Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 13 (21): 4732-4737, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.4732.4737

Pre-integrated Forecasting Method Research of Urban Electricity Consumption Based on System Dynamics and Econometric Model

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Abstract: Urban economic development and its electricity consumption have interactions with each other. Moreover, the currently existing urban electricity demand forecasting methods cannot accurately predict urban electricity based on economic development. For this complex system of urban economic development forecasting and its electricity demand, System Dynamics (SD) has the characteristics of comprehensive and dynamic, while econometrics is adept in seeking the intrinsic link among a lot of data. Thus, these two methods are applied to comprehensively forecast urban power consumption. A case study is taken based on actual data from Shandong Province and the results shows that Gross Domestic Product (GDP) will raise, but it will experience steady decline after brief rise in GDP growth. Moreover, with a lag impact from economic development, power consumption during the same period will be rising, providing endless power for economic development and will remain steady at about 680 billion kWh. This case study verifies the accuracy and scientific of proposed model.

Key words: Urban electricity consumption forecasting, economic development system dynamics, econometric model

INTRODUCTION

The city's economic development has an important impact on its electricity consumption. With the city's economic development to a certain stage, restricted by the economic level, the development of urban power reveals the features accordingly. Studying the city electricity demand forecast, which base on the urban economic development, has attracted more and more attention (Li, 2009).

There are many methods for electricity consumption forecasting, mainly like neural networks, Mining Default Rules Based on Rough set (MDRBR) , artificial neural network, but it is difficult to predict urban electricity consumption accurately based on the state of economic development (Chen and Liu, 2009; Chen *et al*., 2009; Wang and Liu, 2012).

In view of this, first, urban electricity demand and economic development forecasting models are built based on System Dynamics (SD). Following that, Econometric model is applied to study he quantitative relationship between urban economic development and its power consumption for comprehensively predicting urban electricity consumption (Li, 2009). Finally, a case study is taken based on actual data from Shandong Province for verifying the accuracy and scientific of proposed model. This study uses actual data of Shandong province for case study to verify the accuracy and scientific nature of the models.

SD MODEL OF URBAN ELECTRICTIY CONSUMPTION

Overview of SD: SD is not only a feedback system used to analyze investigative information but also a cross-cutting and integral discipline to understand and resolve system problem. (Allaf and Elkhatib, 2009).

Methodology: SD model is a computer simulation model which is devoted to exploring and supervising complex feedback systems.
Steps to apply SD model are:

- Analyze the cases and identify a problem
- Develop a dynamic hypothesis to explain the cause
- Establish a basic structure of a causal graph
- Augment the causal graph with more information
- Convert the augmented causal graph to a System Dynamics flow graph
- Translate the System Dynamics flow graph into DYNAMO equations or programs

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SD model for urban electricity consumption forecasting: The model is to predict the amount of electricity consumption of three industries for the next period. The unit consumption method is adopted in this study. System dynamics tools are used to construct the three industries and residential electricity consumption forecasting models which are shown in Fig. 1-4.

Primary industry electricity consumption forecasting model: Variables involved in Fig. 1 and their meanings are as follows:

PIUC is unit consumption of the primary industry; PIUCIV means the initial value of unit consumption; PIVQUC is the variation of unit consumption of primary industry; UCIVS is data sheet of initial value of unit consumption; WPMI is the weight of improved production method; PIPMI is the improved production method; PIEE is the electricity efficiency; WPIEE means the weight of electricity efficiency; PITP is the progress of technology; WPITP is the weight of progress of technology; PIESP is energy saving policies; PIOTPYEC is the output targets per yuan in the primary industry; PIWSA is the weight of structural adjustment; PISA is the structural adjustment; PIEC is the electricity consumption; PIO is the output of the primary industry; PIOS is the output data sheet of the primary industry; R means the influence of precipitation; RDIEC is the influence of precipitation on irrigation electricity consumption; PDDIECPI is the percentage of irrigation electricity consumption in primary industry; MEPPI is the average electricity price of the first industry; MEPPIS is average electricity price sheet of the primary industry; WPIUCEP is the unit consumption by price factor weight; PIFAI is the investment in fixed asset; WPIFAI is the weight of investment in fixed assets; PIMS is the market structure; WPIMS is the weight of market structure.

The output value of primary industry is based on available historical data. The rate variable PIVQUC is mainly affected by structure and efficiency factors. Due to the weather conditions on the primary industry production will result in a significant impact, so this model takes rainfall into account for the primary industrial power influence.

Secondary industry electricity consumption forecasting model: Variables involved in Fig. 2 and their meanings are as follows:

SIUC is secondary industry unit consumption; SIUCIV means initial value of unit consumption; SIVQUC is the variation of consumption of secondary industry; SIUCIVS is data sheet of initial value of unit consumption; SIMS is market structure; WSIMS is market structure weights; SIWUCEP is unit consumption of electricity multiplied by tariff factor weights; SIFAI is fixed assets investment; WSIFAI is weights of fixed assets investment; MEPSI is average tariff of secondary industry; MEPSIS is data sheet of average tariff of secondary industry; WSISA is structural adjustment weights; SISA is structure adjustment; SIEC is electricity consumption of secondary industry; SIO is secondary industry output value; SIOS is data sheet of secondary

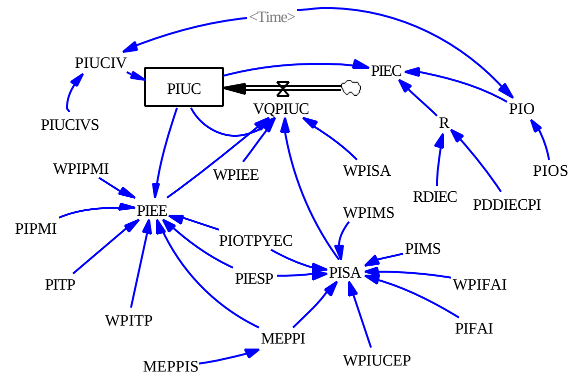

Fig. 1: Primary industry electricity consumption forecasting model

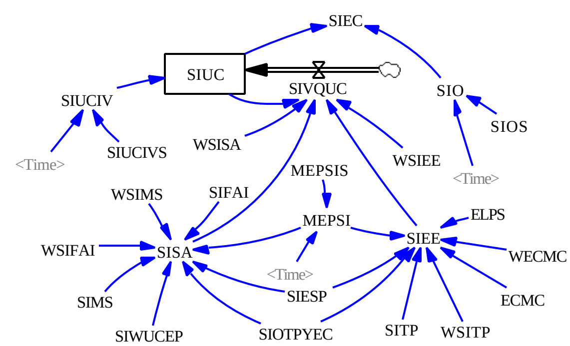

Fig. 2: Secondary industry electricity consumption forecasting model

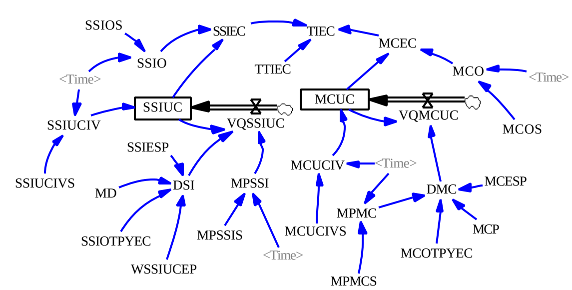

Fig. 3: Tertiary industry electricity consumption forecasting model

weights; SIWUCEP is unit consumption of electricity multiplied by tariff factor weights; SIFAI is fixed assets investment; WSIFAI is weights of fixed assets investment; MEPSI is average tariff of secondary industry; MEPSIS is data sheet of average tariff of secondary industry; WSISA is structural adjustment weights; SISA is structure adjustment; SIEC is electricity consumption of secondary industry; SIO is secondary industry output value; SIOS is data sheet of secondary

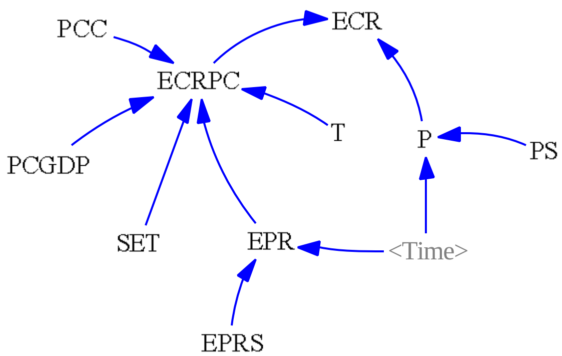

Fig. 4: Residential electricity consumption forecasting model

industry output value; SIOTPYEC is output target per yuan electricity of secondary industry; SIEE is efficiency of electricity consumption; WSIEE is efficiency of electricity weights; SITP is technical progress; WSITP is technical progress weight; SIESP is energy saving policies; ELPS is energy losses due to power shortage; ECMC is the transformation of electricity consumption modes; WECMC is weights of the transformation of electricity consumption modes.

The secondary industry electricity consumption forecasting model is similar to the primary industrial electricity demand forecasting model. The affecting factors of the rate variable SIVQUC are mainly divided into two major categories: structure adjustment and power efficiency.

Tertiary industry electricity consumption forecasting model: Variables involved in Fig. 3 and their meanings are as follows:

SSIOS is data sheet of the output of service sector; SSIO is the output of service sector; SSIUC is unit consumption of service sector; VQSSIUC is the variation of unit consumption of service sector; SSIUCIV is the initial value of unit consumption of service sector; SSIUCIVS is data sheet of the initial value of unit consumption of service sector; SSIOTPYEC is the output target per dollar electricity of service sector; MD is market demand; SSIESP is energy saving policies 1; DSI is the development of service sector; WSSIUCEP is the electricity unit consumption multiplied by consumption factor weights of service sector; SSIEC is power consumption of service sector; MPSSI is average tariff of service sector; MPSSIS is data sheet of average tariff of service sector; TIEC is electricity consumption of the tertiary sector; TTIEC is the influence coefficient of temperature pair the third industrial power; MCUC is unit consumption of municipal building; VQMCUC is the variation of unit consumption of municipal building; MCUCIV is the initial value of unit consumption of municipal building; MCUCIVS is data sheet of the initial value of unit consumption of municipal building; MPMC is average tariff of municipal construction; MPMCS is data sheet of the average tariff of municipal construction; DMC is the development of municipal building; MCO is the output of municipal building; MCOS is data sheet of the output of municipal building; MCOTPYEC is the output target per dollar electricity of municipal building; MCP is municipal building process; MCESP is energy saving policies 2; MCEC is power consumption of municipal building.

According to historical data, tertiary industry power consumption primarily consisted of service industries and municipal building electricity consumption structure and the tertiary industry power consumption = service industries electricity consumption +municipal building electricity consumption.

Residential electricity consumption forecasting model: Variables involved in Fig. 4 and their meanings are as follows:

ECR is residential electricity consumption; ECRPC is per capital residential electricity consumption; PCC is per capital consumption; PCGDP is per capital GDP; ERP is the tariff of residential electricity; ERPS is data sheet of residential electricity tariff; SET is energy saving technologies; T is the effect of temperature; P is population; PS is data sheet of population.

SD MODEL FOR URABAN ECONOMIC DEVELOPMENT

Causal graph: According to the characteristics of urban economy, it is divided into population subsystem and economic subsystem. These two subsystems are interconnected and interacted via the variables. SD model for urban economic development is shown in Fig. 5.

Population subsystem: Variables involved in population subsystem and their meanings are as follows: AP means population gross, NI is total wage of i industry, MI indicates population growth from migration of i industry, NG is natural population growth of i industry, NGRS is data sheet of natural population growth rate, NGR is natural population growth rate, MGRS is data sheet of population growth rate from migration, MGR means population growth rate from migration.

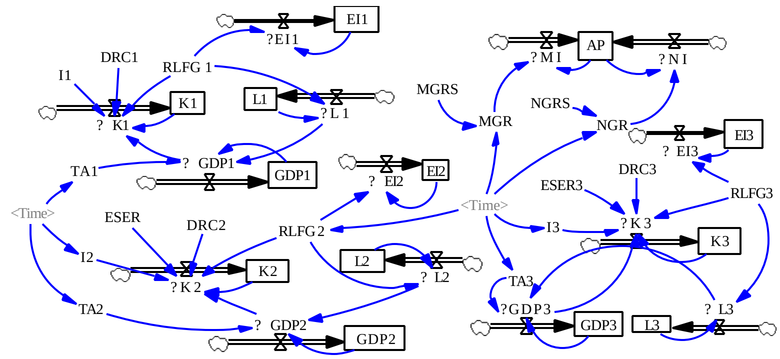

Fig. 5: SD prediction model for urban economic development I = 1, 2, 3, respectively represents the first, second and third industries index value

Economic subsystem: Variables involved in economic subsystem and their meanings are as follows: K_i is total capital of i industry, L_i means total wage of i industry, I_i represents investment rate of i industry, EI_i is employed population of i industry, $RLFG_i$ is labor growth rate of i industry, GDP_i means GDP of i industry, DRC_i is capital depreciation rate of i industry, TA_i indicates technology growth rate of i industry, $ESER_i$ is energy saving investment rate of i industry.

Based on the Solow growth model, economic subsystem considers the impact of energy saving policies, which includes the main three state variables: total capital K_i, investment rate I_i and gross domestic product GDP_i.

MODEL FOR THE RELATIONSHIP BETWEEN POWER CONSUMPTION AND ECONOMIC DEVELOPMENT IN URBAN

The analysis of urban economy and power, firstly, is time series stationary test and then co-integration regression test. Finally, constructing error correction model (ECM) for analysis and forecasting.

Unit root testing of variables: It is assumed that the mean and variance of the time series remain constant over time, which is called stationary series. In general, non-stationary sequence can turn into stationary sequence through *d* differential operation, which is called *d* order single integer sequence.

ADF (augmented dickey-fuller) unit root stationary test is applied in this study. Moreover, it is tested based on model 1 and test null hypothesis H_0 is time series y_t and y_t is non-stationary:

$$\Delta y_t = \alpha + \beta \times t + \rho \times y_{t-1} + \sum_{i=1}^{k} \xi_i \Delta y_{t-1} + u_t \quad (1)$$

where, k is optimal lag period. If ADF test value is greater than the critical value at a certain confidence level, the null hypothesis is accepted which means time series are non-stationary. or the null hypothesis is rejected, namely, time series are stationary.

Co-integration test: Co-integration measures the long-term stable relationship between the variables. Co-integration test of Johansen is adopted in this study.

In general, if the sequences X_{1t}, X_{2t}, ..., X_{kt}, are d order single integer sequence, there exists vector $a = (a_1, a_2, \ldots, a_k)$, which makes:

$$Z_t = aX_t \sim I(d-b) \quad (2)$$

where, if b>0 and $X_t = (X_{1t}, X_{2t}, \ldots, X_{kt})^T$, the sequences X_{1t}, X_{2t}, ..., X_{kt} are (d, b) order single integer.

Error correction model: Basic form of error correction model ECM is showed as the Eq. 3 below:

$$y_t = \beta_0 + \beta_1 \times x_t + \beta_2 \times y_{t-1} + \beta_3 \times x_{t-1} + \varepsilon_t \quad (3)$$

After collation:

$$\Delta y_t = \beta_0 + \beta_1 \times \Delta x_t + (\beta_2 - 1) * \{y - (\beta_1 + \beta_3)x/(1-\beta_2)\}_{t-1} + \varepsilon_t \quad (4)$$

Equestion 4 is ECM, where y-(β1+β3) x/(1-β2) is error correction term, denoted as ecm. If there exists long-run equilibrium relationship between yt and xt, namely yt, then ecm in Eq. 4 can be rewritten as:

$$ecm = y - (\beta_1 + \beta_3)\overline{x}/(1-\beta_2) \quad (5)$$

Therefore, Eq. 6 can be rewritten as:

$$\Delta y_t = \beta_0 + \beta_1 \times \Delta x_1 + \lambda \bullet ecm_{t-1} + \varepsilon_t$$

CASE STUDY

Taking Shandong Province as an example in the study, a case study of comprehensive prediction of power consumption is taken.

Power demand forecasting analysis of a city: Based on SD model for urban consumption and relevant data from Shandong Province, gross primary industry, secondary industry, tertiary industry and electricity consumption of Shandong Province in 2040 can be forecasted. Figure 6 shows the forecasting results of total electricity consumption in Shandong Province.

As is shown in Fig. 6, the total electricity consumption of Shandong Province increases steadily and yet the growth rate will decline after 2026. Electricity consumption growth rate of the tertiary industry is less than the total electricity consumption. However, the electricity consumption growth rate of tertiary industry remains a high level after 2032.

Predictive analysis of a city's economic development: Seen from Fig. 7 that Shandong Province's population will continue to grow steadily in the future, but the growth rate will decline. Its population will reach its peak in 2026 and population growth rate will be negative after 2026.

It can be seen from Fig. 8 and 9 that Shandong Province's GDP will improve steadily and maintain a high level of growth in the future. GDP growth rate will begin to decline and keep a greater falling degree until 2016. The growth rate will remain approximately 3% after 2040.

The analysis of the relationship between power consumption and economic development in urban: This part will analyze GDP, electricity consumption and population in Shandong Province. After consideration of comparability, the economic data are in deflator conversion and 1980 is selected as base year. To eliminate heteroskedasticity, variables are converted into natural logarithm. lnEC, InGDP, InAP, respectively represents electricity consumption, GDP and population after logarithmic conversion.

Unit root testing: Unit root testing of the annual data of variables such as lnEC, InGDP, InAP is conducted and test results are shown in Table 1.

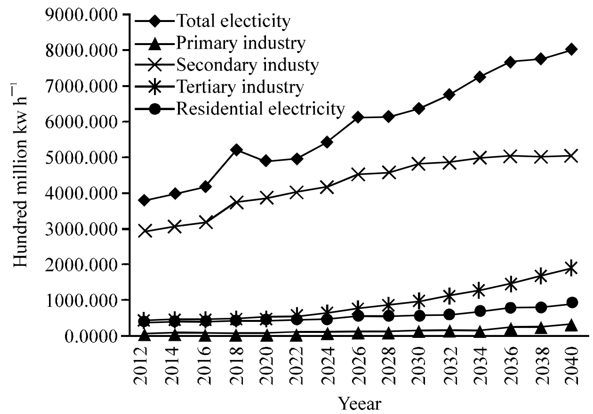

Fig. 6: Total electricity consumption trend of Shandong Province

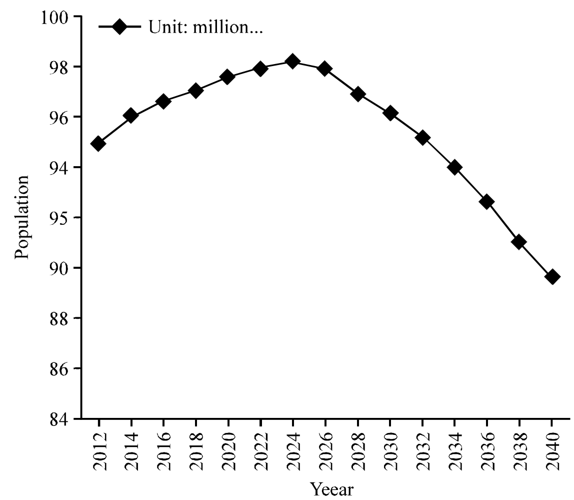

Fig. 7: Population trend of Shandong Province (Vertical axis denotes the number of people, unit: million people)

It can be seen from Table 1 that raw sequences are not stable when each variable is under significance level 5% but first-order differential sequences of each variable is stable. Accordingly, the above three time series are one order single integer sequence, namely, variables are co-integrated.

Co-integration testing: Co-integration testing results indicate that the variables are co-integrated. Co-integration relationship is as follows:

$$\ln TE = 1.21 \ln POP + 0.91 \ln GDP$$

Equestion 7 shows that there exist common long-term fluctuation trend in the three variables and the impact of population and GDP on electricity consumption is positive.

Table 1: ADF testing results of lnEC, lnGDP, lnAP

Variables	lnEC	ΔlnEC	lnGDP	ΔlnGDP	lnAP
ADF value	-1.9580	-5.165	-1.6990	-3.298	-0.3970
critical value under level 5%	-3.2480	-3.030	-3.0300	-3.020	-3.0690
p-value	0.5465	0.001	0.4048	0.0276	0.8175

ADF testing is unit root testing. Variables lnEC, lnGDP, lnAP denote the power consumption, GDP and population after logarithmic transformation, respectively

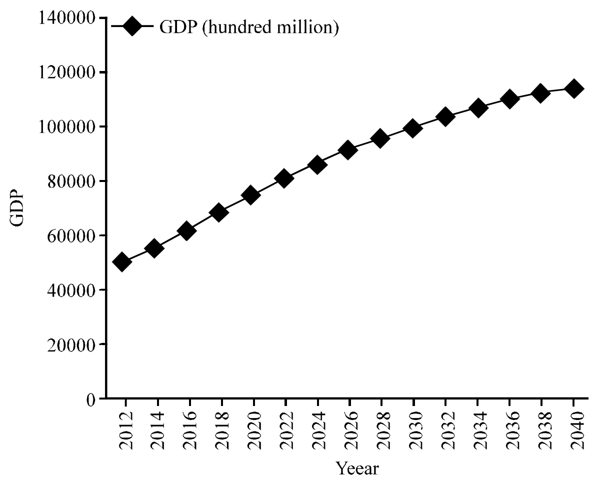

Fig. 8: GDP (Gross Domestic Product) trend of Shandong Province (Vertical axis denotes GDP, unit: hundred million RMB)

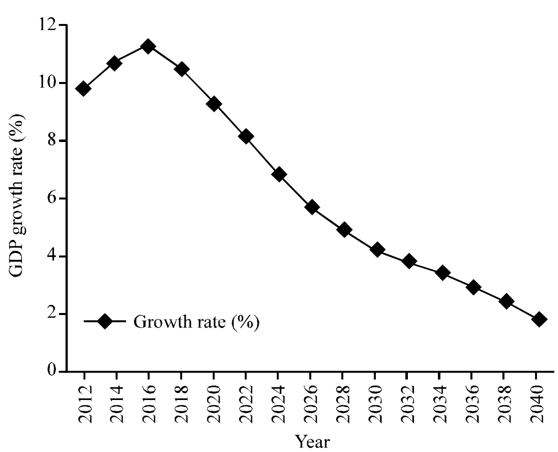

Fig. 9: GDP (Gross Domestic Product) growth rate trend of Shandong Province (Vertical axis denotes the growth rate of GDP)

The analysis of ECM model: A more simple error correction model is obtained through excluding the lag period that the regression coefficient is not significant and the results are as follows:

$$\Delta \ln TE_i = -0.53\Delta \ln GDP_i + 0.51\Delta \ln POP_T - 0.09ECM_{T-1} \quad (8)$$

Equestion 8 explains how short-term fluctuation of electricity consumption is determined. On one hand, it is affected by GDP, the current and previous year's population; on the other hand, it is influenced by the ECM.

Comprehensive prediction results of urban power consumption can be obtained through the calculation results of prediction model SD for urban power consumption and of econometric model. Error rate of comprehensive prediction results is tested and verified. The results show that the model is of higher accuracy and more prominent superiority.

CONCLUSION

The combination of prediction results of system dynamics model and calculation results of econometric model can more scientifically predict urban power consumption trend. A case study is taken using the actual data from Shandong Province and the study results show that GDP of Shandong Province will rise, but after a brief rise, GDP will experience steady decline. Economic development has a lag influence on urban electricity consumption. During this period, electricity consumption will continue to rise, providing endless power for economic development. Electricity consumption will remain approximately steady at 680 billion kWh.

ACKNOWLEDGMENT

The study described in this study was Supported by the National Science Foundation of China (NSFC) (71271082).

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