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Analysis of the Future Petrochemical Industry Consumption in Chinese Energy Structure Based on Lotka-Volterra Model

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China is the one of the only several countries of which energy consumption are coal-dominated in the world. China's current coal production accounts for about a quarter of world production. Energy demand forecast is the basis and prerequisite for the development of energy development strategy and planning. We regard the whole energy demand as an ecological circle, and different types of energy are regarded as a population in the ecosphere. By studying the interaction and development of the population, we forecast the changes in entire ecosystem and even the evolution of the ecosystem. Therefore, for the energy consumption structure forecast, we assume that the three populations are coal consumption, oil consumption and natural gas consumption. Population growth is forecasted by population competition analysis. The three kinds of resources in the competition environment will also have their own impact coefficient at the same time. By using the model, we calculate that coal, oil and natural gas consumption accounted for the proportion of total energy consumption are 62.5%, 29.2% and 8.3% by 2020, respectively. The proportion of total energy consumption of coal declines from 70% in 2008 to around 65%, but it is still a high ratio. Coal consumption is responsible for about 90% of total SO_2 emissions, 60% of total NO_X emissions and 85% of total CO_2 emissions. Oil is mainstream energy in the world, but the prevailing rate in energy consumption is not high in China. In order to increase the ratio of oil, the petrochemical industry capacity needs to be enhanced, and the process needs to continue to improve. The results of the model predictions can help policy makers with better decision, as well as provide some management advice.

1. Introduction

China's energy development will face even more severe challenges in the 21st century. One aspect is resource pressure. With the continuous and rapid development of our economy and the improvement of life quality, the total energy consumption and structure should be greatly improved and changed, which requires a strong energy supply. The other one is environmental stress. Combustible fossil fuels are one of the largest sources of pollution in the world. The evolution of the energy structure requires a long historical process.
For a long period of time in the future, it will not change that the existing fossil fuel-based energy structure holds the dominant position. China also has an energy structure as mentioned above. By 2020, the coal will only account for 25.5% of energy consumption.
At present, the world's energy consumption is mainly based on oil and gas. The process of energy consumption structure is being completed, which changes from coal-based to oil-based consumption. Due to the limitations of the resources, China is the one of the only several countries of which energy consumption are coal-dominated in the world. China's current coal production accounts for about a quarter of world production. In 1986, the proportion of coal in China's energy demand structure is as high as 75%. After the 1990s, coal demand growth slows. The proportion of coal falls to about 66% in energy consumption (Farahbakhsh et al., 1998; Song et al., 2016).
In china, coal consumption is responsible for about 90% of total SO2 emissions, 60% of total nitrogen oxides emissions and 85% of total carbon dioxide emissions. Energy used to generate electricity accounts for more than one third of China's energy consumption, among that coal consumption accounts for about 38% of coal consumption. With this increasing proportion, the control of emissions from electricity generation is paid more and more attention. China's energy demand structure is being turned to oil and natural gas, what will change

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in energy consumption structure, is an important problem concerned by this paper. Therefore, we apply the lotka-Volterra model to predict the proportion of coal, oil and natural gas in energy consumption and analyze the result.

Energy consumption forecast is the basis and prerequisite for making strategy and plan of energy development. So far, many energy consumption forecasting models have been developed by scholars, and these models have their own characteristics and advantages (Fernandes et al., 2005; Sun et al., 2017; Delmastro et al., 2015; Evola et al., 2015; Puglisi et al., 2016; Wang and Liu, 2016; Liu and Liu, 2016; Zhang and Zhao, 2016; Zhang et al., 2016; Tahouni and Panjeshahi, 2017; Valencia-Ochoa, et al., 2017). As being influenced by many factors such as socio-economic, demographic, scientific, technological development, political reform and investment, energy consumption is a very complex system. In the complex system, the relationship between the various factors is intricate that cannot use a mathematical expression to express clearly. Therefore, we regard the whole energy demand as an ecological circle, and different type of energy are regarded as a population in the ecosphere. By studying the interaction and development of the population, we forecast the changes of entire ecosystem and even the evolution of the ecosystem. This is the main idea of the model built in the paper.

2. Related works

According to existing forecasting models, there are two main categories. One is a macro prediction model, which is a study on the overall energy consumption. The target of the model is the overall demand or supply of energy, or the proportion of different energy, which influence each other in energy consumption structure. The second category is a micro predictive model, which is a prediction of a particular type of energy demand or supply. Many scholars use advanced scientific methods on the analysis and prediction of future energy structure. Commonly used methods include time series method, elastic coefficient method, regression analysis, grey model, artificial neural network and combined forecasting method (Intarapravich et al., 1996; GalloA, et al., 2010; GoriF et al., 20107). The advantages and disadvantages of the various prediction methods are shown in Table 1.

Table 1: Comparison of Advantages and Disadvantages of Forecasting Methods of Energy Consumption Structure

Method	Advantage	Disadvantage
Time series	The independent variable is time; Easy to use; Short cycle prediction accuracy is high;	Cannot reflect the inner link; Cannot analyse the interrelationships between factors
elastic coefficient	Pay attention to a certain factor; Apply to rough predictions;	It is difficult to comprehensively predict the energy structure; The accuracy of the prediction is not high
regression analysis	According to various factors to divide the weight; Analysis is comprehensive; Based on historical data; Traditional method;	Data is difficult to obtain; Demand data is large; Data processing and model validation are complex;
grey model	Only need the historical data of energy consumption; Short-term prediction has a high precision；	Data need to have exponential law; Usage has limitations;
artificial neural network	Self-organizing, adaptive artificial intelligence technology；	Easy to fall into the local extreme value in learning process;
combined forecasting method	Combine different individual forecasting models in the form of appropriate weighting; Improve the fitting ability of the model and the prediction accuracy of the model;	Weighted forms require in-depth study
Data mining	Cutting edge science; Forecast method diversity; High precision;	Need a large amount of data; Predictive methods are diverse and difficult to choose;

3. Energy consumption structure forecasting model

3.1 Lotka-Volterra model

Loyka and Volterra put forward the theory of inter specific competition. Lotka-Volterra model is based on the premise that multiple populations exist in a certain natural environment and their survival and development will certainly affect each other. The model gives a description of how this effect is defined and forecasts the changes of population development.

Lotka A J and Volterra V establish a predator-prey system model and a competitive system model, respectively. On the basis of previous studies, Odum extends the model to reciprocal systems (Zhong, et al., 2012). Lotka-Volterra model is an extension of the logistic model. The mathematical expression of the model is given as follows:

$$\frac{dN_1}{dt} = a_1 N_1 - b_1 N_1^2 - c_1 N_1 N_2 \tag{1}$$

$$\frac{dN_2}{dt} = a_2 N_2 - b_2 N_2^2 - c_2 N_1 N_2 \tag{2}$$

When $c_1 > 0,\ c_2 > 0$, it represents the competitive system.

When $c_1 < 0,\ c_2 < 0$, it represents the reciprocal system.

When $c_1 > 0,\ c_2 < 0$, it represents the predator-prey system.

For a competitive system,

N_1 , N_2 represent the number of two populations, respectively.

K_1 , K_2 represent the environmental capacity of the species, respectively.

R_1 , R_2 represent the population growth rates of the two species, respectively.

The mathematical expression of the model is given as follows:

$$\frac{dN_1}{dt} = r_1 N_1 \left(1 - \frac{N_1}{K_1}\right) \tag{3}$$

Where N_1/K_1 can be understood as the space that has been used, and $(1-N_1/K_1)$ can be understood as the vacant space. When the two species compete or use the space at the same time in the environment, the space already used also need to add the space occupancy of population N_2, and then the further revision of formula (3) is given as follows (Zhang, et al., 2001):

$$\frac{dN_1}{dt} = r_1 N_1 \left(1 - \frac{N_1}{K_1} - \frac{\alpha N_2}{K_1}\right) \tag{4}$$

Where α is the competition coefficient of species N_2 to species N_1, that is, the space occupied by each N_2 individual is equivalent to the space occupied by $\alpha \cdot N_1$ individuals.

Similarly,

$$\frac{dN_2}{dt} = r_2 N_2 \left(1 - \frac{N_2}{K_2} - \frac{\beta N_1}{K_2}\right) \tag{5}$$

Where β is the competition coefficient of species N_1 to species N_2, that is, the space occupied by each N_1 individual is equivalent to the space occupied by $\beta \cdot N_2$ individuals.

When the environmental capacity of the population N_1 is K_1, the self-growth inhibition of each individual in the population N_1 is$1/K_1$. In the same way, the inhibition effect of each individual on the growth is $1/K_2$ in the population N_2.

3.2 Energy consumption structure forecast model

According to the definition of the model, we extend the Lotka-Volterra model to three populations. When the population becomes three, the relationship between the three species is more complicated than the case of two species. Assuming that the density of the three populations is N_1, N_2, N_3 (assuming the population density is uniform), the L-V model of the three populations is given (Zhang, 2001):

$$\frac{dN_i}{dt} = N_i\left(b_i + \sum_{j=1}^{3} a_{ij} N_j\right), i = 1, 2, 3 \quad (6)$$

Where b_i>0 is called the rate of change of population *i*. The positive or negative of $a_{ij}(i\neq j)$ represents the effect and intensity of population *j* on population *i*, and the absolute values of $a_{ij}(i\neq j)$ represent the intensity of effect of population *j* on population *i*. a_{ij} represents the influence coefficient of population *i* on itself.

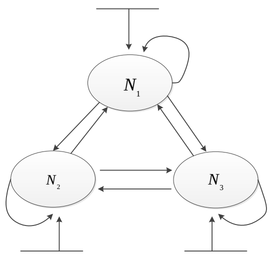

Figure 1. Clockwise competition model

Therefore, we assume that the three populations are coal consumption, oil consumption and natural gas consumption via the energy consumption structure forecast. Population growth is forecasted by population competition analysis. These three kinds of resources in the competition environment will also have their own impact coefficient at the same time. The relationship is in accordance with the clockwise competition model as shown in Figure 1, so values of parameters b_i and a_{ii} follow the rules given by Table 2:

Table 2. The values of b_i and a_{ij} in formula 6

Model	b_i	a_{ij}		
	$b_1 > 0$	$a_{11} < 0$	$a_{12} < 0$	$a_{13} < 0$
Formula(6)	$b_2 > 0$	$a_{21} < 0$	$a_{22} < 0$	$a_{23} < 0$
	$b_3 > 0$	$a_{31} < 0$	$a_{32} < 0$	$a_{33} < 0$

We set the parameters as follows:
N_1, N_2, N_3 represent the share of consumption for the three energy types, respectively.
K_1, K_2, K_3 represent consumption capacity of three energy types, respectively.
r_1, r_2, r_3 represent consumption growth rates of the three energy types, respectively.
When coal, oil and natural gas are in of the same energy structure, the proportion of consumption should take into account the impact of each other, that is, N_1 need to consider the occupation of N_2 and N_3.The following formulas shows the relationships:

$$\frac{dN_1}{dt} = r_1 N_1\left(1 - \frac{N_1}{K_1} - \frac{\alpha_2 N_2}{K_2} - \frac{\alpha_3 N_3}{K_3}\right) \quad (7)$$

And:

$$\frac{dN_2}{dt} = r_2 N_2\left(1 - \frac{N_2}{K_2} - \frac{\alpha_1 N_1}{K_1} - \frac{\alpha_3 N_3}{K_3}\right) \quad (8)$$

$$\frac{dN_3}{dt} = r_3 N_{31}\left(1 - \frac{N_3}{K_3} - \frac{\alpha_1 N_1}{1} - \frac{\alpha_2 N_2}{K_2}\right) \quad (9)$$

4. Simulation experiment and result analysis

We choose the total energy consumption and different type energy consumption every year from 1980 to 2012. The raw data conducted for the forecast are all derived from the China Statistical Yearbook. According to the defined model, we get the predicted data by computer simulation. The forecast includes the total annual energy consumption, annual consumption of coal, oil and gas, respectively. Based on these data we can analyze changes both in energy consumption and energy structure.

The data of 1980~2006 is used as training data, and the data from 2006 to 2012 is used as test data. The comparison between actual and predicted values of energy consumption is shown in Table 1.

Table 3. Comparison between actual and predicted values of energy consumption

Years	Coal actual (percentage)	Coal predicted (percentage)	Oil predicted (percentage)	Oil predicted (percentage)	Natural gas predicted (percentage)	Natural gas predicted (percentage)
2006	69.4	68.7	20.4	20.5	3	3.5
2007	69.5	69.5	19.7	19.9	3.5	3.8
2008	68.7	68.9	18.7	20.5	3.8	3.5
2009	70.4	68.7	17.9	20.5	3.9	3.5
2010	68	67.9	19	21.5	4.4	4.2
2011	67.8	67.5	21.2	22	6	5.5
2012	66.8	67.0	21.9	22.2	7.3	6.8

Choose the following two kinds of error indicators to evaluate the effectiveness of the method in this paper:
(1) Mean absolute percentage error

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}[(x_t - \hat{x}_t)/x_t] \tag{10}$$

(2) Mean Square Percent Error

$$MSPE = \frac{1}{N}\sqrt{\sum_{i=1}^{N}[(x_t - \hat{x}_t)/x_t]^2} \tag{11}$$

Where, x_t is the actual value at t time, $\hat{x}_t$ is the predicted value of some kind of prediction method at t time. According to the above 2 indexes, the checking number of forecasting model is showed on Table 2, and the numerical value is expressed as a percentage.

Table 4. Checking number of forecasting model

ENERGY TYPE	MAPE	MSPE
Oil	2.46	1.37
Coal	1.88	1.11
Natural gas	3.22	2.93

As we consider the data from Table 5, it can be seen from the forecast that the proportion of coal decreases year by year, but the proportion is still high. The proportion of oil and natural gas increases year by year, and the proportion of natural gas has a certain degree of volatility. Overall, the three major energy consumption growth is fast, which is related to rapid economic development of China.

Table 5. Predict of energy consumption

Years	Annual energy consumption (10000 tons standard coal)	Coal (percentage)	Oil (percentage)	Natural gas (percentage)
2013	4902.69	65.7	22.5	7.9
2014	5358.65	64.9	23.1	8.5
2015	5761.98	65	24.6	10.4
2016	6125.96	64.6	25.4	10
2017	6696.79	63.9	27.7	8.4
2018	11039.11	63.1	26.3	10.6
2019	11347.3	63.2	28.6	8.2
2020	12092.28	62.5	29.2	8.3

5. Conclusion

In the future energy consumption structure, the consumption of coal still accounts for a great proportion. By using the model, we calculate that coal, oil and natural gas consumption accounted for the proportion of total energy consumption are 62.5%, 29.2% and 8.3% by 2020, respectively. Although the proportion of total energy consumption of coal declines from 70% in 2008 to under 63%, oil and gas consumption take the first place (70% of total consumption) in the primary energy consumption structure in developed countries. In these counties, coal tightly accounts for 28.8% of energy consumption, so the gap between our country and developed countries is great. The main reason is that China reserve more coal than oil and natural gas. At the same time, coal pricing is unreasonable. Low prices prompts more coal consumption. However, the exploitation and use of coal still has the problem of environmental damage, serious pollution and low resource utilization. In order to tackle the problems, more attentions should be paid to the rational pricing of coal, and improvement of coal production and processing technology. Furthermore, government should encourage development and utilization of new energy resources and renewable energy resources.

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