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Low-carbon development of China's thermal power industry based on an international comparison: Review, analysis and forecast

Xuejiao Ma[a], Yong Wang[a,b,*], Chen Wang[c]

[a] School of Statistics, Dongbei University of Finance and Economics, Dalian 116023, China
[b] Postdoctoral Research Station of Dongbei University of Finance and Economics, Dalian 116023, China
[c] School of Mathematics and Statistics, Lanzhou University, Lanzhou 730000, China

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ABSTRACT

A comprehensive review of the thermal power industry and the accurate forecasting of carbon emissions can provide valuable information to improve energy efficiency and act as a tool for policy makers to realize sustainable and low-carbon emissions from the thermal power industry. In this paper, we study the low-carbon development of China's thermal power industry based on an international comparison from three perspectives: review, analysis and forecast. Initially, we review both the international and national energy consumption of China; although gaps in energy efficiency still exist between China and countries with advanced thermal power technology, China's thermal power industry is gradually following a low-carbon development route. Then, we analyze low-carbon technologies for thermal power units, including ultra-super-critical technology, integrated gasification combined cycle technology, and carbon capture and storage technology and present a design for environmental protection technology for thermal power units. Carbon emissions should be effectively and successfully handled to improve the prospects of China's thermal power industry. Therefore, this paper forecasts carbon emissions by using a hybrid grey model that is optimized by the firefly algorithm and adjusted by weakening buffer operator based on the calculated carbon emissions. If China's carbon emissions from the thermal power industry increase according to the present rate, China will have difficulty in realizing its carbon reduction target by 2020. Finally, related future policies for the 13th Five-Year Plan of China are proposed based on low-carbon policies around the world with regard to financial, technological and industrial aspects to help the thermal power industry achieve healthy and low-carbon development.

1. Introduction

Electric power, which is an essential component of the energy industry, has become a crucial tool to support the development of society and promote human civilization with the stable and continuous growth of the world economy. According to the Statistical Review of World Energy [1], the world's electricity consumption increased by 17% from 2009 to 2014, with a 52% increase in China and only a 4% increase in America. Since 2011, China's electricity generation has surpassed that of America, and China has become the largest producer of electric power in the world. Based on the International Energy Agency (IEA), thermal power generation, which is the main source of electricity in many countries [2], is a major contributor to the supply of electricity and increase in demand for global primary energy [3,4], which occupies a proportion of 67.4% (as shown in Fig. 1 [5]). Thermal power involves burning fossil fuels, including coal, gas and oil, and their shares are 41.3%, 21.7% and 4.4%, respectively. The total renewable power comprises 22.0%, with 16.2% hydro power, 2.9% wind power, 1.8% bio-power, 0.7% photovoltaic and 0.4% other renewable power. Since 1973, coal-fired power generation has re-

Abbreviations: IEA, International Energy Agency; WRI, World Resources Institute; GDP, Gross domestic product; FYP, Five-Year Plan; WBO, Weakening buffer operators; EIA, Energy Information Agency; IPCC, International Panel on Climate Change; WMO, World Meteorological Organization; UNEP, United Nations Environment Programme; IGCC, Integrated gasification combined cycle technology; CCS, Carbon capture and storage; ELC, Environmental logistic curve; EKC, Environmental Kuznets curve; GM, Grey model; BPNN, Back propagation neural network; SVM, Support vector machine; ANN, Artificial neural network; NGBM, Nonlinear grey Bernoulli model; ARIMA, Auto regressive integrated moving average; FBPN, Fuzzy back propagation network; GNF-IO, grey neural network and input–output combined forecasting model; SOPR, Second-order polynomial regression model; PSO, Particle swarm optimization; FA, Firefly algorithm; NDRC, National Development and Reform Commission; NEA, National Energy Agency; CDM, Clean development mechanism; EO, Environment Office; EPA, Environment Protection Agency; NEO, National Energy Office; SASAC, State-owned Assets Supervision and Administration Commission; GOGPG, General Office of the Guangdong People's Government; SERC, State Electricity Regulatory Commission; SC, State Council; MST, Ministry of Science and Technology

* Corresponding author at: School of Statistics, Dongbei University of Finance and Economics, Dalian 116023, China.
E-mail address: ywang@dufe.edu.cn (Y. Wang).

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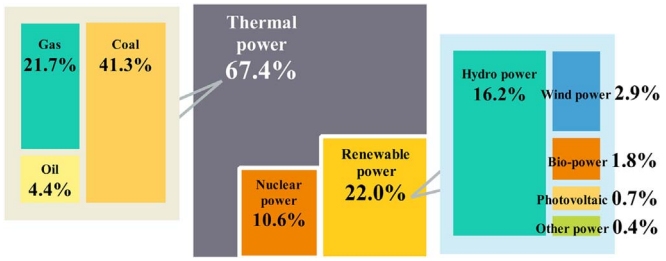

Fig. 1. Sources of global electricity generation in 2013.

mained stable at around 40%. In fact, nearly half of all coals are used to generate electricity. The coal storage on Earth is very rich, especially in China, Russia and America (as shown in Fig. 2 [6]). The global coal storage is estimated to be nearly 13,609 billion tons. Compared to the proven exploitable reserve, only a small proportion has been exploited. According to the annual output of global coals in recent decades and future proven exploitable reserves, the amount of global coals can be exploited for at least another two or three hundred years.

Because of its extensive resources, coal still dominates energy production and consumption throughout the world. Therefore, coal-fired power generation will remain in a dominant position that cannot be replaced in the short run, and other types of energy all play a supportive role for the following reasons:

1. Thermal power has a long history with complete infrastructures. The coal industry has experienced highs and lows in recent decades. Before 2006, the annual coal-fired power generation capacity was 20–25 GW. However, by 2015, this number had increased by 84 GW in the global electricity field. Since 2010, 33 countries have built new coal-fired power plants. According to the IEA, nearly 473 GW coal-fired power plants have become operational from 2010 to 2015. Specifically, until 2012, the coal-fired power generation capacity that was under construction in Europe had surpassed the gas-fired power generation capacity that was under construction. Additionally, Germany, a global pioneer in environmental protection, had increased its coal-fired power generation capacity by 8.5 GW in three and a half years. Holland, Poland and the Czech Republic also developed coal-fired power generation. Some countries are planning to build more coal-fired power plants. According to the World Resources Institute (WRI), approximately 1500 coal-fired power plants will be produced with an installed capacity of nearly 1086 GW. Among them, approximately two thirds are in China and India, while the rest are spread across 59 other countries.
2. Thermal power technology is relatively mature. On the one hand, mature thermal power technology can decrease costs compared to other types of energy, which apparently enhances the competitiveness of thermal power. On the other hand, with the development of science and technology, related technologies to reduce the emissions of pollutants have been researched and developed. For example, people have begun to utilize super-critical thermal power units with high efficiency and low pollutant emissions.
3. In addition to the unique advantages of thermal power, the limitations of other types of energy sources are obvious. The supply of electricity should be steady; however, hydro power fails to meet this requirement because this source is easily affected by the climate, such as droughts. For nuclear energy, the development cost is enormous with low heat efficiency and serious pollution. In terms of renewable energy, such as wind, abandoned wind power has become the bottleneck of wind power's sustainable development [7]. Until 2015, China had exceeded the European Union and become the country with the largest installed wind capacity, occupying nearly a 50% share throughout the world. However, the issue of abandoned wind has plagued China. In 2012, this phenomenon was the most serious, with a rate of abandoned wind of approximately 17%. Thanks to policy guidance and active adjustment, the rate of abandoned wind decreased to 11% and 8.5% in 2013 and 2014, respectively. Nevertheless, the rate of abandoned wind increased to

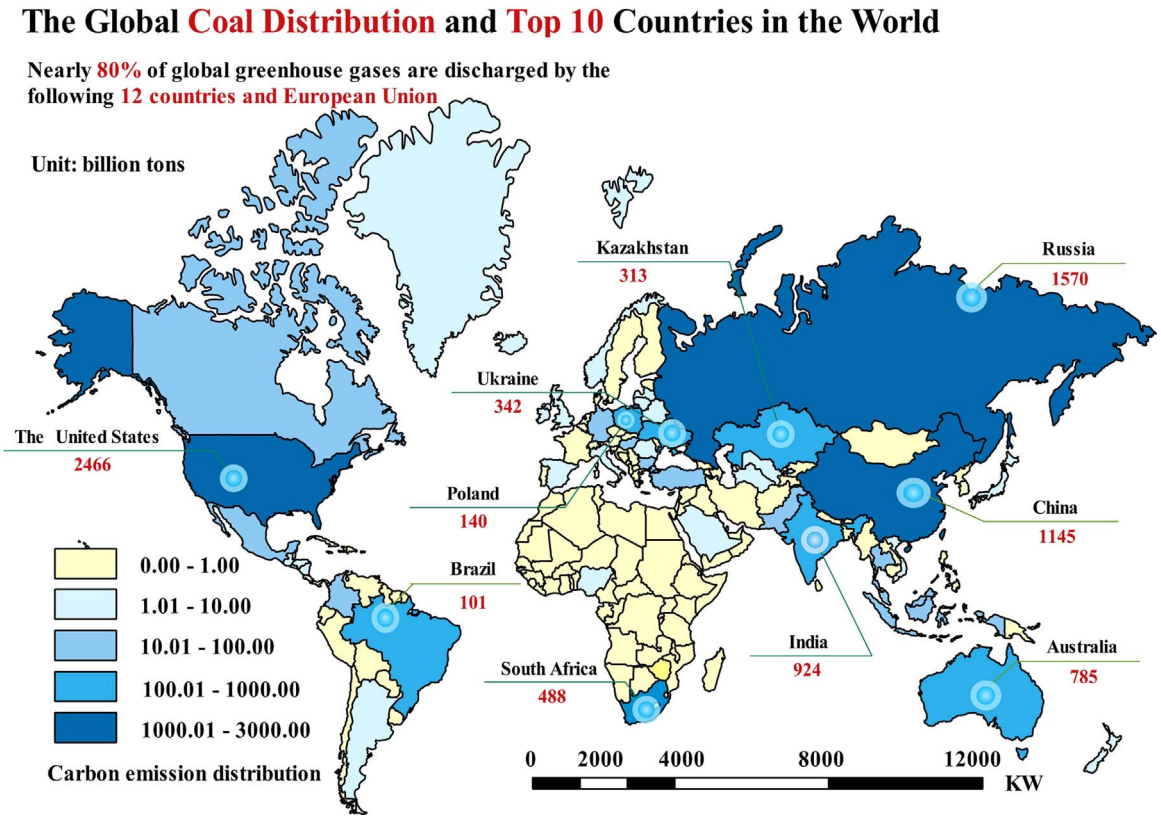

Fig. 2. The global coal distribution.