Risk Factor Analysis in Wind Farm Feasibility Assessments Using the Measure-Correlate-Predict Method

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Abstract- In Handong on Jeju Island, South Korea, an investigation was carried out which looked at risk factors in wind farm development. Wind measurement data was collected over a one-year period in Handong, and reference wind data for a fifteen-year period for the same area was collected from a meteorological observatory at Gujwa. The measure-correlate-predict (MCP) method was applied to obtain long-term artificial wind data for Handong, in order to estimate variations in the annual energy production (AEP) and the net present value (NPV) which in turn helped determine the risk factors. The AEP and the NPV were calculated under the assumption of having installed a Vestas 2 MW wind turbine at the measurement site. Various Probabilities of Exceedance (PoEs) were predicted for both the AEP and the NPV in order to clarify the range of possible risk factors. Other economic analyses were also conducted and studied for comparison. The deviation in mean wind speed, the AEP, and the NPV were estimated assuming that the annual average wind speed varies in a cycle of fifteen years. The results showed an NPV deviation of USD 2,612,738 at a probability of exceedance of 50% (P50) USD 2,436,511 at the P75 and USD 2,277,902 at the P90 within the estimated NPV range, a finding which could not be ignored. The NPV variation (-17% to +24% for one averaged year) was found to be greater than the corresponding variations for either wind speed or the AEP, whose range was 2.41 times that of the wind speed.

Keywords—Wind energy, Measure-Correlate-Predict (MCP), Risk factor, Probability of Exceedance (PoE)

1. Introduction

Project risk is defined as “an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective” [1]. Because of a great uncertainty in future cost–to-benefit ratio in proposing large-scale wind farm development, finding risk factors in the project feasibility assessment is essential. Thus before wind farm development begins, it is important to anticipate the potential risks involved. Cun-bin Li et al. [2] suggested that such risk factors should include the Annual Energy Production (AEP), the costs of wind turbine generator systems, conditions of financial planning and legal constraints. Evaluation criteria included the Net Present Value (NPV), Payback/Period (P/P) and Internal Rate of Return (IRR) for analyzing financial risk in wind power projects [3]. In order to find risk factors in a wind farm development project, H.H. Goh et al. [4] applied a Casual Loop Diagram method of System Dynamics to their study on wind power project management.

The overall process of wind resource assessment is as follows [5]:

A. Preliminary assessment for the potential wind farm site;
B. On-site measurement campaign for at least one year;
C. Spatial extrapolation with multiple site statistics;
D. Long-term hindcasting with multiple reference data sets;

E. Prediction of AEP with turbines;
F. Uncertainty analysis;
G. Financial analysis.

Each of the above steps presents a possible risk factor in any given wind farm development project. Some steps pose more significant risk in predicting energy yield than others [6]. However, fluctuations in annual mean wind speed occurred at various sites [7] due to the fact that wind speed varies continuously as a function of time and elevation [8]. Accordingly, the annual wind variation is one of the risk factors in a wind resource assessment. Measure-Correlate-Predict (MCP) methods have been used to minimize the uncertainty in estimating more accurate wind speed over time [9]. Few studies have been conducted on decreasing project risk using the MCP method, and there were fewer investigations on how much the risk will decrease using the MCP method. In addition, it is very important for investors to estimate the NPV variation with yearly wind speed variation on which there have not been studied.

In this study, the AEP and the NPV were estimated using wind measurement data for one year, and predicted long-term wind data obtained by MCP technique based on reference wind data for fifteen years. Then the ranges for NPV, AEP, and wind speed were determined in order to clarify the risk in the project's economic assessment. Those were compared with the AEP and the NPV for long-term wind data predicted by the MCP method. Also a financial analysis was done using IRR, P/P and Benefit /Cost ratio (B/C) as well as the NPV to determine both the project's economic feasibility and the range of the NPV. Finally, the deviation in wind speed, the AEP, and the NPV were calculated for a given wind climate cycle of fifteen years.

2. AEP Estimation Using MCP

2.1. Sites and Wind Data

Fig.1. left shows Jeju Island in relation to South Korea, On the right are locations of the 60m-met mast at Handong and 10m-Automatic Weather System (AWS) at Gujwa. Both sites are located on Jeju's northeastern coast. The met mast at Handong is located at 3km north-west away from AWS at Gujwa.

Table 1. shows wind sensor specifications for the met mast at Handong and the AWS at Gujwa. The same types were used for the anemometer and the wind vane. Also, the accuracy of the sensors on the met mast is better than of those on the AWS.

Since the first step to estimate the wind resources at a given site is the wind characterization such as wind speed, direction, and wind power density [10], an analysis was done of the wind data at Handong and Gujwa. Table 2. lists a summary of the met mast and AWS wind data. Both had sufficient data recovery rates to conduct wind analysis, and the measurement period at the reference site was long enough for purposes of applying the MCP method [11].

Fig. 1. Left: Jeju Island, South Korea; right: met mast and AWS sites

Table 1. Wind sensor specifications on met mast and AWS

Items	Met mast at Handong		AWS at Gujwa	
	Anemometer	**Wind vane**	**Anemometer**	**Wind vane**
Model	NRG #40	NRG #200P	WM-IV-WS	WM-IV-WS
Type	3 cup	Potentio metric	3 cup	Potentio metric
Measuring range	1 ~ 96 m/s	0 ~ 360°	0 ~ 70 m/s	0 ~ 360°
Threshold	0.78 m/s	1 m/s	0.3 m/s	0.5 m/s
Accuracy	The range of wind speed 5~25 m/s : less than 0.1 m/s	< 1%	The range of wind speed 0~10 m/s : less than 0.3 m/s, Over 10 m/s : less than 3%	< ±5°
Operation temp.	-55 ~ +60°C	-55 ~ +60°C	-40 ~ +80°C	-40 ~ +80°C

Table 2. Summary of met mast and AWS wind data

Items	Met mas wind data	AWS wind data
Measurement period	One year (2011)	15 years (1997 ~ 2011)
Mean wind speed (m/s)	7.3	4.0
Prevailing wind direction	NNW	NW
Wind power density (W/m^2)	457.6	95.7
Data recovery rate (%)	98.9	98.2

2.2. Application of MCP

In general, it is necessary to analyze long-term wind data (e.g. more than twenty years back) to obtain a reliable output of wind energy potential for a given site. However, an estimation of wind energy for a given site is commonly made using short-term wind data (e.g. 1-2 years). This practice can lead to an inaccurate estimation of wind energy and poses a concern given that the wind turbines intended for the site should operate over a lifetime of twenty years. Thus long-term wind data should be predicted for the site, and it should be based on both a few years of measurement data as well as long-term reference wind data for the surrounding area.

The MCP technique is a popular method of predicting long-term wind data for the measurement site. Wind data is needed for a concurrent time period at both the measurement and the reference sites in order to find the appropriate correlation between them. If the correlation is acceptable [13], then it is used to estimate the measurement site's wind speed for that time period. There are a few MCP methods available such as linear regression, the matrix, the Weibull parameter scaling and the wind index [5].

In this study, the widely-used linear regression method was applied to estimate the long-term wind data on the basis of the sector linear relationship between the long-term reference site and the measurement site [11].

The correlation coefficient *r*, which expresses the relationship between wind data in a concurrent time series, is a good indicator for determining the suitability of applying the MCP method [12]. A reference site yielding an *r* value below 60-70% is normally not selected for the MCP application. [13] In this study, *r* was 78% between the measurement site data for Handong and the reference site data for Gujwa which means it was suitable for applying the linear regression MCP method.

Using WindPRO software, the long-term wind data was predicted and divided into wind data for each year. Then, average wind speed and AEP was calculated for each year, under the assumption the distribution of wind speed follows Weibull distribution. AEP was calculated assuming a Vestas V80-2MW wind turbine was installed at the site.

Fig.2. shows both annual mean wind speed and AEP estimated by linear regression MCP method for 15 years at Handong. The variation in annual mean wind speed is nearly the same as AEP variation.

The maximum wind speed and the maximum AEP were predicted to have occurred in 2003, while the minimum wind speed and the minimum AEP were estimated to have taken place in 2008. The wind speed and the AEP averaged for 15 years were predicted to be 7.44 m/s and 6,421 MWh, respectively. If only short-term measurements are used, more reliable AEP estimates may not be obtained due to annual wind variation as shown in Fig. 2. Therefore, it is essential to apply MCP methods when estimating wind speed and AEP.

In this study, wind data for the years 2003 (maximum wind speed) and 2008 (minimum wind speed) were selected for determining the range in yearly wind variation. Additionally, predicted long-term wind data for fifteen years was chosen for reference, and measurement wind data for the year 2011 was chosen to compare the results of real wind analysis with those of other results. The AEPs were calculated using the wind data above as shown in Fig. 3.

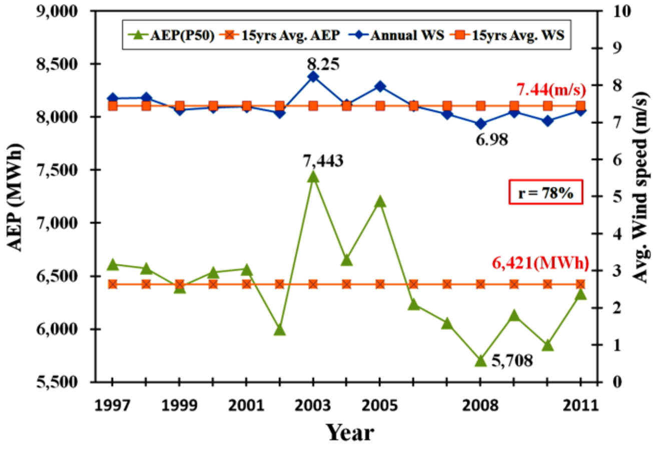

Fig. 2. Predicted annual mean wind speed and AEP for Handong over 15 years

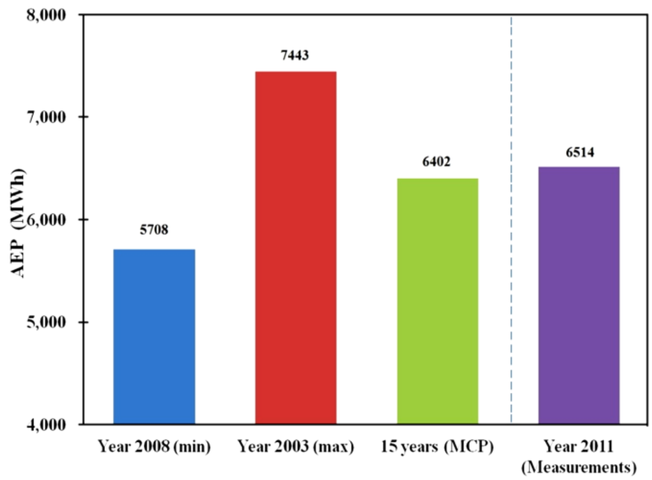

Fig. 3. AEPs for the selected wind data in this work

The AEP analysis which used 2011 measurements is closest to the fifteen-year prediction which used the MCP method. However, the AEP based on fifteen-year wind data is more reliable than the AEP based on one-year measurements. Since a deviation of 1,735 MWh occurred between the minimum and the maximum, it may be inferred that AEP predictions which use only short-term measurements can lead to results containing a high degree of uncertainty. Therefore, when conducting an economic feasibility assessment for a wind project, the minimum and the maximum AEPs should be considered a part of investment risk.

2.3. AEP with Probability of Exceedance (PoE)

Probability of Exceedance (PoE) is a measure of how likely it is a certain value will be exceeded. The AEP predicted by wind data analysis has a 50% PoE, which is expressed as P50. In the case of P75, the AEP has a 25 % probability of not reaching the AEP [14].

The uncertainty of the energy yield prediction in this study was assumed to be at 10%. AEP@PXX represents the

AEP at Probability of Exceedance XX%. That can be calculated with the inverse function of the standard normal distribution, NORMINV, and is expressed in the following equation (1). [15]:

$$AEP@PXX = AEP@P50 \times (1\text{-}Uncertainty \times NORMINV(XX\%, 0, 1)) \quad (1)$$

Table 3. shows the general PoE cases of the sensitivity depending on various financial market conditions. As the PXX figure grows, the financial market condition worsens. NORMINV is also shown in Table 3. The PoE level is generally taken into consideration when determining the sensitivity of project financing in large-scale wind farm development. So it is reasonable to determine the margin of error in benefit estimation by using PoE, since the former can constitute a risk factor in wind projects.

Table.3. PoE sensitivity case with various financial situations

Case of sensitivity	NORMINV (XX%,0,1)	Financial situations
P50	0.0000	Base case 1
P75	0.6745	Base case 2
P90	1.2816	Worst case 1
P95	1.6449	Worst case 2

Fig.4. represents four different estimated AEPs with PoEs over fifteen years at Handong. A higher PoE level results in a lower AEP, and the AEP varies from year to year. The AEP difference between P50 and P95 ranges from 1,735 MWh in 2003 to 1,450 MWh in 2008.

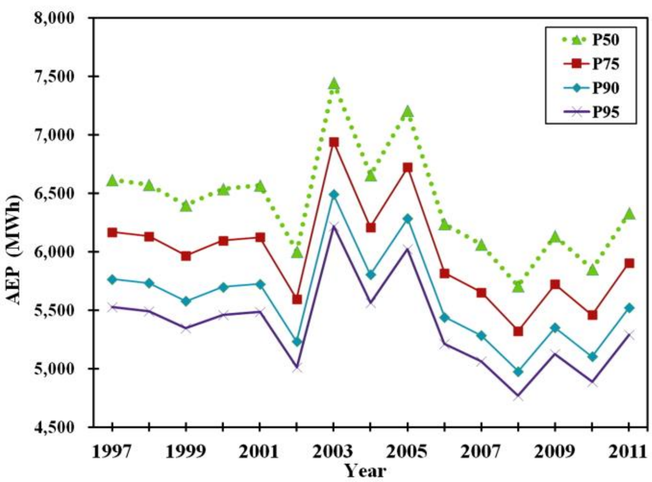

Fig. 4. AEP with PoE at Handong

3. Economic Feasibility Analysis

In an earlier economic feasibility study for another Jeju Island wind project [16], project cost per MW was estimated to be USD 2,033,317.5, an estimate which was used in this study. Other parameters affecting the project costs and benefits are shown in Table 4. Also, the System Marginal Price (SMP) has a crucial impact on project revenues. In this study, we employed USD 0.19 per kWh which has been the average SMP in Jeju for the last three years.

Table 4. The input parameters for economic analysis at Handong

Input parameter		Assumption
Initial investment cost		USD 4,066,635
Wind turbine model		Vestas V80. 2MW
Annual O&M cost		20% of annual net profit (3% of annual escalation rate applied)
Annual taxation cost	Corporate tax	USD 20,648 + 20% of the net profit exceeding USD 187,705
	Local tax	10% of corporate tax (USD)
A discount rate		6%
Depreciation		Straight line method
SMP (Only applicable in Jeju)		USD 0.19

Figs. 5 and 6. show the PoE for the AEP and the NPV, respectively. Both were calculated using the selected wind data in this work. As the PoE increases, the AEP and NPV each decrease. The difference between the NPV's maximum and minimum at P50 was USD 2.613 million, which is not negligible for wind farm investors. Therefore, the NPV as well as the AEP should be estimated using the long-term wind data predicted by the MCP method.

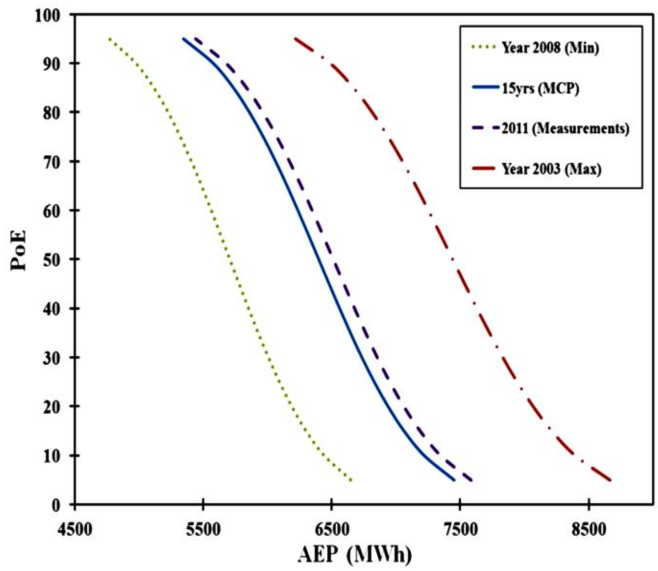

Fig. 5. AEP with PoE

The NPV differences at the P75, P90 and P95 were USD 2.437 million, USD 2.278 million and USD 2.183 million, respectively. In other words, as the PoE increases, the difference between the maximum and minimum NPV decreases. Figs. 5 and 6 may be useful for investors determining the investment value for a potential wind farm.

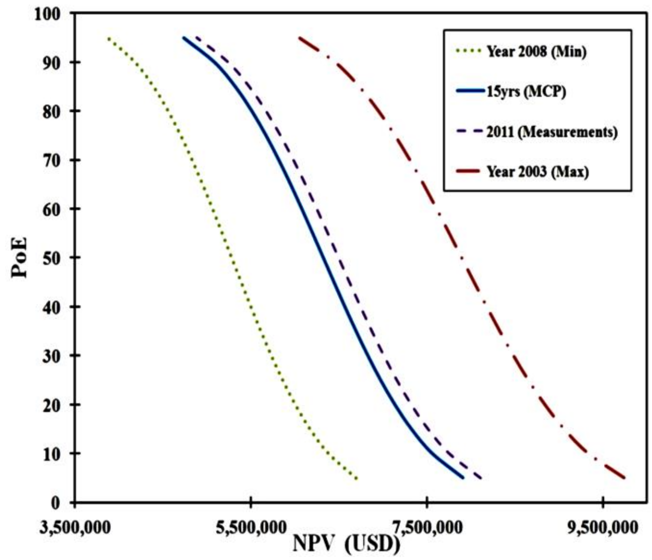

Fig. 6. NPV with PoE

Table 5 shows the AEP, NPV, IRR, P/P and B/C with PoEs for 2003, 2008, 2011, and a fifteen-year period. As described above, there was a difference of USD 2,612,738 between the maximum and the minimum NPV. However, it is important to note that the wind speed deviation of 1.27 m/s between them led to the difference in the NPVs.

Also, all the IRR values are higher than the discount rate of 6% (see Table 4), and all the B/C ratios are higher than 1. All of those values lead to the conclusion that the economic feasibility is quite good. The P/P is also enough to attract the attention of wind farm investors. However, the economic feasibility assessment should be done bearing in mind the variability of parameters shown in Table 5. In addition, since the result above came from the estimation on the basis of using just one Vestas 2 MW wind turbine, the deviation of the NPV would be even greater after factoring in the scale of the wind farm and the twenty-year operating period.

3. Wind Speed, Aep And Npv Deviation With Averaged Years

In general, the variability of annual wind speed is known to be ±10% over the long-term [17]. However, it is not easy to estimate the NPV variation over that long-term. To estimate the NPV variation at P50 in this work, it was assumed that the annual average wind speed varies within a fifteen-year cycle. Then the deviations of wind speed, the AEP and the NPV were estimated and averaged for a given period of fifteen years as shown in Fig. 7.

All deviations decreased in the averaged years. The deviation of the NPV was greatest, containing a range of -17% to +24% for one averaged year, followed by that of the AEP at -11% to +16% and finally the wind speed averaged a yearly deviation of -7% to +10%. The NPV deviation fell within ±10 % at five-year averages, and then, within ±5 % at ten-year averages. Therefore, it is very important to analyze the NPV as well as the AEP using longer-term wind data for a reliable result. In addition, the long-term NPV deviation should be included when the wind project feasibility study is done.

Table 5. The AEP, NPV, IRR, P/P and B/C with various PoEs (1USD=1065.50 KRW, 2014.10.17)

The selected wind data	Avg. wind speed (m/s)	PoE	AEP (MWh)	NPV (USD)	IRR (%)	P/P (Years)	B/C
Year 2008 (Min)	6.98	P50	5,707	5,279,496	19.51	7	1.55
		P75	5,322	4,699,690	18.16	7	1.50
		P90	4,976	4,177,846	16.93	8	1.45
		P95	4,768	3,865,543	16.19	8	1.42
15 years (MCP)	7.44	P50	6,401	6,324,712	21.92	6	1.63
		P75	5,969	5,674,407	20.42	6	1.58
		P90	5,581	5,089,112	19.07	7	1.53
		P95	5,348	4,738,836	18.26	7	1.50
Year 2011 (Measurements)	7.48	P50	6,513	6,493,392	22.29	6	1.65
		P75	6,074	5,831,710	20.78	6	1.60
		P90	5,678	5,236,175	19.41	7	1.55
		P95	5,442	4,879,771	18.59	7	1.52
Year 2003 (Max)	8.25	P50	7,442	7,892,234	25.44	5	1.75
		P75	6,940	7,136,201	23.74	5	1.69
		P90	6,488	6,455,748	22.20	6	1.64
		P95	6,218	6,048,524	21.28	6	1.61

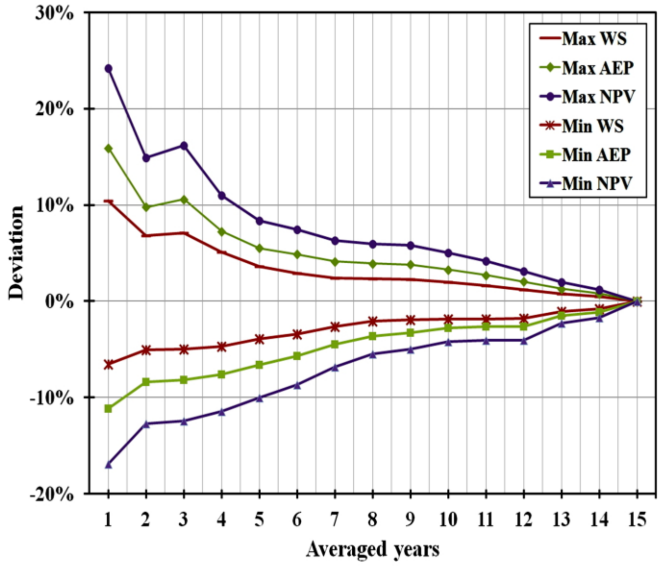

Fig. 7. Deviation of wind speed, AEP and NPV at P50

4. Conclusions

The results are summarized as follows:

(1) The uncertainties of estimations such as average wind speed, AEP and NPV are minimized after applying the MCP method.

(2) The deviation between the maximum and minimum NPV reached up to USD 2,612,738 at the P50, USD 2,436,511 at the P75 and USD 2,277,902 at the P90, which were not negligible. So, the variation in revenue should be considered as a risk factor in the wind project feasibility study.

(3) If the annual average wind speed varies in a cycle of fifteen years, the NPV had the greatest deviation for one averaged year, followed by that of the AEP and then wind speed. The deviation of the NPV ranged from -17% to +24%, which was 2.41 times that of the wind speed and 1.52 times that of the AEP, respectively.

(4) Anticipating the maximum and the minimum values of the NPV, IRR, P/P and B/C via the MCP method may be useful for investors to determine investment value for a potential wind farm.

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