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How to Determine the Critical Conditions of China's Renewable Energy Investment Decision?

Min Fu[a, *], Peilin Xu[a], Lixin Tian[a,b], Zhiyan Shi[a], Xiaomeng Gu[a]
a. Nonlinear Science Research Center, Jiangsu University, Zhenjiang, Jiangsu, 212013. P.R. China
b. School of Mathematical Sciences, Nanjing Normal University, Nanjing, Jiangsu, 210023. P.R. China
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Abstract: Based on the theory of binomial tree in the real options, this paper establishes an investment decision model that can evaluate the development of renewable energy and considers three factors: the price of carbon, feed-in tariff and the progress of technology. Take China's wind power generating project as an example, by dividing the wind resources into five parts, this paper makes scenario analysis of the effects of different feed-in tariff on the investment decision. The critical conditions to invest the wind power generation project are achieved.

Keywords: renewable energy; wind power generation; investment decision; binomial tree.

1 Introduction

With energy crisis and environmental pollution becoming more and more serious, the investment in the development of renewable energy resources is increasing rapidly. As a kind of clean and sustainable energy, renewable energy has gradually become an important part of sustainable development strategy in many countries. However, each development step of renewable energy can not be separated from the support of policies and laws. Globally, those renewable energy policies and laws that have been proposed or are being implemented can be divided into three main categories. The main is mandatory policy, while the others are guidance and voluntary. For example, the U.S. government issued Energy Policy Act and approved product tax credits to promote wind energy in 1992 [1]. In the market developing period, they also introduced feed-in tariff, fixed plus system and renewable energy portfolio standards to stimulate the supply and potential development of renewable energy. In 1997, the European Union (EU) issued the first development strategy white paper on renewable energy [2]. In March 2004, EU was committed to reduce its greenhouse gas emissions to at least 20% below 1990s levels by 2020 [3]. Among these EU members, UK implemented the Non-Fossil Fuel Obligation to promote the steady development of renewable energy in 1990 [4]. Spain achieved its support of renewable energy generation mainly by the No. 54 Electricity Law issued in 1997 [5]. The Dutch government issued a new electricity law in 1998 that developed a series of standards on the production, transportation and supply of electricity and carried out the green certificate program [6]. In the view of mandatory policy, it includes mandatory quota system (such as United States, Australia, UK and France), compulsory purchase system (such as Greece, Spain, Denmark and Germany) and Procurement System (such as UK in the 1990s and China). In 2009, China put the strategy of exploring the renewable energy and other emerging industries to a national height and set the goal that China's non-fossil energy will account for 15% in the primary energy consumption in 2020 [7]. Under the promotion of the renewable energy law and supporting policy, the renewable energy industry will develop rapidly and attract more and more investors.

However, due to the multiple characteristics of huge amount, long period and high risk, many investors are not willing to make investment. Enterprises generally adopt the traditional net present value (NPV) method to assess the value of a project, while the traditional NPV method ignores the flexible value and strategic value contained in the uncertain investment projects. The real option theory just makes up for the deficiencies of traditional NPV method and can evaluate the initiative of investment adjustment. It has been widely used as an investment decision-making method under the

*Corresponding author. *E-mail address*:fmwwjk@163.com

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conditions of uncertain environment. The real option method mainly includes Black-Scholes model and binomial tree method. Compared with the Black-Scholes model, binomial tree method has three advantages. Firstly, it can surmount the real option method, dealing with the complexity of the real option. Secondly, it retains some characteristics of the discounted cash flow analysis method and thus provides convenience for users. Thirdly, it can show the uncertain results in a clear and concise manner for its simple and visual characteristics.

Therefore, this article applies the theory of binomial tree to the establishment of a renewable energy investment evaluation model and takes wind power project as an example for further analysis. According to the reserves of actual wind energy in China, this paper divides the wind energy resources into five kinds, namely rich area, comparatively rich area, general area, comparatively poor area and poor area, and then makes scenario analysis of the effects of different feed-in tariff on the investment decision value, and finally achieves the critical conditions of investing the wind power generating project under different situations. The organization, for the remainder of this research, is as follows: Section 2 devotes to provide a literature review; section 3 considers the influential factors; section 4 contains a description of the model; section 5 describes the parameters in the model; section 6 is an empirical analysis; section 7 presents the conclusions and suggestions based on the results of section 6.

2 Literature review

The real options analysis (ROA) technique has been adopted as the analytical tool for evaluation of RE investment projects and overall benefit for RE development planning in recent years. By applying the real options model, Venetsanos et al. [8] valued wind power investment projects and assessed the profitability of wind power plants within a competitive market environment. They also considered six uncertain factors in an investment project, including environmental regulations, fossil fuel price, supply, demand, initial capital cost and technology, and market structure. Based on the classic text proposed by Dixit and Pindyck [9], Kjaerland [10] analyzed hydropower investment in Norway, considering the fluctuations of fossil fuel price, water resources, risk-free interest rate, investment cost, variable costs, and the best investment time. Lee [11] established a policy benefit evaluation model that can integrate the cost efficiency curve information of renewable power generation technologies into real options analysis methods. He also quantitatively evaluated the policy value of developing renewable energy (RE) under the conditions of uncertain fossil fuel prices and RE policy-related factors. Martłnez-Ceseña et al. [12] proposed a method that relied on the theory of real options to incorporate the uncertainty of the wind power projects while planning and designing wind power projects. It was illustrated that circumstances and assumptions could improve and weaken the effectiveness of the method. C. Palanichamy et al. [13] presented an investment proposal for a 10MWwind farm project, which would be a useful guideline for investors looking for investment opportunities in Mauritius. Jun, S.Y. et al. [14] studied the economic and environmental influence of renewable energies on existing electricity generation market of South Korea with energy-economic model and considered the alternative scenarios. In each alternative scenario analysis, alternation trend of existing electricity generation facilities is analyzed and the cost of installed renewable energy plants and CO2 reduction potential was assessed quantitatively.

In China, relative researches have just started. Based on the investment environment in China, Li, C.B. et al. [15] constructed a process which initially simulated NPV with Monte Carlo method and verified the credibility and accuracy of proposed simulation process, then simulated the NPV and evaluated the investment payback periods as well as IRR under different grid-connected ratios in two conditions. The simulation results indicated the proposed case having high investment risk, so afterward general suggestions on mitigating the investment risks of wind power project in China were presented. Zhu and Fan [16] presented a carbon capture and storage (CCS) investment evaluation model, considering uncertainties from carbon price, thermal power with CCS generating cost, existing thermal power generating cost, and investment in CCS technology deployment, and took China as a case study. The results indicated that the current investment risk of CCS was high, and climate policy had the greatest impact on CCS development.

Based on the above-mentioned researches, this paper, for the sake of enterprises, evaluates the renewable energy investment and has several differences with previous research. First, we use binomial tree method to deal with renewable energy investment problems. This model can reflect the irreversibility and uncertainty of project investment in the same decisional frame. Second, it divides China's actual wind power resources into five different situations to study the investment in different regions. Third, it has considered the cost of wind power project, especially periodically considering the operation and maintenance cost (O&M cost). It is believed that O&M cost changes over time, rather than being simply set to a constant sum. Fourth, it presents the critical conditions of investing and developing the project, thus provides an intuitive guidance and useful judgment for enterprises. All these mentioned above are not available in the precious studies.

3 Main factors in the model

3.1 Carbon emissions trading

Carbon emission trading is a kind of contracting from which the buyer can obtain the right to emit certain amount of greenhouse gas by paying the seller. Practically speaking, the government first sets a total ceiling of the greenhouse gas emissions, and then authorizes or sells the limited discharge permit to the enterprises. Within the required period, if the enterprise's emission exceeds the limit, it has to buy extra carbon emission credits on the carbon exchanges. On the other hand, if the enterprise's emission is lower than the ceiling, it can sell its surplus quota. As RE projects hardly produce greenhouse gas emissions, enterprises can get profits by selling their certified emission reduction (CER) on the carbon exchanges. Obviously, carbon trading can promote RE projects partially or fully offset the high cost of the investment through interest adjustment mechanism. It is one of effective ways to promote the reduction of carbon emissions. So far, a number of large-scale carbon emission trading systems or centers have formed in the international community, such as EU Emission Trading System, CDM projects trading market under the Kyoto Protocol, EU Climate Exchange (ECX) and Chicago Climate Exchange (CCE). China is participating the transferring the right of carbon emissions mainly through the CDM project on the international market. That is to say, if a power generation enterprise's carbon emission is below the original level, it can sell the certificated lower parts to the international market. At present, China has set up carbon emissions trading pilot projects in seven cities, including Beijing and Shanghai. On June 18, 2013, Shenzhen officially launched the first carbon trading market. However, on the current situation, there is not any mature carbon trading market in China, thus the price of CER will be subject to the international trading market. Therefore, the price fluctuation of international carbon trading market is an uncertain factor in the RE investment projects.

3.2 Feed-in tariff

A RE power generation enterprise's income mainly comes from the sale of electricity to the power grid. So the price of feed-in tariff will directly affect the investment decision of RE power generation project. Take wind power generation as an example, from 1980s, China's grid-connected wind power has experienced three stages: initial demonstration phase, building phase, large-scale development and localization stage. At the end of July 2009, China's State Development and Planning Commission (SDPC) issued "a notice on improving the electricity pricing policy of grid-connected wind power", which set the benchmark electricity price of grid-connected wind power according to different resource zones. The four types of wind feed-in tariff were 0.51 yuan/kWh, 0.54 yuan/kWh, 0.58 yuan/kWh and 0.61 yuan/kWh respectively [17].

3.3 Technological progress

The renewable technologies might outperform the conventional power plants, in additional to their advantage of no emitting CO_2. However, the main disadvantage of such "green" technologies is their high fixed cost, which has so far inhibited the large-scale diffusion of renewable technologies in the electricity sector amongst other factors. Proponents of renewable energy have pointed to the fact that these costs are subject to major reductions as technological change progresses. However, technological improvement itself is an inherently uncertain process, which needs to to be taken into account when making renewable energy investment decisions. For many products of RE, unit costs decrease with increasing experience. The idealized pattern describing this kind of technological progress in a regular fashion is referred to as a learning curve, progress curve, experience curve, or learning by doing. In its most common formulation, unit costs decrease by a constant percentage, called the learning rate, for each doubling of experience. The concept of learning curve was first proposed by Wright [18]. While studying the experience of aircraft manufacturing, Wright discovered that the cumulative average unit time would decrease by about 20 percent when the cumulative production of plane doubled. It implied that the cumulative average unit time reduced to 80 percent of the original time. At present, the wind power equipment has had relatively mature and commercial technology. The cost has dropped significantly for the constantly digestion and absorption of foreign advanced technology, breaking the foreign technical barriers and localization of key spare parts. Di [19] studied the impact of technology innovations on cost of China's wind-power industry and discovered that the learning rate of wind power was 12.7 percent until 2012 . Based on this, we set China's investment cost of wind power equipment decreased by 13 percent annually. Assuming the total investment cost of wind power equipment under the present technical condition is I_0, t years later it will turn to I_t, then we get

$$I_t = I_0 \times e^{-0.13t}. \tag{1}$$

4 Model description

4.1 The binomial tree model of carbon emission price (carbon price)

According to the analysis in the section 3.1, the carbon price is influenced by the international carbon trading market changes. As the volatility of carbon trading market, this process is considered as random. For volatile carbon price mechanism, a stochastic process can well reflect the trend of price changes and volatility. Thus in previous related studies [16, 20, 21, 22, 23], carbon prices were assumed to follow the geometric Brown motion. Then we can get Black-Scholes model of carbon prices.

$$dC = \gamma C dt + \sigma C dz \quad (2),$$

where, C is carbon price; dz is the independent increment of Wiener process $dz = \varepsilon\sqrt{dt}$; ε is a normally distributed random variable with mean 0 and standard deviation 1;γ and σ represent the drift and variance parameters of carbon price respectively.

The binomial tree model is a discrete form of Black-Scholes model mentioned above, which was proposed by Cox in 1979. It is more suitable for dealing with complex options. Therefore we use the binomial tree model to describe the carbon price here. Let $C(k, i)$ be the variability in carbon price with k periods elapsed in the RE development planning lifetime and i upward movements to date. For an initial carbon price represented by $C(0, 0)$, the carbon price for the next period is stochastic and can be valued in two ways. It may increase to $uC(0, 0)$ with the probability of $p$or decrease to $dC(0, 0)$ with the probability of $1 - p$.

$$\begin{cases} C(1,1) = uC(0,0), \text{with probability is} p; \\ C(1,0) = dC(0,0), \text{with probability is } 1-p. \end{cases} \quad (3)$$

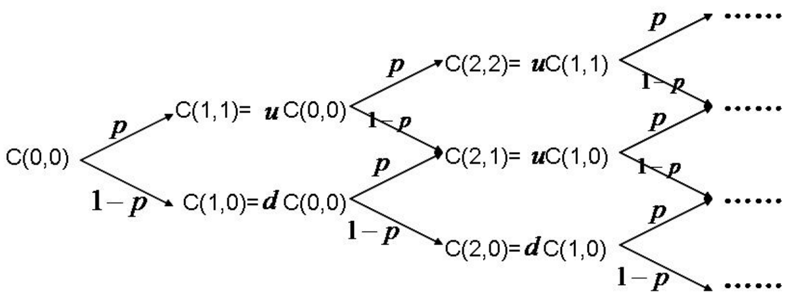

Figure 1: The carbon price of binomial tree stochastic process.

Each node will produce two different results to the next period. Thus we can get the binomial lattice stochastic process of carbon price as Fig. 1 shows. Consider a general node $C(k, i)$, at the next period it turns into:

$$\begin{cases} C(k+1, i+1) = uC(k,i), \text{with probability is } p, 0 \le k \le T, 0 \le i \le k; \\ C(k+1, i) = dC(k,i), \text{with probability is } 1-p, 0 \le k \le T, 0 \le i \le k. \end{cases} \quad (4)$$

By using incomplete inductive method, we can obtain

$$C(k, i) = C(0, 0)u^i d^{k-i}, 0 \le k \le T, 0 \le i \le k. \quad (5)$$

where, C is carbon price; k is time period($0 \le i \le k$); T is the number of time periods; n is the number of volatility periods; u is the range of carbon price upward movement, $u = e^{\sigma\sqrt{T/n}}$; d is the range of carbon price downward movement, $d = 1/u$; $p$is the probability of a price increase, namely the probability of a carbon price increase in the risk-neutral world, $p = (e^{r(T/n)} - d)/(u - d)$; r is risk-free interest rate; σ is the volatility rate of carbon price. The key to describe the binomially stochastic process is determined by σ. σ can be estimated as follows : Let $l + 1$ be the number of observations; C_j, the carbon price at the end of j period$j = 0, 1, ..., l$; Δt, the length of the time, measured in years.

Step1. Based on the historical sample data, the value can be obtained as follows [24]:

$$\mu_j = \ln(C_j / C_{j-1}), (j = 1, 2, ..., l). \quad (6)$$

Step2. Determine the standard deviation s of μ_j:

$$s = \sqrt{\frac{1}{l-1}\sum_{j=1}^{l}(\mu_j - \bar{\mu})^2}, \quad i.e. \quad s = \sqrt{\frac{1}{l-1}\sum_{j=1}^{l}\mu_j^2 - \frac{1}{l(l-1)}(\sum_{j=1}^{l}\mu_j)^2}, \tag{7}$$

where $\bar{\mu}$ is the mean value of μ_j.
Step3. Determine the volatility:

$$\sigma = s/\sqrt{\Delta t}. \tag{8}$$

4.2 The investment evaluation model of RE

4.2.1 NPV method

According to the characteristics of RE projects investment, cash inflows from selling the products and reducing carbon emissions and outflows from investment cost, operation and maintenance cost. This paper takes wind power project as an example to study the investment evaluation. With maximizing profit as the ultimate goal, the target income equation of wind power project can be represented as follows:

$$\text{NPV} = P_W \times Q + C \times CER_S - I_0 - I_{o\&m}, \tag{9}$$

where, P_W is feed-in tariff of wind power project; Q is annual generation capacity of wind power project; C is carbon price; CER_S is certified carbon emission reduction; I_0 is investment cost; $I_{o\&m}$ is operation and maintenance cost; the first item in Eq. (9), i.e. $P_W \times Q$, defines the electricity sale benefits; the second item in Eq.(9), i.e. $C \times CER_S$, defines carbon emissions trading benefits. Generally, the annual maintenance cost in the first two years is very low for the manufacturer warranty of the wind turbines after the wind power project running. It will increase year by year as the wind turbines run over time. Thus we assume that after the construction is complete, the operation and maintenance cost in the first two years is I_1yuan/kWh; from the third year to tenth year is I_2 yuan/kWh; from the eleventh year to the end of the project's lifetime is I_3 yuan/kWh. Let T be the lifetime of the wind power project and r_0 be the benchmark discount rate. The enterprise will invest in the project when $t = \tau$. The construction period is one year, i.e. the wind power equipment will be put into use from the second year to the end of the project's lifetime. Fig. 2 shows the investment planning of wind power project.

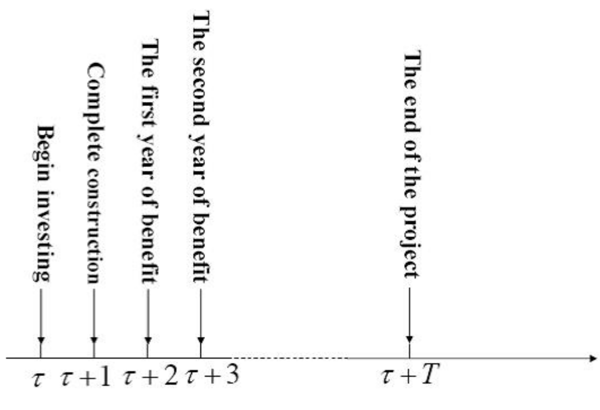

Figure 2: The investment planning of wind power project.

Based on the income equation above, we can obtain NPV of the wind power project as the following,

$$\begin{aligned} V &= \sum_{t=\tau+2}^{\tau+T}(P_W \times Q + C \times CER_S)e^{-r_0(t-\tau)} - e^{r_0\tau}I_0e^{-0.13\tau} \\ &- (\sum_{t=\tau+2}^{\tau+3} I_1Qe^{-r_0(t-\tau)} + \sum_{t=\tau+4}^{\tau+11} I_2Qe^{-r_0(t-\tau)} + \sum_{t=\tau+12}^{\tau+T} I_3Qe^{-r_0(t-\tau)}) \\ &= (P_W \times Q + C \times CER_S)\frac{e^{-r_0} - e^{-r_0T}}{e^{r_0} - 1} - I_0e^{(r_0-0.13)\tau} \\ &-I_1Q(e^{-2r_0} + e^{-3r_0}) - I_2Q\frac{e^{-3r_0} - e^{-11r_0}}{e^{r_0} - 1} - I_3Q\frac{e^{-11r_0} - e^{-r_0T}}{e^{r_0} - 1}. \end{aligned} \tag{10}$$

The first item $(P_W \times Q+C\times CER_S)\frac{e^{-r_0}-e^{-r_0T}}{e^{r_0}-1}$ is the total income from the beginning to the end of wind power project. The second item $I_0e^{(r_0-0.13)\tau}$ is the initial investment cost of wind power project.The third item $I_1Q(e^{-2r_0}+e^{-3r_0})$ is the operation and maintenance cost after construction in the first two years. The fourth item $I_2Q\frac{e^{-3r_0}-e^{-11r_0}}{e^{r_0}-1}$ is the operation and maintenance cost from the third year to tenth year. The last item $I_3Q\frac{e^{-11r_0}-e^{-r_0T}}{e^{r_0}-1}$ is the operation and maintenance cost from the eleventh year to the end of the project's lifetime.

4.2.2 Investment evaluation model

As assumed above, carbon price C follows the binomial lattice stochastic process. We replace C with $C(k, i)$; therefore the investment value of wind power project is:

$$\begin{aligned} V(k,i) &= (P_W \times Q + C(k,i) \times CER_S)\frac{e^{-r_0} - e^{-r_0T}}{e^{r_0} - 1} - I_0e^{(r_0-0.13)\tau} - I_1Q(e^{-2r_0} \\ &+e^{-3r_0}) - I_2Q\frac{e^{-3r_0} - e^{-11r_0}}{e^{r_0} - 1} - I_3Q\frac{e^{-11r_0} - e^{-r_0T}}{e^{r_0} - 1}. \end{aligned} \tag{11}$$

where, $C(k, i)$ is the carbon price with k periods and i upward movements to date. $V(k, i)$ is the corresponding investment value. Fig. 3 presents the binomial decision tree of wind power project. The model assumes that the electricity generation enterprise is faced with two choices at each decision node, namely it must decide whether wind power development should continue or not. If the investment value exceeds 0, it should develop the wind power project; otherwise it should abandon the investment. In such case the investment value can be considered as 0. Therefore the investment value at each node is $\max(V(k, i), 0)$.

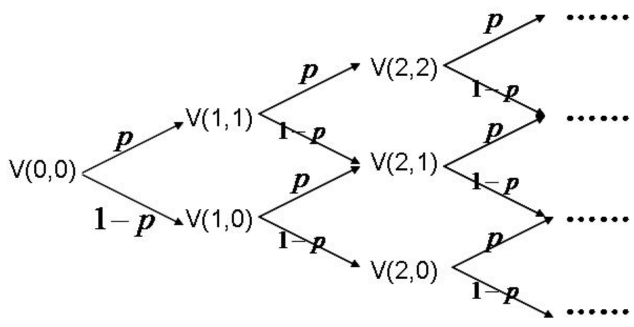

Figure 3: Wind power project investment decision-makng process.

After calculating the investment value at each node during the development period, we can obtain the initial investment decision value on the basis of risk-free interest rates r and risk neutral probability p and backward induction which requires us to calculate starting from the end. As the investment option of wind power project equivalents to American option in the financial option, i.e. investors can invest at any node during the development period; we should balance the value of immediate investment and delayed investment and make optimal decisions. To facilitate the analysis, we consider that the investor can develop at any time node, thus the value rule of the best investment strategy can be shown as follows. The investment value at the end of the project:

$$V(T,i) = \max\{(P_W \times Q + C(T,i) \times CER_S)\frac{e^{-r_0} - e^{-r_0 T}}{e^{r_0} - 1} - I_0 e^{(r_0 - 0.13)\tau} - I_1 Q(e^{-2r_0} + e^{-3r_0}) - I_2 Q\frac{e^{-3r_0} - e^{-11r_0}}{e^{r_0} - 1} - I_3 Q\frac{e^{-11r_0} - e^{-r_0 T}}{e^{r_0} - 1}, 0\}. \tag{12}$$

where, $(P_W \times Q + C(T,i) \times CER_S)\frac{e^{-r_0} - e^{-r_0 T}}{e^{r_0} - 1} - I_0 e^{(r_0 - 0.13)\tau} - I_1 Q(e^{-2r_0} + e^{-3r_0}) - I_2 Q\frac{e^{-3r_0} - e^{-11r_0}}{e^{r_0} - 1} - I_3 Q\frac{e^{-11r_0} - e^{-r_0 T}}{e^{r_0} - 1}$ is the value when investing at the end of the project. For a general node, the investment value is:

$$V(k,i) = \max\{(pV(k+1,i+1) + (1-p)V(k+1,i))e^{-r(T/n)}, (P_W \times Q + C(k,i) \times CER_S)\frac{e^{-r_0} - e^{-r_0 T}}{e^{r_0} - 1} - I_0 e^{(r_0 - 0.13)\tau} - I_1 Q(e^{-2r_0} + e^{-3r_0}) - I_2 Q\frac{e^{-3r_0} - e^{-11r_0}}{e^{r_0} - 1} - I_3 Q\frac{e^{-11r_0} - e^{-r_0 T}}{e^{r_0} - 1}\}(0 \le k < T, 0 \le i \le k). \tag{13}$$

where, r is risk-free interest rate, p is risk-neutral probability of the expected cash flow upward which relates to the value volatility of the project, while the volatility can be determined by the fluctuations of projects which are considerable to the wind power project on the financial market. $(pV(k+1,i+1) + (1-p)V(k+1,i))e^{-r(T/n)}$ is the value when delaying the project. $(P_W \times Q + C(k,i) \times CER_S)\frac{e^{-r_0} - e^{-r_0 T}}{e^{r_0} - 1} - I_0 e^{(r_0 - 0.13)\tau} - I_1 Q(e^{-2r_0} + e^{-3r_0}) - I_2 Q\frac{e^{-3r_0} - e^{-11r_0}}{e^{r_0} - 1} - I_3 Q\frac{e^{-11r_0} - e^{-r_0 T}}{e^{r_0} - 1}$ is the value when investing the project immediately. From the preceding analysis we can see that the investment evaluation model is a single factor model of carbon price. The volatility of carbon price is the most influential factor in the cash flow fluctuations of the investment project. Therefore taking volatility of carbon price as the volatility of the wind power project is reasonable.

4.2.3 Decision rules of real options

Table 1: Decision rules of delayed real option for wind power project.

NPV	Investment value with delayed real options	Decision-making
NPV>0	V>NPV	Delay investment
NPV>0	V=NPV	Invest immediately
NPV≤0	V>0	Delay investment
NPV<0	V<0	Abandon investment

In the traditional NPV method, investment merely requires NPV exceeding 0. However, it is worth investing only if the value is much greater than 0 in real options. For the general investment project, McDonald and Siegle [25] think that the delayed option value plays an important role in determining the value of investment opportunity. It is optimal to wait until benefits are twice the investment costs. For the wind power project, the investment value includes two parts in terms of real options. One is the inherent value without considering real options, namely NPV of the project. The other one is the delayed option value f_w which results from the characteristic of delayed option in wind power project. Then the total value of wind power investment project with real options can be expressed as $V = NPV + f_w$. Here the type of real options is delayed option, which means that the investor only has the right to decide whether to delay the investment. In order to specify decision rules, we should integrate the NPV with the total investment value. Thus we can list the investment decision rules as Table 1 shows.

5 Parameter estimation

For facilitating the calculation, this paper takes ten years as the delayed investment period and analyzes the investment situation from 2012 to 2022.

5.1 Parameter estimation of carbon price

As there is no carbon emission trading market in China, we are unable to obtain the data of carbon emission trading in China. Therefore we collect our data from European market which is comparatively mature and abundant in trading data. Due to the limited data, we take the sample interval from October 31, 2009 to March 30, 2012 [26]. The carbon prices are shown in Fig. 4.

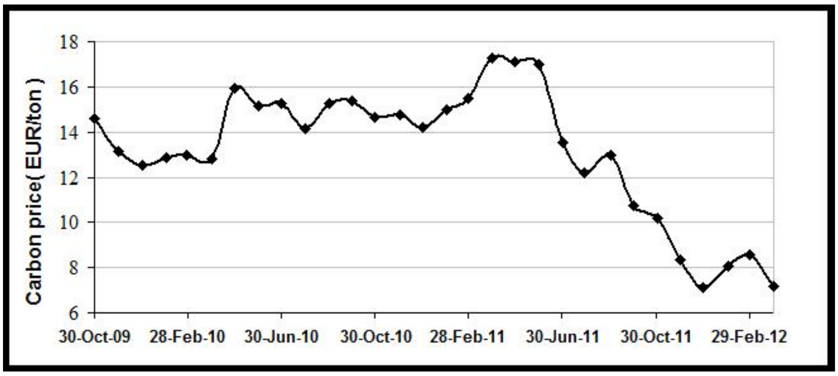

Figure 4: The history of the carbon price data.

Table 2: The carbon price at each binomial tree node (yuan/ton).

Delayed investment timeyearly division										
0	1	2	3	4	5	6	7	8	9	10
118	168	241	344	492	703	1005	1436	2052	2933	4192
	82	118	168	241	344	492	703	1005	1436	2052
		58	82	118	168	241	344	492	703	1005
			40	58	82	118	168	241	344	492
				28	40	58	83	118	168	241
					20	28	40	58	83	118
						14	20	28	40	58
							10	14	20	28
								7	10	14
									5	7
										3

According to the data above, we calculate the volatility of carbon price$\sigma = 0.3571$.

We take the average carbon price of 12 months in 2011 as the initial carbon price, then C(0,0)= 13.0775 EUR/ton. Based on the average Euro against RMB exchange rate in 2011 [27], namely 1EUR=9.016758CNY,C(0,0) can be transformed into 117.8986 yuan/ton. Then we can obtain carbon price at each node (Table 2).

5.2 Generating capacity

In order to scientifically evaluate the investment value of wind power project, this paper concerns the development status of wind power industry in China and divides full-load power generating hours in wind usable regions into five different situations, namely rich area2500h (Fujian, Yunnan), comparatively rich area 2300h (Beijing-Tianjin-Tangshan, Xinjiang, He'nan, Jiangxi, Guizhou), general area 2100h(Shandong, Shanxi, Heilongjiang, Shanghai, Zhejiang, Chongqing, Hainan), comparatively poor area 1900h (Jinan, Liaoning, Jiangsu, Hunan, Hubei, Gansu, Ningxia) and poor area 1700h (Shanxi, Jilin, Anhui, Sichuan, Guangdong, Guangxi). The function of wind capacity is:

$$Q = installed\ capacity\ \times\ full - load\ generating\ hours. \tag{14}$$

5.3 Certificated emissions reduction

Emission factor of coal-fired generation comes from IEA [28]. In 2007, emission per kWh from electricity and heat generation using coal/peat in China is 893g/kWh.

5.4 Other parameters

Other relative parameters are shown in Table 3.

Table 3: Parameters description.

Parameter	Symbol	Value	Notes
Wind project life	T	20 years	Set by this study.
Feed-in tariff	P_W	0.56 yuan/kwh	Average of feed-in tariff in China
Benchmark discount rate	r_0	8%	Mainly used to measure the opportunity cost taken by funds of the project [29]
Risk-free interest rate	r	5%	Long-term loan interest rate in China [30]
Installed capacity		100 MW	Set by this study.
Per kw investment	$I_0/10^5$	8000,9000,10000 yuan/kw [29]	Per kw investment = Investment cost / Installed capacity
Operation and maintenance cost	I_1, I_2, I_3	$I_1 = 0.04$yuan / kwh, $I_2 = 0.08$yuan / kwh, $I_3 = 0.1$yuan / kwh,	The data are a comprehensive assessment result, which refer to [29].

6 Empirical Analysis

6.1 NPV of wind power project

The data in table 4 shows that NPV of the current wind power project is greater than 0 in the majority situations. In these cases we should make investment immediately. It also indicates that wind power technology has increasingly well formed and wind power has been an attractive industry which can bring a handsome sum for investors. On the other hand, when we implement moderate and high investment in the wind poor areas, NPV is much less than 0, thus we should abandon the investment according to the NPV rules. However, based on the decision-making rules under real options, we have to make decisions after considering the real option value. We should also take the same consideration when implementing high investment in the comparatively poor areas.

Table 4: The net present values of wind power project under different conditions.

Investment	Wind resources				
	1700h	1900h	2100h	2300h	2500h
Low investment (8000/kw)	64.185	165.85	267.52	369.19	470.86
Moderate investment (9000/kw)	-35.815	65.854	167.52	269.19	370.86
High investment (10000/kw)	-135.81	-34.146	67.523	169.19	270.86

6.2 Investment value with real options

As Table 4 shows that we should not invest immediately when implementing moderate and high investment in the wind poor areas, and implementing high investment in the comparatively poor areas. Therefore we have to consider the real options of these three situations to determine delaying investment or give up it.

Based on the investment decision-making rules with delayed real options, we can obtain the decisions as shown in the right side of Table 5. It is obvious that investment under real option decision-making rules has much greater flexibilities and is more in conformity with the reality compared to NPV rules. NPV method is decided by today's prediction of future information. It is a current decision which ignores new information of carbon price that may come along and denies the operation flexibility exists during the investment. Real options method considers uncertainties of carbon price, thus the calculated value of investment tends to be larger than NPV.

Table 5: The value of investments and decisions for power project under delayed options.

Investment	Investment value (million yuan)	Decisions
Moderate investment in wind poor areas	38.73	Implement the option, delay investment
High investment in wind poor areas	26.61	Implement the option, delay investment
High investment in wind comparatively poor areas	44.02	Implement the option, delay investment

6.3 Critical conditions of investment

The previous section shows that the option and delay investment should be abandoned in some circumstances. This result is instructive but not specific. When should we determine the delay and start the investment? It is required to calculate critical conditions of investment. By the decision-making rules, critical conditions of investment must meet two requirements, i.e. NPV is greater than 0 and investment value with delayed options equals NPV. Therefore, we get critical conditions of carbon price corresponding to the three situations above. See the results in Table 6.

Table 6: The carbon price thresolds of wind power project investment under the real option rules.

Investment situation	Critical price (yuan/ton)
Moderate investment in wind poor areas	174.70
High investment in wind poor areas	241.56
High investment in wind comparatively poor areas	171.20

From Table 6 we can find that the critical carbon price of high investment in wind comparatively poor areas is the lowest among the three investment situations and moderate investment in wind poor areas comes second. The highest one is high investment in wind poor areas. It indicates that the critical conditions of investment in wind comparatively poor areas are lower than that in wind poor areas. We should give priority to investment in wind comparatively poor areas. For wind comparatively poor areas, it is suitable for investment only when the carbon price reaches 171.2 yuan/ton.

6.4 Variable feed-in tariff

The feed-in tariff in China is determined and published solely by the state government. It is a kind of subsidy policy and aims to encourage and promote the development of wind power. From the middle- long term development, the implementation of this policy has reached the intended purposes and it will reduce the subsidy share properly. At present, the average of wind feed-in tariff in China is 0.56 yuan/kWh, while the thermal power tariff is 0.3 yuan/kWh [16]. With the development and popularization of wind power technology, the difference between the two types of prices will level off someday in the future. Therefore, this research tries to simulate the investment situations when the wind feed-in tariff reduces gradually from 0.56 yuan/kWh to 0.3 yuan/kWh.

6.4.1 Low investment

From Fig. 5 we can obtain NPV corresponding to different wind feed-in tariffs in low investment situation. From wind rich areas to wind poor areas, the critical carbon prices are 0.35 yuan/kWh, 0.38 yuan/kWh, 0.42 yuan/kWh, 0.46 yuan/kWh and 0.52 yuan/kWh respectively. When the feed-in tariff is higher than the critical price, immediate investment is necessary. When the feed-in tariff is less than the critical price, its real option value should be considered according to the investment rules If the real option value is greater than 0, the investment should be delayed or even abandoned. Calculated by the real option model, when the full-load power generating hours is 1700 hours and the feed-in tariff is 0.3 yuan/kWh, the investment value of the wind power project is 22.65 million yuan. At this time, it is suitable to develop the wind power. Besides, this situation is the minimum yield condition in low investment, i.e. NPV in other situations is greater than 22.65 million. It means that no matter how low the feed-in tariff is, we should not abandon the wind power investment. The corresponding critical carbon prices are shown in Table 7.

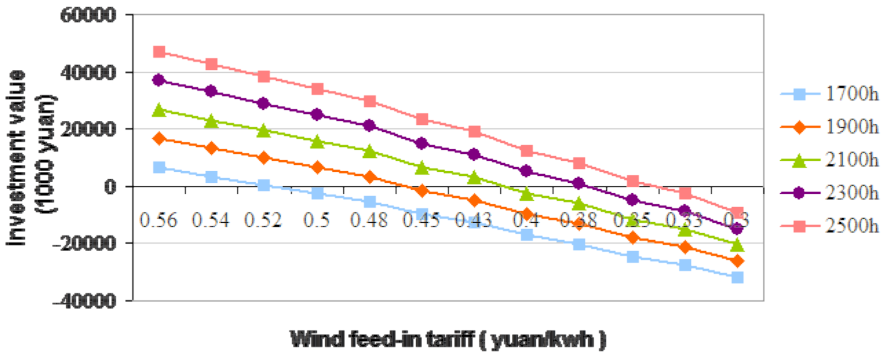

Figure 5: The net present values of the wind power project with low investment under different wind feed-in tariff.

Table 7: The carbon price thresolds of the wind power project with low investment.

Feed-in tariff (yuan/kwh)	1700h	1900h	2100h	2300h	2500h
0.5	168.87				
0.48	189.12				
0.45	219.63	163.44			
0.43	239.99	183.64			
0.4	270.54	214.14	168.62		
0.38	290.90	234.50	188.88		
0.35	323.03	265.05	219.40	181.71	
0.33	344.84	285.43	239.76	202.05	170.47
0.3	377.56	316.10	270.35	232.59	200.91

6.4.2 Moderate investment

From Fig. 6 we can find that it is not reasonable to make investment under any feed-in tariff above. From wind rich areas to wind comparatively poor areas, the critical carbon prices are 0.4 yuan/kWh, 0.43 yuan/kWh, 0.48yuan/kWh and 0.52 yuan/kWh respectively. Calculated by the real option model, when the full-load power generating hours is 1700 hours and the feed-in tariff is 0.3 yuan/kWh, the investment value of the wind power project is 19.12 million yuan. The investment delay brings benefits. Therefore we should delay the investment when the wind feed-in tariff ranges from 0.56 yuan/kWh to 0.3 yuan/kWh. The corresponding critical carbon prices are shown in Table 8.

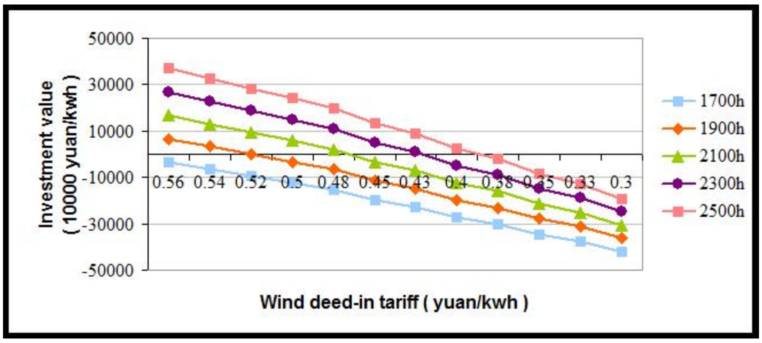

Figure 6: The net present values of the wind power investment project under different wind feed-in tariff.

Table 8: The critical carbon price thresholds of wind power project under moderate investment.

Feed-in tariff (yuan/kwh)	1700h	1900h	2100h	2300h	2500h
0.56	174.70				
0.54	195.00				
0.52	215.34				
0.5	235.68	172.35			
0.48	256.05	192.64			
0.45	287.41	223.15	171.90		
0.43	309.19	243.51	192.19		
0.4	341.89	274.06	222.70	180.31	
0.38	363.70	294.43	243.06	200.65	165.17
0.35	396.41	326.89	273.61	231.18	195.56
0.33	418.23	348.70	294.01	251.55	215.91
0.3	450.94	381.42	325.14	282.16	246.46

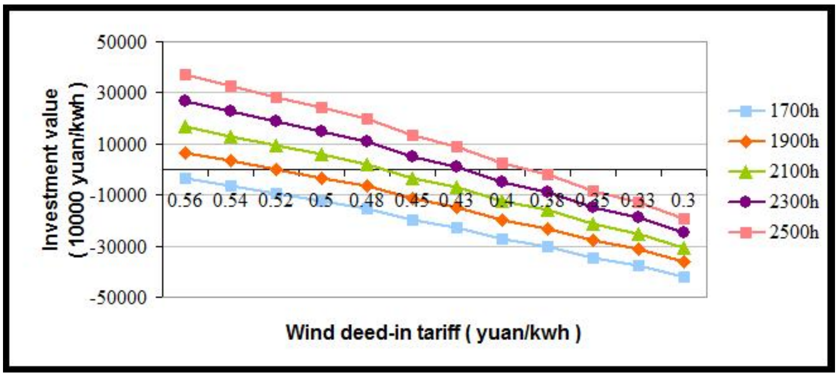

Figure 7: The net present values of wind power project with high investment under different wind feed-in tariff.

6.4.3 High investment

Fig. 7 shows that investment under any feed-in tariff should be abandoned. It is the same results as with that in moderate investment situation. From wind rich areas to wind general areas, the critical carbon prices are 0.45 yuan/kWh, 0.48 yuan/kWh and 0.54yuan/kWh respectively. Calculated by the real option model, when the full-load power generating hours is 1700 hours and the feed-in tariff is 0.3 yuan/kWh, the investment value of the wind power project is 15.59 million yuan. According to the investment rules, investment delay in all the wind resource areas is proper.

7 Conclusions

By considering the factors of carbon price, feed-in tariff and technological progress and applying the theory of real options, this paper takes renewable energy project as an investment option and establishes a model to evaluate the investment of renewable energy for power generation enterprises. Taking China as a case study, this paper divides the wind resources into five parts and makes scenario analyses of the effects on different feed-in tariff on the investment decision, and proposes the critical conditions when delaying investment, namely the critical carbon price. The results show that at present we can invest the wind power project immediately in some areas, such as wind rich areas, comparatively areas and general areas. In some areas, decisions should be made in accordance with the specific conditions, for example, implementing low and moderate investment in wind comparatively areas, or implementing low investment in wind poor areas. However, in other cases investment should be delayed In General, the current wind power project in China has very good prospects. As long as we choose the right investment opportunity within a certain time, we can obtain good benefits. The critical carbon prices of moderate and high investment in wind poor areas are 174.7 yuan/ton and 241.56 yuan/ton respectively, while the critical carbon prices of high investment in wind comparatively poor areas is 171.20 yuan/ton(Table 9). By adjusting the wind feed-in tariff, we can find that all the NPV or real options are greater than 0 when feed-in tariff ranges from 0.56 yuan/kWh to 0.3 yuan/kWh. Thus we can make immediate investment or delay the investment.

In the low investment situation, from wind rich areas to wind poor areas, the critical carbon prices are suitable for immediate investment, which are 0.35 yuan/kWh, 0.38 yuan/kWh, 0.42 yuan/kWh, 0.46 yuan/kWh and 0.52 yuan/kWh respectively. In the moderate investment situations, from wind rich areas to wind comparatively poor areas, the critical carbon prices are 0.4 yuan/kWh, 0.43 yuan/kWh, 0.48 yuan/kWh and 0.52 yuan/kWh respectively. In the high investment situations, from wind rich areas to wind general areas, the critical carbon prices are 0.45 yuan/kWh, 0.48 yuan/kWh and 0.54 yuan/kWh respectively.

Table 9: The critical carbon prices of wind power project under high investment.

Feed-in tariff (yuan/kwh)	1700h	1900h	2100h	2300h	2500h
0.56	241.56	171.20			
0.54	262.76	191.48			
0.52	284.48	211.82	155.05		
0.5	306.26	232.15	175.18		
0.48	328.05	252.52	195.49		
0.45	360.75	283.58	226.00	178.91	
0.43	382.56	305.33	246.37	199.25	159.877
0.4	415.27	338.03	276.91	229.77	190.2008
0.38	437.08	359.84	297.33	250.14	210.5358
0.35	469.80	392.55	330.02	280.68	241.0824
0.33	491.61	414.36	351.83	301.10	261.4485
0.3	524.33	447.08	384.55	332.89	292.0783

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