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Multi-criteria decision making on strategic selection of wind farms

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ABSTRACT

With maturity of advanced technologies and urgent requirement for maintaining a healthy environment with reasonable price, China is moving toward a trend of generating electricity from renewable wind resources. How to select a suitable wind farm becomes an important focus for stakeholders. This paper first briefly introduces wind farm and then develops its critical success criteria. A new multi-criteria decision-making (MCDM) model, based on the analytic hierarchy process (AHP) associated with benefits, opportunities, costs and risks (BOCR), is proposed to help select a suitable wind farm project. Multiple factors that affect the success of wind farm operations are analyzed by taking into account experts' opinions, and a performance ranking of the wind farms is generated.

1. Introduction

The rapid development in wind energy technology has made it the most promising alternative to conventional energy systems in recent years [1]. In China, with potential capacity of 250 GW, the installed capacity of wind power increased steadily from 54, 25, 84, 90, 67, 93, 134, 756 to 1200 MW for year 1998 through year 2006 [2]. In order to encourage the installation of renewable and sustainable energy in China, Renewable Energy Law (REL), January 2006, stipulated that renewable energy must contribute 10% of national energy supply by year 2020. Electricity grid dispatchers are obligated to purchase electricity generated from renewable and sustainable sources. The REL is administrated by the National Development and Reform Commission (NDRC), but is implemented by governments at regional and local levels. Decisions on regional targets will be based upon regional circumstances including the availability of renewable energy [3].

It is foreseeable that the move to generating electricity through wind farms in China will become the main trend in future years. However, because of increasing complexity in the socio-economic surroundings and rapidly changing technologies, the selection of a suitable wind farm is an important issue for private associations, political groups, and private sectors. In the authors' understanding, no work, except Moran and Sherrington [4] and Strbac et al. [5], which assesses the economic feasibility of a large-scale wind farm project by benefit and cost analysis, has ever described and analyzed such an important issue based on benefits, opportunities, costs and risks simultaneously. In order to fill the vacancy, the paper will briefly introduce a wind farm and its critical success criteria, and then develop a selection model to help evaluate wind farm projects. In conventional AHP, a well-known multiple criteria decision-making method, pairwise comparison of relative criteria (or alternatives) is applied to rank the final priority. However, considering the benefits (B), opportunities (O), costs (C) and risks (R) of an alternative, and synthesizing the positive criteria of benefits (B) and opportunities (O) and the negative criteria of costs (C) and risks (R) with rating calculation (not pairwise comparison) by a method such as additive, subtractive and multiplicative is a more comprehensive way to deal with a much more complicated problem. Accordingly, AHP associated with BOCR is adopted in the paper to handle this kind of positive and negative criteria in public-oriented projects.

2. Project evaluation and project management

The issues related to project evaluation and project management have been discussed in various management functions such as research and development, environmental energy management, and quality management. The project selection prior to investment is customarily done using marketing, technical, manufacturing, and financial information in industry. Due to risk uncertainty and limited resources, portfolio decisions were prevailing because of the difficulty of allocating a scarce budget over multiple periods, because of multi-period consequences, and because of uncertain and often interdependent products that compete for a common pool of resources. Strategic intent of project, criteria for project

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selection, and various qualitative and quantitative project selection models were studied. A review of literature reveals that project management is primarily based on a few perspectives, and that the emphasized perspectives have changed over time [6]. While task perspective was the most emphasized in the past, leadership perspective is dominant today. Synthesis of results revealed that relationship management, resource management, time management, cost management and risk management all displayed consistent significance throughout the past 10 years [7]. However, by contrast, finalization, scope and marketing seemed to be ignored, while project evaluation and improvement of strategic attainment were both increasing in their significance in the research on project management. Evidence also suggests that the significance of quality management and interpersonal issues has waned, although these issues have previously been of great interest to writers in project management.

Environmental assessment and social assessment are mainly carried out to satisfy the requirements of statutory agencies [8]. Because environmental regulations have become stricter all over the world, the impact assessment suggests that alternative sites, technologies, designs, and implementation methods are considered as mitigating measures. The situations faced by electricity companies have become more complex and riskier. In the past, moderate security in electrical supply and price stability made fuel price and electric demand as sole uncertainties. Liberalization of markets has increased the sources of uncertainty. In particular, electricity companies need to face variant risks such as future demand, supply and prices and regulatory risks when making their investment decisions [9]. Feasibility analysis and final selection usually take a long time, and the implementation must wait until the statutory regulatory authority approves the project. Moreover, project analysis through above process often leads to sub-optimal projects because either financial analysis may eliminate better options or environment friendly alternatives will always be non-economical.

Under these circumstances, finding an integrated framework for evaluating projects with respect to market, technologies, social and environmental impact and so on is very important for most power enterprises. If the critical success criteria of wind farms can be fully understood and a method for solving multi-criteria decision-making problems can be built up, strategic selection and operations of wind farms can be further implemented successfully.

Wind farms and critical success criteria Most of the world's energy consumption is largely dependant on fossil fuel, which is exhaustible and causes atmospheric degradation. The utilization of energy from renewable sources, such as wind, is becoming increasingly attractive. Wind energy is non-depleting, site-dependant and non-polluting. Renewable resources have great potential to reduce fuel costs, contribute to system adequacy, and provide security against price volatility. Renewable energy, especially wind power, will play an important role in the 21st century. This valuable resource needs to be converted, and various conversion systems need to be explored. A wind farm generates wind-powered electricity by a collection of wind turbines in the same location. Individual turbines are interconnected with a medium-voltage collection system and communications network. This medium-voltage electricity is then stepped up with a transformer to a high voltage transmission system and an electric grid. American Wind Energy Association [10] lists the most important 10 steps in building a wind farm: understanding wind resource, determining proximity to existing transmission lines, securing access to land, establishing access to capital, identifying reliable power purchaser or market, addressing site and project feasibility considerations, understanding wind energy's economics, obtaining zoning and expertise, establishing dialogue with turbine manufacturers, and securing agreement.

The development in wind technology has resulted in wind turbine generators (WTG) that are relatively comparable to conventional units in terms of both cost and capacity ratings. Parameters like reliability, capacity factor, power factor, technical availability, and real availability are important factors affecting the performance of WTG [11]. Variation of wind speed has an impact on the economics, duration of life, and smooth running of the wind energy conversion system. With recent developments in power electronic converters, variable speed generations seem to be feasible and cost effective [12]. In order to study the long-term trend of mean wind speed, annual mean of the wind speed and wind power density need to be measured, calculated and analyzed [13]. Interconnection with electric networks, influence of selected height of installation above ground, effect of wind gusting and micro-siting of WEGs are also main influences of annual energy output [18]. In addition, it is necessary to consider electrical connection costs, mainly, on step-up transformers and between WPT. Wind farm investment costs consist of the costs of foundation, electrical connection, grid connection, land purchase, planning, approvals, infrastructure, wind turbines, and management, and so on. The current fixed tariff remuneration for wind energy is not compatible with the deregulation of the electric power industry. The US government has supported wind power primarily through the tax code, via 5-year accelerated depreciation and the federal production tax credit. Under clean development mechanisms (CDM) program, industrialized countries indirectly pay for projects that cut or avoid emissions in developing nations by buying credits called Certified Emission Reductions (CER) that can be applied to meet their own emission targets. Recipient countries benefit from the infusion of advanced technology and investment that allows their factories or energy generating plants to operate more efficiently [14]. Since October 12, 2005, China has decided on some measures regulating the legal modalities of CDM implementation. The wind power concession program auctions off wind power development rights including a guaranteed tariff and concession operation agreements. Such on-grid tariff of wind power is decided by bidding. If the tariff is higher than the referenced on-grid tariff of desulfurized coal-fired power, then the difference will be shared in the selling price at the provincial and national grid levels [15]. Agterbosch et al. [16] stated that steering strategies that have been developed at the national level to solve the planning problems at the operational level do not address the right problems. Jobert and Laborgne [17] showed how local acceptance is influenced by both planning rules and local factors.

Experts predict wind power, with superior economics and improved technologies, could capture 5% of the world energy market by the year 2020. The economic potential depends upon factors such as average wind speed, statistical wind speed distribution, turbulence intensities, and cost of wind turbine systems [12]. Wind turbines can be designed for optimum power production with less cost and higher efficiency, under the improved technologies such as experimental and theoretical methods to analyze vibration problems of wind turbines, aero-acoustic tests to find noise in the aerofoil, computer-based supervisory control to identify operating characteristics of wind turbines, static reactive power compensator to improve stability of large wind farms, Parato analysis and simulation models to analyze grid-related problems, control system modeling to keep the operating parameters of the wind turbine within the specified limit, and so on [18].

For the purpose of feasibility analysis, an evaluation committee shall be established. The committee shall be composed of 7–13 members who have relevant professional knowledge about the objectives to be evaluated. Among the members, at least one third of the total number shall be outside experts or scholars. The evaluation committee's duties are [19]

1. setting or approving the evaluation items, the evaluation criteria, and the evaluation method;
2. project conceptualization, site identification and wind atlas analysis;
3. project financing and technical analysis;
4. public outreach and feedback; and
5. feasibility analysis (technical, social and economic).

The first duty of the committee is to find critical success criteria and build up an effective model to evaluate the project. Then, the performances of projects under different sites and wind potential atlas with respect to benefits, opportunities, costs, and risks are evaluated based on expectations, sensitivity to environmental changes, and realistic assessment. Subsequently, the market analysis for the project is taken up to decide the throughput for the project in line with projected supply and demand scenario. Technical analysis identifies a few feasible project alternatives with respect to project sites, throughput, technology, service mix, and implementation method depending on the type of projects. Due to increasing concern of the project-affected people and statutory environmental regulatory authorities, all projects are required to obtain environmental and social clearances before receiving approval of competent authorities for implementation. Accordingly, an environmental and social impact assessment study is required to determine the positive and negative impact of projects on environment and to develop measures for mitigating the negative impacts. The outcome of the project feasibility analysis is the instrument for receiving approval from central authorities.

Based on literature reviews and practical experiences, the evaluation committee considers the criteria shown in Table 1 as the most important factors for wind farm project, and these criteria will be used to select the best wind farm project in the subsequent real case study.

Table 1
The criteria and sub-criteria for wind farm project

Merits	Criteria	Sub-criteria
Benefits	(a) Wind availability	(a1) Geographical distribution of wind speed frequency
		(a2) Mean wind power density
		(a3) Annual mean wind speed
	(b) Site advantage	(b1) Influence of selected height of installation
		(b2) Effect of wind gusting
		(b3) Micro-siting of WEGs
	(c) WEG functions	(c1) Real and technical availability
		(c2) Affordable, reliable, and maintenance free
		(c3) Power factor, capacity factor
Opport.	(d) Financial schemes	(d1) Switchable tariff
		(d2) Discount of tax rate and duty rate
		(d3) Other investment and production incentives
	(e) Policy support	(e1) Wind power concession program
		(e2) Clean development mechanisms program
		(e3) Other policy supports
	(f) Advanced technologies	(f1) Computerized supervisory
		(f2) Variable speed wind power generation
		(f3) Swept area of a turbine rotor
		(f4) Static reactive power compensator, etc.
Costs	(g) Wind turbine	(g1) Design and development[a]
		(g2) Manufacturing[a]
		(g3) Installation, maintenance[a]
	(h) Connection	(h1) Electric connection[a]
		(h2) Grid connection[a]
	(i) Foundation	(i1) Main construction[a]
		(i2) Peripheral construction[a]
Risks	(j) Concept conflict	Entrepreneurs, policy makers, residents[b]
	(k) Technical risks	Technical complexity and difficulties[b]
	(l) Uncertainty of land	Loyalty or lease agreement, geology suitability, etc.[b]

[a] The value of each sub-criterion is the amount of cost needs to spend. The costs of sub-criteria under each cost criterion will be summed up for the evaluation.
[b] Definition of criterion. For criteria under the *risks* merit, there is no lower-level sub-criterion.

3. Analytic hierarchy process associated with BOCR

The analytic hierarchy process (AHP), proposed by Satty [20], is a simple, mathematically based multi-criteria decision-making tool to deal with complex, unstructured and multi-attribute problems. Saaty [21] further proposed a method to let decision makers to deal with the benefits, opportunities, costs, and risks (the BOCR merits) of a decision. A hierarchy can consist of four sub-hierarchies: benefits, opportunities, costs, and risks.

A systematic AHP model with BOCR is proposed in this section. The steps are summarized as follows [21–25]:

Step 1. Form a committee of experts in the industry and define the wind farm selection problem.

Step 2. Construct a control hierarchy for the problem. A control hierarchy contains strategic criteria, the very basic criteria used to assess the problem, and the four merits, benefits, opportunities, costs and risks.

Step 3. Determine the priorities of the strategic criteria. A questionnaire with Satty's nine-point scale is prepared to obtain pairwise comparison results of the importance of strategic criteria toward achieving the overall objective. Form a pairwise comparison matrix, and calculate the priorities of the strategic criteria [20]. Examine the consistency property of the matrix. If an inconsistency is found, experts are asked to revise the questionnaire, and the calculation is done again.

Step 4. Determine the importance of benefits, opportunities, costs and risks to each strategic criterion. A five-step scale is used, and the values of each scale is assigned to be very high, 0.42; high, 0.26; medium, 0.16; low, 0.10; very low, 0.06 [22].

Step 5. Determine the priorities of the merits. Calculate the priority of a merit by multiplying the score of a merit on each strategic criterion from Step 4 with the priority of the respective strategic criterion from Step 3 and summing up the calculated values for the merit. Normalize the calculated values of the four merits, and obtain the priorities of benefits, opportunities, costs and risks, that is, b, o, c, r, respectively.

Step 6. Decompose the wind farm selection problem into a BOCR hierarchy with four sub-hierarchies. Based on literature review and experts' opinions, a hierarchy with four sub-hierarchies, benefits (B), opportunities (O), costs (C) and risks (R), is formed in achieving the overall goal. For instance, for the sub-hierarchy for benefits (B) merit, there are criteria and sub-criteria that are related to the achievement of the benefits of the ultimate goal, and the lowest level contains the alternatives that are under evaluation.

Step 7. Formulate a questionnaire based on the BOCR hierarchy to pairwise compare elements, or factors, in each level with respect to the same upper level element. Experts in the field are asked to fill out the nine-point scale questionnaire.

Step 8. Calculate the relative priorities in each sub-hierarchy. A similar procedure as in Step 3 is applied to establish relative importance weights of criteria with respect to the

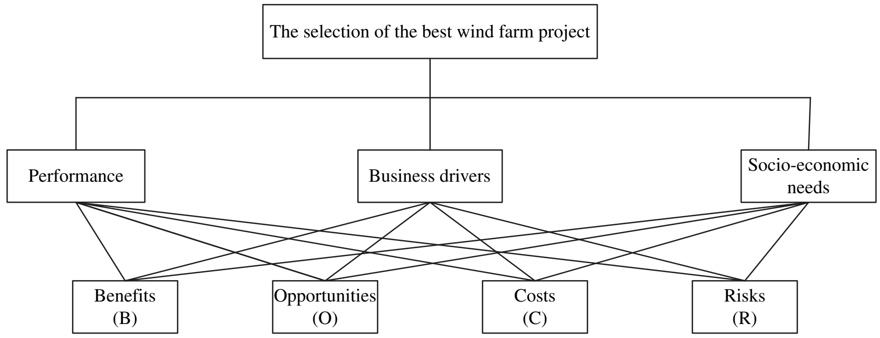

Fig. 1. The control hierarchy for wind farm selection.

same upper level merit, the relative importance weights of sub-criteria with respect to the same upper level criterion, and the relative performance weights of alternatives with respect to each sub-criterion (or criterion).

Step 9. Calculate the priorities of alternatives for each merit sub-hierarchy. The priorities of the alternatives under each merit are calculated by synthesizing the relative importance weights of criteria with respect to the same upper level merit, the relative importance weights of sub-criteria with respect to the same upper level criterion, and the relative performance weights of alternatives with respect to each sub-criterion (or criterion).

Step 10. Calculate overall priorities of alternatives by synthesizing priorities of each alternative under each merit from Step 9 with corresponding normalized weights *b*, *o*, *c* and *r* from Step 5. There are five ways to combine the scores of each alternative under *B*, *O*, *C* and *R* [22].

1. Additive

$$P_i = bB_i + oO_i + c(1/C_i)_{\text{Normalized}} + r(1/R_i)_{\text{Normalized}}$$

where B_i, O_i, C_i and R_i represent the synthesized results of alternative *i* under merit *B*, *O*, *C* and *R*, respectively, and *b*, *o*, *c* and *r* are normalized weights of merit *B*, *O*, *C* and *R*, respectively.

2. Probabilistic additive

$$P_i = bB_i + oO_i + c(1 - C_i) + r(1 - R_i)$$

3. Subtractive

$$P_i = bB_i + oO_i - cC_i - rR_i$$

4. Multiplicative priority powers

$$P_i = B_i^b O_i^o \left[(1/C_i)_{\text{Normalized}}\right]^c \left[(1/R_i)_{\text{Normalized}}\right]^r$$

5. Multiplicative

$$P_i = B_i O_i / C_i R_i$$

4. A real case study

According to REL, a wind farm project in China should be implemented by regional government at the discretion of local circumstances. In order to examine the practicality of the project selection model, an anonymous province in China aiming to select a best wind farm is used as an example. The scheme proposes the installation of 500 wind turbines, each with a generating capacity of 2.5 MW, a hub height of 80 m and a blade diameter of 120 m (total height 140 m). In addition, one of the turbines needs to have a viewing platform. Taking 3 years to construct, the project is designed with an operational life of 30 years. In the first step of the evaluation process, an evaluation committee with 11 members, including three power entrepreneurs, two scholars, three legislative servants, three government officers, is formed. The first duty of the committee is to select critical success criteria as described in Section 3. Then, performance, business drivers and socio-economic needs are considered as the firm's strategic criteria based on literature reviews and practical experiences [18].

The control hierarchy for determining the firm's overall performance is shown in Fig. 1. In the second level, three strategic criteria are considered; namely, *performance*, *business drivers*, and *socio-economic needs*. *Performance* concerns the capabilities of the conversion system for delivering the results, such as availability and efficiency, in variant processing environments. *Business drivers* are defined as the expectations of participants about the wind farm, such as potential, challenge, and opportunities. *Socio-economic needs* consider whether the project possesses advanced methodology to satisfy socio-economic needs in comparison with other competitors. In the third level, there are four merits: benefits (*B*), opportunities (*O*), costs (*C*) and risks (*R*).

In the BOCR hierarchy, 12 selected criteria in Section 3 are applied here to evaluate each wind farm project. Under *benefits* merit, there are three criteria, group factors (a)–(c). Under *opportunities* merit, there are three criteria, group factor (d)–(f). Group factors (g)–(i) are the criteria of *costs* merit, and group factors (j)–(l) are the criteria of *risks* merit. In the next level, each criterion has its own sub-criteria as shown in Table 1. Five potential sites

Table 2
Priorities of benefits, opportunities, costs and risks

	Performance (0.592)	Business drivers (0.111)	Socio-economic needs (0.297)	Priorities	Normalized priorities
Benefits	0.3760	0.1549	0.1661	0.2891	0.3327
Opportunities	0.1547	0.2502	0.2323	0.1884	0.2168
Costs	0.2501	0.1663	0.1794	0.2198	0.2530
Risks	0.1386	0.2504	0.2080	0.1716	0.1975

Table 3
Relative priorities of criteria and sub-criteria

Merits	Criteria	Priorities	Sub-criteria	Local priorities	Global priorities
Benefits (0.3327)	(a)	0.6317	(a1)	0.191	0.1709
			(a2)	0.497	0.2637
			(a3)	0.312	0.1971
	(b)	0.1324	(b1)	0.489	0.0648
			(b2)	0.195	0.0258
			(b3)	0.316	0.0419
	(c)	0.2359	(c1)	0.221	0.0522
			(c2)	0.286	0.0674
			(c3)	0.493	0.1164
Opportunities (0.2168)	(d)	0.3077	(d1)	0.2107	0.0649
			(d2)	0.4476	0.1377
			(d3)	0.3417	0.1051
	(e)	0.4579	(e1)	0.4247	0.1945
			(e2)	0.2082	0.1680
			(e3)	0.3671	0.0422
	(f)	0.2344	(f1)	0.1872	0.0438
			(f2)	0.2781	0.0652
			(f3)	0.1045	0.0245
			(f4)	0.4302	0.1008
Costs (0.2530)	(g)	0.5595	[a]	0.5595	0.5595
	(h)	0.3195	[a]	0.3195	0.3195
	(i)	0.1209	[a]	0.1209	0.1209
Risks (0.1975)	(j)	0.5639	[b]	0.5639	0.5639
	(k)	0.1208	[b]	0.1208	0.1208
	(l)	0.3153	[b]	0.3153	0.3153

[a] The costs of sub-criteria under each cost criterion are summed up in the evaluation.
[b] For criteria under the *risks* merit, there is no lower-level sub-criterion.

Table 4
The qualitative and quantitative results of different sub-criteria (criteria) under different projects

Sub-criteria/criteria	A	B	C	D	E
a1	63	77	42	73	85
a2 (W/m^2)	349	451	337	502	426
a3 (m/s)	4.9	5.7	4.4	5.3	4.5
b1	85	78	61	77	86
b2	63	74	83	75	76
b3	76	89	75	88	83
c1 (%)	63	76	71	74	78
c2 (%)	98	97	98	97	98
c3 (%)	51	57	50	59	53
d1	82	82	78	83	85
d2	87	81	76	84	86
d3	90	80	73	83	88
e1	67	84	73	81	85
e2	75	81	68	78	80
e3	73	88	70	85	81
f1	83	77	73	78	81
f2	84	76	88	75	77
f3	75	79	73	73	74
f4	79	76	81	79	82
g1	140M	150M	150M	155M	160M
g2	170M	190M	180M	180M	200M
g3	140M	150M	155M	155M	160M
h1	35M	60M	30M	65M	80M
h2	40M	55M	25M	50M	85M
i1	25M	35M	35M	40M	50M
i2	20M	30M	25M	30M	50M
j	78	74	80	76	72
k	75	70	75	71	70
l	78	73	83	75	68

participated in the feasibility analysis are represented as alternatives A–E. Sites A and B are located in the northwestern region of the province. Sites C and D are located in the southern region, while site E is located in the middle region.

A questionnaire is designed, and the members of the evaluation committee are invited to contribute their professional experience. Based on the collected opinions of the experts and the proposed model, the performance of the five sites can be generated.

In the first part of the model, experts are asked to evaluate the priorities of benefits, opportunities, costs and risks. Based on each expert's opinion, a pairwise comparison matrix is formed to evaluate the three strategic criteria, and the priorities of the strategic criteria are calculated. The consistency property of the matrix is also examined [20]. Geometric average method is applied to generalize the opinions among the members. The final pairwise comparison of the experts on the three strategic criteria with respect to the goal is

$$\mathbf{W_{s1}} = \begin{array}{r} \\ \text{Performance} \\ \text{Business drivers} \\ \text{Socio-economic needs} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Performance} & \text{Business drivers} & \text{Socio-economic needs} \end{array} \\ \begin{bmatrix} 1.0000 & 4.9640 & 2.1481 \\ 0.2014 & 1.0000 & 0.3481 \\ 0.4655 & 2.8727 & 1.0000 \end{bmatrix} \end{array}$$

An eigenvector is calculated using the eigenvalue method [20].

$$w_{s1} = \begin{array}{r} \text{Performance} \\ \text{Business drivers} \\ \text{Socio-economic needs} \end{array} \begin{bmatrix} 0.592 \\ 0.111 \\ 0.297 \end{bmatrix}$$

Next, experts are asked to assess BOCR according to strategic criteria by the five-step scale. The ratings of the four merits on strategic criteria by the geometric average method are shown in Table 2. The normalized priorities of BOCR are calculated and shown in the last column of Table 2.

In the second part of the model, the priorities of the alternatives under each merit are calculated. There are four sub-hierarchies, namely benefits, opportunities, costs, and risks. The relative importance weights of criteria with respect to the same upper level merit and the relative importance weights of sub-criteria with respect to the same upper level criterion are calculated using the geometric average method to combine the pairwise comparison results. The priorities of criteria and sub-criteria are shown in Table 3.

The importance of criteria in making the wind farm project selection should be understood by the management. Under the *benefits* merit, the most important criterion is *wind availability*, with a very high benefit priority of 0.6317. The most important sub-criterion, out of the nine sub-criteria, is *mean wind power density* with a benefit global priority of 0.2637, followed by *annual mean wind speed* with a priority of 0.1971. This means that the major benefit concern for the firm in building a site is having sufficient wind for operation. Under the *opportunities* merit, both *wind power concession program* (0.1945) and *clean development mechanisms program* (0.1680) are the most important sub-criteria. This implies that policy support is one of the most important drives to develop wind power at present stage. Under the *costs* merit, the cost of *wind*

Table 5
Priorities of alternatives under four merits

Merits	Benefits (0.3327)		Opportunities (0.2168)	
	Relative	Normalized	Relative	Normalized
Alternatives				
Site A	0.7296	0.1753	0.9542	0.2026
Site B	0.9348	0.2246	0.9374	0.1990
Site C	0.7532	0.1809	0.9141	0.1941
Site D	0.9121	0.2191	0.9314	0.1977
Site E	0.8332	0.2001	0.9728	0.2066

Merits	Costs (0.2530)				Risks (0.1975)			
	Relative	Normalized	Reciprocal	Normalized	Relative	Normalized	Reciprocal	Normalized
Alternatives								
Site A	0.8120	0.1809	5.5294	0.2203	0.9342	0.2049	4.8804	0.1952
Site B	0.8623	0.1921	5.2069	0.2075	0.8983	0.1970	5.0750	0.2030
Site C	0.9578	0.2133	4.6877	0.1868	0.9217	0.2022	4.9465	0.1978
Site D	0.9042	0.2014	4.9655	0.1978	0.9082	0.1992	5.0201	0.2008
Site E	0.9536	0.2124	4.7085	0.1876	0.8967	0.1967	5.0841	0.2033

turbine (0.5595) is the major concern, followed by *connection* (0.3195). Under the *risks* merit, *concept conflict* (0.5639) is the problem the firm worries most about. This implies that the main problem to develop wind power is the disparity among different parties. Note that even though there are sub-criteria under each *cost* criterion, the performances of a wind farm under these sub-criteria are estimated in monetary values. Therefore, no pairwise comparison of the importance of these sub-criteria is necessary since the values of the sub-criteria in a wind farm with respect to the same upper level criterion can simply be summed up into a single value. In addition, the experts agree that there is no need for sub-criteria under the *risks* merit because criteria themselves can clearly express the risks that may be faced by the wind farms.

The performance results of different wind farm projects under various criteria are collected from each expert individually in order to limit the number of pairwise comparisons [20]. All sub-criteria, except those under the *costs* merit, are qualitative criteria and are rated in a range from 0 to 100. For the criteria under *benefits* and *opportunities* merits, the higher the score, the better the performance of the project is. On the other hand, for the criteria under *costs* and *risks* merit, the higher the value, the worse the performance of the project is. The synthesized performance value of each site on each criterion is calculated by geometric averaging the results from all the experts. The results are shown in Table 4. These performance values are further transformed into a number between 0 and 1 by dividing the performance value of a project on a criterion by the largest performance value among all projects on the same criterion. The above performance values of projects and the priorities of criteria are synthesized to obtain the overall performance of each project under each merit. The normalized performances of projects under the four merits are calculated as shown in Table 5.

The final ranking of the alternatives are calculated by the five methods to combine the scores of each alternative under *B*, *O*, *C* and *R*. The results are as shown in Table 6. Under all five methods of synthesizing the scores of alternatives, the ranking is exactly the same in sequence: sites B, D, E, A and C. However, note that the ranking under the five methods may be different depending on the case. Site B is expected to be the best wind farm mainly because it has the best performance in the benefits merit, including the highest wind availability, and is the second least costly. Site D ranks the second overall because it ranks the second in the benefits merit (and the second in wind availability) and has a relatively better performance in other merits. Even though site E has a wind availability similar to that of site D, it has higher costs and risks than site D, and thus only ranks the third.

5. Conclusion and discussion

It is foreseeable that the move toward generating electricity from renewable wind resources will become the trend in future years. It is surprising that no work has been carried on the selection of such an important project as wind farm in power industry. In addition, because of increasing complexity in social environments along with rapidly changing technologies, integrating critical factors of wind farm to select the best project have a great potential since it does not only considers the costs, but also concerns variant facets of projects. From the process of analyzing critical factors, we find that some of the factors like policy support, new technologies, and financial mechanisms do accelerate opportunities of adopting wind power from suitable wind farm. However, some factors such as the disparity of different parties and uncertainty of land usage do have negative impacts. In order to handle positive and negative criteria, AHP with BOCR is proposed to facilitate the wind farm selection. The model replaces conventional AHP models since it is a more instinctive evaluation method in daily life, especially for arriving at a project with positive criteria like benefits and opportunities,

Table 6
Final synthesis of priorities of alternatives

Synthesizing methods	Additive		Probabilistic additive		Subtractive		Multiplicative priority powers		Multiplicative	
	Priority	Rank	Priority	Rank	Priority	Rank	Priority	Rank	Priority	Rank
Alternatives										
Site A	0.1965	4	0.4665	4	0.0160	4	0.1957	4	0.9581	4
Site B	0.2104	1	0.4809	1	0.0304	1	0.2102	1	1.1810	1
Site C	0.1886	5	0.4589	5	0.0084	5	0.1885	5	0.8143	5
Site D	0.2055	2	0.4760	2	0.0255	2	0.2052	2	1.0801	2
Site E	0.1990	3	0.4693	3	0.0188	3	0.1989	3	0.9896	3

and negative criteria like costs and risks, at the same time. Finally, from our theoretical modeling and empirical demonstration, an AHP with BOCR model can effectively and precisely handle such a complicated problem and lead to an outstanding result.

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