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RECYCL-3316; No. of Pages 11

ARTICLE IN PRESS

Resources, Conservation and Recycling xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

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

Full length article

Scenario prediction of China's coal production capacity based on system dynamics model

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ARTICLE INFO

Article history:
Received 14 April 2016
Received in revised form 4 July 2016
Accepted 26 July 2016
Available online xxx

Keywords:
Coal production capacity
Prediction
System dynamics
Scenario analysis

ABSTRACT

Given the primary status of China's coal in the energy structure, the scientific prediction of China's coal production capacity (CPC) is of great significance to the orderly exploitation and use of coal resources and emission-reduction policy-making. This paper proposes a system dynamic (SD) model to forecast the change of China's CPC in three scenarios – Baseline as Usual Scenario (BUS), Policy Regulation Scenario (PRS) and Strengthening Policy Scenario (SPS). Results show that: (1) SD model performs well in simulating the historical data and has a remarkable consistency between model behavior and actual situation. (2) Because of the continuous economic growth, China's coal demand and carbon dioxide emissions will continue increasing and not peak by the year 2020 in the three scenarios, although the energy efficiency and energy consumption structure have actually improved. However, the expected goal of China's carbon dioxide emission reduction is fully achieved in both the PRS and the SPS. (3) In the PRS, China's coal production and demand in the year 2020 will be 4.334 and 3.852 billion tons, respectively. The relative overproduction appears to be aggravated, and the "supply-over-demand" situation in the coal market will not change noticeably. (4) China's CPC will reach 5.144, 4.635 and 4.492 billion tons per year by the year 2020 in the BUS, the PRS and the SPS, respectively. China's coal overcapacity will continue and face a severe challenge in the future. (5) The gap between coal supply and demand tends to be greater in the PRS and the SPS, and the PRS is considered to be the most conducive scenario to control China's CPC because this scenario is consistent with China's national circumstances. Finally, for abating the amount of China's CPC, some suggestions are given from the perspective of supply-side reform in China's coal industry.

1. Introduction

With the slowdown of China's economic development, its demand for coal has decreased remarkably. The relative overcapacity has occurred in China's coal industry, and the coal price has been relatively low (Yang et al., 2016). Simultaneously, the large-scale development and utilization of coal resources in China not only directly led to great ecological destruction, such as farmland damage and surface subsidence, but also generated the issues of carbon dioxide emissions, water wastage and environmental pollution (Hu et al., 2014; Song et al., 2015; Chen et al., 2015; Mani et al., 2016; Yuan et al., 2016). As one of the greatest energy consumers in the world, China has many problems to solve: how much coal is necessary to allow the engine of the Chinese economy to run at a middle/high speed? What will the trends of China's coal supply and demand be in the year 2020? Can China fulfill its emissions-reduction promise to reduce the carbon dioxide emissions (CDE) levels of 2005 by 40%–45%? In such circumstances, it would be extremely helpful for the orderly exploitation of China's coal resources and emission reduction policy-making if the development trend of China's coal production capacity (CPC) could be predicted scientifically.

Because coal resources are nonrenewable and finite, scholars have been greatly concerned both at home and abroad regarding the prediction of CPC. The Bell-Shaped Theory proposed by Hubbert (1956) has been widely applied to research on fossil energy peak value prediction because of its simplicity and intuitiveness (Hubbert, 1976; Tao and Li, 2007a; Maggio and Cacciola, 2009; Höök and Aleklett, 2009; Maggio and Cacciola, 2012). It is important to note that the prediction results may be seriously influenced

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http://dx.doi.org/10.1016/j.resconrec.2016.07.013
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by the accumulated coal production and the reserve because this theory is based on the logistic curve of resource exhaustion (Höök et al., 2010; Wang and Feng, 2016). Robert et al. (2013) conducted a study on American coal reserves and their production peak, and noted that the prediction results were quite uncertain because the current reserve data were unreliable. Nathan and Sanjay (2014) also observed that the coal reserves in America have been overestimated. When applying the Hubbert model in China, the prediction accuracy of CPC is not only influenced by the estimate of coal reserves but also closely related to the complicated classification of coal resources in China. Wang et al. (2013a) maintained that the prediction deviation regarding the peak value of China's coal production was largely caused by the disagreement on the estimate of coal reserves. According to those authors, the root of this disagreement lay in the lack of a universally acknowledged classification of coal resources. Generally, scholars have focused on research on the peak value of global coal production or the primary coal-producing countries. Mohr and Evans (2009), Höök et al. (2010), and Tadeusz and Gregory (2010) conducted studies on the peak value of global CPC; Höök and Aleklett (2009), Robert et al. (2013), and Nathan and Sanjay (2014) researched the peak value of American CPC; Mohr et al. (2011) conducted a comprehensive study on the evolution of Australian CPC over time using various models.

China, as one of the primary energy producing and consuming countries, its high-speed economic growth is still largely dependent on massive energy consumption (Song et al., 2011). Many scholars have conducted lengthy studies on issues such as predicting China's coal supply and demand as well as greenhouse gas emissions (Adams and Shachmurove, 2008; Yu et al., 2012b; Li et al., 2015). Based on their analysis of the influence of coal consumption on resources and the environment in China, Malcolm and James (2010) observed that China would generate increasingly more carbon dioxide because of the sharp increase in coal demand; these authors also posited that the reduction in coal reserves year after year would also greatly affect China's economic growth over the long term. Hao et al. (2015) conducted a scenario prediction and suggested that China's coal demand would peak (4.16 billion tons) in 2019 in a scenario in which the GDP growth rate is 7.8%. Tao and Li (2007b) analyzed the factors of China's coal production using the STELLA model and maintained that China's coal production would peak (which may vary from 3.339 to 4.452 billion tons) between 2025 and 2032; Tao et al. also noted that current energy policies, in which coal represents the dominant share, would face severe environmental challenges. Lin and Liu (2010) suggested that China's CPC would peak by the end of the 2020s and noted that the drastic increase in CPC would be a serious threat to future energy security. Yu and Wei (2012) analyzed China's coal production and environmental pollution using a system dynamics (SD) model, concluding that China's coal production would consistently increase until 2030. Based on their analysis of China's energy structure, Wang et al. (2013b) claimed that with the increase in coal demand, eventually, the short supply of coal in China and the instability of international coal imports would seriously challenge China's economic development.

The methods employed to predict coal production generally fall into two categories: trend extrapolation and scenario analysis. The former predicts a possible future situation based on historical trends. Trend extrapolation includes Time Series Analysis, the Neural Network Model, Grey System theory, and the Chaotic Dynamics Model (Ediger and Akar, 2007 Limanond et al., 2011; Geem and Roper, 2009; Ekonomou, 2010; Canyurt and Ozturk, 2008; Lee and Tong, 2011). For example, on the basis of regression analysis (e.g., the ARIMA and SARIMA models), Ediger et al. (2006) constructed the integrated decision system to predict fossil energy production and then simulated the historical data of Turkey's energy production between 1950 and 2003. Based on Grey System theory, Wang et al. (2011) presented DGM, RDGM and p-RDGM models and concluded that the p-RDGM model has the best prediction effect of the three. Li et al. (2015) conducted a comparative study on China's coal demand over the medium and long term with multiple models. Those authors observed that the PSO-DEM model has better prediction accuracy, with a mean absolute error below 2%. Generally, trend extrapolation methods are more accurate for short-term prediction of energy supply and demand although the results of long-term prediction often deviate from the actual value because of the influence of some non-quantifiable factors such as policies not being taken into consideration. By contrast, scenario analysis is based on the policy target of future social and economic development, which enables this method to jettison traditional analytical models. Scenario analysis combines traditional quantitative forecasting and qualitative analysis to approach the prediction subject multi-dimensionally. Scenario analysis has been widely employed to solve problems of energy, water and waste management (Richard et al., 2003; Nie et al., 2010; Yu et al., 2012a; Pingale et al., 2014; Rigamonti et al., 2014). For example, Tao and Li (2007b) applied scenario analysis and the Hubbert peak theory to estimate China's coal production by 2030. Maggio and Cacciola (2012) studied the future trend of global fossil energy production and maintained that global coal production would reach its peak value by 2052 (4.5Gtoe per year).

In fact, the formation of CPC is a complicated process, which is influenced not merely by the supply-and-demand of the market but also by many non-market factors. As a whole, the majority of the existing studies approach the prediction of excess CPC from a single perspective, either the supply perspective or the demand perspective (Tao and Li, 2007b; Lin and Liu, 2010; Mohr et al., 2011; Yu and Wei, 2012; Robert et al., 2013; Nathan and Sanjay, 2014). Rarely are the two perspectives considered together. In this paper, one of the key points in the modeling process is the feedback mechanism that can objectively reflect the fluctuation of coal production capacity using the relevant factors. In terms of research method, the model based on the Hubbert theory fails to reflect the formation mechanism of coal production fluctuation objectively because the factors involved in this model are too few (Wang and Feng, 2016). Moreover, its prediction results rely heavily on a rough estimate of coal reserves (Höök et al., 2010; Lin and Liu, 2010; Maggio and Cacciola, 2012; Wang et al., 2013a; Nathan and Sanjay, 2014). Therefore, this model is generally used for long-term predictions of coal production. Similarly, the conventional linear programming method is too crude and often applied to short-term prediction (Ediger et al., 2006; Ediger and Akar, 2007). To predict coal production capacity scientifically, it is crucial to construct an appropriate moderate-term prediction model to objectively reflect the interaction between China's CPC and its correlative factors; system dynamics is an excellent method in such a situation.

System dynamics can address complicated and highly nonlinear problems by feedback loop coupling, which justifies its wide application in the prediction of coal production. System mechanics, although analyzing the internal feedback structure of the system and its dynamic behaviors, can present corresponding measures to improve system behaviors. Some scholars adopted SD model to do the scenario research regarding China's coal production. For example, Fan et al. (2007) studied the issues of coal industry investment and indirectly predicted the capacity of China's state-owned coal mines; however China's total coal production capacity was not considered systematically. Yu and Wei (2012) took the utilization rate of coal production capacity as an exogenous variable during the model construction of China's coal production estimation, which needs further discussion. Actually, as a reflection of coal productivity, utilization rate of coal production capacity may be influenced by total labor productivity, mechanization degree of coal production, efficiency of assets utilization and so on. Considering the deficiency