Real Options for a Wind Farm in Wapakoneta, Ohio:
Incorporating Uncertainty into Economic Feasibility Studies for Community Wind

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Abstract

This paper uses real options analysis, specifically a hybrid Monte Carlo simulation – decision tree analysis as well as a binomial tree analysis, to look at optimal decision-making for investment by a small community wind farm under uncertainty. In particular, the uncertainty due to forecasting of electricity prices and the potential for carbon pricing are considered. Two options are considered: a "call option" whereby a farm may be scaled up in terms of power generation capacity and a "put option" for shutting down operations are treated. It is found in general that options enhance the overall economic value for wind farm projects and such analysis can be easily implemented using common spreadsheet tools. The differences between two analytical tools are compared and it is found that they differ with respect to their suitability for different scenarios of analysis.

Introduction

For a community interested in Wind Energy projects, financial considerations are daunting and incredibly complex due to considerable sources of uncertainty in electricity price and demand. Organizations such as Windustry have sought to simplify and clarify the financial aspects of such projects so that community organizers have a better understanding and may be less overwhelmed by the process. However, efforts to simplify the process for economic feasibility can lead to oversimplification of the financial prospects for such projects and mask uncertainty that could have large effects on the project's overall economic performance. The uncertainties of Wind Energy projects range from the site's inherent wind power characteristics, project costs (both for installation and maintenance), supplanted utility costs, and regulatory incentives that may change over time. Indeed, when comparing project options, the studies may show a few outcomes for different alternative scenarios.[1] With all the uncertainty involved in such projects, the chance of a single NPV value being correct is essentially zero and in fact the true NPV may be vary by a wide degree.

This paper presents an alternative and more accurate way of assessing the economic feasibility of Wind Energy projects. This method, Real Options analysis[2], will explicitly incorporate the main sources of uncertainty for the project. The result will be a distribution of NPV outcomes for different scenarios that will allow community leaders to make much more educated assessments of the financial prospects for Wind Energy projects. Specifically, this paper will compare two techniques within the Real Options framework for assessing a decision to build a small prototype versus a large 20+ MW scale project. Wapakoneta, Ohio which is home to a municipal utility will serve as a case study for this project. The methods used for this purpose will involve a hybrid analysis using a decision tree method and Monte Carlo simulation techniques for evaluating project uncertainty in comparison to a binomial lattice approach.[3] The merits of each will be explored and evaluated with respect to this project.

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[1] Windustry Wind Project Calculator, http://www.windustry.org/CommunityWindToolbox
[2] De Neufville, R. Applied Systems Analysis. McGraw-Hill, Inc; New York, New York, USA: 1990.
[3] Ibid.

More importantly, the improved accuracy provided by these techniques in an economic feasibility study for community wind will be demonstrated. A straightforward and easy-to-use tool can be created to augment existing community wind analysis tools to explicitly and effectively incorporate project uncertainty. The result is a Microsoft Excel Macro that can be added to existing tools for a better overall analysis of wind farm economic feasibility. Such a tool can be designed to be extremely user-friendly so that the end-users experience is not made any more complicated than using tools where uncertainty is not explicitly incorporated. An example case-study demonstrates and discusses the tool's design and use. Thus, the paper will illustrate an appropriate approach for addressing uncertainty in Wind Energy economic feasibility studies and will compare two Real Options methods for this type of assessment.

Project Description

There has been a lot of political activity in recent years across many states in adoption Renewable Portfolio Standards (RPS) that require the use of alternative energy sources such as wind, hydraulic, biomass and solar power. Though lagging behind its neighbors, such as Pennsylvania, adoption of such standards in Ohio was assumed to be forthcoming and in fact with the introduction of a new administration within the state, some sort of legislation is expected in 2008 or soon thereafter. A commercial wind farm is considered to be a cost effective way of achieving an RPS and merits proper evaluation. In terms of the general benefits of RPS standards, commercial wind would reduce the reliance on coal and natural gas for electricity production as well as reduce emissions such as NO_x, CO_2, SO_2 etc that are associated with the burning of fossil fuels. Thus, home grown wind energy is an attractive alternative for the state. In addition, recent studies have shown that Ohio is well-positioned to benefit from manufacturing jobs created by a growing wind industry.

Green Energy Ohio (GEO) is a not-for-profit organization dedicated to promoting policy for and educating Ohioans about "environmentally and economically sustainable energy" technologies and practices.[4] For the past several years, the organization has led a DOE-funded effort to conduct wind assessment studies at heights up to 100 m. No earlier attempts to measure wind data had been performed at such heights and the information from the study was used to validate forecast models and improve state wind maps. To conduct the study, four sites across the state of Ohio were selected including sites at Wapakoneta, Cuyahoga Falls, Sullivan and Bryan. Over the 18 month period of study, the performance at the Wapakoneta site was consistently the strongest of the four sites.[5] Normalizing to historical trends in annual wind speed averages, Wapakoneta even outperformed the Bowling Green site which was monitored from 2000 to 2001. This is significant since the study at Bowling Green led to successful installation and operation of four commercial 1.8 MW wind turbines via a joint-venture between 10 northern-Ohio municipal utilities and American Municipal Power (AMP)-Ohio, a non-profit electricity

[4] Green Energy Ohio, Mission Statement: http://www.greenenergyohio.org/page.cfm?pageID=3
[5] Dykes, K. "Wapakoneta Test Site Study Report," DOE Grant DE-PS26P04-NT42068-08, Green Energy Ohio, July 2007.

supplier and advocate for the municipal utilities.[6] The next step in assessing the prospects for a wind farm in Wapakoneta involves an economic feasibility study.

In order to do an economic feasibility study of the potential for a wind farm at any given test site, a good idea of the wind performance, an understanding of the detailed structure of the utility involved (including economic savings from wind turbine operation), knowledge of applicable regulatory incentives, as well as costs of turbine installation and operation are all necessary. In this case, the thorough testing at 100 m for the Wapakoneta site coupled with knowledge of technical specifications for various manufacturers' turbines gives us an idea of the amount of energy output that can be expected from wind turbines on an annual basis.[7] If necessary, information is available to break down wind characteristics on a seasonal or even monthly hourly performance. However, with respect to the other 3 areas listed above, utility price structure, regulatory incentives, and project costs, significant uncertainty exists. In order to accurately assess the economic feasibility of a wind farm at Wapakoneta, these uncertainties should be appropriately explored.

Detailed Discussion of Uncertainties Involved in Project

The first uncertainty mentioned above is with respect to utility price structure. Power produced from wind is likely to be a small fraction of overall electricity provided to Wapakoneta. Thus, the main benefit, in economic terms, from the wind farm project is offsetting demand for electricity that would have to be purchased from a wholesale electricity supplier (negotiated via AMP-Ohio). Thus, the price of substitute electricity generation determines the "revenue" for the wind farm and uncertainty associated with the evolution of this price will directly impact the project's economic viability. In terms of the utility structure for Wapakoneta, the municipality runs 8 electric substations.[8] These substations are all powered by electricity provided by AMP-Ohio, and the dominant source of fuel for the generation stations are coal and natural gas.[9] AMP-Ohio runs generation stations and negotiates wholesale electric power for its member communities, adds a small service fee and then sells the electricity to the municipalities.[10] Real time wholesale prices for both peak and off-peak electricity in the region of Ohio are available. However, because AMP-Ohio has some generating capacity of its own (capacity to produce approximately 50% of the electricity by its municipal consumers), the prices that AMP passes on to its customers are not perfectly correlated with regional wholesale prices.[11] AMP-Ohio's yearly average electricity sale prices are available for the period from 1998 to 2006 in AMP-Ohio's annual report:

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[6] AMP-Ohio, "Ohio Municipal Electric Generation Agency – Joint Venture 6, 2005 Annual Report": http://www.amp-ohio.org/pdf/OMEGA_JV6_2005_Annual_Report.pdf
[7] Dykes, K. "Wapakoneta Test Site Study Report"
[8] Wapakoneta Electric Department: http://www.wapakoneta.net/electric/
[9] AMP-Ohio, "About Us": http://www.amp-ohio.org/aboutus.html
[10] AMP-Ohio, "About Us"
[11] AMP-Ohio, "2006 Annual Report": http://www.amp-ohio.org/pdf/AMP_Ohio_2006_Annual_Report.pdf

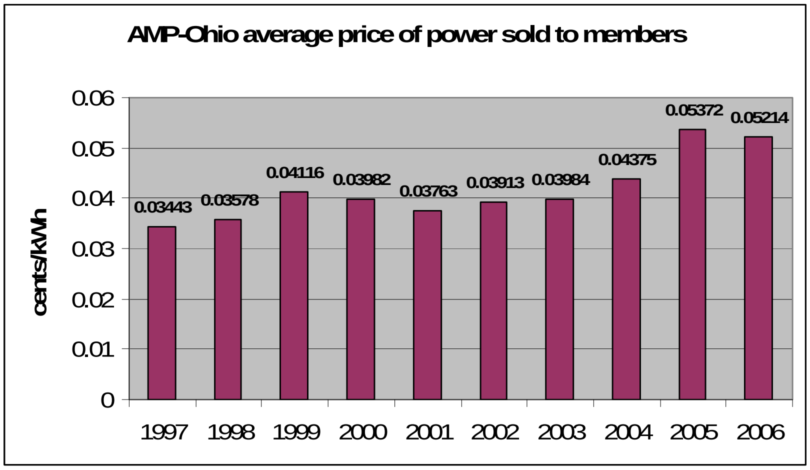

Figure 1: Average annual electricity prices from AMP-Ohio to its members[12]

Analysis of the above graph could result in several conclusions about the expected behavior for future electricity prices from AMP-Ohio. One method is to assume that the price will continue to hover around the average electricity price for the last several years; however, this may be an inappropriate technique for price forecasting. On the other end of the spectrum, a Geometric Brownian Motion (GBM) model can be used to forecast AMP-Ohio's electricity prices into future year. Using this method, the trend in prices over the dataset is expected to continue in a stochastic fashion with an average growth rate, drift, and variability, standard deviation, equal to those found in the historical data set.[13] For AMP-Ohio, the drift for yearly increase in the electricity price data from Figure 1 is 5.07% and the volatility is 9.31%. These values can be used with a GBM model starting with the 2006 price $52.14/MWh in order to forecast prices into future years. Finally, a more detailed approach may be taken that incorporates subtle factors that determine electricity prices that are not captured in the above Figure 1. For instance, aspects having to do with renegotiation of contracts, addition of new capacity, incorporation of carbon costs among other factors may impact the forecasted electricity price. Since it is near impossible to capture all of the exogenous "shocks" that may afflict the trends in electricity prices for AMP-Ohio, the default GBM model aims at encompassing implicitly such shocks through creating trend lines on an extensive historical dataset. This justifies the use of a GBM for this analysis.

While wholesale electricity prices represent the dominant source of uncertainty for the project, there are other sources of uncertainty as well. One area of uncertainty that has affected the development of the wind industry since the 1970's is the extent to which regulatory incentives favor wind farm projects.[14] There are periodic federal and state programs to provide grants, tax credits, and low-interest loans for renewable energy programs such as the project proposed for Wapakoneta. However, the timing of the programs depends on the political climate and there may be more demand for such programs in many cases than the funding can support. Thus, there is a large amount of

[12] Ibid.
[13] De Neufville, R. Applied Systems Analysis.
[14] Cason, Bill. Wind Energy in America U. Oklahoma Press: 2006.

uncertainty surrounding which incentives will be available to Wapakoneta even in the near future let alone 10 to 15 years. For this case, a range of expected outcomes which encompass the different types of cases that could occur is the most practical way to address this type of uncertainty:

1. No grant, loan, or tax incentives: this case represents the worst possible situation in which Wind has to compete head on with coal, natural gas and other types of electricity generation without any policy incentives whatsoever
2. Some grants, loans or tax incentives available: this represents the current political climate without change. There may be a variety of incentives in the form of grants for a large commercial wind project, production incentives and property tax exemption on the state level, and production incentives as well as tax exemptions at the federal level.
3. Increase in grants, loans or tax incentives available: this represents the best case scenario in which the previously mentioned incentives are available and potentially augmented. In addition, financing incentives are also added to the mix.

In addition to electricity price and regulatory incentives, the cost of turbines may change over time. The likelihood is that cost for turbines will trend downwards as technology and economies of scale come into play. This of course is dependent on the growth of the wind industry as a whole. The dominance of coal and natural gas as sources for electricity production may continue into the future and stifle the growth of the wind industry. An estimate for turbine installation cost is about $1,800,000 / MW turbine capacity installed.[15] Economies of scale are expected to reduce this as the capacity is increased (i.e. a 26 MW commercial wind farm is expected to cost about $20,000,000 for installation).[16] There has been only one successful commercial wind generation project in Ohio to date at Bowling Green in a joint-venture project run by AMP-Ohio and various northern Ohio municipalities. The installation costs for the 4 1.8 MW turbines (7.2 MW total) was $9,861,000 or $1,369,583.33 / MW.[17] In general, there has been a downward trend in the cost of wind energy over the years.

In this case, the uncertainty revolves around the reliability of forecasts by experts from these various organizations. In general, the cost seems to be leveling off as seen in the above trend. However, experts are still projecting some cost reduction as the wind industry grows which would need to be considered for decisions of timing for when and how many turbines to install. More accurate information on costs of installation and maintenance could be obtained from wind developers and current project owners, such as at Bowling Green, but this information is difficult to access and information from Bowling Green is not necessarily applicable for the current project under consideration.

Since cost information is difficult to obtain and regulatory incentives are difficult to predict and cover only a fraction of the project costs, the focus of uncertainty for this study will thus be the wholesale electricity price from AMP-Ohio to its member utilities.

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[15] AWEA, "10 Steps in Building a Wind Farm": http://www.awea.org/pubs/factsheets/10stwf_fs.PDF
[16] Ibid
[17] AMP-Ohio, "Ohio Municipal Electric Generation Agency – Joint Venture 6, 2005 Annual Report"

Specifically, the trends in electricity cost will be considered and in addition the role of carbon pricing will be treated in the below analysis. Using this main source of uncertainty, the trade-offs between a decision involving a small-scale (3 MW) wind farm as a pilot project versus upfront investment in a large-scale (26 MW) wind farm will be evaluated. This will be done in two ways. The first analysis will evaluate the effects of a decision to build a small wind farm at first to "test the waters" versus diving in with installation of a large wind farm under two different scenarios: with and without carbon pricing. This will be done using a decision tree that incorporates chance outcomes based on the uncertainty from wholesale electricity prices. In the second analysis, the choice of building and then expanding a small 3 MW wind farm will be compared against the initial building of a 26 MW wind farm using a binomial lattice to assess the impact of uncertainty from fuel price. Both the analysis techniques will be implemented in common spreadsheet and could be added these analytical tools to a deterministic approach of assessing economic feasibility for a wind farm.

Discussion of Project Options: To Build (Big) or Not to Build (Big)

Recognizing flexibility and the possibility to phase the project is an appropriate approach to deal with the different sources of uncertainty affecting the project's economic value. Recognizing this in the appraisal process is ultimately what decision-makers need to do. Flexibility reduces initial capital expenditure by a wide margin which reduces exposure to downside risk. However, designing for the flexibility upfront will allow a project to capture upside opportunities should economic conditions favor expansion at a later date.

One of the big decisions that a community, such as Wapakoneta, interested in wind projects faces is the scale of the project. Should a community start off by installing a few turbines and assess the initial success of the program or should the community take advantage of the economies of scale associated with installation of a large-scale commercial wind turbine? This analysis will look at the potential trade-offs of large number wind turbine program economies of scale versus small number flexible wind turbine programs. Specifically, 2 different scenarios will be analyzed with differing degrees of flexibility:

1. Installation of a large scale commercial wind farm of 20 MW of electricity generation capacity
2. Installation of 3 MW initial capacity which can be scaled after 10 years in the "second phase" of the project if conditions seem favorable

The next step to be described here is a comparison of three different planning scenarios. The first scenario involves the upfront investment of a large 20 MW wind farm. The advantage of this approach is that there are significant economies of scale involved in wind farm development, which reduces the average cost per kWh as more power is produced. The next approach is a more conservative approach. Since the cost of wholesale electricity in the future is difficult to predict, it may make sense to install a smaller number of turbines upfront (3 MW capacity) and then if prices of wholesale electricity over the next 10 years escalate, a larger wind farm can be developed.

Analysis Using a Decision Tree

These two scenarios will be compared using two different scenarios of outcomes for wholesale electricity prices: with and without carbon pricing. Since the carbon pricing scenarios represent a discrete set of options, a decision analysis technique is more appropriate. In all cases, a Geometric Brownian Motion trend function was used based on price data from 1997 to 2006 where the drift, or average growth, was found to be 5.07%/year, and the volatility, or standard deviation of the growth, was found to be 9.31%/year. The starting price used for the model is the 2006 wholesale electricity price was $52.14/kWh. On top of the GBM model, the presence or lack of an artificial carbon tax will simulate the different scenarios relevant to the decision, in this case either building a small scalable wind farm or a large 20+ MW wind farm. Again, since the discrete uncertainty of various carbon tax scenarios is the main source of uncertainty in this particular analysis, the decision tree is the more appropriate choice.

The figures below contain the data used for the analysis. The numbers are not exact data from wind developers since such information is proprietary and thus hard to access. The below information comes from predominantly two sources: AWEA wind fact sheets and the Windustry Community Wind Development Calculator.[18] AWEA suggests in a report that economies of scale reducing wind turbine prices to ~$1 Million / MW for 20MW+ wind farms; the Windustry model suggests that small installations (<= 3MW) cost ~$1.9 Million/MW. Thus, small installations in this model will incur the Windustry cost and large installations will incur the AWEA cost. In this assessment a 750 kW turbine is used for 4 turbines producing 3 MW and 26 turbines producing 20 MW; however, this analysis could easily be modified for use with larger turbines of 1.8 MW sizes which are more typical for today's wind farm installations.

For maintenance costs, the Windustry model costs will be used across the board for all scenarios. The Windustry model forecasts growth in maintenance costs for a range of variables; this forecast will be used directly in the scenarios without modification though more detailed analysis would address this source of uncertainty as well. It is assumed in this paper that the major source of uncertainty, fuel prices of from fossil-fuel based electricity generation, will be a much more significant factor in determining the economic viability of the project than these other factors. However, future work may explore these other sources of uncertainty in more detail. The price data for wholesale electricity comes from the AMP-Ohio 2006 annual report as described in part 2.[19] The Geometric Brownian Motion forecast is derived directly from this data. A discount rate for the NPV calculations was selected to be 8%, again taken from the Windustry model. Finally, incentives are not addressed in the analysis. These present another significant source of uncertainty and should be considered carefully for a project, but in the interest of focus, the fuel-price was selected as the only source of uncertainty for analysis within this paper. In subsequent steps, the effects of these incentives on the outcomes for the different scenarios may be evaluated.

[18] Windustry Wind Project Calculator & AWEA, "10 Steps in Building a Wind Farm"
[19] AMP-Ohio, "2006 Annual Report"

Plan 1: large upfront investment for large-scale wind turbine farm		
Turbine #	26	
Size Turbine	750	kW
Total MW	19.5	MW
Yearly kWh production / turbine	1,408,464.65	
Total Cost	20,000,000.00	
Economies of Scale?	yes	
Maintenance Costs / MW	63,000.00	
Total Maintenance Costs	1,638,000.00	
Current Price per MWh	52.14	
Total Savings	1,909,371.02	

Figure 2: Model characteristics for the small 3 MW wind farm project plan

Plan 2: small upfront investment for small-scale wind turbine farm (scalable)		
Turbine # / installation	4	
Size turbine	750	kW
Total MW	3	MW
Yearly kWh production / turbine	1,408,464.65	
Total Cost	5,700,000.00	
Economies of Scale?	no	
Maintenance Costs / MW	63,000.00	
Total Maintenance Costs	252,000.00	
Current Price per MWh	52.14	
Total Savings	293,749.39	

Figure 3: Model characteristics for the large 20 MW wind farm project plan

In order to capture the effects of carbon pricing on fuel pricing, additional analysis was required before the decision-tree analysis could be completed. Firstly, forecasts for carbon pricing were needed. The MIT Joint Program on the Science and Policy of Global Change has done a series of analysis resulting in forecasts for carbon pricing in the next 50 years as well as the effects of such pricing on welfare.[20] They look at three scenarios of 287, 203, and 167 billion metric tons of carbon permit allocations and using their Emissions Prediction and Policy Analysis (EPPA) model, put forth a carbon price forecast for each scenario. Shown below is a graph of the resulting prices estimated by their analysis.

[20] Paltsev, S. et. al. "Assessment of US Cap and Trade Proposals," *MIT Joint Program on the Science and Policy of Global Change*, Report No. 146, April 2007.

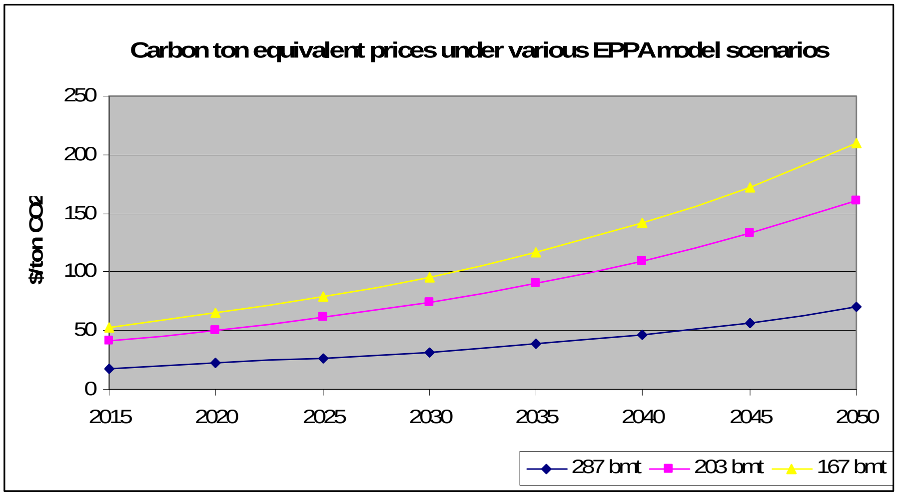

Figure 4: Prices for tons of CO_2 equivalent using the three test case scenarios of the MIT EPPA model[21]

Carbon prices were determined by interpolation or extrapolation of the above trends to get Carbon prices in terms of tons of CO_2-equivalent from 2007-2050. In order to assess the quantity of tons CO_2–e likely offset by operation of a wind farm in a per-MW basis, a rule-of-thumb was used of 1000 tons CO_2–e per MW. This was based on analysis performed by Tarek Rached where avoided emissions were modeled for the offshore location of Hull, MA.[22] Rached's analysis resulted in an expected 1900 tons CO_2–e per MW avoided emissions, but this number needed to be adjusted down for Wapakoneta due to the difference in wind class. 1000 tons CO_2–e per MW is thus seen as a conservative estimate.

Having all of the relevant data at hand (installation and operating costs, expected energy output, forecasted fuel prices, forecasted carbon prices and the discount rate), a decision tree is built. For this model a two-stage decision process is used to compare case 1, large wind farm, versus case 2, a few test turbines and then ramp up if conditions in ten years are favorable (i.e. if electricity prices have grown substantially). In order to obtain an expected value for each scenario (12 in total) a Monte-Carlo simulation was run adjusting the trend in fuel prices for the GBM model in each case. Under the flexible plan, there is a 50-50 chance of legislation in the next 10 years being lax or stringent and this affects the probabilities of each of the carbon-price scenarios. 50-50 was chosen given the current political climate in the US where the next election may have a significant impact on carbon legislation but to date, the population supports neither candidate by a significant margin. Figure 5 shows the decision tree and expected values of the different outcomes for the two scenarios.

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[21] Ibid.

[22] Rached, T. MS Thesis: Communicating Complexity and Informing Decision Makers, Engineering Systems Division, MIT, June 2008.

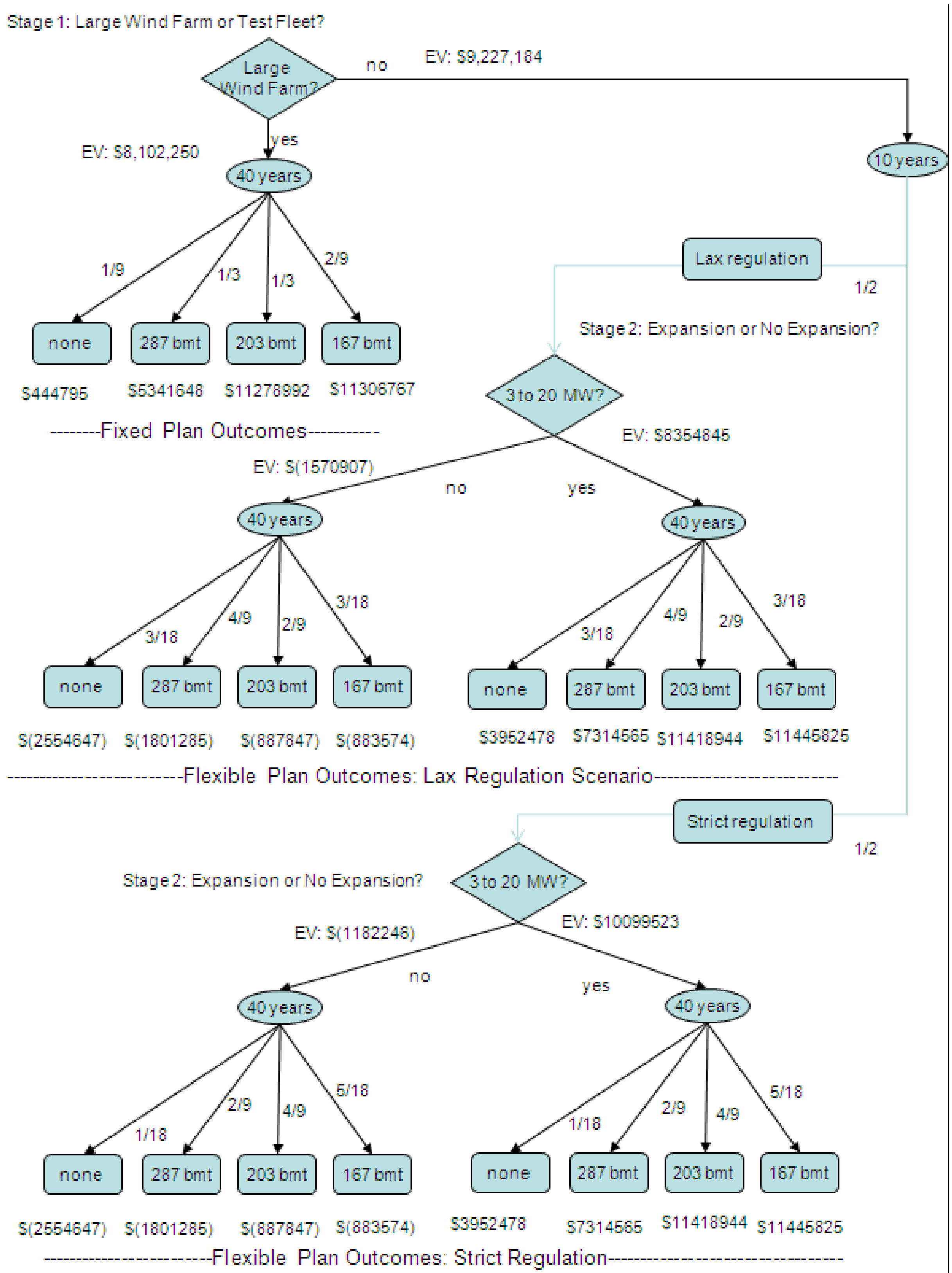

Figure 5: Decision Tree Analysis of option to build a small test wind farm versus upfront investment in a large wind farm

The benefits of flexible decision making are readily visible on inspection of the decision tree. The expected values for the case where the project is scaled up from 3 to 20 MW after 10 years are the largest for all scenarios. The reason for this is that this particular scenario captures the benefits of having a large wind farm installation (more revenue when fuel and carbon prices are high) as well as the benefits of the small wind farm installation (less risk if fuel and carbon prices are low). For a risk adverse community interested in wind farm development, a pilot project that is designed for scaling in the long-term mitigates a large amount of downside risk while still saving the option for large revenue gains in the future. This is illustrated graphically in the next figure which shows the value-at-risk-and-gain (VARG) curves for the three decision outcomes (large-farm, small-farm, scaled-farm) in the case where there is no carbon pricing. These curves are essentially a cumulative frequency distribution of the possible scenario outcomes. The heavy tail of the large-farm decision on the negative side is mitigated by scaling, while some of the upside potential is captured. The small farm does avoid large downside risk but loses upside potential by not allowing for expansion at a later date.

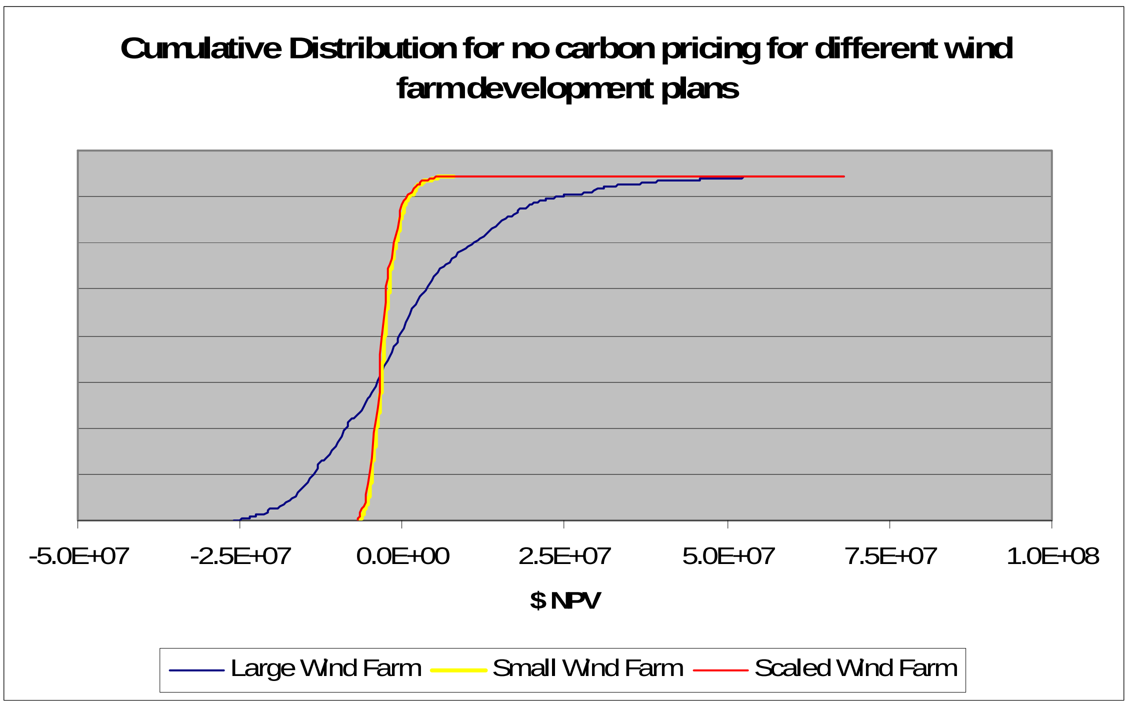

Figure 6: VARG curves for the NPV of the different wind farm plans for Wapakoneta

Alternatively, a second way of reducing the downside risk of low wholesale would be through the use of an option to close the wind farm and sell off the assets if growth of the wholesale electricity prices were to remain stagnant. This alternative will be explored in a second analysis that uses a binomial tree lattice to assess the value of an option to close either a small wind farm if wholesale electricity prices do not grow as expected in the first 10 years of operation (during stage 1).

Analysis Using a Binomial Tree

Using a Lattice Decision Analysis, next we will model the Option of Closing a Small-Scale Wind Farm due to non-performance (a "put" option for a wind farm). The first step in the process involves the creation of a binomial lattice for the price of wholesale electricity based on the historical trend with a drift of 5.07%, a volatility of 9.31% and a starting price of $52.14 /MWh for the most recent year (2006). This resulted in an upside factor of 1.0976, a downside factor of 0.9111, and an upside probability of 0.7723. The resulting binomial lattice probabilities and corresponding price values for the wholesale electricity price are shown in the figures below.

	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7	t = 8	t = 9	t = 10	t = 11	t = 12	t = 13	t = 14	t = 15
Price ($/kWh)	0.05214	0.05723	0.06281	0.06894	0.07567	0.08305	0.09115	0.10005	0.10981	0.12052	0.13228	0.14519	0.15935	0.17490	0.19197	0.21070
		0.04750	0.05214	0.05723	0.06281	0.06894	0.07567	0.08305	0.09115	0.10005	0.10981	0.12052	0.13228	0.14519	0.15935	0.17490
			0.04328	0.04750	0.05214	0.05723	0.06281	0.06894	0.07567	0.08305	0.09115	0.10005	0.10981	0.12052	0.13228	0.14519
				0.03943	0.04328	0.04750	0.05214	0.05723	0.06281	0.06894	0.07567	0.08305	0.09115	0.10005	0.10981	0.12052
					0.03593	0.03943	0.04328	0.04750	0.05214	0.05723	0.06281	0.06894	0.07567	0.08305	0.09115	0.10005
						0.03273	0.03593	0.03943	0.04328	0.04750	0.05214	0.05723	0.06281	0.06894	0.07567	0.08305
							0.02982	0.03273	0.03593	0.03943	0.04328	0.04750	0.05214	0.05723	0.06281	0.06894
								0.02717	0.02982	0.03273	0.03593	0.03943	0.04328	0.04750	0.05214	0.05723
									0.02476	0.02717	0.02982	0.03273	0.03593	0.03943	0.04328	0.04750
										0.02256	0.02476	0.02717	0.02982	0.03273	0.03593	0.03943
											0.02055	0.02256	0.02476	0.02717	0.02982	0.03273
												0.01872	0.02055	0.02256	0.02476	0.02717
													0.01706	0.01872	0.02055	0.02256
														0.01554	0.01706	0.01872
															0.01416	0.01554
																0.01290

Figure 7: Binomial Lattice for wholesale electricity price outcomes based on starting price, drift and volatility values as described above

	t=0	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11	t=12	t=13	t=14	t=15
Probabilities:	1.00	0.77	0.60	0.461	0.356	0.275	0.212	0.164	0.127	0.098	0.075	0.058	0.045	0.035	0.027	0.021
for wholesale electricity price		0.23	0.35	0.407	0.420	0.405	0.375	0.338	0.298	0.259	0.223	0.189	0.159	0.133	0.111	0.092
			0.05	0.120	0.186	0.239	0.277	0.299	0.308	0.306	0.295	0.279	0.258	0.236	0.212	0.189
				0.012	0.036	0.070	0.109	0.147	0.182	0.210	0.232	0.247	0.254	0.255	0.251	0.242
					0.003	0.010	0.024	0.043	0.067	0.093	0.120	0.145	0.168	0.188	0.203	0.214
						0.001	0.003	0.008	0.016	0.027	0.042	0.060	0.079	0.100	0.120	0.139
							0.000	0.001	0.002	0.005	0.010	0.018	0.027	0.039	0.053	0.068
								0.000	0.000	0.001	0.002	0.004	0.007	0.012	0.018	0.026
									0.000	0.000	0.000	0.001	0.001	0.003	0.005	0.008
										0.000	0.000	0.000	0.000	0.000	0.001	0.002
											0.000	0.000	0.000	0.000	0.000	0.000
												0.000	0.000	0.000	0.000	0.000
													0.000	0.000	0.000	0.000
														0.000	0.000	0.000
															0.000	0.000
																0.000
Cumulative Prob	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure 8 Probability values associated with respective wholesale electricity price outcomes as shown in the figure above.

Using the values above, a lattice model was developed to assess an option for closing the wind turbine if the trend in price was not favorable to continued operation of the wind farm. Several assumptions were needed in order to make this analysis viable:

1) Up front costs for investment in the small wind farm were assumed to be funded by debt with a 0% interest rate (i.e. special government program for renewable energy investment) and a term of 15 years. Actual debt for wind farm installed by AMP-Ohio at Bowling Green also carries a term of 15 years but the interest rate is set by an index currently at 2.88%
2) From the above, the debt was thus divided into equal installments of $5.7 Million over 15 years and each yearly payment was rolled into the operating costs along with maintenance costs of $252,000.
3) It was assumed that at any time if the plant was closed, no future costs would be incurred (i.e. the wind turbine farm could be sold to pay off the remaining debt). This is a simplifying assumption to make the analysis more manageable. Thus, the decision for shutting down is based on whether operating revenue is less than the operating costs as defined above.
4) The discount rate is the same as suggested by earlier application portfolios and comes from AWEA specifications for wind programs at 8%

Below is a depiction of the scenario for closure and the effects on NPV. The value of the option to close in this case is found to be $710,807 when compared to the scenario where the firm continues operation even under adverse economic conditions. Both represent a negative expected NPV, but this is also due to the fact that the operation time for the wind farm is kept at only 15 years.

	t = 0	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7	t = 8	t = 9	t = 10	t = 11	t = 12	t = 13	t = 14	t = 15
PV(Net Revenue)	585,185	894,774	863,316	828,789	570,874	266,293	56,160	365,687	645,387	883,087	1,066,292	1,180,375	1,208,156	1,129,511	920,939	555,051
WITH OPTIONS		949,549	923,436	894,774	863,316	828,789	675,090	412,034	130,257	129,317	349,060	516,837	618,819	638,771	557,688	353,380
(check next year)			973,342	949,549	923,436	894,774	863,316	828,789	734,080	494,527	246,320	33,972	129,606	231,404	256,150	185,971
				995,019	973,342	949,549	923,436	894,774	863,316	828,789	731,702	491,202	276,493	106,755	5,842	47,004
					1,014,769	995,019	973,342	949,549	923,436	894,774	863,316	828,789	613,599	387,463	201,941	68,354
						1,032,763	1,014,769	995,019	973,342	949,549	923,436	894,774	863,316	620,480	374,424	164,113
							1,049,158	1,032,763	1,014,769	995,019	973,342	949,549	923,436	813,910	517,602	243,603
								1,064,095	1,049,158	1,032,763	1,014,769	995,019	973,342	949,549	636,456	309,589
									1,077,704	1,064,095	1,049,158	1,032,763	1,014,769	995,019	735,118	364,364
										1,090,104	1,077,704	1,064,095	1,049,158	1,032,763	817,017	409,834
											1,101,401	1,090,104	1,077,704	1,064,095	885,003	447,578
												1,111,694	1,101,401	1,090,104	941,438	478,910
													1,121,072	1,111,694	988,285	504,919
														1,129,616	1,027,174	526,509
															1,059,455	544,431
																559,308

Figure 9: Present Value of revenue streams for different outcomes in a binomial tree analysis using wholesale electricity prices derived from a binomial lattice

The results of this analysis indicate that in the first few years of operation, the option to shut down should be exercised as the wholesale electricity price is too low to merit operation of a small-scale wind farm. However, further along if the price for the first few years is consistently high then operation of a small scale wind farm does become viable. This is an important result, since the tree shows that later on the small-wind farm does have positive revenue streams. Using a binomial tree, this can be seen explicitly. However, regardless of the approach the overall revenue streams for the first 15 years of operation for the small-scale wind farm are still negative. Unfortunately, even the inclusion of the "option to close" does not make a small-scale pilot project wind farm look economically attractive within the first 15 years of operation. The flexibility still has value as it reduces exposure to downsides even in losing economic conditions since overall losses are minimized. This lattice model could also be easily adapted to look at the option for expansion (a "call" option) based on probabilities associated with fuel price growth.

Discussion and Conclusion

In the first analysis, a discrete set of probable scenarios having to do with carbon taxation were presented. Such a discrete number of outcomes did lend itself to decision analysis. Coupling the carbon taxation decision – analysis with Monte Carlo simulations of fuel price led to an analytical technique for assessing a "call" option for wind farm expansion. In the second analysis, a binomial lattice was used to look at the specific effects of uncertainty in fuel price. This allowed the inspection of effects from using a "put" option of shutting down a wind farm under adverse economic conditions.

Based on these initial results, it is possible to say that a large-scale wind farm will certainly provide advantages in terms of economies of scale so long as the growth in wholesale electricity prices does not fall substantially. However, significant downside risk can be avoided by adopting a flexible plan in which small turbine capacity (3MW) is installed initially. This downside risk can further be mitigated by an "option to close" if the wholesale prices in the first few years after installation do not rise in accordance with the historical trend of 5%. If wholesale prices in the first few years do show strong growth, assessment at a later data can be used to make a decision to expand to a 20 MW (or larger) wind farm. An alternative to this entire process is simply to "wait it out"; that is, to monitor wholesale electricity prices, regulations, and wind costs over the coming years. If wholesale electricity prices show strong growth, wind farm costs fall, or regulations begin to favor investment in renewable energy programs, then a wind farm could be installed at Wapakoneta at any later date. However, all such analysis depends largely on the specifics of the economic conditions and options for a specific community wind project

Of the major sources of uncertainty mentioned above, only uncertainty in wholesale electricity prices and carbon prices were considered. Uncertainty from maintenance and installations costs as well as policy incentive programs have been ignored to simplify this analysis for the given scope and time constraints of course project. More thorough analysis will need to consider these additional sources of uncertainty. With respect to regulatory incentives, this is especially important considering the fact that for a given project, most incentive programs are capped at a certain amount. With respect to cost uncertainties, improved collaboration with wind developers or an economic feasibility study that incorporates developer input would be beneficial. In this analysis, estimations were made for all such costs. The economies of scale that a project may face were substantial in this analysis as suggested by the information accessible via AWEA and Windustry. However, this needs to be validated by talking with developers and thoroughly researching existing projects to see what cost values may be more realistic and to attempt to quantify additional uncertainty for such costs.

The above analysis is a first step towards an economic feasibility study for a wind farm in Wapakoneta, Ohio. In order to make any decision regarding wind power for Wapakoneta, an extensive analysis that includes a detailed economic feasibility study as well as environmental impact is recommended. This paper seeks only to show that in designing an economic feasibility study, uncertainty in the various underlying determinants of the project's success should be considered and that incorporating flexibility into the design of the wind farm can improve the overall economic viability of the project. All of the analysis can be done easily in a spreadsheet as long as accurate data is available. Such analysis can benefit tools already at the disposal of those interested in Community Wind projects to better enhance the overall decision-making process.

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References

Cason, Bill. Wind Energy in America U. Oklahoma Press: 2006.

de Neufville, R. Applied Systems Analysis. McGraw-Hill, Inc; NY, NY, USA: 1990.

Paltsev, S. et. al. "Assessment of US Cap and Trade Proposals," *MIT Joint Program on the Science and Policy of Global Change*, Report No. 146, April 2007.

Rached, T. MS Thesis: Communicating Complexity and Informing Decision Makers, Engineering Systems Division, MIT, June 2008.