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Research on China's energy supply and demand using an improved Grey-Markov chain model based on wavelet transform

Sun Wei, Xu Yanfeng*

Department of Economics and Management, North China Electric Power University, Baoding, 071003, China

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ABSTRACT

Energy is an essential foundation for the economic growth and social development of a country. Since the reform and opening up, the economy in China has been in a state of rapid development and the paradox of the energy supply-demand has become increasingly prominent. An improved Grey-Markov chain model based on the wavelet transform is presented in this paper which takes various energy forms into account. The model uses the discrete wavelet transform for denoising, substitutes the extended grey model to the traditional one and introduces the fuzzy theory and metabolic principle into the Markov chain. Then an empirical example of China's energy production and consumption data during the period of 1990–2014 were selected as the research objects. Comparing with other methods, the proposed model was proved feasible and valid, and the energy production and consumption situation from 2015 to 2020 was predicted. Besides, the trend of energy supply and demand gap was analyzed as well as the energy structure which utilized the Shannon Wiener index. The results show that in the foreseeable future, the energy supply and demand gap in China will narrow and the energy structure tends to be diversified. Finally some opinions and suggestions are put forward.

1. Introduction

As is known to all, energy is irreplaceable in many countries all over the world. Especially from decades, China is in such a phase of the industrial restructuring, dweller consumption structure upgradation, acceleration in urbanization and rapid economic development, which will increase the dependence on energy. Accordingly it has become an important issue with great concern at home and abroad that whether the future energy supply could keep up with the sustainable economic growth in China.

At present, scholars have launched the corresponding research in the field of the energy demand side management. Ardakani and Ardehali [1] applied the optimal artificial neural network (ANN) model based on improved particle swarm optimization (IPSO) and shuffled frog-leaping (SFL) algorithms to investigate the effects of historical DSM data on accuracy of electrical energy consumption modeling and long-term forecasting in U.S. and it was found that the addition of the demand side management data to socio-economic indicators data could reduce the mean absolute percentage error of the model. Miara et al. [2] carried the electricity demand-side-management research and the results indicated the study could enhance the social and environmental benefits as well as facilitate to the development of the energy and environmental plans. Quiggin and Buswell [3] presented a new model to estimate the national supply and demand hour-by-hour based on the Published UK 2050 energy scenarios. It was found that achieving demand reduction targets are far more important than meeting electrification targets. Khanna et al. [4] estimated the effects of three demand side management measures empirically towards China's residential electricity demand and the residential electricity demand is found to be price- and income-inelastic. From the whole point of view, more importance is attached to the demand-side research rather than the supply side.

Similarly, scholars domestic and overseas put forward their own views on the energy supply and demand issues from many aspects and angles. Liu [5] analyzed the changes in the structure of China's future energy and gives the suggestions from the perspective of supply and demand based on the fully understanding of our existing energy structure and the results showed China's energy structure would gradually turn to be comprehensive and diverse. José et al. [6] used the Long-range Energy Alternatives Planning program (LEAP System) to study the trend of evolution of the Brazilian Energy Matrix which could propose different scenarios under the definition of socioeconomic scenarios. Huang et al. [7]

* Corresponding author.
E-mail addresses: bdsunwei@163.com (S. Wei), ncepuxyf@163.com (X. Yanfeng).

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also utilized the LEAP model to compare the future energy demand and supply patterns as well as greenhouse gas emissions in Taiwan under several alternative scenarios of energy policy and energy sector evolution. They provided an interpretation of the implications of model results for future energy and climate policies in Taiwan. Li et al. [8] adopted five types of models to predict the China's medium- and long-term coal demand respectively based on the historical data of coal consumption and related factors from 1987 to 2012. The models in this paper included the vector autoregressive model (VAR), radial basis function (RBF) neural network model, genetic algorithm demand estimation model (GA-DEM), particle swarm optimization demand estimation model (PSO-DEM) and input–output model (IO). Aizenberg et al. [9] used a Multilayer Neural Network with Multi-Valued Neurons (MLMVN) to conduct the univariate and multivariate one-step- and multi-step ahead prediction of reservoir dynamics of an oilfield asset located in the coastal swamps of the Gulf of Mexico. Shaikh and Ji [10] implemented the Levenberg–Marquardt Algorithm (LMA) to improve the forecasting precision of the logistic and logistic-population model based approach then the new model was developed to forecast the medium- (2020) to long- (2035) term natural gas demand in China and the outcomes of this study were expected to assist the energy planners and policy makers to chalk out relevant natural gas supply and demand side management policies. Melikoglu [11] selected two semi-empirical models to generate accurate forecasts for Turkey's natural gas demand between 2013 and 2030. Specifically speaking, the logistic equation was used for the long term natural gas demand forecasting while the linear equation for the medium term. Khan [12] examined both the short and long-term dynamics of natural gas consumption in Pakistan through an econometric model over the period 1978–2011. In order to determine the future outlook of natural gas demand, both the moderate and extreme demand scenarios are simulated as baseline for the period 2012–2020. The findings of this study could provide useful support for designing an appropriate infrastructure and investment plan with reference to gas market in future. Giglmayr et al. [13] analyzed the power and energy supply outlook from an annual time series simulation of all approved utility-scale PV facilities in South Africa and the results showed the supplied power and energy performances were well within the best practice spinning reserve of the national grid. Perwez et al. [14] provided an overview of structure of electric power sector of Pakistan and a summary of historical electricity demand & supply data and a LEAP model was applied to analyze the supply policy selections and demand assumptions based on the current status of divergent set of energy policies, which had an impact for the futuristic power generation and environmental policies in Pakistan.

From a regional perspective, scholars have conducted studies about the energy supply or demand of some countries, including China, Brazil, Taiwan, Mexico, Turkey, Pakistan and South Africa. As for the research object, it paid attention to different energies, such as the coal, oil, natural gas and electricity power. From the angle of the methods, various methods are applied, including LEAP, neural network model, LMA, VAR, DEM, IO model and so on. In a nutshell, there is no paper at home and abroad currently, which regards the total energy and sub-energy as the object and makes a comparison and analysis of the energy supply and demand in one region. Furthermore, in this research field, the easy-to-understand Grey-Markov chain is used less.

As a widely used forecasting model, the Grey-Markov chain has been applied in many fields since it was proposed. Scholar Hsu et al. [15] presented an integration prediction method including grey model, Fourier series, and Markov state transition (MFGM) to predict the turning time of Taiwan weighted stock index. Ujjwal Kumar and V.K. Jain [16] employed the model to forecast crude-petroleum consumption and grey model with rolling mechanism to forecast coal, electricity consumption and singular spectrum analysis (SSA) to predict natural gas consumption in India. Mao and Sun [17] established a new forecasting model (Grey-Markov model) to forecast fire accidents effectively. And an optimized single variable discrete grey forecasting model was adopted by Xie et al. [18] to forecast the total amount of energy production and consumption while a novel Markov approach based on quadratic programming model to predict the trends of energy production and consumption structures under the influence of China's energy saving policy. Others [19] used the optimal input subset and Cuckoo search algorithm to optimize the conventional Grey-Markov chain model for the purpose to forecast the annual foreign tourist arrivals towards China. However the grey-Markov prediction model used in the existing literature are usually fundamental and conventional, which will lead to a relatively large error.

Consequently, the purpose of this paper is mainly divided into two aspects on account of the above literature review: (1) Based on the traditional Grey-Markov chain model, an improved one optimized by the wavelet transform will be presented. In detail, the extended grey model, wavelet transform, fuzzy set theory and metabolic principle will be introduced into the new model. Then the prediction precision of the original model can be improved. (2) In the empirical analysis section, China's energy production and consumption in recent years will be taken as the object and the change trend as well as the energy gap in the future will be predicted.

Firstly, some improvements are proposed in this paper to modify the traditional Grey-Markov chain model and the specific operation are as follows: 1) The wavelet transform is chosen to decompose and reconstruct the original data to obtain the useful data after denoising; 2) The traditional grey model is replaced by the extended one; 3) The fuzzy theory and principle of metabolism, namely referred to the progressive transition probability matrix, are both introduced into the Markov chain. Through the above operations a new model of the improved Grey-Markov chain based on the wavelet transform is constructed in this paper.

Secondly, in the case study, this paper will take the relevant data of China's energy supply and demand from 1990 to 2014 as the object. Compared with the direct use of total energy to simulate and forecast, different kinds of energy are applied to the proposed model and the total values are gotten by accumulation. The feasibility and validity of the presented model to study the issue of China's energy supply and demand in this paper will be proved by contrast with other models including the traditional grey model (GM), extended grey model (EGM), extended grey model based on wavelet transform (WT-EGM), Grey-Markov chain based on the wavelet transform etc. On this basis, the energy supply and demand situation in 2015–2020 can be doped out with the new model. Besides the trend of energy supply and demand gap will be discussed and analyzed as well as the energy-resource structure which will utilize the Shannon Wiener index. Finally, some targeted comments and opinions are put forward according to the results.

In conclusion, a scientific analysis model of energy supply and demand can not only provide an effective way to safeguard China's energy security and solve the energy bottleneck, but also offer a scientific basis for the formulation of China's energy planning policy. The concrete flow chart of this paper is presented in Fig. 1.

2. Algorithm introduction

2.1. Conventional Grey-Markov model

The grey system theory [20] was a new discipline founded by

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