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Study on optimized decision-making model of offshore wind power projects investment

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Abstract. China's offshore wind energy is of great potential and plays an important role in promoting China's energy structure adjustment. However, the current development of offshore wind power in China is inadequate, and is much less developed than that of onshore wind power. On the basis of considering all kinds of risks faced by offshore wind power development, an optimized model of offshore wind power investment decision is established in this paper by proposing the risk-benefit assessment method. To prove the practicability of this method in improving the selection of wind power projects, python programming is used to simulate the investment analysis of a large number of projects. Therefore, the paper is dedicated to provide decision-making support for the sound development of offshore wind power industry.

1. Introduction

China has abundant wind energy resources. According to China Meteorological Administration, wind energy reserves in China is about 1 TW, of which the onshore wind energy reserves is about 253 GW (10m height from ground), and the offshore wind energy reserves is about 750 GW. In order to protect the environment and meet the energy demand, offshore wind energy is gradually being developed and exploited [1]. According to the " China wind power installed capacity briefing 2016", the total installed capacity of offshore wind power in China in 2016 reached 1.63 GW. While the "Electric power development '13th Five-year' plan" of China clearly points out that the national offshore wind power capacity will research 5GW by 2020. However, the offshore wind power resources exploitation is far less developed than onshore wind power, of which the cumulative installed capacity was 169 GW in 2016. Because most of the coastal areas of China are usually more developed, and have higher energy demand, and at the same time the infrastructure support is also stronger to ensure more effective offshore wind power development. Therefore, offshore wind power has a lot of advantages compared to onshore wind power.

With China's energy industry transformation and upgrading in the future, the development of renewable energy, including wind power, will become the main direction. As one of the important clean energy alternation, and with future technological progress, offshore wind power will also play a vital role in promoting the eastern region of China to improve the environment protection. However, various risk factors of offshore wind power should be taken into account in order to ensure the orderly development of offshore wind power industry and avoid blind investment. When reviewing the researches on decision-making method, most of the literatures would focus on either the risk aspects or the benefits aspects and rarely combined these two dimensions together. It is necessary and practical to create a quantitative method to ensure risk factors are fully evaluated other than just the return of investments, thus help the investor to optimize their investment decisions.

2. Risk-benefit assessment method

2.1. Definition of the method

The investment of offshore wind power project is accompanied by a number of risks. Investment decisions on specific projects are based mainly on the comprehensive assessment and consideration of benefits and risks. Investors naturally prefer low-risk & high-yield projects, and dislike high-risk & low-yield projects. While different investors have different preferences when making choices between low-risk & low-yield projects and high-risk & high-yield projects.

Therefore, this paper puts forward the method of risk-benefit assessment, which focuses on the evaluation of risks and benefits jointly based on AHP (Analytic Hierarchy Process) and NPV (Net Present Value). Investors can use the risk-benefit coordinate system (Figure 1) to combine the evaluation results of the two dimensions, then make investment decisions based on the coordinates of a specific project.

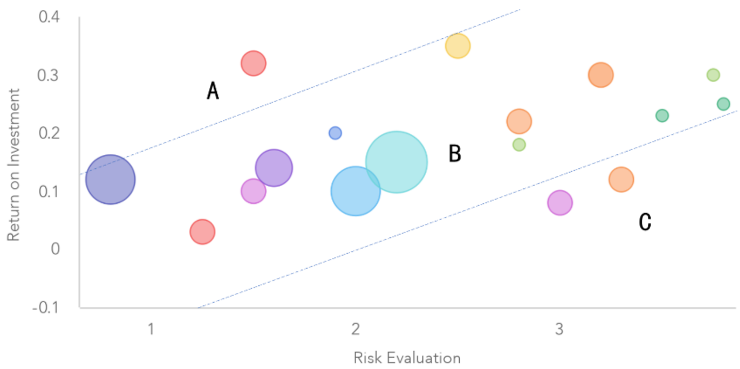

Figure 1. Risk-benefit assessment method system.

As shown in Figure 1, the horizontal axis is for the project risk assessment results, the vertical axis for the investment income assessment results. It is deduced that when the number of observed projects is big enough, most of the projects will fall into area B, called as "reasonable area" in this paper. Some projects will fall in area A or area C, respectively called as high-quality area (with low risk and high yield) and low-quality area (with high risk and low yield).

2.2. Risk identification and assessment

Offshore wind power projects are facing many risks [2]. As a risk complex, first of all, the development mode is not yet mature, and the prospect remains to be verified, therefore both the international and domestic market development are of high risk; Secondly, offshore wind power is a new energy technology with serious policy dependence, and it is pretty uncertain whether the governmental encouragement policies will be robust and long-term; Thirdly, the natural environment of offshore wind power project is relatively severe, the risks of a variety of natural disasters coexist, and the normal construction and operation of the project may be threatened; Lastly, offshore wind power projects are normally large, technology-intensive, and with long service cycle, risks in technical and management level have to be faced all along the process from construction to normal operation.

Three levels of risks of offshore wind power projects are considered in this paper based on literature review [3], [4], [5]. The first level is the project risk, and the second level includes natural risk, policy risk, economic risk and technical & management risk. On third level, the natural risk includes natural disaster risk and wind energy resource fluctuation risk; The policy risk includes policy change (net price) risk, equipment safety risk and government relationship risk; The economic risk includes cost budget risk, market price fluctuation risk and interest rate risk; The technical management risk includes construction risk and operation management risk, as shown in Figure 2.

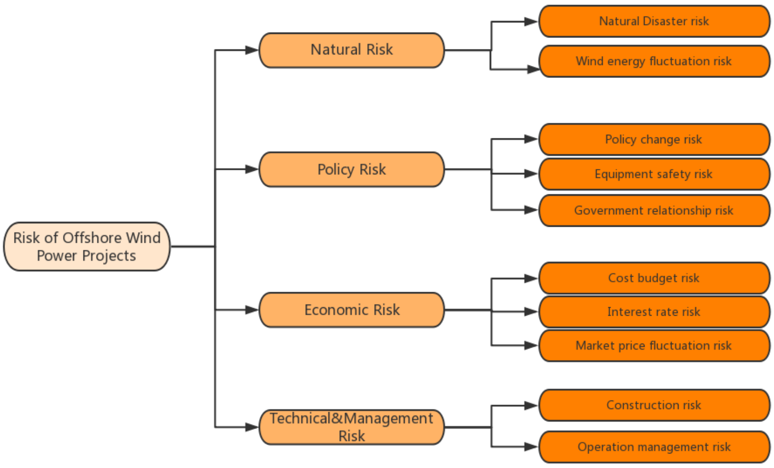

Figure 2. Risk identification in offshore wind power projects.

Based on the fuzziness of risk factors of offshore wind power projects, fuzzy comprehensive evaluation method is adopted to evaluate different risk factors. The main idea of this method is:

- to establish risk index, namely the risk identification results;
- to determine the risk factors of different grades, namely the possibility of the occurrence. In the fuzzy comprehensive evaluation method, the way of expert scoring can be adopted to get the membership grade of individual factors to the risk level. More simply, experts can also give a clear risk level directly;
- to determine the weights of different risk factors, which are the relative importance degree of different risk factors, generally calculated by AHP;
- to combine with grade and weigh of the risk factors and make the final evaluation, namely the importance of risk factors.

In the example analysis given in the following section, it is assumed that different projects have the same risk factor weights, while the risk factors have different grades. The comparative judgment matrix in Table 1 is constructed by AHP to determine the weights of risk factors (matrix for second level risk factors are not shown in this paper due to the limited length of the paper). By combining the viewpoints in several literatures, the weights of each risk factor are identified according to the scale of the direct economic losses caused by each risk. The consistency ratio is also investigated, and the rationality of the weight evaluation is proved. The analysis shows that the weights of first level risk factors are {0.5065, 0.0666, 0.2871, 0.1398}, and the second level risk factors are {0.4221, 0.0814, 0.0493, 0.0062, 0.0111, 0.0469, 0.1549, 0.0853, 0.0932, 0.0466}.

2.3. Investment assessment

The paper uses net present value (NPV) and internal rate of return (IRR) to get the final description of whether a specific offshore wind power project is investable. For a single project, the initial investment and operating investment, the operation period price income, subsidy income and carbon trading income are considered in determining the NPV and IRR.

From the capital structure, the whole process of offshore wind power projects generally consists of four stages: construction period, subsidy policy period, contract price period, and the period of sales at market prices. In the return of the project, it also includes: contract pricing income, market pricing income, policy subsidy income and carbon emissions trading income. The present value of asset is as follows [6], [7], [8],:

Table 1. First level risk factor comparative judgment matrix.

Offshore wind power project risk	Natural risk	Policy risk	Economic risk	Technical & management risk	Weight
Natural risk	1	5	3	3	0.5065
Policy risk	1/5	1	1/7	1/2	0.0666
Economic risk	1/3	7	1	2	0.2871
Technical & management risk	1/3	2	1/2	1	0.1398
Consistency test result	consistency ratio: 0.0698; λmax : 4.1863				

$$V = \sum_{t=t_1+1}^{t_1+t_2} p_1 hMe^{-it} + \sum_{t=t_1+t_2}^{T_s} p_2 hMe^{(a-i)t} + \sum_{t=t_1+1}^{t_1+t_3} p_3 hMe^{-it} + \sum_{t=t_1+1}^{T_s} p_4 hMe^{-it} \quad (1)$$

In formula (1), p_1 is the contract price, p_2 is the market price, p_3 is the subsidy price, and p_4 is the carbon emissions trading price; h is the annual average generating hours; M is the total installed capacity; t_1 is the construction period; t_2 is the contract period; t_3 is the subsidy duration; T_N is construction period plus operating period; a is the inflation rate; i is the discount rate.

NPV at time 0 is:

$$\text{NPV} = V_0 - I_0 - D \quad (2)$$

In formula (2), V_0 is the asset value of the project at time 0; I_0 is initial investment cost of the project; D is project operation cost.

$$\text{D} = \sum_{t=t_1+1}^{T_N} c_t hMe^{-it} \quad (3)$$

c_t is power generation cost.

Accordingly, considering the net present value is 0, then the project's IRR can be derived.

3. Application of risk-benefit assessment method

This section shows the application of risk-benefit assessment method through applying it to 200 offshore wind power projects that are constructed by Python programming. In the risk assessment part, the range of risk level for different risk factors was determined through literature review, and then risk level of 200 projects are given in the corresponding range by Python programming; In the investment assessment part, the general ranges of different parameters are reasonably determined, and parameter assignments are then made within these ranges also by Python programming.

This section selects one of the results of the projects constructed using programming, in which 103 out of 200 projects have either negative present value, or the net present value is unreasonably large, or the risk is very low and the internal rate of return is unreasonably too large. These 103 constructions are removed and the remaining 97 projects are considered to be reasonable, shown in the following sections.

3.1. Risk assessment results

The risk is divided into 1,2,3,4,5 five levels, indicating that the possibility of occurrence is minimum, small, medium, large, and great. Based on the 10 risk factors (natural disasters, wind energy fluctuations, policy changes, social security risks, government relations risk, cost risk, market price fluctuations, interest rate risk, construction risks, and operation management risk), the risk level matrix of the 97 projects is as table 2 shows:

Table 2. Risk level matrix of the 97 projects

A_{97x10}=

Risk factors / Project number	Natural disasters risk	Wind energy fluctuations risk	Policy changes risk	…	Interest rate risk	Construction risk	Operation & management risk
1	1	1	4	…	3	2	2
2	2	4	1	…	3	3	2
3	2	3	3	…	2	4	2
…	…	…	…	…	…	…	…
95	1	4	2	…	1	3	1
96	1	2	5	…	3	3	2
97	2	3	2	…	2	4	1

The risk weight matrix given above is:

R_{10x1} = [0.4221, 0.0814, 0.0493, 0.0062, 0.0111, 0.0469, 0.1549, 0.0853, 0.0932, 0.0466]^T

The corresponding risk assessment result for the 97 projects is:

B_{97x1} = A·R =

[2.82, 1.2, 2.34, 1.92, 2.43, 2.43, 1.84, 1.9, 1.84, 2.67, 2.83, 1.64, 2.06, 1.91, 2.28, 2.4, 2.22, 2.95, 2.52, 2.41, 2.04, 2.44, 2.6, 2.31, 2.35, 1.99, 2.49, 2.11, 1.51, 1.87, 2.25, 2.3, 2.88, 1.25, 1.66, 2.42, 2.26, 2.11, 2.27, 1.87, 2.33, 2.12, 2.0, 2.8, 2.44, 2.44, 2.37, 2.2, 2.28, 1.93, 2.11, 2.1, 2.67, 2.85, 2.37, 2.34, 2.28, 2.48, 1.74, 2.09, 2.39, 1.85, 2.32, 2.28, 2.44, 1.92, 3.02, 1.94, 2.27, 1.74, 2.4, 2.54, 2.69, 2.35, 1.71, 2.92, 2.59, 2.69, 2.19, 2.62, 2.21, 2.63, 2.46, 2.53, 3.02, 2.01, 2.52, 1.84, 2.04, 2.29, 2.34, 2.35, 1.64, 2.41, 2.33, 1.38, 1.88]

3.2. Investment assessment results

From the perspective of {project capacity (MW), total investment (Million dollar), contract price (Dollar / kWh), market price (Dollar / kWh), subsidy price (Dollar / kWh), carbon trading price (Dollar / kWh), operating costs (year), starting period (year / kWh), construction period (year), operating period (year), contract period (year), subsidy period (year), duration of the year (hour), discount rate, inflation rate}, the economic parameters of the 97 projects are as table 3 shows:

Table 3. Economic parameters of the 97 projects

Economic parameter / Project number	Project capacity	Total investment	Contract price	…	Duration of the year	Discount rate,	Inflation rate
1	169	516.0	0.08	…	264	0.11	0.06
2	98	302.3	0.09	…	340	0.09	0.04
3	178	543.5	0.10	…	297	0.09	0.05
…	…	…	…	…	…	…	…
95	171	522.1	0.10	…	328	0.12	0.05
96	69	210.7	0.09	…	304	0.09	0.06
97	144	439.7	0.08	…	323	0.09	0.04

This gives the following results:

NPV (Million dollar)=[9.01, 16.18, 57.71, 25.65, 56.18, 47.94, 33.74, 112.21, 18.78, 71.60, 25.04, 18.93, 7.63, 84.58, 70.08, 62.44, 78.93, 56.49, 27.33, 0.92, 46.56, 14.96, 105.04, 6.72, 1.53, 120.92, 25.80, 50.38, 41.98, 116.79, 69.31, 11.91, 37.71, 72.67, 6.72, 106.56, 39.69, 1.68, 47.33, 8.85, 73.28, 40.31, 29.77, 10.99, 88.24, 22.75, 66.72, 67.94, 86.11, 34.50, 21.83, 27.33, 90.84, 4.12, 66.41, 43.05, 28.40, 105.50, 22.29, 74.20, 67.79, 12.52, 3.51, 111.15, 86.56, 0.61, 4.89, 30.84, 115.11, 18.78, 19.39, 11.15, 20.46, 95.57, 6.41, 39.08, 70.53, 31.45, 80.31, 102.29, 5.65, 66.26, 22.29, 54.20, 109.77, 9.31, 21.07, 75.57, 89.47, 27.79, 33.89, 50.08, 12.98, 67.02, 54.20, 15.73, 62.75];

IRR =[0.09, 0.06, 0.1, 0.08, 0.08, 0.09, 0.08, 0.1, 0.12, 0.09, 0.1, 0.08, 0.1, 0.08, 0.09, 0.08, 0.09, 0.12, 0.09, 0.08, 0.12, 0.1, 0.08, 0.08, 0.11, 0.1, 0.07, 0.08, 0.07, 0.13, 0.11, 0.09, 0.08, 0.08, 0.07, 0.1, 0.09, 0.11, 0.11, 0.08, 0.11, 0.08, 0.09, 0.07, 0.08, 0.1, 0.09, 0.08, 0.08, 0.09, 0.09, 0.1, 0.07, 0.08, 0.08, 0.1, 0.09, 0.1, 0.07, 0.11, 0.08, 0.11, 0.08, 0.08, 0.11, 0.07, 0.07, 0.07, 0.1, 0.07, 0.08, 0.11, 0.08, 0.08, 0.06, 0.1, 0.08, 0.11, 0.12, 0.1, 0.1, 0.09, 0.09, 0.12, 0.1, 0.07, 0.07, 0.09, 0.11, 0.1, 0.09, 0.1, 0.08, 0.1, 0.11, 0.07, 0.12]

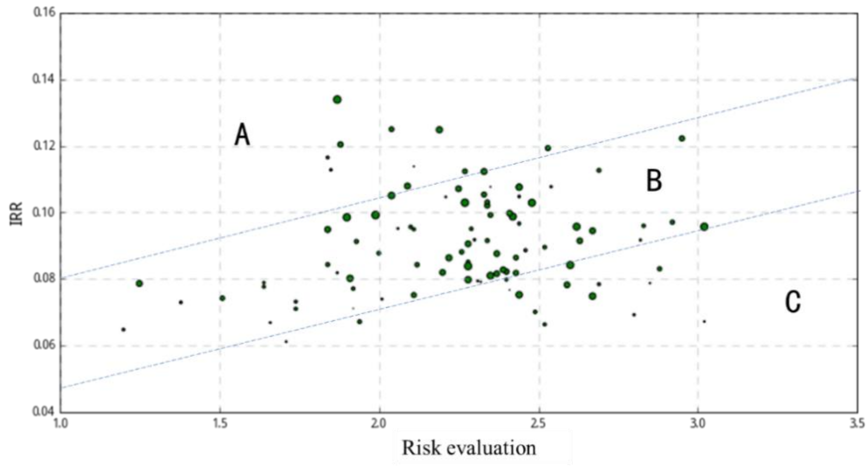

Figure 3. Relationship between risk evaluation and IRR.

According to the results of the risk assessment and investment assessment, the position of the project is given in the risk-benefit assessment coordinate system, which is presented in Figure 3. The abscissa is the risk assessment value, and the ordinate is IRR, and the NPV is represented by size of the bubble.

In Figure 3, among the 97 projects, 10 projects are in the high-quality area, which means low risk and high IRR; 16 projects are in the low-quality area, which means high risk and low IRR; The remaining 71 projects fall into the reasonable area and the IRR variation is only about 3.5%, which

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makes the risk preference of investors undoubtedly the leading factor when facing investment choices in this area.

4. Summary and outlook

In this paper, the investment decision-making model of offshore wind power project is improved. Through the simulation of a series of offshore wind power projects, the paper applies the model to the risk and investment analysis. It is verified that the risk-benefit assessment method proposed in this paper is capable of comprehensively evaluating the investment value of offshore wind power project. This approach integrates risk identification and assessment into investment decision-making to optimize the evaluation of offshore wind power projects, and it can improve investment efficiency and avoid wasting of resources, therefore provide strategic support for a healthy development of offshore wind power industry.

This method could be improved in the following aspects: First, the offshore wind power project investment is usually large, irreversible and with long payback period, and a variety of uncertainties could occur during construction and operation, all these give it real options characteristics. Thus, the use of a real options theory based investment model is more suitable for the risk-benefit assessment method. Second, an important aspect of the fuzzy comprehensive evaluation method is to analyze the membership degree of the risk level according to experts' opinions, which is not the case in this paper, and could be optimized in further research.

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