Electrical Power and Energy Systems 66 (2015) 1–8

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Forecasting China's energy demand and self-sufficiency rate by grey forecasting model and Markov model

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ARTICLE INFO

Article history:
Received 8 August 2013
Received in revised form 28 August 2014
Accepted 12 October 2014
Available online 7 November 2014

Keywords:
Energy
Energy structure
Grey forecasting model
Markov chain
Energy policy

ABSTRACT

This paper applies novel models to forecast the developing trends of China's energy production and consumption under the influence of China's energy saving policy. An optimized single variable discrete grey forecasting model is adopted to forecast the total amount of energy production and consumption while a novel Markov approach based on quadratic programming model is proposed to forecast the trends of energy production and consumption structures. The proposed models are used to simulate China's energy production and consumption during 2006–2011 and forecast its trends in 2015 and 2020. Results demonstrate that proposed models can effectively simulate and forecast the total amounts and structures of energy production and consumption. And by comparing with regression model, results show proposed model is a little better than regression in simulating and forecasting the case. Although the growth rate of energy consumption in China has decreased under the energy saving policy, total amount of energy consumption and the proportions of natural gas and other energies keep growing while the self-sufficiency rate of crude oil and natural gas continues to drop.

Introduction

The industrialization and urbanization in China have developed into a crucial stage, and it is expected to continue its role as a huge engine for China's economic growth in the next ten or twenty years. However, the process of industrialization and urbanization in China has so far been conducted with high energy consumption. It is unsustainable in the long run due to its environmental impact and the limited resources in China. The energy consumption in China needs a change from low efficiency and high consumption to high efficiency and saving. The growth rate of energy consumption has to be controlled and reduced. In 2006, China's government introduced an energy saving policy in its 11th Five-Year Development Plan. In this plan, the target for energy saving was set to 20% saving in energy consumption per Unit GDP in 5 years to 2010. To continue the energy saving policy, the target was further modified to 16% reduction in the 12th Five-Year Development Plan (2011–2015). Considering the environmental degradation associated with carbon dioxide emissions, the proportion of coal and crude oil should be decreased while the proportion of clean energies, such as natural gas and other new energies, should be increased. Based on the energy saving policy, in 2010 and 2012, China's government separately made new energy development plan (2011–2020) and natural gas development plan (2011–2015). Under these energy policies, the developing trends of China's energy production and consumption have been significantly changed. Given such a policy shock to the system, what can be done to provide meaningful forecasts of energy production and consumption? How about the self-sufficiency of different kinds of energies in the future?

There have been many forecasting models applied in energy problems, such as regression analysis (RA), time series analysis, artificial neural network, semi-parametric approach and non-parametric method [1–8]. However, these models typically require large numbers of observations and complicated input factors to make sensible predictions. Under the shock influence of energy saving policy, the general developing trends of the energy system are changed significantly and the available observations are limited and cannot satisfy the requirements of those traditional methods. To forecast the developing trends with limited data sequence, a new model working with small data sets is necessary to overcome the limited data availability. The emerging Grey System Theory (*GST*) provides an ideal alternative solution. *GST* mainly focuses on problems with small samples and poor information [9,10]. As a result of our previous work in this field, we proposed an optimized single variable discrete grey forecasting

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http://dx.doi.org/10.1016/j.ijepes.2014.10.028
0142-0615/

model to improve *GM (1, 1)* model [11]. *GM (1, 1)* model is the main forecasting model in *GST* and it has been successfully applied in various prediction problems [12-17]. By accumulating generation operation in *GM (1, 1)* model, the developing trend of a short sequence is revealed and its random disturbance is weakened. In fact, China's energy policies have been widely discussed in the past decades [18-24]. *GM (1, 1)* model and its optimized models have been applied in analyzing and forecasting energy problems. For example, Zhou et al. [25] developed a trigonometric grey prediction approach by combining *GM (1, 1)* with the trigonometric residual modification technique for electricity demand forecasting. Akay and Atak [26] improved the forecasting accuracy of *GM (1, 1)* model to predict Turkey's industrial electricity consumption. Pao and Tsai [27] applied grey forecasting models to predict pollutant emissions and energy consumption during 2008–2013 in Brazil. Lee and Tong [28] developed an improved grey forecasting model combining residual modification with genetic programming sign estimation and applied it in energy consumption forecasting. Li et al. [29] applied *AGM (1, 1)* model in forecasting short-term electricity consumption with some Asian cases and compared the results with back propagation neural networks and support vector regression. The grey models are also applied in CO_2 emissions forecasting and renewable energy forecasting [30-37]. Although grey forecasting models have been successfully applied to energy demand and consumption prediction, its application to predict and analyze the developing trends of the total amounts and structures of energy production and consumption under the new energy policies is still to be investigated. As aforementioned, the general developing trend of the energy system is changed under the shock influence of new energy policies and the available data fitting to the new condition are too limited to satisfy the requirements of traditional forecasting approaches. Therefore, this paper aims at constructing novel models to simulate and forecast the new developing trends of the total amounts and structures of China's energy production and consumption under the shock influence of the energy saving policy made in 2006.

The paper is structured as follows. In the next section, the historical development of the total amount, self-sufficiency rate and structures of energy production and consumption in China since 1990 are discussed and analyzed. Then section 'Methodology' establishes two forecasting models to predict the trends of total amounts and structures separately. Based on the proposed models, section 'Simulation and forecasting of China's total amount and structure of energy production and consumption' simulates and forecasts the total amounts, self-sufficiency rate and structures of China's energy production and consumption. And proposed model with regression model are compared in this section. Finally, in section 'Conclusions' we draw out the conclusions.

Data

The annual data of total amounts and structures of energy production and consumption of China for the period 1990–2011 are provided by the National Bureau of Statistics of China [38], as shown in Figs. 1 and 2. Although the increase of the total amount of energy production accelerated in the recent years, the total amount of energy consumption grew even faster. The maximum growth rate of energy consumption was not more than 6% before 2002, and it rapidly climbed to more than 10% after 2002. There is a huge pressure for energy supply in China. Since 1993, China's energy supply could not meet its energy demand and the situation is getting more serious than ever. In 2006 and 2007, the self-sufficiency rates were lower than 90%. With the increased energy consumption, the gap between energy production and energy consumption is getting wider. Furthermore, the self-sufficiencies

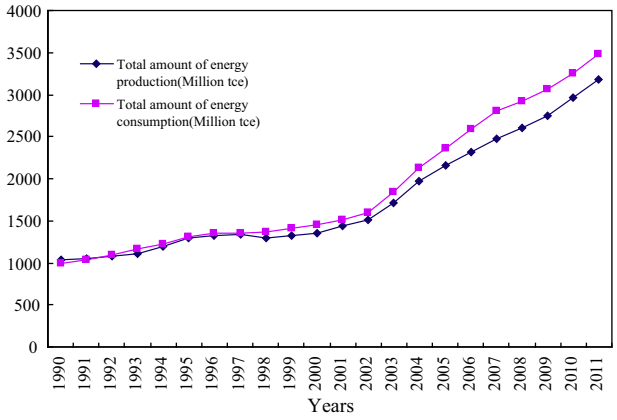

Fig. 1. Total amount of energy production and consumption.

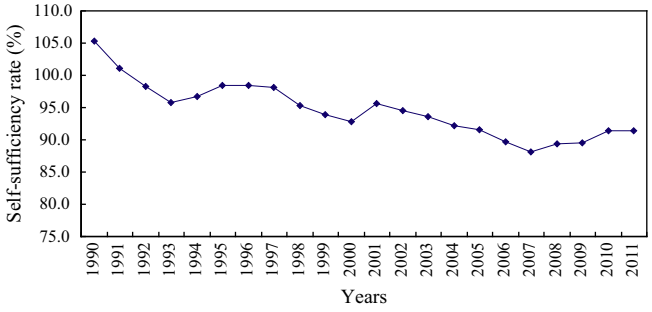

Fig. 2. Self-sufficiency rate of total energy amount (%).

of coal, crude oil, natural gas and other new energies are unbalanced. As is shown in Fig. 3, coal and other new energies have so far been in self-sufficient status while crude oil and natural gas have moved away from self-sufficient status. China had to start to import crude oil in 1993 and natural gas in 2007. In 2011, only 44.7% of crude oil and 78.6% of natural gas were supplied domestically.

The structures of China's energy production and consumption were also unbalanced during 1990–2011. China is a country with abundant coal and scarce crude oil and natural gas, as shown in Fig. 4. Since 1990, the proportion of coal has kept as approximately 75% of the total amount of energy production in China. The proportion of crude oil dropped from 20% in early 1990s to 9.1% in 2011 while the proportions of natural gas and other new energies productions increased slightly. Obviously, large amount of coal production and consumption increases carbon dioxide emissions and exacerbates the damage to the environment. Energy consumption structure is also unbalanced in the same period. But the

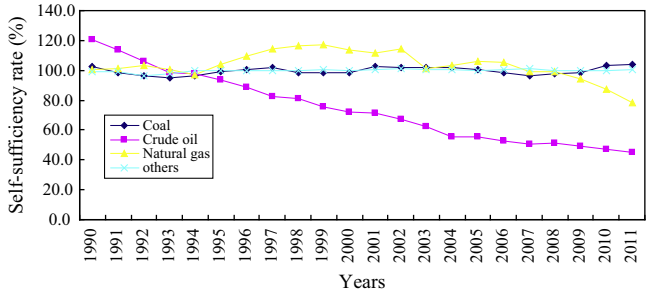

Fig. 3. Self-sufficiency rate of different kinds of energy (%).