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A Real Options Model to Value Offshore Wind Power Project under Market Linkage Mechanism

Yiqing Li[1,2*], Weiguo Yang[2] and Lixin Tian[1,3]

[1]Energy Development and Environmental Protection Strategy Research Center, Jiangsu University, Zhenjiang Jiangsu, 212013, P.R. China.
[2]Faculty of Science, Jiangsu University, Zhenjiang 212013, P.R. China .
[3]School of Mathematical Sciences, Nanjing Normal University, Jiangsu, 210023, P.R. China.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study puts forward a real options model and uses it to evaluate the investment value of offshore wind power project under market co-movement effect. The main purpose is to check investment benefit of offshore wind power project, as an investor. Several uncertainties are taken into account, including investment costs, feed-in tariffs, carbon prices and policy subsidy. Moreover, an additional uncertain factor, i.e. the market linkage of investment costs, is considered. As a case study, Jiangsu Xiangshui offshore wind park is used to illustrate the model in scenario analysis. Using a least-squares Monte Carlo simulation method, we obtain that the project value is negative. Therefore investors should abandon or postpone investment until better conditions prevail. Furthermore, this paper shows sensitivity analysis of the impact of uncertain factors on the project value. Especially sensitivity analysis of variable costs, it shows a certain impact on project value in here, which has been ignored in previous real options studies. The research results would be helpful for renewable energy project assessment and the decision-making process associated with it.

Keywords: Real options; offshore wind power; market co-movement effect; least squares Monte Carlo simulation.

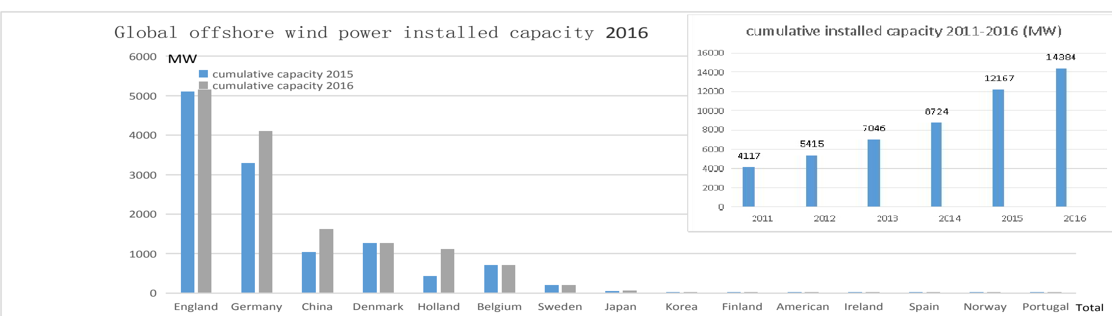
**Corresponding author: E-mail: lyq_1011@ujs.edu.cn;*

1. INTRODUCTION

Energy crisis, global warming, and extreme weather have prompted state policies to improve the efficiency of energy use and to develop a low-carbon economy; hence renewable energy (RE) become the main alternative energy sources in the future. Offshore wind power is favored by many countries because of its rich resources and less emissions. According to the global wind power statistics that the global offshore wind new and cumulative installed capacity reached 2,219 *MW* and 14,384 *MW* in 2016 respectively. In China, the data were 590 *MW* and 1,630 *MW* in 2016. The installed capacity of offshore wind power generation, the top five countries were United Kingdom, Germany, China, Denmark, Holland. China relied on greatly increased installed capacity in 2016 beyond Denmark and among the world's top three (see Fig. 1. the data comes from the Global Wind Energy Council).

In China, the reserve of offshore wind energy exploitable and available is 750 *GW*, which is 3 times of the amount of onshore wind energy resources. Therefore, there has a vast developing prospective. In according with *Wind power development "13th Five-Year" plan*, by the end of 2020, China's grid installed capacity of wind power would reach more than 210 *GW*, including offshore wind power would reach more than 5 *GW*. And yearly wind power generation will be insured to arrive at 420 billion *kWh*, accounting for about 6 percent of the total generating capacity [1]. In keeping with an average of 14,000 *yuan/kw* investment scale, the market space for offshore wind power reached 56 billion *yuan*! With billions of *RMB* invested every year, how to make decisions is crucial. Private investors hence require appropriate tools to assess their investment decision. Likewise, policymakers need those tools to choose suitable incentive mechanism, because most new energy investments still depend on subsidy and supportive policies.

The traditional method of evaluating RE investment is the net present value (NPV) method, which has been proved to underestimate the investment value of the project. Another more accurate assessment method is the real option approach (ROA). Real options derive from the financial options theory developed by Black and Scholes [2] and Merton [3] in the 1970s. Myers [4] put forward the concept of real options firstly. He pointed out that an investment scheme generated cash flow which created profits from the use value of currently owned assets add to the choice value of future investment opportunities. Trigeorigis and Mason [5] present the project investment value of an options value with managerial flexibility was a kind of "expanded" or "strategic" NPV. This value is the sum of the conventional NPV and managerial flexibility value. Moreover many literatures [5-10] further confirm that ROA is more effective than NPV when dealing with uncertainty. So, we also applied ROA proposed by Trigeorigis and Mason [5] to calculate the offshore wind power project (OWPP) project investment value *V*. Note the managerial flexibility value or the choice value of future investment opportunities as V_{ROA} (options value). Hence, in this study, the project value *V* can be given as: $V = V_{NPV} + V_{ROA}$. When $V \geq 0$, investors will invest OWPP; when $V < 0$, investors will give up investment.



	England	Germany	China	Denmark	Holland	Belgium	Sweden	Japan	Korea	Finland	American	Ireland	Spain	Norway	Portugal	Total
cumulative capacity 2015	5, 100	3, 295	1, 035	1, 271	427	712	202	53	5	32	0. 02	25	5	2	2	12, 167
new capacity 2016	56	813	592	0	691	0	0	7	30	0	30	0	0	0	0	2, 219
cumulative capacity 2016	5, 156	4, 108	1, 627	1, 271	1, 118	712	202	60	35	32	30. 02	25	5	2	2	14, 384

Fig. 1. The installed capacity of global offshore wind power generation

About investment under uncertainty, Dixit and Pindyck [11] give an overview and introduction. In RE investment evaluation, uncertain factors usually include non-renewable energy costs, RE costs, carbon prices, feed-in tariffs (FIT), research and development expenditure, RE technological, support policy, market situations, etc. For example, Sarkin and Tamarkin [12] applied the options assessment model to estimate the PV power project investment under the uncertainty of technology and electricity price. Under power producers with the uncertainty of price, market, and policy, Wolf [13] used a discrete real options model to analyze investment in a new energy power generation project, selection of technology type, and decision on optimal operation. Li et al. [10] present a policy benefit model of a PV power generation project based on ROA and the two-factor learning curve model under thermal power cost, PV power generation cost, carbon prices and government subsidy uncertainty. In [9-10, 14], RE costs is considered as an uncertain factor. But market causality of raw materials in RE costs isn't taken into account. In our study, the market co-movement effect of OWPP investment cost is considered as an additional uncertain factor, as a result that the model is closer to the real investment environment. This is because that investment cost will be a jump instantaneously under the linkage mechanism.

In wind power project (WPP) investment, Boomsma et al. [15] present a real options model to analyze investment timing and capacity choice for RE projects under different support schemes. Kitzing et al. [16] developed a real options model to evaluate offshore wind energy investments under 3 different support schemes. But, in those studies [15-17], the impact of variable costs (VARC) is neglected. In fact, the VARC of OWPP accounts for 50% of total costs. So, the VARC have a certain impact on the investment value of OWPP. This article further confirms this view.

Based on the above discussion, we put forward a real options model to evaluate OWPP's project value under market linkage mechanism. In fact, there are few studies on WPP evaluation under market co-movement mechanism. This is one major part of our article. In addition, uncertain factors (such as investment costs, FIT, carbon prices and subsidy prices) are governed by geometric Brownian motion (GBM). Using a least square Monte Carlo method (LSM), we obtain the OWPP's actual project value *V* get the project value in scenario analysis. Finally, the influence of each uncertainty factor on the project value is disclosed. Especially, the impact of VARC on the project value, is ignored in previous WPP studies [15-17]. In fact, our research result show that VARC has a certain impact on the project value *V*. This is another main content in this article. The proposed model provides private investors a more accurate and valuable evaluation approach.

The reminder of study is organized as follows. Section 2 presents a real options model, and provides general steps of the LSM. Using a case study of Xiangshui offshore wind park, Section 3 analyze the influence of uncertainties on the project value. Section 4 concludes this paper and explains further research areas.

2. REAL OPTIONS MODEL

2.1 Model Framework

Fig. 2 shows the presented framework of the OWPP assessment model. Under basic assumptions, we analyze the GBM characteristics of uncertain factors. Using ROA, we construct an evaluation model of OWPP. The universal model is used to a specific case of offshore wind in Jiangsu Xiangshui, where the influence of uncertainty factors on project value is revealed. Finally, by comparing NPV method with real options method, we further confirm the scientific rationality of the latter, and give the conditions for achieving profitability of the project.

2.2 Offshore Wind Investment Model

The investment costs of OWPP contain capital costs and operating costs. The former is called fixed costs (FIXC) dominated by the turbine's costs, while other major costs compositions are connected with foundations, grid-connected system, and ground rents and the latter is called variable costs (VARC), which contain the repair costs, administration, replacement parts, and insurance.

FIXC composes a major source of uncertainty for a RE investment project. We suppose that the uncertainty is driven by the prices of raw materials. For OWPP, the foundations and several components of the turbines are usually made of steel, which becomes the most major stuff. Hence, we only consider the steel spot prices, which is determined in a competitive market. And VARC includes operation and maintenance costs.

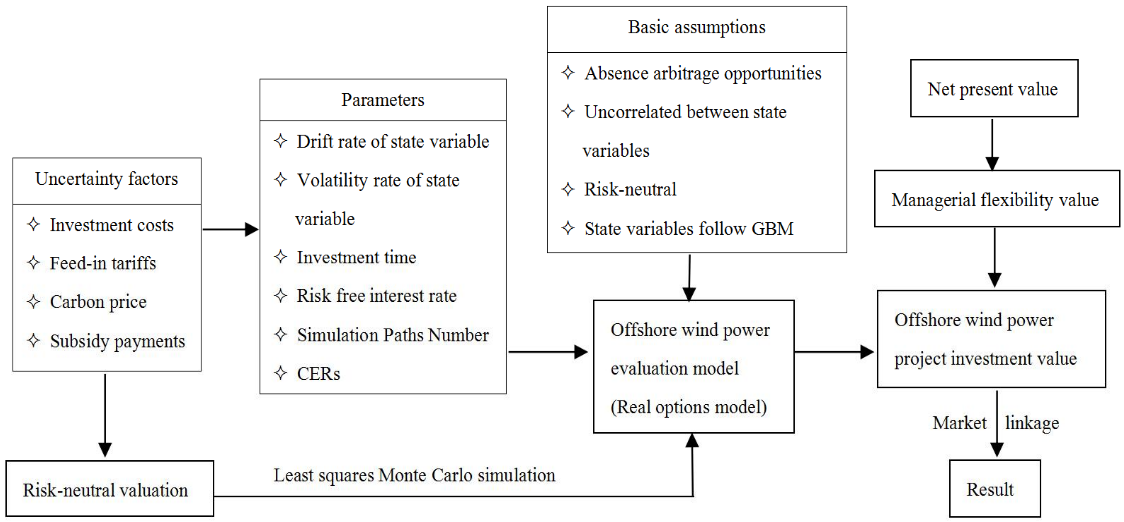


Fig. 2. Scheme of OWPP evaluation model

In summary, we suppose that investment cost is the sum of FIXC and VARC. Therefore, investment costs $I(P_1(t), B(t); x)$ satisfies with the following expression [15]:

$$I(P_1(t),B(t);x)=(k_1x+b_1)P_1(t)+ (k_2x+b_2)B(t), k_1,b_1,k_2,b_2>0 \quad (1)$$

where $(k_1x+b_1)P_1(t)$ denotes FIXC, while x is the installed capacity, $P_1(t)$ is the steel spot price. $(k_2x+b_2)B(t)$ is VARC, $B(t)$ denotes annually average operating costs.

In fact, the steel prices, labor wages are determined by supply and demand relationship of the market, and fluctuated around the balance price. However, the steel prices determine the investment costs. Hence, here exist a market linkage between labor wages, steel prices and investment costs. We assume that the investment costs I is governed by GBM as below:

$$dI = I(t)\mu_I dt + I(t)\sigma_I dW_I^P(t) + \sum_{j=1}^{J}\gamma_j dq_j \quad (2)$$

where μ_I, σ_I are the drift and volatility, $dW_I^P(t)$ is an increment of independent standard Brownian motion (SBM). The market causality between labor wages, steel prices and investment costs is represented by $\sum_{j=1}^{J}\gamma_j dq_j$, J is the jump point's number, γ_j is the amplitude of jump point of j, q_j is a Poisson distribution. and $dq_j=\begin{cases}0,1-vdt\\1,vdt\end{cases}$, while vdt is a minimal probability.

OWPP's profit relies on FIT, government subsidy and carbon price. We note profit by $\Pi(P_2(t),P_3(t),P_4(t);x)$, where $P_2(t)$, $P_3(t)$,and $P_4(t)$ are annually average FIT, subsidy price and carbon price. In China, the wind power sale price consists of two parts: one part is average desulfurization coal-fired electricity price, the other is subsidy price which is decided by the state policy. And we suppose that the construction period is enough short without affecting long period FIT and carbon price. Hence, the profit is given by [15]:

$$\Pi(P_2(t),P_3(t),P_4(t);x) = (P_2(t)+P_3(t))A(x)+\lambda P_4(t) \quad (3)$$

where λ is the certified emission reductions (CERs), $A(x)$ is total annual production. In here, we simplify the production function by [15]:

$$A(x)=ax^b \text{ with } a>0 \text{ and } 0<b<1 \quad (4)$$

2.2.1 Uncertainty

We wish to value state variable (i.e. investment cost, power prices, subsidy prices and carbon prices) as contingent claims of underlying assets. And the market is arbitrage-free iff equivalent martingale measure exists. Under basic assumption of no-arbitrage in the market, equivalent martingale measure permits risk-neutral valuation [18,19]. And this measure is unique in a sufficiently complete market. We apply futures/forward prices to value the process of electricity spot price. Assumed that contracts with all maturities are sustainedly traded in a frictionless market, and the forward or futures price equals the spot price of the underlying asset at maturity [15]. Under the equivalent martingale measure, forward or futures prices are martingales [20], as a result that the drift equal 0 and the volatility is large simplified.

Considering the technical progress and learning curse effect of cost, the state should reduce the subsidy, but the fact is that subsidy policy is determined by the OWPP's development. At present, domestic carbon market doesn't yet mature, low carbon price fluctuates greatly, but the overall tendency is upwards. In addition, we will not consider the possible correlations between state variables for simplicity. Therefore, assumed that $P_i(t)$ (i=1,3,4) and $F_2(t, T)$ satisfy with the following GMB.

$$dP_i(t) = P_i(t)\mu_i^P dt + P_i(t)\sigma_i dW_i^P(t), i = 1,3,4 \quad (5)$$

$$dF_2(t,T) = F_2(t,T)\mu_2^P dt + F_2(t,T)\sigma_2 dW_2^P(t) \quad (6)$$

where $F_2(t, T)$ is the price of electricity forward or futures contracts with maturity date T, μ_i^P, σ_i i=1,…,4 denote the drifts and volatilities, respectively; $dW_i^P(t),\ i = 1,\cdots,4$ are increments of independent SBM under the martingale measure of $\mathbb{P}$.

2.2.2 LSM and real option pricing

Under risk-neutral valuation, the market prices of risk, θ_i, i=1,…,4 is given as follows:

$$\theta_i = \frac{\mu_i^P + \delta_i - r}{\sigma_i}, i = 1,3,4\ ,\quad \theta_2 = \frac{\mu_2^P}{\sigma_2} \quad (7)$$

where r denotes risk-free rate, and δ_i>0, i=1,3,4 are the dividend payments. Through making $dW_i^Q(t) = dW_i^P(t) + \theta_i dt$, i=1,…,4, we can get from (5) and (6)

$$dP_i(t) = P_i(t)(r - \delta_i)dt + P_i(t)\sigma_i dW_i^Q(t),\quad i = 1,3,4 \quad (8)$$

$$dF_2(t,T) = F_2(t,T)\sigma_2 dW_2^Q(t) \quad (9)$$

Defined the measure $\mathbb{Q}$ by L= d$\mathbb{P}$/d$\mathbb{Q}$ and $dL(t) = L(t)\sum_{i=1}^4 \theta_i dW_i^P(t)$, we obtain that $dW_i^Q(t)$, i=1,…,4 are increments of independent SBM under measure of $\mathbb{Q}$. Therefore, the risk-adjusted processes (8), (9) are still independent GBM. Obviously, martingale measure $\mathbb{Q}$ and $\mathbb{P}$ are equivalent.

In order to value the process of electricity spot prices, we take into account the forward or futures prices process in (9). Applied Ito's lemma to above two prices, we have

$$dP_2(t) = P_2(t)\mu_2^Q dt + P_2(t)\sigma_2 dW_2^Q(t), \quad (10)$$

where $\mu_2^Q = \partial \ln F_2(0,t)/\partial t$ is a constant and $\mu_2^Q < r$. For simplicity, we let $\mu_i^Q = r - \delta_i$, i=1,3,4, for steel spot prices, subsidy prices and carbon prices.

As mentioned above, the offshore wind power's development decides subsidy prices. Due to hysteresis effect of decision process, the wind power's growth in the past year determines this year subsidy prices. If the growth is good in the past year, thus the state would cut down the subsidy payments this year, while if the growth is difficult, the state would raise the subsidy payments this year. After this, government subsidy is handed over to state grid, and then state grid pays subsidy to wind power plant in a certain proportion, which leads to a serious lag. Theoretically, this implies subsidy prices change follows a continuous-time Markov process $X(t)$ with a finite state space {1,. . .,M}, rate matrix $C = (c_{mn})_{M\times M}$, where $c_{mn}dt(m \neq n)$ is a switch probability from state m to state n.

Assumed that the Markov process is independent of the GBM, hence, subsidy price follows a Markov modulated GBM under the true probability measure:

$$dP_3(t) = P_3(t\text{-})\mu_3^P(X(t\text{-}))dt + P_3(t\text{-})\sigma_3(X(t\text{-}))dW_3^P(t) \quad (11)$$

While t- is the left limit of t. $\mu_3^P(m)$, $\sigma_3(m)$ are drift and volatility, while $X(t$-) is in state m. The shifting risk of market price is generally small. Hence, we suppose that the switching risk is zero, or near to zero. And then, market price of risk in state *m* is:

$$\theta_3(m) = \frac{\mu_3^P(m) + \delta_3(m) - r}{\sigma_3(m)}, m = 1, \cdots, M$$

Thus, the subsidy price (under $\mathbb{Q}$) is:

$$dP_3(t) = P_3(t\text{-})(r - \delta_3(X(t\text{-})))dt + P_3(t\text{-})\sigma_3(X(t\text{-}))dW_3^Q(t), \quad (12)$$

while $(r - \delta_3(X(t\text{-})))$ and $\sigma_3(X(t\text{-}))$ are the drift and volatility, $dW_3^Q(t)$ is the increment of independent SBM under $\mathbb{Q}$.

Uncertain factors are described by GBM and Markov modulated GBM above. We see OWPP as a options, then calculate the options value. Using a LSM [21], we get the options value of OWPP. LSM includes the three steps as below.

Step 1: randomly generate multiple sample paths of the underlying assets price process.

Firstly, discrete risk-adjusted processes (8), (10), (12). For this reason, insert points $t_0, t_1, \cdots, t_L$ in the lifetime [0, T] ($0 = t_0 \le \cdots \le t_L = T$), denote $\Delta t = T / L = [t_l, t_{l+1}]$. Eqs. (8), (10) are changed into:

$$P_i(t_{l+1}) = P_i(t_l) + P_i(t_l)\mu_i^Q \Delta t + P_i(t_l)\sigma_i e_i(t_{l+1})\sqrt{\Delta t}, i = 1, \cdots, 4 \quad (13)$$

where $\mu_i^Q = r - \delta_i, i = 1,3,4$, $\mu_2^Q = \partial \ln F_2(0,t) / \partial t$ and $e_i(t_1), \cdots, e_i(t_L), i = 1, \cdots, 4$ are independent standard normal random variables with mean of 0 and standard deviation equivalent to 1.

Equally, deal with Eq. (12):

$$P_3(t_{l+1}) = P_3(t_l) + P_3(t_l)\mu_3^Q(X(t_l))\Delta t + P_3(t_l)\sigma_3(X(t_l))e_3(t_{l+1})\sqrt{\Delta t} \quad (14)$$

where $\mu_3^Q(X(t_l)) = r - \delta_3(X(t_l))$.

Step 2: Calculate the optimal stopping time for each sample path and the option value at each moment.

Based upon Eqs. (13), (14), we simulate *N* sample paths to underlying assets applying Monte Carlo Approach. By comparing the intrinsic values of options from exercise with the expected value of discounted ex post payoffs from continuation, and execute the options once the former exceeds the latte [15], we get an optimal stopping time t_l (l=1,…,L) at each sample path. Thus, the immediate exercise options value at stopping time t_l is

$$g(P_1(t_l), P_2(t_l), P_3(t_l), P_4(t_l); t_l, t_L) = \max_{x \ge 0}\{\Pi(P_2(t_l), P_3(t_l), P_4(t_l); x) - I(P_1(t_l), B(t_l); x), 0\}$$

The continuation value at stopping time t_l is

$$f(P_1(t_l), P_2(t_l), P_3(t_l), P_4(t_l); t_l, t_L) = E_{t_l}^Q\left[\sum_{t=t_l+1}^{t_L} e^{-r(t-t_l)} g(P_1(t), P_2(t), P_3(t), P_4(t); t_l, t_L)\right]$$

where $E_{t_l}^Q[\cdot]$ is the conditional expected value in measure $\mathbb{Q}$. Applying a set of basis functions, an assessment of the continuation options value is described by

$$\hat{f}(P_1(t_l), P_2(t_l), P_3(t_l), P_4(t_l); t_l, t_L) = \hat{\alpha}_0 + \sum_{i=1}^{4} \hat{\alpha}_{1i} P_i(t_l) + \sum_{i,j=1}^{4} \hat{\alpha}_{2ij} P_i(t_l) P_j(t_l)$$

while $\hat{\alpha}_0$, $\hat{\alpha}_{1i}$, $\hat{\alpha}_{2ij}$, $i, j = 1, \cdots, 4$ are regression parameters.

Step 3: Average options value of optimal stopping time for each sample path

For each sample path ω, the options value (i.e. options value of optimal stopping time) can be obtained. Then average the option value of all paths, we obtain the options value V_{ROA}:

$$V_{ROA}(t_l, P_i(t_l), \omega) = \frac{1}{N}\sum_{\omega=1}^{N} e^{-rt_l} g(t_l, P_i(t_l), \omega), \quad i = 1, \cdots, 4$$

Finally, investors should invest in OWPP when *V* ≥0 or give up invest while *V*<0. The investment value of OWPP is given as follows:

$$V = \begin{cases} V_{NPV} + V_{ROA}(P_i(t_l)) & dq_j = 0 \\ V_{NPV} + V_{ROA}(P_i(t_l)), \sum_{j=1}^{J} \gamma_j dq_j) & dq_j = 1 \end{cases}$$

where

$$V_{NPV} = \Pi(P_2(t), P_3(t), P_4(t); x) - I(P_1(t), B(t); x)$$

3. SCENARIO ANALYSIS

3.1 Parameters Estimation

We confine our research goal to Xiangshui offshore wind park of Jiangsu Province, because this wind farm is one-time construction of the largest monomer capacity offshore wind power project in China [22]. The relevant parameters of offshore wind park are shown in Table 1. The date of steel price is from My steel com [23], the FIT is determined by National Development and Revolution Committee [24]. For carbon price, we adopt the data from Shenzhen Carbon Emission Exchange (SHCEE), because SHCEE is earliest and most mobile of domestic carbon market.

Using the method mentioned above, we can obtain that the NPV of OWPP is -1,382.29 million *yuan*. In view of NPV method, investors should give up investment. Actually, in RE project investment, NPV method is unsuitable, because of many uncertain factors in here. Firstly, due to the progress of wind power technology, the wind power average generation costs is 1.2 *yuan*/*kWh* in 2010, and drop to 0.95 *yuan*/*kWh* in 2016. Secondly, the coal prices fluctuate greatly. Bohai-Rim steam-coal annually average price is dropped from 817 *yuan*/*ton* in 2010 to 427 *yuan*/*ton* in 2015, and added to 585 *yuan*/*ton* in 2017 (data form trading announcement of Qinhuangdao sea coal trading market). Thirdly, FIT changed from 1.2 *yuan*/*kWh* in 2010 to 0.85 *yuan*/*kWh* in 2016 [24] and the subsidy price is the difference between FIT and desulfurization coal-fired electricity price. Hence, subsidy price will also change accordingly. Fourthly, at present, domestic carbon market isn't mature yet, the overall trend is increasing. However, ROA is able to quantify the value of above uncertainties and is more effective than the NPV method. Hence, we evaluate the OWPP's project value using ROA. In this paper, the project value V include both V_{NPV} and V_{ROA}. And the expected cash flow and optimal stopping time are simulated using LSM, and shown in Fig. 3 and Fig. 4.

Likewise, we calculate the options value V_{ROA}=651.80 million *yuan* and the project value V=-730.49 million *yuan*, investors should abandon investment in OWPP. Although the results obtained by the two methods are consistent, uncertainty is considered under ROA. Because of neglecting the worthiness of uncertainty, traditional NPV underestimates the project value, the difference is exactly the options value. Therefore, ROA is more accurate than NPV method.

Table 1. The parameter of offshore wind power project model

Symbol	Description	Value	Notes
I	Initial investment cost of offshore wind power	3,519 million *yuan*	[22]
μ_I	Drift rate of initial investment cost	-0.08	[25]
σ_I	Volatility rate of initial investment cost	0.04	[25]
B	Operating cost	45.07 million *yuan*/*year*	[22]
x	Install capacity	202 *MW*	[22]
P_1	Steel price	4,200 *yuan*/T	[23]
μ_1	Drift rate of steel price	0.025	[15]
σ_1	Volatility rate of steel price	0.627	[15]
P_2	Electricity price	0.8 *yuan*/*kWh*	[24]
μ_2	Drift rate of electricity price	0.036	[26]
σ_2	Volatility rate of electricity price	0.075	[27]
P_3	Subsidy prices	0.4 *yuan*/*kWh*	
P_4	Carbon Price	20 yuan/*ton*	SHCEE
μ_4	Drift rate of Carbon Price	0.02	[25]
σ_4	Volatility rate of Carbon Price	0.115	[25]
T	Lifetime	25 year	
r	Risk-free rate	3.5 percent	
N	The number of simulation paths	25/200	
λ	CERs	16,565 *ton*	[15]

3.2 Scenario Analysis

3.2.1 Case 1: Fixed Costs (FIXC)

Conventional energy generation consume raw materials, such as coal, oil, etc. But, wind power generation uses wind energy as materials. In OWPP investment, the foundations and several elements of the turbines are usually made of steel, which become the main materials. So we suppose that the materials prices drive the uncertainty of investment costs. However, steel price has market linkage and is affected by market supply and demand balance. Investment costs, notably FIXC, also have a linkage effect with the market. Under the linkage mechanism, FIXC will be a jump instantaneously.

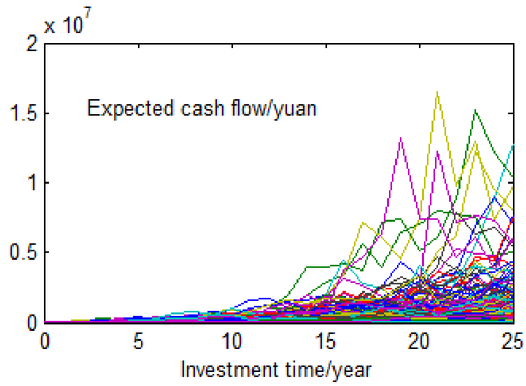


Fig. 3. The expected cash flow

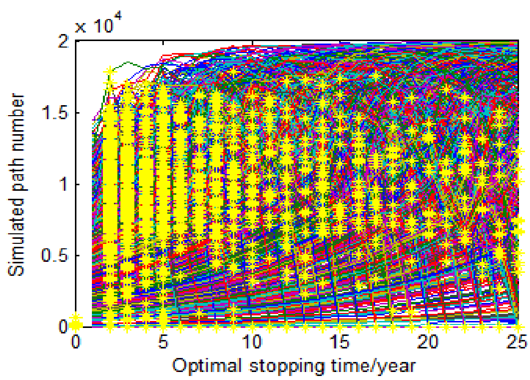


Fig. 4. The optimal stopping time of options

Under the market co-movement effect, the simulate paths of FIXC is shown in Fig. 5. We can see that the fluctuation is significant, and there has been a jump. This is due to the market linkage of raw materials (steel or turbine) prices, which leads to FIXC market causality. This is more obvious in Fig. 6. It shows the single simulation path of FIXC under two different mechanisms. Under the market linkage, FIXC fluctuate greatly and will jump in a moment. However, under the non market linkage, the curve is relatively gentle.

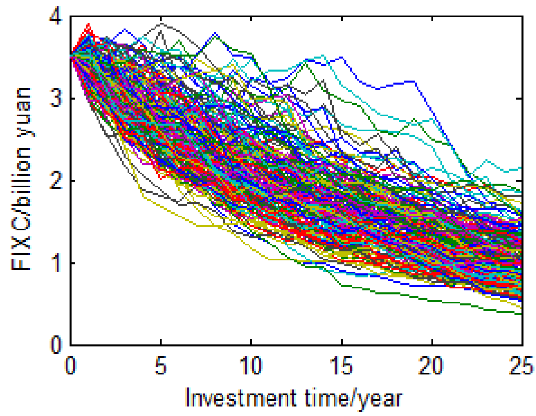


Fig. 5. The offshore wind power FIXC (200 paths)

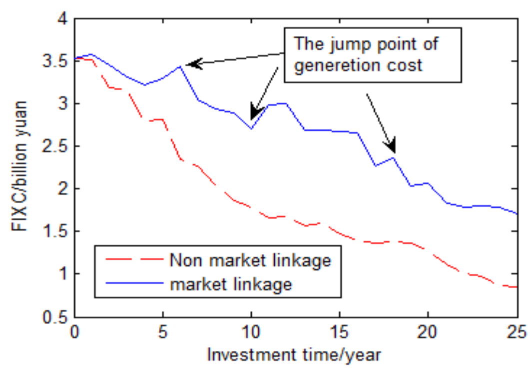


Fig. 6. The offshore wind power FIXC (two mechanisms)

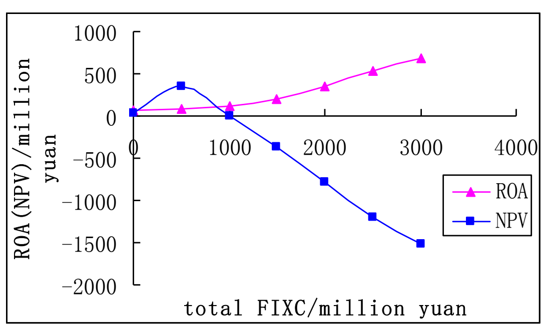


Fig. 7. Sensitivity analysis of FIXC to ROA/NPV

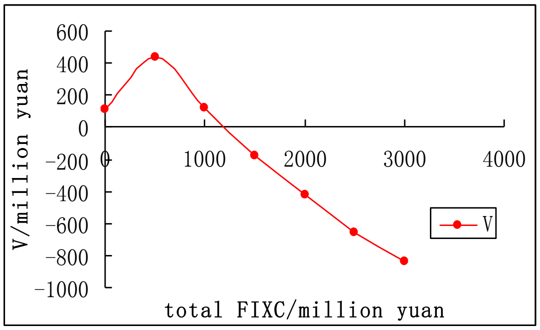


Fig. 8. Sensitivity analysis of FIXC to *V*

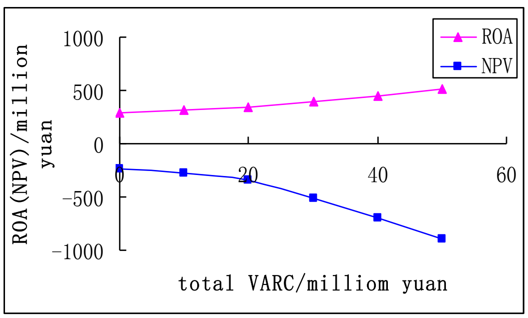


Fig. 9. Sensitivity analysis of VARC to ROA/NPV

Fig. 7 presents a sensitivity analysis of the impact of FIXC on ROA/NPV. Options value curve is increase. However, NPV is first ascended and then descended, arrive at a peak while the FIXC is 500 million *yuan*. NPV< 0, when the FIXC > 1000 million *yuan*. A sensitivity analysis of FIXC to *V* is shown in Fig. 8. *V* > 0, when the FIXC < 1200 million *yuan*, and investors can get a maximum benefit while FIXC reach to 500 million *yuan*. Therefore, if investors can reduce FIXC, the value *V* will increase. And the OWPP would be no profits while FIXC > 1200 million *yuan*.

3.2.2 Case 2: Variable Costs (VARC)

VARC is an important uncertainty source in OWPP investment. For onshore WPP, the VARC are relatively small, representing about 25 percent of all costs, contain the repair costs, administration, insurance, and spare parts. This is usually neglected, see [2,3,17]. However, the operation cost of OWPP is twice as much as onshore wind power, representing about 50% of total costs. Therefore, VARC can't be ignored. Otherwise, the established model is inconsistent with the actual situation.

Fig. 9 shows sensitivity analysis of VARC to ROA/NPV. ROA is increasing and positive, but NPV is decreasing and negative. Fig. 10 shows sensitivity analysis of VARC to *V*, which is decrease. When VARC<20 million *yuan*, *V*>0; after this *V*<0. That is, the project value *V* can be increased by reducing VARC. When VARC<20 million *yuan*, investors should start investing. In fact, the VARC of Xiangshui offshore wind plant is 45.071 million *yuan*. In this respect, the OWPP has not benefits. But, investors could be mark profits by developing wind power technology, raising power prices, etc.

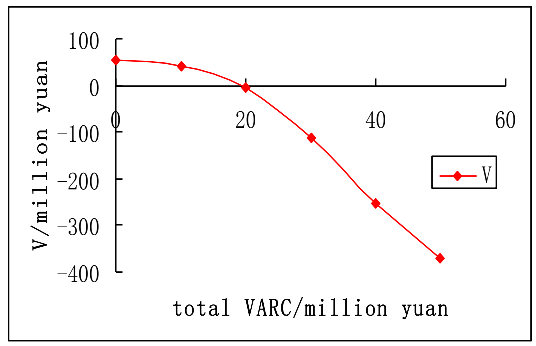


Fig. 10. Sensitivity analysis of VARC to *V*

3.2.3 Case 3: Feed-in tariffs (FIT)

In theory, the chief profit of offshore wind plant is power selling. With the rapid development of wind power technology, FIT is decreasing year by year. When electricity price <0.85 *yuan/kWh*, investors should abandon invest in the OWPP. In fact, the FIT is about 0.8 *yuan/kWh* at current [24].

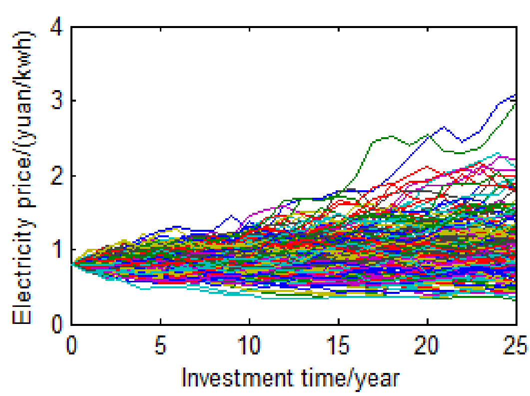


Fig. 11. The change of electricity price (25 paths)

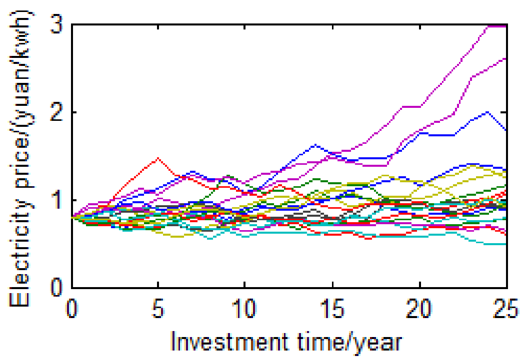


Fig. 12. The change of electricity price (200 paths)

Under two different paths, the simulations result of FIT is shown in Fig. 11 and Fig. 12. Fig. 13 shows a sensitivity analysis of FIT to ROA/NPV, and the initial value of ROA is about 1,700 million *yuan*. While it decreases quickly, which drop from 1,693 to 133.3. But, NPV of some interval increases while that of others decreases, and the fluctuation of data is relatively large. Fig. 14 shows a sensitivity analysis of FIT to *V*. *V* rises when FIT< 0.6 *yuan/kWh*, then it reduces in the interval of 0.6–1 *yuan/kWh*. But after then, it rises again and eventually greater than zero. So, investor can make a profit when FIT more than about 1.75 *yuan/kWh*. In accordance with FIT is 0.8 *yuan/kWh* at present, this implies OWPP has been unprofitable only just sale power.

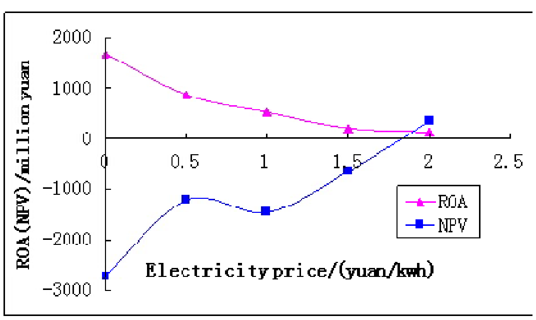


Fig. 13. Sensitivity analysis of FIT to ROA/NPV

3.2.4 Case 4: Subsidy price

OWPP is a capital intensive investment. And the purpose of private investors is to make a profit. Although they can benefit from selling power and carbon emission trading, as a new energy project, it still needs the support of government subsidy. The subsidy price is given by the difference between FIT and desulfurization coal-fired electricity price. The average FIT of desulfurization coal-fired is 0.4 *yuan* in Jiangsu [28], so the subsidy price is 0.4 *yuan/kWh*.

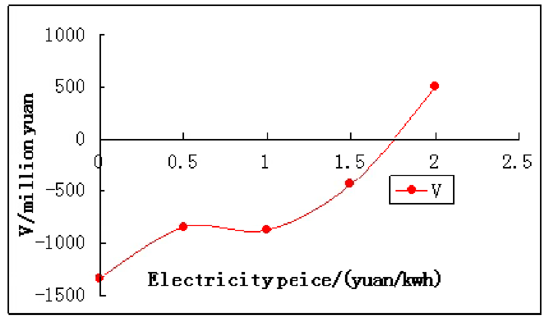


Fig. 14. Sensitivity analysis of FIT to *V*

Fig. 15 shows a sensitivity analysis of subsidy to ROA/NPV. We can see that ROA is deducing and remain more than 0. Conversely, NPV has been rising; and when subsidies price > 0.46 *yuan*/kWh, NPV>0. Fig.16 shows sensitivity analysis of subsidy to *V*, and *V* is increase. When subsidy price < 0.37 *yuan*/kWh, *V* is negative; after then, *V* is positive. Hence, investors should not invest in OWPP until subsidy price arrive at 0.37 *yuan*/kWh. It is crucial in OWPP investment, while the subsidy price is 0.4 *yuan*/kWh, which works a little bit.

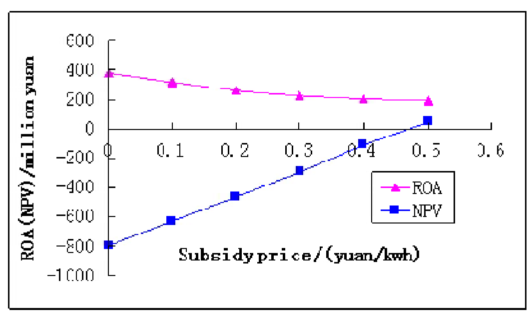


Fig. 15. Sensitivity analysis of subsidy to ROA/NPV

3.2.5 Case 5: Carbon price

Traditional energy generation may create massive greenhouse gas, while wind power generation emission is zero. So, investors can benefit from carbon emission trading. In here, we consider OWPP under the Clean Development Mechanism. And carbon price follows GBM. We adopt the trading price of China SHCEE as our carbon price data source.

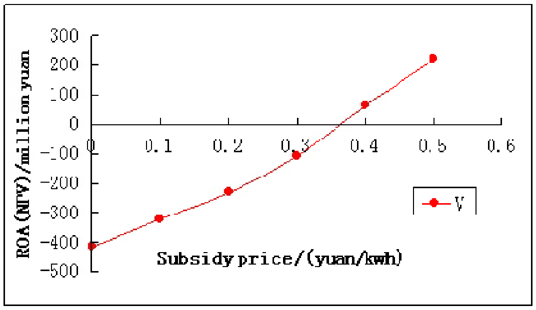


Fig. 16. Sensitivity analysis of subsidy to *V*

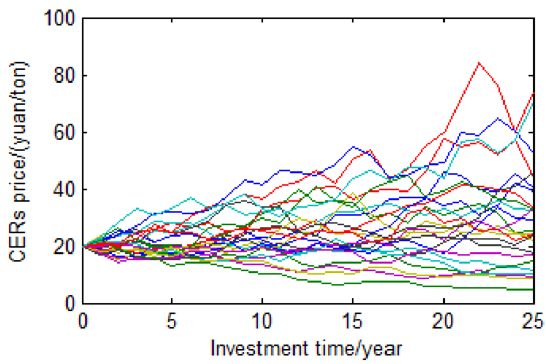


Fig. 17. The change of carbon price (25 paths)

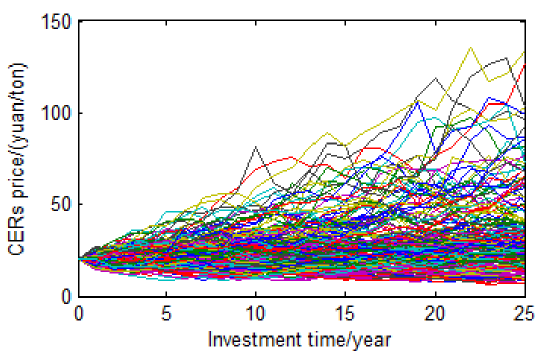


Fig. 18. The change of carbon price (200 paths)

CERs price's simulate paths is shown in Figs. 17 and 18. A sensitivity analysis of CERs to ROA/NPV are shown in Fig. 19. We can see that ROA has been positive and decreased from 425 million *yuan* to 212.5 million *yuan*. While NPV has raised from -820 million *yuan* to 10 million *yuan*. Likewise, Fig. 20 shows a sensitivity analysis of CERs to *V*. The project is unprofitable if carbon price beyond 37.5 *yuan*/*ton*, which is hard to achieve this level. This is because the price of domestic carbon emissions is affected by multiple factors, such as, carbon prices in the international market, carbon trading policies, supply and demand, and so on. Although, it has realized that the reduction of carbon emission is so important to us, but enterprises neglect it as the economic aspects. This causes the carbon price even below than the expectation of people.

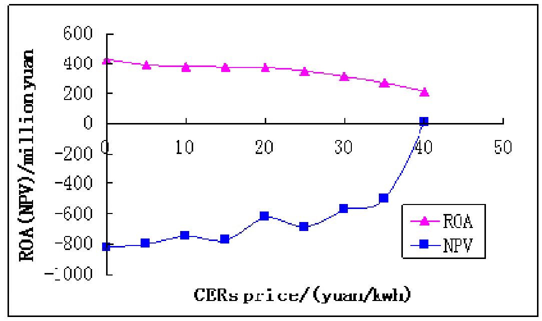


Fig. 19. Sensitivity analysis of CERs to ROA/NPV

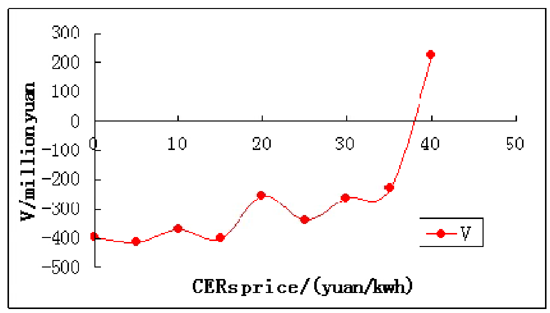


Fig. 20. Sensitivity analysis of CERs to *V*.

4. CONCLUSION AND RECOMMENDATIONS

This study presents an OWPP investment evaluation model based on a real options method, and four uncertain factors (i.e. investment costs (FIXC and VARC), carbon prices, FIT and subsidy payments) are taken into account. Especially, we consider the market linkage effect of investment costs and study the impact of VARC on the project value. Using LSM, we calculate the project value, and evaluate the project from the point of private investors. We obtain that the options value of OWPP is 651.80 million *yuan*, the project value is -730.49 million *yuan*. Therefore, investors should abandon investment of the OWPP in the present environment, but investors can invest if the condition turns favorable.

Through the sensitivity analysis mentioned above, we can obtain the following results.

Advanced wind power technology is always conducive to reducing costs. While the FIXC of OWPP has a certain influence on the project value. When the FIXC is < 1200 million *yuan*, the OWPP would make a profit. And investors would get the maximize income when the FIXC reach to 500 million *yuan*. Hence, investors would decrease investment costs to gain incomes. Meanwhile, we obtain that the VARC also has a certain impact on investment value. Investors will benefit from lowering VARC. When VARC decreased to 20 million *yuan*, the enterprise would mark profits. In fact, the VARC of Xiangshui offshore wind farm is 45.071 million *yuan*. From this point, offshore wind power plant is a loss. However, we need to consider other factors comprehensively, such as high electricity price, low fixed costs, and high carbon price, etc.

Improve the electricity power matching system to ensure the quota sales of RE power. RE power generation need to increase the FIT to obtain benefit. Obviously, offshore wind generation is no exception. But, high FIT lead to excessive financial burdens for the government, which can achieve a balance by levying heavier environmental tax when the electricity is from the traditional energy generation. Meanwhile, the state should introduce punitive measures for those who “abandon the wind” or “abandon the light”.

Promoting carbon market and raising carbon price. The reason is that carbon price has some affect on the investment of OWPP. When carbon price >37.5 *yuan*/*ton*, investors would invest. Obviously, it’s hard to reach this level. Therefore, China should raise the voice on international carbon market so as to make more benefits for investors.

In addition, as a new energy project, subsidy is essential. In OWPP, subsidy price should beyond 0.37 yuan/kWh, otherwise investors will suffer losses. To encourage investors to invest in RE, the government has introduced many subsidy policies. Moreover, the effect of subsidy is obvious. Of course, while the FIT and carbon price are adequate to assure the ordinary profits of OWPP, the subsidy payment would be canceled.

Our findings in this study would be helpful to the assessment of OWPP; and also fitting for other RE, such as photovoltaic, biomass, and geothermal. However, RE projects involve complex investment under uncertainty factors, and the uncertainties studied here may still be not sufficient. Such as wind speed, call of minute reserve capacity and loss of electricity during transportation are not considered, which remains to be further studied in future articles.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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