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Models for forecasting growth trends in renewable energy

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ABSTRACT

The advantages of renewable energy are that it is low in pollution and sustainable. Energy shortages do not apply to renewable energy. In this study, we primarily forecast growth trends in renewable energy consumption in China. Renewable energy is an emerging technology, and thus this study comprises only 22 pieces of sample data. Because the historical data comprised a small sample and did not fit a normal distribution, big data analysis was not an appropriate prediction method. Therefore, we used three grey prediction models, the GM(1,1) model, the NGBM(1,1) model, and the grey Verhulst model, for theoretical derivation and scientific verification. The accuracy and fitness of the prediction models were compared using regression analysis. Regarding the three indicators of mean absolute error, mean squared error, mean absolute percentage error, this study's comparison of the forecast accuracy of the three grey prediction models and regression analysis indicated that NGMB(1,1) had the highest forecast accuracy, followed by the grey Verhulst model and the GM(1,1) model. Regression analysis exhibited the lowest results. In addition, this study confirmed that, for predictions that use small data samples, the modified grey NGBM(1,1) model and the grey Verhulst model had higher forecast accuracy than the original GM (1,1) model did. The models used in this study for forecasting renewable energy can be applied to predicting energy consumption in other countries, which affords insight into the global trend of energy development.

1. Introduction

Renewable energy refers to the use of natural environmental cycles to generate an infinite supply of energy that is nonpolluting [1,2]. Renewable energy includes solar energy, hydropower, wind energy, marine energy, geothermal energy, hydrogen power, and biomass energy. A number of people also call these “green energies” [3,4].

Renewable energy is sustainable and low in pollution and energy consumption. In addition, it is unaffected by energy shortages [4–6]. However, they are influenced by natural conditions—for example, hydraulic, wind, and solar power generation are all necessarily dependent on resource availability [7–9]. In addition, investment and maintenance costs are high, and efficiency is low. Therefore, the costs of power generation are high [10,11]. A number of scientists are seeking new technologies and methods for improving renewable energy. Renewable energy is certain to play an increasingly critical role as Earth's resources are depleted [11–13].

Renewable energy offers renewability and cleanliness as two advantages over conventional energy [14,15].

China surpassed the United States as the number one consumer of primary energy in 2010 and retained this position in both 2011 and 2012, truly becoming a major energy consumer. In 2012, annual growth in Chinese petroleum consumption was 5.3%, which was once again the highest increase in petroleum consumption globally. Chinese coal consumption also constituted 50.2% of global coal consumption in 2012; this marked the first time that China exceeded 50% of global coal consumption. China's primary energy consumption structure remains focused on coal. In 2012, coal was

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67.8% of China's primary energy consumption, followed by petroleum at 18.2% and natural gas at 4.8%. Renewable energy constituted 9.2% of Chinese energy consumption [16].

China is currently the world's second-largest economy, the top energy consumer, and the top emitter of greenhouse gases; however, its energy efficiency remains low. Because of increased global warming, the deterioration of the ecological environment, and shortages in conventional energy, the importance of developing renewable energy has achieved an international consensus. In response to environmental demands and the exhaustion of oil supplies, the development of renewable energy has become the core focus of China's energy policy [17].

On January 1, 2006, China passed the Renewable Energy Law. The purpose of this law is to promote the development and use of renewable energy, to increase the energy supply, to improve the energy structure, to ensure energy security, to protect the environment, and to realize sustainable economic and social development. Renewable energy refers to wind energy, solar energy, hydropower, biomass energy, geothermal energy, ocean energy, and other nonfossil energy sources [17,18].

In addition, China presented the Outline of the Twelfth Five-Year Plan for the National Economic and Social Development of the People's Republic of China. This plan proposed specific indicators for renewable energy: "We hope for renewable energy consumption to reach approximately 10% of total energy consumption by 2015 and 15% of total energy consumption by 2020." Therefore, forecasting the development trends in China's consumption of renewable energy has become a critical task. If the development trends in China's consumption of renewable energy could be predicted accurately, the development direction of renewable energy in China and even worldwide could be determined [17–20].

This study forecasted growth trends in the consumption of renewable energy in China. Because the historical data on renewable energy comprise a limited sample size and do not conform to a normal distribution, forecasting methods used in analyzing large data amounts (e.g., conventional regression analysis, neural networks, and genetic algorithms) are unsuitable.

Deng [21] proposed grey system theory, which is directed primarily at the uncertainties and incomplete information of system models. System relational analysis and model construction are performed. Prediction and decision-making methods are used to investigate and understand the condition of a system. Originally, grey system theory was primarily applied to the control field. It has since been developed for application in other fields including management decisions, socioeconomic research, and weather and water resource forecasting. It is a prediction model that uses quantitative analysis.

Grey system theory is applied primarily in system models with incomplete information, uncertain behavior patterns, and unclear operating mechanisms. It can be used for performing comprehensive analysis, observing system developments, and making long-term predictions. Its most useful feature is that a model can be established using only four pieces of data. In addition, the population distributions of the samples do not require numerous rigorous assumptions to be made. Numerous studies have shown that the GM(1,1) model has extremely high forecast accuracy with small data samples [22–25].

However, multiple studies have also indicated that, although the GM(1,1) model has high accuracy when the experimental sample data exhibits steady growth trends, if the sample data contain substantial fluctuations, the GM(1,1) model must be modified to improve its forecast accuracy. Examples of revised models include the modified nonlinear Bernoulli model and the modified Markov model [26–30].

In this study, we used the GM(1,1) model and two revised models, the nonlinear grey Bernoulli model and the grey Verhulst model, to improve the inadequate diversity of prior forecasting methods while simultaneously increasing forecast accuracy. Theoretical derivation and verification were performed using these three grey prediction models. The forecast accuracy of these models was also compared using regression analysis. Finally, we determined an optimal prediction method from the four prediction models.

2. Literature review

2.1. Development trends in global renewable energy

Along with the trend of environmental sustainability induced by the green revolution of the twenty-first century, the connection between environmental protection and industrial development has changed from contradictory to complementary. The renewable energy industry has become the economic mainstream in the twenty-first century regarding high oil prices and limited resources [14].

Even countries such as United Arab Emirates (UAE) and Russia, which have the most oil reserves worldwide, must use renewable energy. For instance, UAE generated more than 50% of its electricity from oil in 2011. In 2012, its solar power capacity was near zero. The King Abdullah City for Atomic and Renewable Energy project expects to reduce the 50% crude oil and natural gas that is currently used for its electricity supply by developing climate- and environment-friendly solar energy. According to governmental plans, more than 10% of its electric consumption or 5 GW of electricity by 2020 will be generated by solar energy. In 2014, the Minister of Petroleum and Mineral Resources reported in Paris that the goal of UAE was to become a global leader of solar power and wind power, expecting one day to export clean green energy instead of oil [14,15].

Clean Edge published the annual *Clean Energy Trends* report in March 2011, reporting developmental trends in global green energy. Growing 35.2% compared with 2009, the total global output value of major renewable energies such as biofuels, wind power, and solar energy reached $188.1 billion (30 times higher than in 2000) and is expected to reach $349.2 billion by 2020. In 2010, the global production of biofuels, wind power, and solar energy reached $ 56.4 billion, $60.5 billion, and $71.2 billion, respectively; by 2020, it is expected to reach $112.8 billion, $122.9 billion, and $113.6 billion (growth rates of 116%, 103%, and 60%), respectively. It is forecasted that the global renewable energy industry will prosper over the next twenty years [19,20].

2.2. Grey system theory

Jasemi and Kimiagari [31] stated that forecasting is estimating events or situations that an organization is unable to control in the future and providing managers with a foundation for planning. Therefore, forecasting is critical to the decision-making process [32–35].

The "grey" in grey theory is a combination of black and white, where black represents a complete lack of information and white represents complete information. Grey refers to incomplete information; in other words, information that is partially clear and partially unclear. In this study, the characteristics and structure of the system itself were explored. Information is supplied at appropriate times to allow the system to shift from grey to white. This prompted the development of grey theory. The real world contains numerous systems, which may contain multiple subsystems while simultaneously being enclosed by multiple subsystems. Because systems comprise complex and multileveled

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