Determining Probabilistic Estimates of Net Present Value for US Offshore Wind Projects

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Introduction

Wind power is the fastest growing sector of electricity generation in the world with installed capacity increasing from 2,500 MW in 1992 to 120,800 MW at the end of 2008[1]. The development of offshore wind resources has become a key component of this growth. Of the wind generating capacity in operation worldwide in 2009, about 1,900[9] MW of those were offshore. Figure 1 shows offshore wind energy growth.

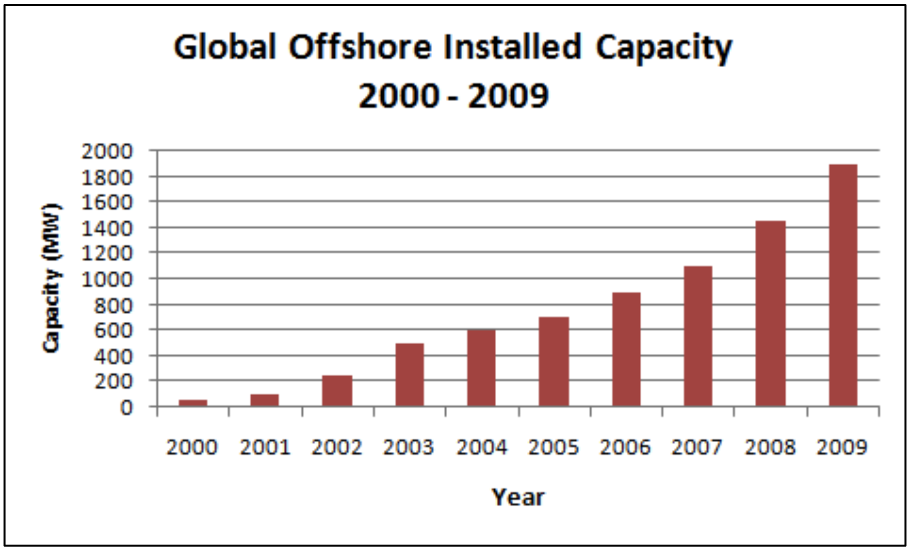

Figure 1: Global Offshore Installed Capacity[6]

At the end of 2010 there were forty-seven offshore wind power projects installed in nine countries in Europe and two in Asia, including demonstration projects[7], with more under development on both continents. In contrast, offshore wind power is a fledgling industry in the United States that must contend with numerous challenges. These range from technical and design environment considerations, to regulatory and impact uncertainty, to concerns about cost and economic viability.

This paper develops estimates of net present values (NPV) for offshore wind projects in the United States. It further discusses the distributions of NPV and probabilistic estimates of project value for hypothetical utility-scale offshore wind projects.

Economic Factors Affecting the Industry

To be economical, offshore wind projects must be large-scale which requires considerable capital expenditure, and because of the nature of these projects capital costs represent a larger percentage of total project costs than is typical of conventional electricity plants. As a result of this capital intensity, many potential offshore wind projects may not achieve satisfactory project economics.

Relative to onshore wind power projects, the total costs for the development of offshore wind power generation is larger for comparable projects--in some cases by an order of magnitude. This larger cost is the result of increases in site surveys, pre-project assessments and planning, additional installation/construction costs, and larger operational and maintenance expenses. Although capital costs for offshore projects are larger than those for onshore projects they represent a lower percentage of the total project costs for the life of the project[2], as shown in Table 1.

Table 1: Comparison of Onshore and Offshore Wind Power Project Costs by Category[4]

Cost Category	Offshore Percentage (%)	Onshore Percentage (%)
Turbines (Capex)	33	68
Support Structure (Capex)	24	9
Grid Connection (Capex)	15	14
Roads/Buildings (Capex)	--	6
Project Management	2	3
Operations & Maintenance	23	--
Decommissioning	3	--

In order for offshore wind projects to be economical they generally must be large scale, which requires a considerable expenditure of capital[12]. High capital costs and expensive operation and maintenance costs equal sensitivity to the amount of equity available and the cost of capital. As a result, the capital costs required to develop an offshore wind power generation project act as a significant barrier to entry into the industry. Access challenges, weather delays, technical challenges, and current drafting of permit requirements, also introduce uncertainty.

Methods

This research project paired capital and overall cost models with traditional cash flow analysis, design of experiments, and random sampling techniques to generate equations for NPV and probabilistic estimates for project value for offshore wind projects in the United States. A capital cost model was developed and then used to estimate total project costs and to set up a cash flow analysis. After completion of the cost model and cash flow analysis, three hypothetical projects were designed and their design parameters were used to determine the applicable cash flows and NPV's. The three model cases were chosen to capture small, medium, and large size classes.

The value used to examine project viability was NPV. In order to generate probabilistic estimates of project NPV, equations for NPV had to be generated. Once the cash flow analysis was complete the sensitivity of output (NPV) to the various cash flow inputs was estimated via an experimental design following the Box Behnken method. Regression techniques were used on the results of these experiments to generate characteristic equations for NPV. Once the characteristic equations were determined, random sampling techniques were used to develop probabilistic estimates of project NPV.

Capital Cost Model

The cost models are based on published studies, primarily state-level feasibility studies, which provide specific data and methods for estimating costs for the major components of offshore wind projects in the United States. The source reports adapt costs from the European experience and/or obtain quotes for domestic component manufacturing and installation. While each of these studies focused on different areas of offshore development, they each included some economic analysis. The approaches taken in these studies and work done by the National Renewable Energy Laboratory (NREL)[8] on grid connection were adapted to create a composite capital cost model. Once the capital costs were calculated, total project costs over the life to the project were estimated by using percentages of total project costs compiled by Delft University[4].

This capital cost model includes specific assumptions about the type of foundation, type of grid connection, and installation costs which create project scenarios that may not be optimized for the individual project configurations examined. For example all projects are modeled on monopile foundations, while the only installed offshore wind project using the largest turbines examined was constructed using jacket foundations. Also, the cable size used to calculate grid connection costs is optimized for the model's medium size wind farms. These facts may negatively affect the results for some model configurations.

Based on the offshore trend toward larger turbines and larger overall project capacity, three project capacities and three commercially available turbine sizes were selected for examination. The nine combinations and their resulting capital costs are shown in Table 2. These results show an economy of scale as project capacity increases within a given turbine size, but not as turbine size increases. The latter is inconsistent with industry observations and likely results from the foundation and grid connection assumptions in the cost models.

Table 2: Project Capital Costs in $/kW

Project Capacity (MW)	**Turbine Size (MW)**	**Rotor Diameter (ft, m)**	**CAPEX ($)**	**CAPEX ($/kW)**
300 MW	3 MW	295.2, 90	935,100,000	3,117
500 MW	3 MW	295.2, 90	1,553,100,000	3,106
700 MW	3 MW	295.2, 90	2,171,100,000	3,102
300 MW	3.6 MW	257.5, 109	966,600,000	3,222
500 MW	3.6 MW	257.5, 109	1,606,800,000	3,211
700 MW	3.6 MW	257.5, 109	2,244,500,000	3,206
300 MW	5 MW	410, 125	1,083,100,000	3,610
500 MW	5 MW	410, 125	1,799,800,000	3,600
700 MW	5 MW	410, 125	2,516,400,000	3,595

To simplify the rest of the analysis the field of project combinations was narrowed to examine three different project classes as outlined below.

- Medium Capacity/ Medium Turbine Size (MED/MED)

    - 500 MW project capacity.
    - 3.6 MW turbines
    - 357.5 ft (109 m) rotor diameter
- Lower Capacity / Small Turbine Size (LOW/SML)
    - 300 MW project capacity
    - 3 MW turbines
    - 295.2 ft (90 m) rotor diameter
- Higher Capacity / Large Turbine Size (HIGH/LGE)
    - 700 MW project capacity
    - 5 MW turbine size
    - 410 ft (125m) rotor diameter

Cash Flow Analysis

Once capital cost elements could be determined a traditional cash flow analysis was generated to compute the NPV for offshore wind projects. The model inputs are wind farm capacity, turbine size, rotor diameter, capacity factor (cf), average mean wind speed (AMWS), electricity price (P), royalty rate, nominal growth rate in electricity price, OPEX present value from capital cost model, growth rate in OPEX, CAPEX from capital cost model, decommissioning cost from the capital cost model, discount rate, and corporate tax rate. CAPEX, OPEX, and decommissioning costs were calculated by the cost model.

Basic Assumptions

- The cash flow assumes a project life span of twenty years. This value was chosen because it corresponds to the operational life span of traditional wind turbines. In reality new offshore projects may benefit from technological advancements that are likely to lengthen project life spans which would probably increase NPV, thus the estimates here can be considered conservative.
- Decision variables such as project capacity, turbine size, and rotor diameter were considered to be fixed for the hypothetical projects once these choices were made.
- Rates such as discount rate (10%), corporate tax rate (35%), royalty rate (6.5%) and the growth rates for price (1%) and OPEX (2%) were fixed.

- There is no growth or deterioration in annual production throughout the life of the project.

Model Explanation

In order to calculate NPV, the amount of electricity that would be generated by the selected project per year is computed using the following equation.

$$\Pr = \frac{0.5\rho AV^3 cf(Ta)(\#T)(31536000)}{3.6x10^6}$$

Where *Pr*=production in kWh, ρ = air density (kg/m^3), *A* = rotor swept area (m^2), *V* = average mean wind speed (m/s), *cf* = capacity factor, *Ta* = turbine availability, *#T* = the number of turbines, 31536000 = seconds/year, and 3.6E6 = the conversion factor from Joules to Kilowatt Hours.

The cash flow then subtracts the royalty portion due to the leasing entity and calculates annual net revenue based on an electricity price that increases by 1% per year. Next, operational expenses (OPEX) and depreciated capital costs (CAPEX) are subtracted to get the taxable income. CAPEX represents the total capital cost and is depreciated using straight-line depreciation with a seven-year term and no salvage value.

$$Dt = \frac{CAPEX - 0}{7}$$

The OPEX costs are drawn from the total project costs portion of the cost model. This OPEX value is the present value for total project OPEX and was amortized for the cash flow analysis using the following equation:

$$O_1 = \frac{OPEXcc}{\left[1 - \frac{(1+g)^t}{(1+r)^t}\right]}(r-g)$$

Where O_1= OPEX in year 1, *OPEXcc* = OPEX costs from the capital cost model, *g* = OPEX growth rate, *r* = discount rate, and *t* = years of project life (which was 20 years).

After calculation of taxes due, using an average corporate tax rate of thirty-five percent, the annual after tax cash flows to equity are calculated as follows:

$$ATCF = ATI + Dt - CAPEX - DC$$

Where *ATCF* = after tax cash flow, *ATI* = after tax income, *Dt* = annual depreciation allowance, *DC* = decommissioning cost. The decommissioning cost for year 20 is calculated using the present value of decommissioning cost from the capital cost model and the future value function in Excel with a 10% discount rate and 20-year period.

Last, to obtain project NPV, the annual ATCF's are discounted by the equation:

$$DATCF = \frac{ATCF}{(1+r)^t}$$

where *DATCF* = discounted after tax cash flow, *ATCF* = after tax cash flow, *r* = discount rate, and *t* = time in years. The DATCF's are summed to get project NPV:

$$NPV = \Sigma DATCF$$

Design of Experiments

Once the cash flow spreadsheet was complete the sensitivity of output (NPV) to the various cash flow inputs was estimated. Figure 2 shows a typical tornado diagram of the relevant factors.

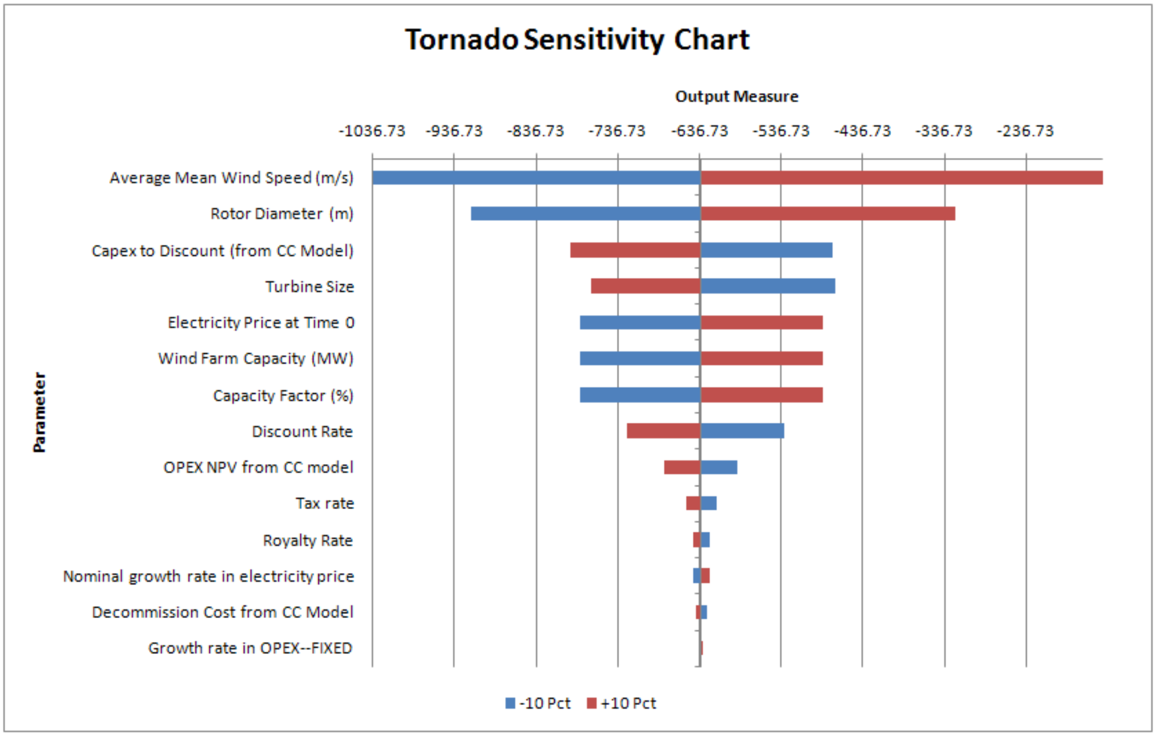

Figure 2: Typical Tornado Sensitivity Chart of Cash Flow to Inputs (in Mill$)

The sensitivity analysis was conducted for all of the cash flow inputs by estimating the range in NPV that would result from varying each input by +/_ 10%. Results that varied less than 50 million dollars were considered insignificant. Nine factors exceeded this threshold and the range of their effect on NPV is shown in Table 3 below.

Table 3: Range in Millions of Dollars of NPV Resulting from Fluctuating Each Parameter

P A R.	AvgMn Wind Speed	Rotor Diameter	CAPEX	Turbine Size	Price per kWh	Wind Farm Capacity	Capacity Factor	OPEX	Disc. Rate
R N G.	893.3	593.6	321.2	299.8	296.8	296.8	296.8	193.1	89.6

To simplify the analysis, decision variables – rotor diameter, turbine size, and wind farm capacity – were considered to be fixed at the values used in the CAPEX model, and discount rate was fixed at 10%. The remaining five variables were investigated in an uncertainty analysis.

To estimate the effect of each uncertainty on overall project NPV response surface methodology (RSM) was employed. RSM allows for exploration of the relationships between variables and the overall outputs by examining key points on the three-dimensional geometric shape that corresponds to the number of changing variables[10].

For this analysis the Box Behnken Design (BBD) RSM was used to determine which combination of the selected variables needed to be analyzed to evaluate the response in NPV. For a five-factor experiment each factor is assigned three levels – good (+1), base (0), and bad (-1) – and two factors are varied per trial. The BBD method provides a means to determine a characteristic response from five variables in 41 data runs – 1 run in which all values are considered at the base (0) value, and 40 runs where two of the variables are considered at their (+1) or (-1) values[10]. The matrix of experimental runs for a 5 factor BBD is shown in Table 4.

Table 4: Five-Factor BBD Design of Experiments[10]

X1	**X2**	**X3**	**X4**	**X5**
+/- 1	+/- 1	0	0	0
+/- 1	0	+/- 1	0	0
+/- 1	0	0	+/- 1	0
+/- 1	0	0	0	+/- 1
0	+/- 1	+/- 1	0	0
0	+/- 1	0	+/- 1	0
0	+/- 1	0	0	+/- 1
0	0	+/- 1	+/- 1	0
0	0	+/- 1	0	+/- 1
0	0	0	+/- 1	+/- 1
0	0	0	0	0

Each of these 41 data combinations was run through the cash flow model and 41 corresponding NPV's were computed. The combination of variables run during each trial and the resulting NPV's were recorded and linear regression was used to find the equation that best fit the recorded data. Other regressions were investigated (i.e. with quadratic and cross product terms), but the linear model was judged to be satisfactory based on test statistics.

<u>Monte Carlo Simulation</u>

Once the characteristic equations were determined, random sampling techniques were used to determine a probabilistic estimate of project value. For each of the five uncertainties 1000 random number samples were generated using uniform distribution between max and min values that were within the ranges used during the design of experiments. From each of these 1000 sets of uncertain sample data a distribution of NPV was calculated using the linear equations found via regression as described above.

From this data mean NPV, P90 values, P10 values, and the percentage of negative NPV results were calculated. For each case a histogram showing the NPV distribution and cumulative density function was generated.

Results

The base case experiments used to derive equations for NPV of offshore wind projects showed the majority of results to be negative, however, individual projects can have favorable project economics.

In each case the equation by linear regression for NPV was of the following form:

where β_0 = the y-intercept, β_1 - β_5 = specific coefficients from regression, *cf* = capacity factor, *AMWS* = average mean wind speed, *P* = electricity price, *Op* = OPEX, and *Cap* = CAPEX. The models exhibited good fits with R^2 values exceeding 0.90. The three levels of each variable and sample NPV distribution for each of the model cases are displayed below.

The MED/MED case:

Table 5: Five Uncertain Variable Ranges for the MED/MED Case

MED/ MED	Capacity Factor (%)	AMWS (m/s)	Electricity Price ($/kWh)	OPEX (Mill$)	CAPEX (Mill$)	Calculated NPV (Mill$)
-1	0.28	6	0.04	618	1900	-2443
0	0.35	9	0.12	537	1606	-635
+1	0.42	12	0.2	456	1400	4009

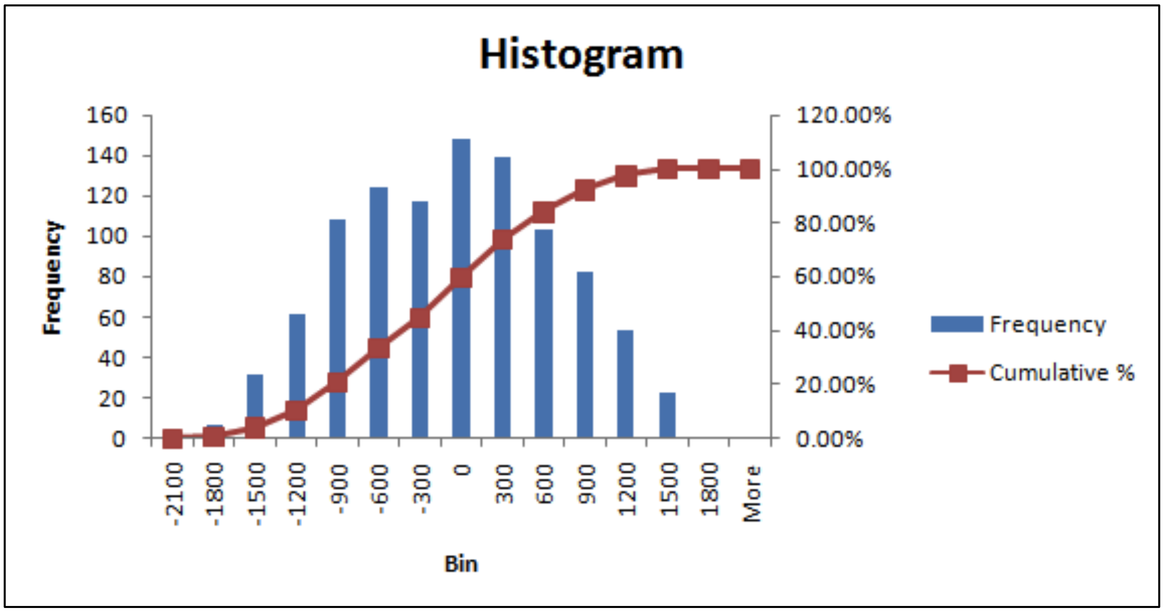

Figure 3: NPV Distribution Resulting from the MED/MED Case

<u>The LOW/SML case:</u>

Table 6: Five Uncertain Variable Ranges for the LOW/SML Case

LOW/ SML	Capacity Factor (%)	AMWS (m/s)	Electricity Price ($/kWh)	OPEX (Mill$)	CAPEX (Mill$)	Calculated NPV (Mill$)
-1	0.28	6	0.04	359	1140	-1468
0	0.35	9	0.12	312	935	-504
+1	0.42	12	0.2	265	840	840

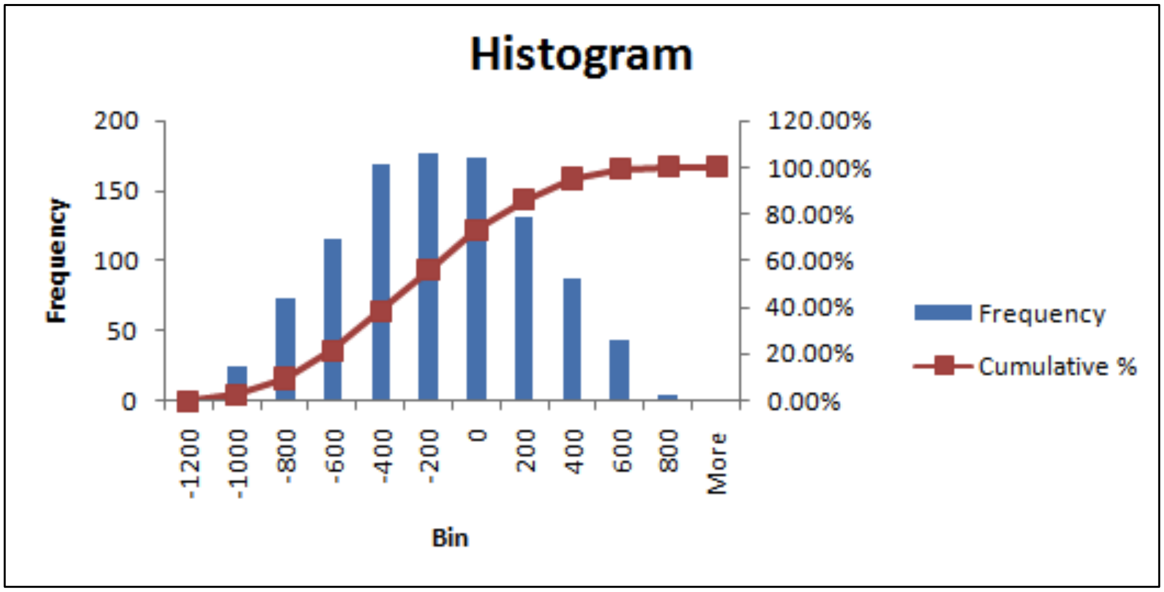

Figure 4: NPV Distribution Resulting from the LOW/SML Case

__The HIGH/LGE Case:__

Table 7: Five Uncertain Variable Ranges for the HIGH/LGE Case

HIGH/ LGE	Capacity Factor (%)	AMWS (m/s)	Electricity Price ($/kWh)	OPEX (Mill$)	CAPEX (Mill$)	Calculated NPV (Mill$)
-1	0.28	6	0.04	968	2660	-3545
0	0.35	9	0.12	842	2516	-1353
+1	0.42	12	0.2	716	1960	5147

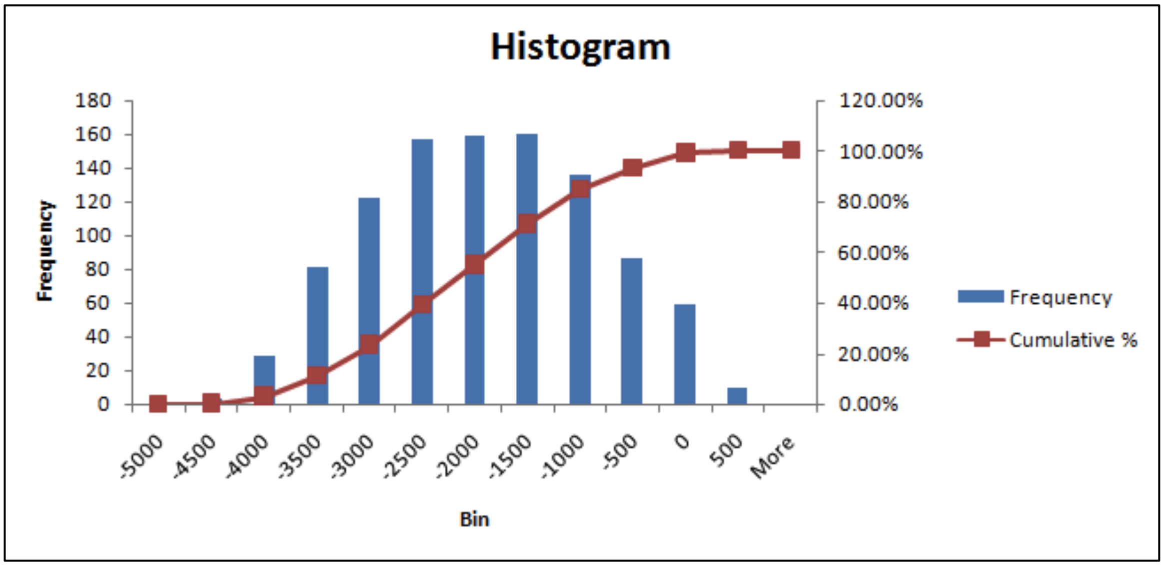

Figure 5: NPV Distribution Resulting from the HIGH/LGE Case

For all three cases the statistical values are shown in Table 8, below. The last column of the table shows the percentage of negative NPV's that resulted from the random samples.

Table 8: Model Case Statistical Values

Case	**Mean (Mill$)**	**P90 (Mill$)**	**P50 (Mill$)**	**P10 (Mill$)**	**% Negative**
MED/MED	-211.8	753.0	-211.8	-1176.6	61%
LOW/SML	-261.8	245.1	-261.8	-768.8	75%
HIGH/LGE	-2148.8	-800.3	-2148.8	-3497.2	98%

Break Even Points

As can be seen in the data shown above, for all three base cases the means are negative and the majority of simulated NPV's are negative. For further evaluation, the electricity price and wind speed necessary to make the projects break even, or give a mean NPV equal to zero were calculated using the cash flow model. However, a break-even point defined in this way would not represent a typical investment threshold as observed in practice because of the large risk of negative NPV. In order to estimate a more realistic investment threshold in terms of electricity price and wind speed, values of price and wind speed that make the P90 NPV equal to zero (that is, the levels that make 90% of the NPV's positive) were computed. Table 9 shows both the break even and low risk values for all three experimental cases.

Table 9: Base Case Break Even (BE) and Low Risk (LR) Points

Project/Case	**BE Price ($/kWh)**	**BE AMWS (m/s)**	**LR Price ($/kWh)**	**LR AMWS (m/s)**
MED/MED	0.1714	10.135	0.2495	11.488
LOW/SML	0.2032	10.726	0.2546	11.565
HIGH/LRG	0.2025	10.716	n/a	n/a

According to the Energy Information Agency (EIA) current residential electricity prices range from 7.28 – 16.98 cents/kWh[5]. NREL estimates that 16.8% of US offshore areas have average mean wind speeds between 9 – 10 m/s at 90 m altitude and only 2.1% have average mean wind speeds higher than 10 m/s[11]. As one can see from Table 9 for all of the basic experiments the necessary prices and wind speeds to motivate investment exceed the EIA and NREL estimates for both cases (Mean NPV=0 and P90 NPV=0). This does not bode well for offshore wind power investment in the foreseeable future unless some economic incentives are offered to investors, or real reductions in the current costs of offshore wind projects can be achieved.

Real World Cases and Model Calibration

Similar to the base case experiments break even and low risk points were calculated for three real-world cases. Each of these cases closely copies an installed project or a well-developed planned project, and the characteristics of each project are shown in Table 10. The Massachusetts Hypothetical case is modeled after a planned project in Massachusetts, which has completed the leasing and permitting processes in federal waters. The specifications of this case are similar to the MED/MED base case. The Thanet Hypothetical project is modeled after the Thanet project in the United Kingdom. It was chosen because its foundations were used as the basis in the source study from which portions of the capital cost model were derived. The Thanet project is similar to the LOW/SML case. The Texas Hypothetical project is modeled after large-scale planned projects that have leases in Texas. The Texas project is similar to the HIGH/LGE case. Individual project parameters are a combination of actual project data and reasonable measurements, which were used to fill gaps where actual project data was not publically available.

Table 10: Real World Project Parameters

Project Name	**Similar Class**	**Water Depth (ft, m)**	**Distance to Shore (nm)**	**Total Capacity (MW)**	**Turbine Size (MW)**	**Rotor Diameter (ft, m)**
Massachusetts Hypothetical	MED/ MED	65.6, 20	10.4	468	3.6	377.2, 115
Thanet Hypothetical	LOW/ SML	73.8, 22.5	6.5	300	3	295.2, 90
Texas Hypothetical	HIGH/ LGE	131.2, 40	8	700	5	410, 125

The break even and low risk values for the real world cases are shown in Table 11. As one can see from the table, some of the real world cases have values that are within the established ranges for wind speed and electricity price, even though the experiment cases did not. (To determine the low-risk values for the real world cases the P90 values for the base cases were used.)

Table 11: Real-World Break Even (BE) and Low Risk (LR) Points

Project/Case	**BE Price ($/kWh)**	**BE AMWS (m/s)**	**LR Price ($/kWh)**	**LR AMWS (m/s)**
Massachusetts Hypothetical	0.1494	9.683	0.2246	11.091
Thanet Hypothetical	0.1951	10.583	0.2466	11.442
Texas Hypothetical	0.2092	10.832	n/a	n/a

The table shows break-even points of approximately 15 ¢ and 9.7 m/s for the Massachusetts Hypothetical project. These values fall within the ranges of current electricity prices and reasonable wind speeds discussed above. As these values were the most reasonable of the real world projects, the Massachusetts Hypothetical was run through the entire model to generate a probabilistic estimate of project NPV, using the MED/MED equation. In this analysis the electricity price was fixed at 0.18 $/kWh, which removed the price uncertainty. This adjustment was made because the Cape Wind and Associates project upon which the Massachusetts Hypothetical project is based has a contract to sell its generated electricity at this price[3]. The samples of the other four variables were randomly generated along a uniform distribution, in the same manner as the base case experiments.

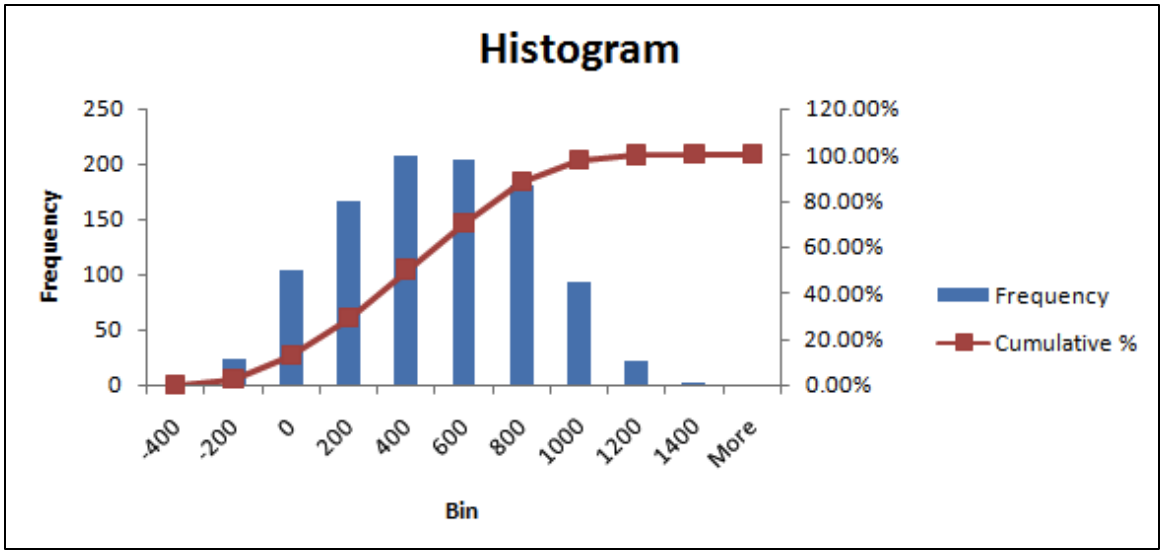

Figure 6: NPV Distribution Resulting from the Massachusetts Hypothetical Project

The results for the Massachusetts Hypothetical project are shown in Figure 6. The mean was $397 million, the P90 value was $812 million and only 11% of the sample NPV's were negative. The model shows this project to be economically viable.

Conclusions

- The uncertainty analysis workflow proposed and demonstrated here can be used to estimate NPV and economic viability of offshore wind projects in the United States.

- Analysis suggests that typical projects exhibit negative expected NPV; however, there are outcomes in the simulations that result in positive NPV.

- Investment in offshore wind projects will be difficult to obtain unless long-term economic incentives are offered, or real reductions in the current costs of offshore wind projects can be achieved.

- Additional analysis is warranted to estimate production and/or investment tax credits that will motivate investment, either by the break-even or low-risk definitions, because electricity price, wind speed, and other uncertainties often are difficult or impossible to influence.

- Additional model analysis is needed to determine the affect of more practical or better optimized project configurations on NPV distribution.

References

1. American Wind Energy Association. 2011. The American Wind Energy Association. www.awea.org (accessed 2009 - 2011)

2. Breeze, Paul. 2004. "The Technology, Economics and Impact of Wind Power Generation." Offshore Wind Farms. www.offshorewindfarms.co.uk.

3. Cape Wind and Associates. 2010. "National Grid paying Cape Wind $0.207/kwh." 2010. http://www.capewind.org/news1114.htm

4. Delft University (Duwind). 2001. "Offshore Wind Energy: Ready to Power a Sustainable Europe, Final Report" Concerted Action on Offshore Wind Energy in Europe, December 2001, NNE5-1999-562, Report Reference: Duwind 2001.006.

5. Energy Information Agency. 2011. "Average Retail Price of Electricity to Costumers by End-Use Sector." http://www.eia.doe.gov/cneaf/electricity/epa/epat7p4.html

6. European Wind Energy Association. 2009. “Oceans of Opportunity: Harnessing Europe’s Largest Domestic Energy Resource.” http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Offshore_Report_2009.pdf

7. European Wind Energy Association. 2010. “The European Offshore Wind Industry – Key Trends and Statistics 2009”. www.ewea.org

8. Green, Jim, et. al. 2007. “Electrical Collection and Transmission Systems for Offshore Wind Power.” Paper presented at the Offshore Technology Conference 2007, Houston, TX.

9. Koppits, Steve and Adam Westwood. 2009. “Offshore Wind: Time for a Market Take-off?” Renewable Energy World.com October 8. http://www.renewableenergyworld.com/rea/news/article/2009/10/large-wind

10. Myers, Raymond H., and Douglas C. Montgomery. 1995. Response Surface Methodology Process and Product Optimization Using Designed Experiments. New York, NY: Wiley-Interscience Publication.

11. Schwartz, Marc, et. al. 2010. “Assessment of Offshore Wind Energy Resources for the United States.” http://www.nrel.gov/docs/fy10osti/45889.pdf

12. Szarka, Joseph. 2007. Wind Power in Europe. Hampshire, England: Macmillan Distribution.