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Risk analysis and aversion of renewable energy supplies in China based on the Monte Carlo stochastic simulation method

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Abstract: In China, the power industry is thermal power dominated and it is facing the risk of insufficient supply of coal and other non-renewable fossil fuels. In addition, in the power generation process, the thermal power units using fossil fuels will generate a large number of emissions of pollutants, and directly harm the ecological environment. Therefore, China urgently needs to add renewable energy sources. This paper makes risk recognition and analyzes the planning process of renewable energy generation. The probability distribution and Monte Carlo simulation method are applied to analyze risks quantitatively, and then a risk evaluation model of renewable energy supplies is established. Meanwhile, taking wind power as an example, a sensitivity analysis is performed to analyze the various risks. Finally, risk aversion of renewable energy supplies is studied and the measures of risk aversion are raised in order to propose reasonable suggestions with regards the development of renewable energy generation in China.

Keywords: Renewable energy, Risk analysis, Probability distribution, Monte Carlo Simulation, Sensitivity analysis, Risk aversion.

1. Introduction

China's electric power industry is dominated by thermal power and currently faces concerns over the insufficient supply of non-renewable fossil fuels such as coal. In addition, in the generation process thermal power units, which use fossil fuels, release large amounts of pollutants that directly endanger the ecological environment. Therefore, China urgently needs to reduce its coal consumption and pollutant emissions based on existing power structures, increase the installed capacity of its hydropower, wind power and other renewable energy sources, and improve its power structure. However, renewable energy power supplies have also had various uncertain risks until now.

Theoretical study of risk analysis is generated by the formation and development of the international engineering and construction market. With the gradual deepening of risk analysis, researchers have proposed extreme risk models, probability risk models, grey stochastic risk models, fuzzy mathematical risk models and risk analysis of maximum entropy models. In the probabilistic risk analysis model, analytical method and random simulation method parameters are commonly used. The risks of generating electricity with renewable energy have been studied by scholars at home and abroad. The work [1] introduced two methods of the risk analysis, the Monte Carlo simulation method and the time sequence method. The authors in [2, 3]and [4] analyzed the insurance of energy risk and risk problems. [5] used the grey multilevel evaluation method to evaluate the risks of a renewable energy vehicle project in Henan province. According to the current development of renewable energy vehicles, a risk evaluation index system was also established. At the same time, the rough sets theory and the improved grey multiple evaluation method were used to evaluate the project. The authors in [6–8] studied the risks when taking wind energy as the main object. The work [9, 10] analyzed the risks by taking solar energy as an example while [11] studies nuclear energy. According to most of the researchers mentioned above, although the technical risks of renewable energy generation have been studied, a complete and scientific index system and evaluation method, which is used to evaluate the whole risks of renewable energy generation in a specific condition, have still failed to form. So, an overall quantitative conclusion can not be brought about. The work [12–14] applied the mean-variance analysis (MV) method to study

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the risks of investment portfolios and practical applications. [15] introduced a model based on an investment framework of renewable energy in the Spanish power market, and expounded that in a power market, risk should be minimized while investment return is maximized as far as possible. The work [?] proposed a new coherent risk measure called iso-entropic risk measure. [?] proposed Fuzzy consistent matrix to sovle the risk. However, the references above fail to deeply analyze and evaluate the risks of China's renewable energy. In addition, risk aversion also needs to be studied.

With the rapid development and application of number theory (especially the theory of mathematical statistics) and computer simulation analysis technology, the Monte Carlo method, i.e. the Stochastic Simulation Method shows a good prospect. Based on the Monte Carlo stochastic simulation method, this paper performs a risk analysis and risk aversion of renewable energy supplies in China. In the first part we identify the risk source of renewable energy supplies. The second part is a comprehensive evaluation of renewable energy supply risk based on the Monte Carlo simulation method by using the probability distribution of various sources of risk, and analyzing and calculating the case, then obtaining the influence value of risk factors on the renewable energy and total supply value of various renewable energy sources by considering various risks. Using wind power as an example, the third part draws a conclusion that economic and policy risks have small sensitivity while natural and technological risks have great sensitivity through the sensitivity analysis. Similarly, we can analyze risks of a variety of other renewable energy sources and general renewable energy in China by this method, and target those to avoid.

2. Overview of renewable energy in China

2.1. Problem description

The energy production structure of China is shown in Fig. 1 , the proportion of coal, the main supply, is more than 70%. Therefore there is an urgent need to adjust the energy structure, to provide alternative energy for power generation. The leading industry of the electric power industry now is thermal power, but non-renewable fossil fuels such as coal are in short supply, have a limited reservation and no environmental protection, so it is necessary to develop new renewable energy. China's renewable energy development and utilization have made significant progress, as shown in Table 2.1. At the end of 2010, China's total wind power capacity reached 35 million kilowatts, ranking second in the world for wind power capacity. Biomass, nuclear energy, geothermal energy, hydrogen energy, ocean energy and other renewable energy development have great potential, and have received greater development in recent years.

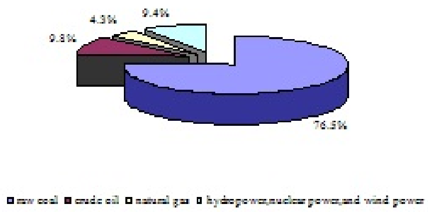

Figure 1 China's basic energy production structure in 2010.

The types of renewable energy	Year 2010	Year 2020
Small Hydropower	5000	7500
Wind Power	3500	15000
Biomass power generation	550	3000
Solar power	200	2000

3. Probability distribution of renewable energys major risk sources

The electric power supply of renewable energy can be divided into four types according to the source of risks, including technical risks, natural risks, economic risks and policy risks. Based on the Delphi method, the recognition of risk sources can be distinguished from wind energy, solar energy and other renewable energy, respectively. We take wind energy and solar energy for example.

3.1. Natural risk assessment

3.1.1. Natural risk assessment of wind energy

Wind speed is intermittent and uncontrollable, it has brought more uncertainty to the power system that connects large-capacity wind power to the grid. The power output of wind turbines change with the wind speed, so it is necessary to study the change and distribution of wind speed before determining the output power of the wind turbine. The Weibull distribution of the two-parameter curve is considered to be the most suitable probability density function for the statistical description of wind speed[2,18,19], the probability density function can be expressed as Eq. 1.

$$f(v) = \frac{k}{c}(\frac{v}{c})^{k_1} exp[-(\frac{v}{c})] \tag{1}$$

where v is an average wind speed during some wind speed segment; k and c are the two parameters of the Weibull distribution, k is the shape parameter and c is the scale parameter.

The parameters of the Weibull distribution can be calculated approximately by wind speed v and the standard

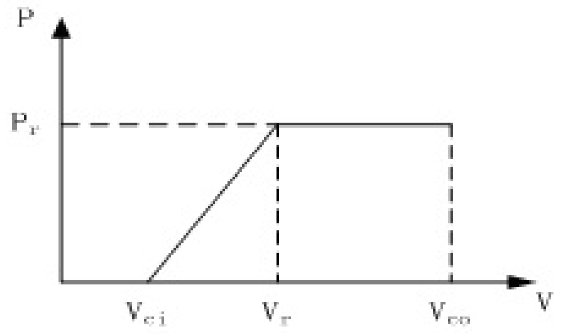

Figure 2 Power output curve of wind energy.

deviation σ, and the formulas can be expressed as Eq. 2 and Eq. 3.

$$k = (\frac{\sigma}{v})^{-1.086} \tag{2}$$

$$c = \frac{v}{\Gamma(1+\frac{1}{k})} \tag{3}$$

where Γ is the Gamma distribution.

Through the approximate relationship between the output power of the wind turbine and wind speed, the random distribution of the output power can be obtained. The functional relation between the output of the wind turbine and wind speed is shown in Fig. 2. Among them, P_r is the wind turbine rated power, v_{ci} is the cut in wind speed, v_r is the rated wind speed, v_{co} is the cut out wind speed.

From Fig.2, the functional relationship between the output power P_w of wind power generation and the wind speed v can be obtained, and the formulas can be expressed as Eq. 4, Eq. 5 and Eq. 7.

$$P_w = \begin{Bmatrix} 0, & 0 \le v \le v_{ci} \\ k_0 v + k_2, & v_{ci} \le v \le v_r \\ P_r, & v_r \le v \le v_c o \\ 0, & v > v_{co}. \end{Bmatrix}. \tag{4}$$

$$k_1 = \frac{P_r}{v_r - v_c i} \tag{5}$$

$$P_w = \begin{cases} 0, & 0 \le v \le v_{ci}; \\ k_1 v + k_2, & v_{ci} \le v \le v_r; \\ p, & v_r \le v \le v_{c0}; \\ 0, & v > v_{c0}. \end{cases} \tag{6}$$

$$k_2 = -\frac{k_1}{v_c i} \tag{7}$$

According to statistics, wind speed maintains between $v_c i$ and v_r most of the time, based on Eq. 4, the relation between P_r and v approximates linear function, so the probability density of wind energy active power can be obtained as follows.

$$f(P_w) = \frac{k}{k_1}(\frac{P_w}{k_1 c})^k exp[-(\frac{P_w - k_2}{k_1 c})^k] \tag{8}$$

3.1.2. Natural risk assessment of solar energy

Solar cells are the foundation and core of the photovoltaic generation system, its output power is closely related to light intensity. Due to the randomness of the light intensity, the output power is also random. According to statistics, solar light intensity in a certain period of time can be approximately regarded as the beta distribution, the probability density function can be expressed as Eq. 9.

$$f(r) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}(\frac{\gamma}{\gamma_m ax})^{\alpha-1}(1-\frac{\gamma}{\gamma_m ax}^{\beta-1}) \tag{9}$$

where γ is the actual light intensity in this period, $\gamma_m ax$ is the maximum light intensity in this period, α and β are the shape parameters of the beta distribution, Γ is the gamma distribution. Here, it is assumed that given a solar cell square which has M battery components, the area and the photoelectric conversion efficiency of each component are A_m and η_m , respectively, so the total output power can be obtained as Eq. 10:

$$P_M = \gamma \text{A} \eta \tag{10}$$

where P_M is the total output power, A is the total area of the square, η is the total square photoelectric conversion efficiency.

$$A = \sum_{m=1}^{M} A_m \tag{11}$$

$$\eta = \frac{\sum_{m=1}^{M} A_m \eta_m}{A} \tag{12}$$

The probability density function of light intensity can be calculated by Eq. 10, so it can be obtained that solar cell array probability density function of output power also follows beta distribution, the formulas can be expressed as Eq. 13.

$$f(r) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}(\frac{P_M}{R_M})^{\alpha-1}(1-\frac{P_M}{R_M}^{\beta-1}) \tag{13}$$

where the formula $R_M = \gamma A \eta_m ax$ is the maximum output power of the matrix.

3.2. Technical risk assessment

3.2.1. Technical risk assessment of wind energy

According to historical data, the exponential distribution function is well fitted among the probability distribution of the core technology risk. The distribution function can be expressed as Fig. 3, and the formula is as Eq. **??**.

where r is the determined value of the wind energy technological progress, $r > 0$ stands for there being a certain degree of progress in technology, while $r \le 0$ stands for the opposite.$f(r)$ is the distribution function when the

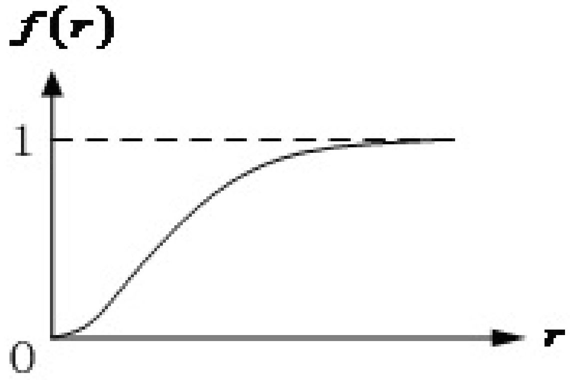

Figure 3 The function curve of influence value of technological advances on the risk.

determined value of wind energy technological progress is r.

The wind power output is P_f and technological progress coefficient is r. After the emergence of technological progress, the formula can be expressed as Eq. 14.

$$P_f = P_w e^{rt} \tag{14}$$

where P_w is the output power of wind generation before the existence of technological progress, t is the numbers of years for the continuous application of technology. Through Eq. 14 can we can obtain that also follows exponential distribution. Through Eq. 14 can we can obtain that P_f also follows exponential distribution.

where λ is the parameter.

3.2.2. Technical risk assessment of solar energy

The main technical risk faced by solar energy is the risk of technological progress, namely, if it is difficult to break through when a certain stage of technology has been reached, then the exponential distribution function is well fitted to the core technology risk. The relation between solar energy supply after the existence of technological progress P_f' and the technological progress coefficient r can be expressed as Eq. 15

$$P_f' = P_M e^{rt} \tag{15}$$

where P_M is the output power of solar cell array, P_f' is the solar energy supply t is the continuous application of technology. Similarly, P_f' follows the exponential distribution.

3.3. Technical risk assessment of solar energy

The major risk sources of wind power and solar power can be generally summarized as follows: financial risk, market risk and so on. After making a comprehensive analysis of these risk sources from a profitable view, we use the 0C1 distribution to analyze the economic risk. The distribution function of the 0C1 distribution is shown as Eq. 16.

$$f(k) = (1-p)^k p^{1-k}, (k = 0, 1) \tag{16}$$

where $f(k)$ is the probability distribution function of economic risk, p is the profitable probability of renewable energy development, k is the profitability determination value of renewable energy development, that is, if the formula $k = 1$, the development of renewable energy will gain profits, otherwise, $k = 0$. Power plants adjust their output power based on how much profit they earn, for the convenience of research, we can regard it as a simple linear function. So the relation between the output power of wind generation P_g' and profit coefficient k caused by economic risk factors can be expressed as follows.

$$P_g = P_w k \tag{17}$$

where P_g , P_w stands for the output power of the wind generation plant before and after the existence of profit respectively, due to the size of generated energy being affected by the number of profits generation enterprises earn, the output power will change after the existence of profit. Similarly, the relation between output power of solar power generation P_g' and profit coefficient k caused by policy risk factor can be expressed as follows.

$$P_g' = P_M' k \tag{18}$$

where P_g', P_M' stands for the output power of the solar generation plant before and after the existence of profit respectively. Based on Eq. 17 and Eq. 18, it can be concluded that P_g and P_g' obey 0C1 distribution.

$$f(P_g) = (1-p)^{P_g} p^{1-P_g}, (k = 0, 1) \tag{19}$$

$$f(P_g') = (1-p)^{P_g'} p^{1-P_g'}, (k = 0, 1) \tag{20}$$

3.4. Policy risk assessment

According to the characteristics of policy factors, based on historical data, statistics and fitted price policy, industrial policy probability distribution, the policy risk of wind power and solar power is well fitted by exponential distribution. The distribution function using the following formula function can be expressed as follows.

where x is the degree of policy support to wind power,$x \leq$ 0 stands for there is no support from the policy while 0 <x≤ 0 stands for there is support of policy to some degree, λ is the parameter. The relation between output power of wind generation P_l and the degree of policy support x caused by policy risk factor is expressed as follows.

$$f(P_l) = \left\{ \begin{array}{ll} 0, & x \leq 0 \\ P_w(1-e^{-\lambda x}), & 0 < x \leq 0 \end{array} \right\}. \tag{21}$$

The relation between the output power of solar generation P_l' and the degree of policy support x caused by policy risk factors is expressed as follows.

$$f(P_l') = \begin{cases} 0, & x \leq 0 \\ P_M(1 - e^{-\lambda x}), & 0 < x \leq 0 \end{cases} \quad (22)$$

Based on Eq. 21 and Eq. 22, and both obey the exponential distribution.

$$f(P_l) = 1 - e^{-\lambda P_l} P_l > 0) \quad (23)$$

$$f(P_l') = 1 - e^{-\lambda P_l'} P_l' > 0 \quad (24)$$

4. Comprehensive risk evaluation of renewable energy supplies

4.1. Establishing the comprehensive risk evaluation model of renewable energy supplies

A risk assessment model of renewable energy supplies based on considering the above probability distributions of risk factors can be established as follows.

$$V = S - R \quad (25)$$

where V is the renewable energy generation power considering the risk; S is the total generation power of renewable energy; R is the risk value which reflects the impact of various factors to the renewable energy power generation.

$$R = P \times I_i \quad (26)$$

where P is the occurrence probability of integrated risk for the renewable energy; I_i is the renewable energy supply considered risk factors.

$$I_i = \sum_{i=1}^{n} P_i(e^{r_i t} + k_i + 1 - e^{-\lambda x_i}) \quad (27)$$

where i is the total class of renewable energy; P_i is the generation output power of renewable energy under the natural risk; n is the total number of renewable energy; $e^{r_i t}$ is the technology progress coefficient of species i renewable energy; k_i is the profitability determination value of the of species i renewable energy; $1 - e^{-\lambda x_i}$ is the degree of influence that policy has impact on the development of species i renewable energy.

4.2. Comprehensive risk evaluation of renewable energy supplies based on the Monte Carlo method

It is assumed that technical, natural, economic and policy risk factors are considered in a given function.

$$Y = f(x_1, x_2, x_3, x_4)) \quad (28)$$

where variables x_1, x_2, x_3, x_4 represent technical, natural, economic and policy risk factors, respectively, combined the previous section analysis of the probability distribution followed by the various risk factors of wind energy, solar energy and the impact on supply capacity, based on the Monte Carlo method and using a random number generator, the values of a set of random variables can be obtained directly and indirectly. Then by following the corresponding function relationship between X and Y, the corresponding expression Y_i can be obtained, namely,$Y_i = f(x_{1i}, x_{2i}, \ldots, x_{ni})$.

5. Case Study

5.1. Basic data

Recently, in order to respond to low-carbon energy policy positively, a thorough and effective planning of renewable energy needed to be developed in the city, and supply capacity risks needed to be evaluated. In the city, the average annual sunshine hours are between 2200 and 3000 hours. The total installed capacity of solar energy is 70000kW. Wind energy density is 100C150 watts per square metre. The most rapid wind speed reaches 25m/s. The total installed capacity of wind energy is 50000kW. So wind and solar energy can be used in the urban area. For a variety of renewable energy reserves, and in order to facilitate the analysis, wind energy and solar energy are regarded as the main objects, and other energy analysis is ignored.

5.2. Integrated risk assessment of wind energy and solar energy

(1) Based on the probability distribution of risk factors which affect wind and solar energy, the values of random variables are randomly selected by Monte Carlo simulation. So the risk probability of wind and solar energy is 17.02%.The risk probability distribution is shown in Fig. 4.

(2) According to the basic data, Eq. 4 and Eq. 10, and considering the natural risk factors, the expected output power of wind and solar energy are 48690kW, 68900kW, respectively. (3) According to probability distributions of risk factors which affect wind and solar energy and Monte Carlo simulation, the probability distributions of wind and solar energy are shown in Fig. 5 and Fig. 6, respectively and the risk probability values are 9.35% and 7.655%. Finally, based on Eq. 8 and considering the risk, renewable energy supply is 119375.31kW.

(4) According to Eq. 2 and Eq. 3, the impact value of risk factors on renewable energy is 1672.52kW. The total output power of wind and solar energy are 118327.48kW.

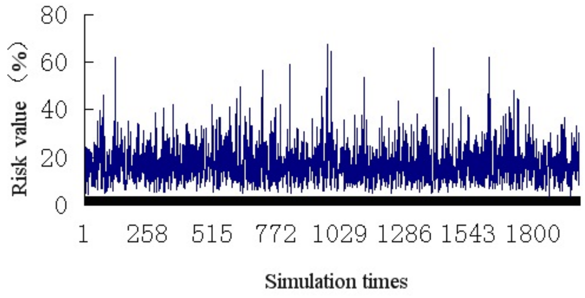

Figure 4 Risk probability distribution of wind energy and solar energy based on Monte Carlo.

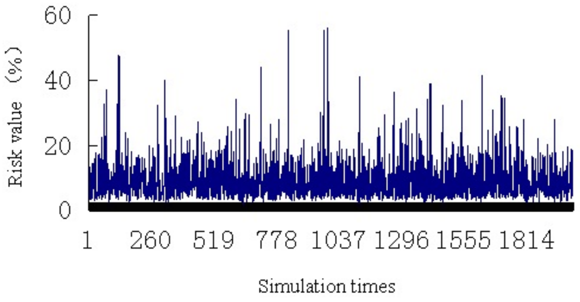

Figure 5 Risk probability distribution of wind energy based on Monte Carlo simulation method.

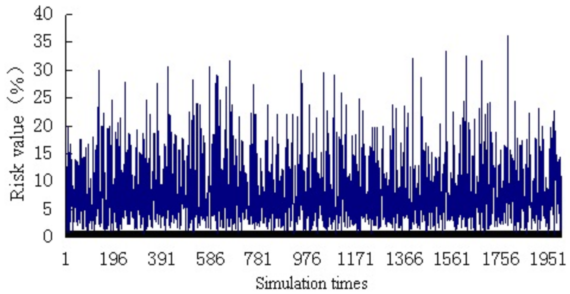

Figure 6 Risk probability distribution of solar energy based on Monte Carlo simulation method.

6. Sensitivity analysis

Based on the analysis of these four risk factors, the results of sensitivity analysis are shown in Fig. 4 when risk indicators are changed by 10 and 20% sensitivity.

Figure 7 shows that the costs of transmission, operation and maintenance and some economic risks indicators have little effect on evaluation results and shows weak sensitivity. Wheel height and some technology indicators show some strong effect and sensitivity on the results. But

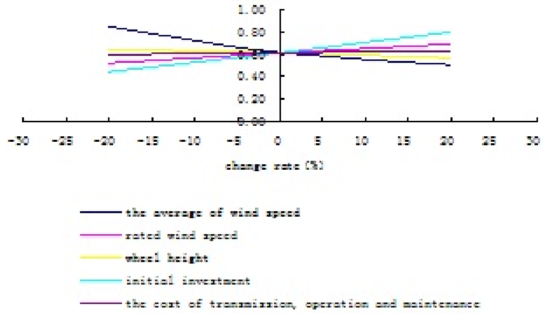

Figure 7 Sensitivity analysis of risk indicators.

initial investment, average wind speed, rated wind speed and some other policy and nature indicators have a great impact on the evaluation results and show their strong sensitivity to the results. Therefore, the policy support from the government is really important, enterprises should focus on how to improve the localization rate of wind turbines, how to use advanced technology to reduce the fan cost and how to make the assessment level of fan resources better in the planning and management process. Based on this analysis, enterprises can develop good risk aversion measures, reduce the risk of the use of wind power and promote China's wind power industry in sustainable development.

7. Conclusions

Based on Monte Carlo simulation, a risk evaluation model of renewable energy supplies is established and a reasonable risk evaluation method of renewable energy projects is provided. Finally taking a specific city as an example, the analysis results show that this model is credible and practical. The Chinese government should play a harmonizing role in the process of renewable energy planning in order to avoid the risks, strengthen the research and development of renewable energy technologies and reserves. The mechanisms of risk-share and benefit-share should be established to increase the investment subjects, bring in venture capital, and establish cooperation.

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