized by changing the value of "energy-saving technology". The original value of energy-saving technology, 50% of energy-saving technology and 200% of energy-saving technology correspond to the three scenarios of M, L and H respectively. The operation results of the three scenarios are shown in Figure 4.

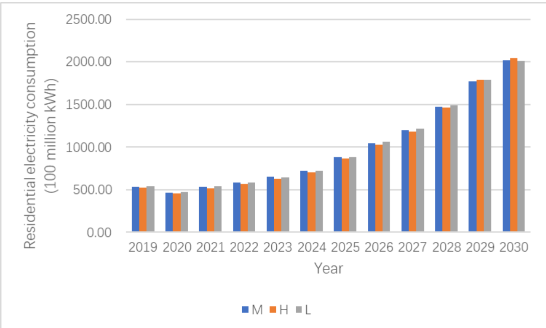

Fig. 4. Residential electricity consumption under different energy-saving technologies.

Fig. 4 shows that the impact of energy-saving technology on the reduction of residential electricity consumption is becoming less during 2019-2030. The reason may be that the improvement of energy-saving technology has promoted the popularization of household appliances, and the overall electricity consumption of residents is still growing.

CONCLUSIONS

Based on system dynamics, the first, second and third industries and residential power consumption systems in Hebei Province are established respectively. The forecasting results show that the model is applicable. Based on the total social electricity consumption in Hebei Province from 2019 to 2030, this paper studies the impact of energy-saving technology changes on the residential electricity consumption in Hebei Province. The results show that energy-saving technology has a certain potential for slowing down the growth of electricity consumption.

ACKNOWLEDGEMENTS

This work was supported by the Science and Technology Project of the State Grid Corporation of China (Project Name: Research on the Comprehensive Evaluation Method of Economic, Social and Environmental Benefits of Transnational Networking Projects).

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