An Analysis of the Profitability, the Economic, & Environmental Impacts of Increasing Wind Energy

Harrison Abrams

Ashley M. Edwards

Roger Madejski

Ekin Oflazer

Emmie Schlessinger

Table of Contents

I. Abstract

The purpose of this paper is to explore the economic feasibility, technological prospects, and environmental impacts of increasing the proportion of wind energy in the U.S. total energy portfolio. In order to engage in this discussion, we have first set the stage for the paper by providing an overview of the wind energy space, its market structure, and the technological components involving wind energy use. Following the presentation of background information, we have discussed the process, methodology, and findings of the cost-benefit analysis that we have conducted as a means of determining at which levels and during which future years wind energy will become profitable from an economic standpoint. The paper then explores wind energy policy considerations and engages in an analysis of the environmental impacts and externalities associated with increasing wind energy in the portfolio.

II. Introduction

Renewable energy has received increasing interest in recent years due to several factors including but not limited to: high energy prices, energy supply uncertainties, and environmental concerns. People are currently working to generate energy sources that can be domestically generated, and cost-effective while also being safe for the environment and mindful of climate change concerns [4]. There are several different types of renewable energy sources that have been considered and explored. Among them, hydropower holds the most significant portion as it generated about 6% of the electricity produced by the electric power sector in 2007 in the United States. Non-hydropower renewable energy sources contributed approximately 2.5% of the 2007 total, with wind power experiencing the most growth compared to biopower, geothermal, and solar, whose growth has been much more stagnant over the past couple of decades [8]. As such, we have opted to focus our research and analysis on the wind power segment, as we feel there is a vast amount of untapped potential for investment in this field.

One major factor to consider when weighing the costs and benefits of increasing wind power penetration in the energy mix of the United States is the cost associated with the technology. Wind turbines are extremely expensive to construct and maintain. In addition, varying wind currents and consistency of wind makes certain regions more or less adept for harnessing wind power. Additional technology improvements are expected to improve the cost-efficiency of wind power in the coming years, and although the research and development will be expensive and time-consuming, there is potential to bring down the cost of wind turbines significantly.

The objective of our paper is to determine at which point and at what levels wind power will become economically feasible and beneficial for the United States. In order to determine the net profit of wind power each year, and further to discover at which point wind power can be estimated to become profitable, we subtracted the net cost from the net benefit. We projected variables such as cumulative installed capacity and energy prices from the energy grid using historical figures to best estimate when we can expect wind energy to become cost-effective as a renewable energy source.

In addition to the model we created, we have taken into account and discussed several of the implications of the model, such as decreased CO_2 emissions and increased water conservation, both of which speak positively for wind energy. In order to maintain wind energy growth over the coming years, we believe it will be important for the government to continue to create policies that support investment in wind technology and development. Overall, we are happy with our projections and think that wind energy can be a vital asset to the United States in the coming years.

The paper is organized as follows. Sections III and IV provide a more detailed analysis of the current market situation for wind power as well as the developing technological components of wind energy equipment. Section V illustrates our Cost-Benefit analysis, including discussing both the methodology and limitations of our model demonstrating the future point at which wind power becomes economically profitable. Sections VI and VII expound on the current wind policies in action today along with the implications of our cost-benefit analysis in terms of environmental externalities.

III. Wind Market Structure & Overview

While hydropower still accounts for the highest proportion of currently used renewable energy, wind power has seen steady growth rates over the past 20 years that other renewable energy sources have not. In 2007, wind power accounted for less than 1 percent of total U.S. electricity generation. However, wind power grew at a compounded annual rate of 15.5% from 1990-2007 and of 25.6% from 1997-2007 [8]. Unfortunately, the recession in 2008 threatened to slow the progress of establishing wind power facilities, although certain regulations and legislation to be discussed later on have been successful in continuing to promote the development of wind energy.

While there are no monumental shifts in wind technology in the foreseeable future, certain modifications to certain aspects of wind turbines have the potential to cause a 30-40% increase in cost effectiveness by 2017 [8]. At the same time, there are some major barriers associated with widespread adoption of wind power. In particular, as is the case with many renewable resources, even with a 30-40% increase in cost effectiveness, the cost-competitiveness of wind power relative to fossil based electricity is still questionable. Further, the research and development necessary to realize continued improvements and further cost reductions for wind is a major investment of both time and money. Finally, the quality of wind power varies based on speed and constancy which makes energy costs more difficult to calculate compared to other energy sources, making it highly difficult to reach economies of scale due to the uncertainty surrounding various locations for wind turbines.

IV. Wind Turbine Technology Overview & Advancements

In order to successfully complete a cost-benefit analysis regarding when wind energy would become profitable such that the net profits of its implementation as an energy source in the portfolio are positive, it is important to first explore the nature of the technology itself and also the prospect of enhancing it. The origin of wind technology to generate electricity dates back to the 1970s, but since the innovation was discovered, there have been drastic technological developments to increase its efficiency. The technological components of a wind energy apparatus are very important, because it is an aspect that weighs into their cost which is a key determinant in the degree of their use. It is important to note also that the development of wind energy technology is limited by the land usage factor. Not all geographies across the globe are suitable for the use of wind farm and in addition not all places have adequate wind as a source to generate the level of electricity needed for functionality. Within the United States, the Midwest and the regions between Texas and North Dakota are equipped with ample resources for the development of wind energy technology. Technological advancements are not only important from a cost perspective because they can make the turbines more efficient and this may contribute to cost savings, but innovations can be made such that they will reduce the amount of energy that is lost instead of harnessed, which is environmentally more beneficial as well as an additional cost saving economic benefit.

The typical and modernized version of the wind turbine today is set atop a 60-80m long tower, and has three blades as the rotors which are 70-80m in diameter [4]. The wind turbines are usually conglomerated in groups of 30-150 tower apparati. The energy that is available to be extracted by the wind turbine increases by a cubic degree of wind speed, i.e. if there were a 10% increase in wind speed that would result in a 33% increase in energy [4].

There are projected technology improvements in terms of the structure of the wind turbine technology itself and its wind energy harnessing capabilities. Some of the basic improvements could be implementing taller towers, larger rotors, and improved design and manufacturing of the items that compose the wind turbine. However, it is important to note that technological advancements in wind energy also have risks associated with their execution because turbine manufacturers have to be absolutely certain of the nature of performance before going through with the innovations. In the case of wind technology development, the improvement of the rotor is the highest priority, since it is the means through which the energy is actually captured. There are two approaches to how to improve upon the rotors in order to reduce the electricity load levels or to create load-resistant designs for the rotors. The first approach is to use the actual blades to reduce the gravity and turbulence driven loads [4]. The second approach is to incorporate an active control into the turbine which will suppress the loads transferred from the rotor to the remaining components in the turbine's structure [4]. The innovations just mentioned allow for the rotor to have a larger range and better ability to capture more energy without throwing off the balance of the turbine system. Another innovation in progress by an Idaho based energy company, Energy Unlimited, Inc. is to create rotor models that have the capacity to use variable diameter rotors, and this would greatly increase the capacity factor of the turbine itself [4]. In the case that this is developed, the variable diameter rotor will have a larger area to capture more energy even in times of low wind availability, and they will additionally allow for the reduction in the size of the rotor which will be beneficial during heightened times of wind availability.

In addition, there could be innovation in terms of the blades of the wind turbine, for larger rotors with longer blades (i.e. blades with increased weight) will increase the capacity for energy capture and the power generated by the turbines [See Diagram 1, 2]. Longer blades are useful because they can endure great structural loads should the innovation also include increasing the strength to weight ratios of the blades. Additional research and the testing of turbines have proven that a 10-35% increase in capacity factor can come about from blades that are elongated 5-16% [4]. In regard to innovation on the towers of the wind turbine, there is not much that can be done as there can be with the other components. There is an issue though of tower height and the top heavy weight of the turbine, so manufacturers are trying to solve this dilemma by having either more slender, taller towers with streamlined turbines that are not as top heavy, or vice versa with shorter towers that are thicker to support the more top heavy turbines.

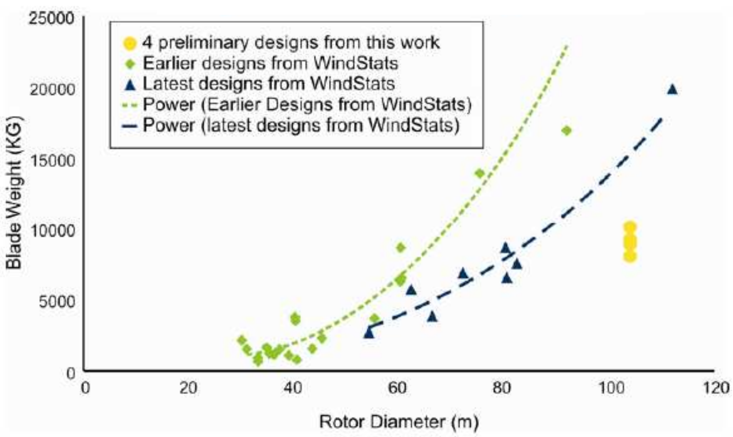

Figure 1: Growth in Blade Weight and Rotor Diameter are positively correlated and directly proportional.
Source: Department of Energy

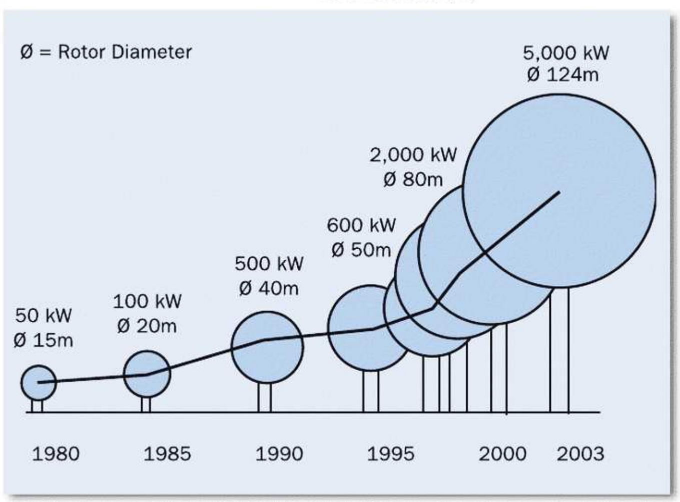

Figure 2: Rotor diameter of the wind turbines has increased historically which has resulted in a corresponding increase in the capacity for wind energy generated.
Source: EWEA

V. Cost-Benefit Analysis

We have conducted a cost-benefit analysis for wind energy production and the potential for an increased level of wind energy within the total U.S. energy portfolio. The analysis is forward looking and evaluates wind production over the next 20 years, to gauge the level of wind energy that will be feasible from a cost-benefit standpoint. In order to complete this analysis, we projected a few important figures, such as the cumulative installed wind capacity and the price of energy from the electric grid. These numbers were projected out until 2030, using historical data sets from 1999 to 2008. Historical data was collected from this time range, as 1999 was as far back as we could find for all data lists. Also, 2008 marks the beginning of the financial crisis, which has and will have a large effect on the growth of the energy industry for the coming years. Using 1999 to 2008 as our range gave us 10 data points, a sufficient number for projecting values into 2030.

The historical data and projected values were used to eventually calculate when wind power will produce a net profit. We arrived at total yearly profits by simply subtracting total cost from total revenue. Detailed explanations of what composes our total cost and total revenue, as well as how the curves were calculated are provided.

A) Cost

The most complicated part of our model was calculating total cost. In finding our total cost we multiplied a unit cost of wind energy by the cumulative installed wind capacity of the U.S. Before getting into how we calculate cost, we needed to project cumulative installed capacity.

	Year	Cumulative Installed Wind Capacity (MW)
Historicals	1999	2,472.48
	2000	2,539.32
	2001	4,231.77
	2002	4,687.36
	2003	6,349.94
	2004	6,723.12
	2005	9,147.06
	2006	11,574.51
	2007	16,907.05
	2008	25,410.04
	2009	34,863.35
	2010	40,266.96
	2011	46,916.00
	2012	51,630.00

Table 1: Cumulative Installed Wind Capacity from 1999 to 2012
Source: Department of Energy

Years following the financial crisis have shown that growth in capacity has slowed down significantly. While some years in the past have shown growth of almost 50% [5], we don't know when (if ever) rates will return to that level. For that reason, we chose to use far more conservative rates, similar to those that we've seen in post-recessionary years, such as 5%, 10%, and 15%. Thus, projecting to 2030, we applied these linear growth rates to our 2008 value for cumulative installed wind capacity.

Finding a reasonable unit cost of wind energy was the more complex part. We chose to break cost down into two components, ''levelized cost of energy" and "operation & maintenance cost."

Operation and maintenance cost was left constant; the reasoning for this will be explained later. Levelized cost of wind energy is defined as the cost to install the renewable energy system divided by its expected lifetime energy output. To project levelized costs, we used the learning curve equation, written as:

$$C_t = C_0 \left(\frac{Q_t}{Q_0}\right)^b$$

C_t is levelized unit cost of cumulative production in year t, Q_t is cumulative installed capacity in year t, and b is the rate of innovation or learning parameter. Learning curves describe how cost declines with cumulative production, (in our case producing wind power) where cumulative production is used as an approximation for the accumulated experience in producing and employing a technology [1]. The cost reductions in the experience curve refer to total costs and changes in production (process innovations, learning effects, and scaling effects), products (product innovations, product redesign, and product standardization), and input prices.

The Department of Energy states that wind energy today costs between 10-15 cents/kWh [6]. To be conservative in our projections we used the high end of this range for the levelized cost of energy in 2008. Using our 1999 and 2008 historical data for cumulative installed capacity and levelized cost of energy we were able to plug values into the generic learning equation to solve for b.

$$b = \frac{ln\left(\frac{C_{2008}}{C_{1999}}\right)}{ln\left(\frac{Q_{2008}}{Q_{1999}}\right)} = \frac{ln\left(\frac{1{,}314{,}000\ \$/\text{MWyr}}{2{,}735{,}883\ \$/\text{MWyr}}\right)}{ln\left(\frac{25{,}410\ MW}{2{,}472\ MW}\right)} = -0.31477$$

We then assumed this b to stay constant through 2030, giving us an equation we can use to project levelized cost in future years, as we know all other values, and have already made projections for any Q_t up to 2030.

$$C_t = C_{2008}\left(\frac{Q_t}{Q_{2008}}\right)^{(-0.31477)}$$

Now that we have calculated levelized cost, it is necessary to elaborate on the composition of operation & maintenance cost. Every year, regardless of the power generated by a wind turbine, there are various costs to keep the machine from breaking down and costs the operator of the wind farm must pay. Some of these costs are insurance, maintenance, administration, electricity, and rent, as they are in any type of business.

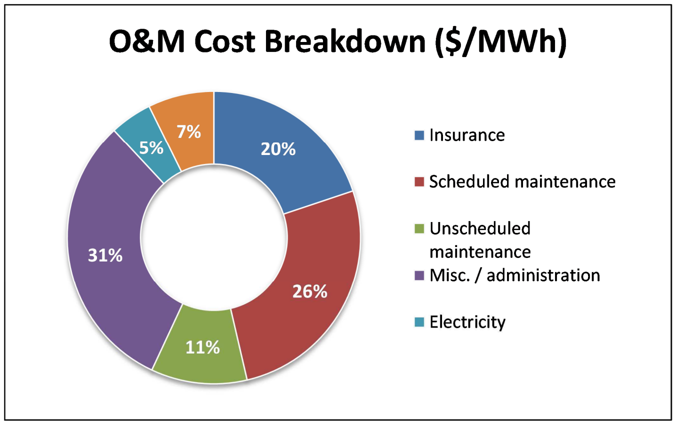

Figure 3: Operational & Maintenance Cost Breakdown
Source: Wind Power Monthly

For simplicity reasons, we have chosen to keep these costs constant throughout our projection, as it is beyond the scope of our research to predict the changing costs of all of these services and what net effects would be. Total cost is calculated by adding levelized cost and operational & maintenance costs. Thus, $19.60/MWh [3] has been added to the levelized cost calculated above for each year, to attain a total cost for each year up to 2030.

	Year	Total cost (5% Growth)	Total cost (10% Growth)	Total cost (15% Growth)
Projections	**2009**	1,465,656	1,446,846	1,429,128
	2010	1,445,935	1,409,159	1,375,010
	2011	1,426,515	1,372,585	1,323,220
	2012	1,407,392	1,337,093	1,273,660
	2013	1,388,559	1,302,650	1,226,232
	2014	1,370,014	1,269,224	1,180,846
	2015	1,351,751	1,236,786	1,137,413
	2016	1,333,767	1,205,307	1,095,849
	2017	1,316,056	1,174,759	1,056,074
	2018	1,298,616	1,145,113	1,018,011
	2019	1,281,441	1,116,344	981,586
	2020	1,264,529	1,088,424	946,729
	2021	1,247,873	1,061,330	913,372
	2022	1,231,472	1,035,037	881,451
	2023	1,215,321	1,009,521	850,903
	2024	1,199,416	984,758	821,671
	2025	1,183,753	960,728	793,696
	2026	1,168,329	937,408	766,925
	2027	1,153,140	914,777	741,307
	2028	1,138,182	892,815	716,791
	2029	1,123,453	871,502	693,330
	2030	1,108,947	850,819	670,879

Table 2: Projected Total Cost at 5%, 10% and 15% Growth

B) Revenue

The second factor included in computing the net profit for our model is the revenue. We projected the revenue that would be generated by the sale of electricity from the grid, between the years 2008 and 2030. For our model purposes regarding wind energy, we will compute the projected revenue for each year in our range from 2008 to 2030, using the projected electricity prices multiplied by the projected cumulative installed wind capacity in the United States.

We obtained the average electricity prices for the US from 1999 to 2008 from the Department of Energy [7]. We projected these values for price from 2008 to 2030 under two scenarios. The first scenario is a growth of the electricity prices at the rate of average U.S. inflation rate of 3% [2]. The second scenario considers the possibility of the electricity prices growing at a rate less than the average U.S. inflation rate. For simplicity purposes, we used 2% for this scenario. Below are the electricity price projections for the two scenarios mentioned from 2008 to 2030:

	Year	Total Electricity price ($/MW-year) 2% Growth	Total Electricity price ($/MW-year) 3% Growth
Projections	2009	802,381.0	810,247.4
	2010	818,428.6	834,554.9
	2011	834,797.2	859,591.5
	2012	851,493.1	885,379.3
	2013	868,523.0	911,940.6
	2014	885,893.4	939,298.9
	2015	903,611.3	967,477.8
	2016	921,683.5	996,502.2
	2017	940,117.2	1,026,397.2
	2018	958,919.5	1,057,189.1
	2019	978,097.9	1,088,904.8
	2020	997,659.9	1,121,572.0
	2021	1,017,613.1	1,155,219.1
	2022	1,037,965.3	1,189,875.7
	2023	1,058,724.6	1,225,572.0
	2024	1,079,899.1	1,262,339.1
	2025	1,101,497.1	1,300,209.3
	2026	1,123,527.1	1,339,215.6
	2027	1,145,997.6	1,379,392.0
	2028	1,168,917.5	1,420,773.8
	2029	1,192,295.9	1,463,397.0
	2030	1,216,141.8	1,507,298.9

Table 3: Projected Average Electricity Prices with 2% and 3% Growth

C) Results

Using the projections for cumulative installed wind capacity, electricity prices, O&M and levelized costs of wind energy for 1999 and 2008, we determined the years in which we would achieve positive net profits with the three cumulative installed wind capacity growth rates under the two electricity price growth rates. Hence our results present the six different intersections from the figure below, which summarizes our results graphically. The earliest year with a positive net profit is 2018.

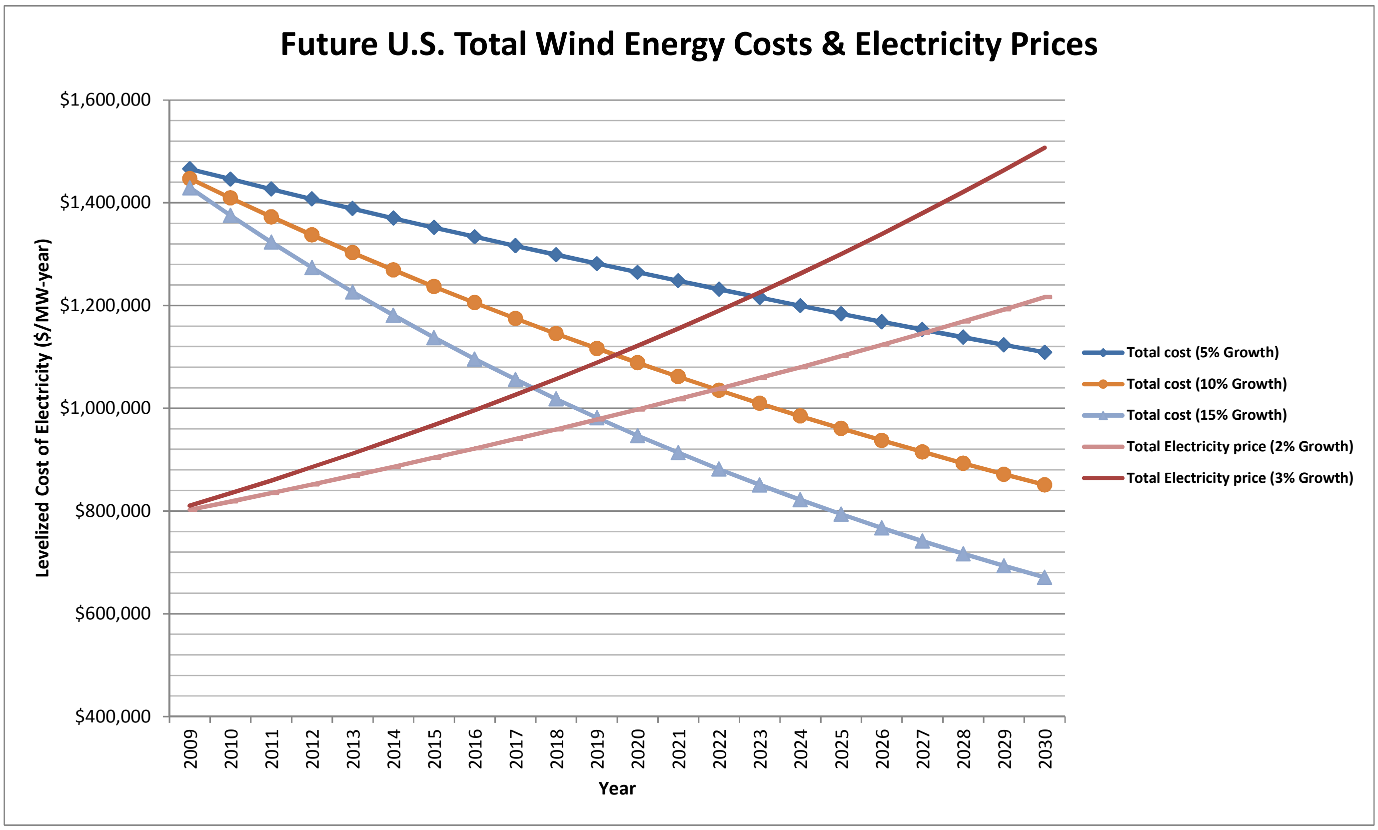

Figure 4: Future U.S. Total Wind Energy Costs & Electricity Prices

The summary of the above figure is shown in Table 4. Years in the table represent the first year under a given scenario that a positive net profit is observed.

		Capacity Growth		
		5%	**10%**	**15%**
Price Growth	**2%**	2028	2022	2020
	3%	2023	2020	2018

Table 4

SCENARIO A: Electricity Price growth rate is 3%

Year	Case 1.b 5% ($ in billions)			Case 2.b 10% ($ in billions)			Case 3.b 15% ($ in billions)		
	Revenue	Cost	Net Profit	Revenue	Cost	Net Profit	Revenue	Cost	Net Profit
2009	21.62	39.10	-17.49	22.65	40.44	-17.79	23.68	41.76	-18.08
2010	23.38	40.51	-17.13	25.66	43.33	-17.67	28.05	46.21	-18.16
2011	25.29	41.96	-16.68	29.07	46.42	-17.35	33.22	51.14	-17.92
2012	27.35	43.47	-16.12	32.94	49.74	-16.81	39.35	56.60	-17.26
2013	29.57	45.03	-15.46	37.32	53.31	-15.99	46.61	62.67	-16.06
2014	31.98	46.65	-14.67	42.28	57.13	-14.85	55.21	69.40	-14.20
2015	34.59	48.33	-13.74	47.91	61.24	-13.34	65.39	76.88	-11.49
2016	37.41	50.07	-12.66	54.28	65.65	-11.37	77.46	85.18	-7.72
2017	40.46	51.88	-11.42	61.50	70.39	-8.89	91.75	94.40	-2.65
2018	43.76	53.75	-9.99	69.68	75.47	-5.79	108.68	104.65	4.03
2019	47.32	55.69	-8.37	78.94	80.93	-1.99	128.73	116.04	12.69
2020	51.18	57.70	-6.52	89.44	86.80	2.64	152.48	128.71	23.77
2021	55.35	59.79	-4.44	101.34	93.10	8.24	180.61	142.80	37.81
2022	59.86	61.96	-2.09	114.82	99.88	14.94	213.93	158.48	55.45
2023	64.74	64.20	0.54	130.09	107.15	22.93	253.40	175.94	77.47
2024	70.02	66.53	3.49	147.39	114.98	32.41	300.16	195.37	104.78
2025	75.72	68.94	6.78	166.99	123.39	43.60	355.53	217.03	138.50
2026	81.90	71.45	10.45	189.20	132.43	56.77	421.13	241.17	179.96
2027	88.57	74.04	14.53	214.37	142.16	72.20	498.83	268.08	230.75
2028	95.79	76.74	19.05	242.88	152.62	90.25	590.86	298.10	292.77
2029	103.60	79.53	24.07	275.18	163.88	111.30	699.88	331.59	368.29
2030	112.04	82.43	29.61	311.78	175.99	135.79	829.01	368.98	460.03

SCENARIO B: Electricity Price growth rate is 2%

Year	Case 1.a 5% ($ in billions)			Case 2.a 10% ($ in billions)			Case 3.a 15% ($ in billions)		
	Revenue	Cost	Net Profit	Revenue	Cost	Net Profit	Revenue	Cost	Net Profit
2009	21.41	39.10	-17.70	22.43	40.44	-18.01	23.45	41.76	-18.31
2010	22.93	40.51	-17.58	25.16	43.33	-18.16	27.50	46.21	-18.70
2011	24.56	41.96	-17.41	28.23	46.42	-18.19	32.26	51.14	-18.88
2012	26.30	43.47	-17.17	31.68	49.74	-18.07	37.84	56.60	-18.76
2013	28.17	45.03	-16.86	35.54	53.31	-17.77	44.39	62.67	-18.28
2014	30.17	46.65	-16.49	39.88	57.13	-17.26	52.07	69.40	-17.34
2015	32.31	48.33	-16.02	44.74	61.24	-16.50	61.08	76.88	-15.80
2016	34.60	50.07	-15.47	50.20	65.65	-15.45	71.64	85.18	-13.54
2017	37.06	51.88	-14.82	56.33	70.39	-14.06	84.04	94.40	-10.37
2018	39.69	53.75	-14.06	63.20	75.47	-12.27	98.57	104.65	-6.07
2019	42.51	55.69	-13.18	70.91	80.93	-10.02	115.63	116.04	-0.41
2020	45.53	57.70	-12.18	79.56	86.80	-7.24	135.63	128.71	6.92
2021	48.76	59.79	-11.03	89.27	93.10	-3.83	159.10	142.80	16.30
2022	52.22	61.96	-9.74	100.16	99.88	0.28	186.62	158.48	28.14
2023	55.93	64.20	-8.27	112.38	107.15	5.22	218.91	175.94	42.97
2024	59.90	66.53	-6.63	126.09	114.98	11.11	256.78	195.37	61.40
2025	64.15	68.94	-4.79	141.47	123.39	18.08	301.20	217.03	84.17
2026	68.71	71.45	-2.74	158.73	132.43	26.29	353.31	241.17	112.14
2027	73.58	74.04	-0.46	178.09	142.16	35.93	414.43	268.08	146.35
2028	78.81	76.74	2.07	199.82	152.62	47.20	486.12	298.10	188.03
2029	84.40	79.53	4.87	224.20	163.88	60.32	570.22	331.59	238.63
2030	90.40	82.43	7.97	251.55	175.99	75.57	668.87	368.98	299.89

Table 5: Net Profit Scenarios

In addition to finding when we would achieve positive net profits using the price and capacity growth rates, we went further to create a data sensitivity table. Our data sensitivity table provides potential values of net profit for any year given different growth rates for the grid electricity prices as well as different growth rates for the cumulative installed wind capacities. We chose to include negative electricity price growth rates because it is possible that electricity prices get driven down significantly over time; so much so, that they would decline more than the 3% inflation that we cited above, causing the total growth rate to be negative. The table below is for the year 2020:

2020		**Electricity Price Growth Rate**							
		-2%	**-1%**	**0%**	**1%**	**2%**	**3%**	**4%**	**5%**
Cumulative Installed Wind Capacity Growth	**5%**	-29.54	-25.89	-21.81	-17.25	-12.18	-6.52	-0.23	6.76
	10%	-37.57	-31.19	-24.07	-16.11	-7.24	2.64	13.64	25.86
	15%	-44.79	-33.91	-21.76	-8.20	6.92	23.77	42.51	63.35
	20%	-48.56	-30.44	-10.19	12.41	37.61	65.69	96.92	131.65
	25%	-44.39	-14.81	18.24	55.13	96.26	142.08	193.06	249.73
	30%	-24.95	22.39	75.30	134.37	200.22	273.58	355.20	445.93
	35%	21.09	95.56	178.78	271.68	375.26	490.64	619.02	761.72
	40%	110.84	226.05	354.81	498.53	658.79	837.30	1,035.92	1,256.70

Table 6: Data Sensitivity Analysis for 2020

As we can see above, if we had a 10% growth rate for the wind capacity and a 2% growth for the electricity price, we would have negative net profit, however with the same capacity growth rate, but a 3% growth for electricity price, we would have positive net profits.

This data sensitivity table, could be a very useful tool for policymakers regarding renewable energy, since they will be able to see the possible net profits of a selected year given certain capacity and price growth rates, and make renewable energy decisions based on this information.

These findings conclude the cost-benefit analysis for the implementation of wind energy, given different capacity growth rates which would result from an increase in wind energy in the total U.S. energy portfolio. Therefore, this analysis proposes to compute when, according to our projections, wind energy will be profitable given different scenarios due to price growth rates and capacity growth rates. This analysis therefore could be used by policy makers, environmentalists, and economists when seeking a greener solution to energy production that is still feasible economically and provides net profit.

D) Limitations

Our cost-benefit analysis results are not exhaustive because of several limitations regarding our research and assumptions. Our limitations can be classified under the headings of O&M costs, price growth rate and levelized cost of wind energy.

Realistically, operations & maintenance costs would not stay constant for 20 years. However, due to the unclear future balance of the parts that make up this cost, we did not make broad assumptions for the change in these parts and kept this cost constant for our research purposes. If we were able to predict more realistic O&M costs (not a constant), it may have provided us with different results.

In addition, our model includes electricity price growth rates of an average inflation rate and another rate below this rate. Further research should be done to find the relation of average electricity prices and the average inflation rate of the U.S., and with these analyze possible scenarios where the growth rate of electricity prices is higher than the average inflation rate. However, our data sensitivity analysis tool does provide the possible net profits for a given year, for growth rates of electricity prices higher than 3%.

Lastly, we used 15 cents/kWh for our levelized cost for 2008 to be conservative with our assumptions. However, there would have been a shift in our findings if we had made an optimistic assumption and used the low end of the levelized cost range, which was 10 cents/kWh.

VI. Wind Energy Policy Considerations

While it is commonly agreed upon that renewable energy sources will be important in the future and should start being seriously considered and implemented now, it is also recognized that wind power is very expensive, at least initially, to develop. As such, both U.S. national and state government legislation is necessary to promote further penetration of wind energy in the U.S. market. We will now expound briefly on a few of the more effective and prominent pieces of wind energy legislation.

First, the American Recovery and Reinvestment Act (ARRA) of 2009 more than doubled the amount of wind power generation seen by 2012 than would have existed otherwise. Immediately following the recession in 2008, which saw a large decrease in wind energy prospects, the ARRA was an important piece of legislation that helped to keep wind energy on track.

Renewable Portfolio Standards (RPS) are policies that require a minimum percentage of energy sold in a state to come from renewable resources. Because RPS's are established at the state level, they vary to a vast degree by various factors, including both type of renewable sources required and the amount required, of both each type of source and total. As of 2008, 27 states had RPS's in place. Six additional states had voluntary rather than compulsory programs along similar lines. With full compliance to Renewable Portfolio Standards, significant increases in the energy generated by renewable resources would be possible.

One of the strongest incentives for wind power investment is the Federal Renewable Electricity Production Tax Credit, or PTC, which provides a $19 tax credit for every megawatt-hour of electricity generated in the first 10 years of life for a private or investor-owned renewable energy product brought online through the end of 2008. Due to changes in the Emergency

Economic Stabilization Act of 2008 and the ARRA, the PTC for wind was extended through 2012, meaning that the PTC will be granted for wind turbines and wind farms through 2012. As can be seen in the chart below, the PTC significantly diminishes the cost of wind energy making it much more attractive to potential investors.

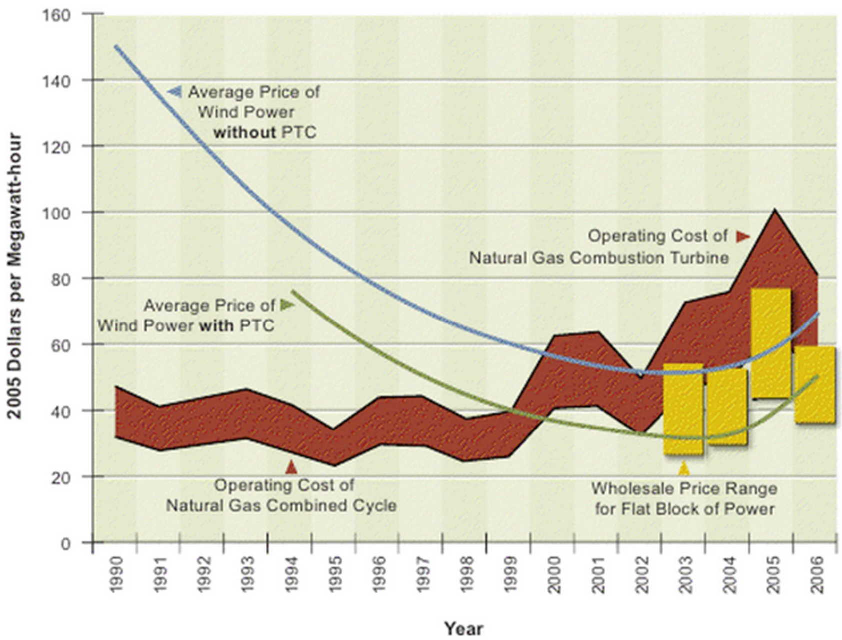

Figure 5: The addition of PTCs have historically decreased the price of wind energy over time
Source: Committee on America's Energy Future

Overall, due to the expense of wind power, consistent policies and legislation will be vital to the continued implementation of wind power facilities. The current policies are a good start, but stable government support for wind development will continue to be important in the coming years.

VII. Environmental Impacts of Wind Energy Implementation

There are several advantages from an environmental standpoint to incorporating more wind energy into the overall portfolio. The impacts that the following section concentrates on are related to the use of wind energy as a means to reduce carbon emissions that result from using other sources of energy, as well as wind energy's ability to potentially slow the effect of greenhouse gas emissions and postpone the rapid process of global climate warming. In addition, the section discusses the prospect of increased human health due to these reduced emissions of greenhouse gases (GHGs) in the atmosphere. There is also a huge impact on the amount of water conservation that occurs as a result of increasing the use of wind energy for generation.

Currently, CO_2 emissions in the United States are upwards of 6 billion metric tons produced annually, for which 39% is CO_2 emitted as a result of burning fossil fuels [4]. Research has been conducted by the U.S. Department of Energy that acknowledges that if 20% of the energy portfolio were wind energy, this could prevent the emissions of 825 million metric tons of CO_2 that would annually be released into the atmosphere from now until 2030 [4]. The main benefit of wind energy in terms of its ability to reduce carbon dioxide emissions is the fact that 1.5MW produced by a wind turbine is capable of displacing 2,700 metric tons of CO_2 per year as compared with the current U.S. average utility mix [DOE]. This is a sizable portion of CO_2 that could be displaced by wind energy sources, which only generates very minimal emissions of CO_2. Wind energy having such a huge environmental impact in terms of its ability to mitigate the emission of CO_2 because it can replace a portion of the energy provided by fossil fuels which are the cause of these emissions is monumental and lends credibility to the discussion of increasing the wind energy production in the total energy portfolio. The capability of wind energy to reduce carbon emissions is also fundamental in terms of acting as a temporary solution to mitigating the rapidly occurring process of global warming, because it will significantly reduce the emission of GHGs which are making the process of global warming more expedient. Additionally, wind energy use does not generate other pollutants such as nitrogen oxide, sulfur dioxide, and mercury, which also contributes to the overall health of the population because the air is cleaner as a result of this renewable energy source. Wind energy provides a zero emissions energy generation solution to an ever increasing process toward global climate warming and CO_2 emissions [4].

The U.S. relies heavily on the water supply, and demand for water is high as competition for water resources increases. As a result of this increased need of water, more electricity is needed to expand the water services supply. This being the case, it is important to evaluate the environmental impacts that wind energy has from a water conservation standpoint. Wind energy use does not require the significant level of water use that other energy sources require for generation. Wind energy sources can also contribute to energy production that will service water collection systems and other important systems for the use of water resources. Studies have been done in the Western United States to quantify what effect different wind energy capacity amounts will serve to increase water savings. Wind energy production of 1200, 3000, and 4000 MW equate to 3.15, 7.88, and 10.51 billion gallons of water saved [4]. Therefore, the increased use of wind energy in the portfolio not only provides a means of generating energy production to assist in the retrieval of water resources, but also its use results in significant water conservation.

VIII. Conclusion

The model created for purposes of exploring the profitability of increasing the capacity of wind energy in the total U.S. energy portfolio was all encompassing. It indicated that there would be net profits due to the incorporation of set levels of wind energy as soon as 2018 under the 15% capacity growth rate and 3% total energy price growth rate scenario. The latest year considered in the analysis that included a realization of net benefits in terms of wind energy profitability is 2028, under the 5% capacity growth rate the 2% total energy price growth rate. The analysis was significant in terms of proving the economic feasibility of increasing wind energy. Other considerations to be taken into account surrounding the proposal to increase wind energy are the environmental impacts that the increase will have, including but not limited to the reduction of CO_2 emissions which result in cleaner air overall as well as help to mitigate the pending global warming dilemma by reducing the level of GHGs in the atmosphere. Additionally, wind energy generation also has a beneficial impact on water conservation. Government legislation is also a crucial aspect of the continued development, success, and profitability of wind energy because it provides incentives to investors who might otherwise be uninterested in such expensive endeavors. The conclusion following all of this research, analysis, and computation is that wind energy, although very expensive to implement, does have great potential for a recognizable level of profitability and is a relatively environmentally sound form of energy generation.

IX. Acknowledgements

We as a group would like to thank Professor Tolley and Professor Berry for their instruction throughout the quarter. We really enjoyed taking this class and the material presented throughout the course. The guest lecturers were very accomplished, and their insights provided us with professional expertise and perspectives regarding the current state of the energy market. We enjoyed the process of completing this project, and found the research very interesting. The analytical component of the project helped us to flex our modeling and cost-benefit analysis skills as a means of using them for practical application for a discussion of the future potential for wind energy as a renewable generation source. We would also like to thank our teaching assistant for the course, Jing Wu, for being present throughout the process. It is with our sincerest gratitude that we have finished this course.

X. Bibliography

[1] Bhandari, Ramchandra, and Ingo Stadler. *Grid Parity Analysis of Solar Photovoltaic Systems in Germany Using Experience Curves.* Germany: Institute for Electrical Engineering, Cologne University of Applied Sciences, 2009. ScienceDirect. 20 Nov. 2012. <http://www.sciencedirect.com/science/article/pii/S0038092X0900125X>.

[2] "Long Term U.S. Inflation." Inflation Data. Nov. 2012. 28 Nov. 2012. <http://inflationdata.com/inflation/inflation_rate/long_term_inflation.asp>.

[3] Milborrow, David. "Breaking down the Cost of Wind Turbine Maintenance." Wind Power Monthly. 15 June 2010. Web. 29 Nov. 2012. <http://www.windpowermonthly.com/news/1010136/Breaking-down-cost-wind-turbine-maintenance/>.

[4] United States of America. Department of Energy. *20% Wind Energy by 2030, Increasing Wind Energy's Contribution to U.S. Electricity Supply.* July 2008.

[5] United States of America. Department of Energy. *Wind Powering America - Installed Wind Capacity*. 8 Nov. 2012. 28 Nov. 2012. <http://www.windpoweringamerica.gov/wind_installed_capacity.asp>.

[6] United States of America. Department of Energy. *Wind Turbines*. 16 Apr. 2012. 28 Nov. 2012. <http://www1.eere.energy.gov/tribalenergy/guide/wind_turbines.html>.

[7] United States of America. U.S. Energy Information Administration. *Average Price by State by Provider*. 27 Nov. 2012. <http://www.eia.gov/electricity/data/state/>.

[8] Committee on America's Energy Future, and National Academy of Sciences. *America's Energy Future Technology and Transformation*. Washington, D.C.: National Academies, 2009.

XI. Appendix

	Year	Growth 5%	Growth 10%	Growth 15%
		Cumulative Installed Capacity (MW)		
	2008	25,410	25,410	25,410
Projections	2009	26,681	27,951	29,222
	2010	28,015	30,746	33,605
	2011	29,415	33,821	38,645
	2012	30,886	37,203	44,442
	2013	32,430	40,923	51,109
	2014	34,052	45,015	58,775
	2015	35,754	49,517	67,591
	2016	37,542	54,469	77,730
	2017	39,419	59,916	89,389
	2018	41,390	65,907	102,798
	2019	43,460	72,498	118,217
	2020	45,633	79,748	135,950
	2021	47,914	87,722	156,343
	2022	50,310	96,495	179,794
	2023	52,826	106,144	206,763
	2024	55,467	116,758	237,778
	2025	58,240	128,434	273,444
	2026	61,152	141,278	314,461
	2027	64,210	155,406	361,630
	2028	67,420	170,946	415,874
	2029	70,791	188,041	478,256
	2030	74,331	206,845	549,994

5 % Growth

	Year	Ct ($/MW-year) 5%	O&M	Total cost (5% Growth)
Projections	**2009**	1,293,974	171,681	1,465,656
	2010	1,274,254	171,681	1,445,935
	2011	1,254,834	171,681	1,426,515
	2012	1,235,711	171,681	1,407,392
	2013	1,216,878	171,681	1,388,559
	2014	1,198,333	171,681	1,370,014
	2015	1,180,070	171,681	1,351,751
	2016	1,162,086	171,681	1,333,767
	2017	1,144,375	171,681	1,316,056
	2018	1,126,935	171,681	1,298,616
	2019	1,109,760	171,681	1,281,441
	2020	1,092,848	171,681	1,264,529
	2021	1,076,192	171,681	1,247,873
	2022	1,059,791	171,681	1,231,472
	2023	1,043,640	171,681	1,215,321
	2024	1,027,735	171,681	1,199,416
	2025	1,012,072	171,681	1,183,753
	2026	996,648	171,681	1,168,329
	2027	981,459	171,681	1,153,140
	2028	966,501	171,681	1,138,182
	2029	951,772	171,681	1,123,453
	2030	937,266	171,681	1,108,947

10 % Growth

	Year	Ct ($/MW-year) 10%	O&M	Total cost (10% Growth)
Projections	**2009**	1,275,165	171,681	1,446,846
	2010	1,237,478	171,681	1,409,159
	2011	1,200,904	171,681	1,372,585
	2012	1,165,412	171,681	1,337,093
	2013	1,130,969	171,681	1,302,650
	2014	1,097,543	171,681	1,269,224
	2015	1,065,105	171,681	1,236,786
	2016	1,033,626	171,681	1,205,307
	2017	1,003,078	171,681	1,174,759
	2018	973,432	171,681	1,145,113
	2019	944,663	171,681	1,116,344
	2020	916,743	171,681	1,088,424
	2021	889,649	171,681	1,061,330
	2022	863,356	171,681	1,035,037
	2023	837,839	171,681	1,009,521
	2024	813,077	171,681	984,758
	2025	789,047	171,681	960,728
	2026	765,727	171,681	937,408
	2027	743,096	171,681	914,777
	2028	721,134	171,681	892,815
	2029	699,821	171,681	871,502
	2030	679,138	171,681	850,819

15 % Growth

	Year	Ct ($/MW-year) 15%	O&M	Total cost (15% Growth)
Projections	**2009**	1,257,447	171,681	1,429,128
	2010	1,203,329	171,681	1,375,010
	2011	1,151,539	171,681	1,323,220
	2012	1,101,979	171,681	1,273,660
	2013	1,054,551	171,681	1,226,232
	2014	1,009,165	171,681	1,180,846
	2015	965,732	171,681	1,137,413
	2016	924,168	171,681	1,095,849
	2017	884,393	171,681	1,056,074
	2018	846,330	171,681	1,018,011
	2019	809,905	171,681	981,586
	2020	775,048	171,681	946,729
	2021	741,691	171,681	913,372
	2022	709,770	171,681	881,451
	2023	679,222	171,681	850,903
	2024	649,990	171,681	821,671
	2025	622,015	171,681	793,696
	2026	595,244	171,681	766,925
	2027	569,626	171,681	741,307
	2028	545,110	171,681	716,791
	2029	521,649	171,681	693,330
	2030	499,198	171,681	670,879

2015		Electricity Price Growth Rate							
		-2%	-1%	0%	1%	2%	3%	4%	5%
Cumulative Installed Wind Capacity Growth	5%	-23.91	-22.12	-20.20	-18.18	-16.02	-13.74	-11.32	-8.75
	10%	-27.43	-24.94	-22.29	-19.48	-16.50	-13.34	-9.98	-6.43
	15%	-30.72	-27.32	-23.71	-19.87	-15.80	-11.49	-6.91	-2.06
	20%	-33.51	-28.93	-24.07	-18.90	-13.42	-7.60	-1.44	5.09
	25%	-35.43	-29.34	-22.86	-15.99	-8.69	-0.95	7.25	15.94
	30%	-36.02	-28.00	-19.48	-10.43	-0.83	9.36	20.15	31.58
	35%	-34.69	-24.25	-13.15	-1.37	11.14	24.40	38.46	53.35
	40%	-30.76	-17.29	-2.97	12.23	28.36	45.46	63.60	82.81

2018		Electricity Price Growth Rate							
		-2%	-1%	0%	1%	2%	3%	4%	5%
Cumulative Installed Wind Capacity Growth	5%	-27.15	-24.30	-21.19	-17.78	-14.06	-9.99	-5.55	-0.71
	10%	-33.11	-28.58	-23.63	-18.20	-12.27	-5.79	1.27	8.98
	15%	-38.58	-31.52	-23.78	-15.32	-6.07	4.03	15.05	27.07
	20%	-42.35	-31.54	-19.71	-6.76	7.40	22.86	39.73	58.13
	25%	-42.57	-26.32	-8.52	10.96	32.25	55.50	80.88	108.56
	30%	-36.53	-12.48	13.87	42.70	74.22	108.64	146.21	187.17
	35%	-20.36	14.73	53.16	95.21	141.18	191.38	246.17	305.92
	40%	11.33	61.81	117.09	177.59	243.71	315.94	394.76	480.71

2025		Electricity Price Growth Rate							
		-2%	-1%	0%	1%	2%	3%	4%	5%
Cumulative Installed Wind Capacity Growth	5%	-36.44	-30.32	-23.13	-14.68	-4.79	6.78	20.30	36.07
	10%	-51.73	-38.23	-22.36	-3.74	18.08	43.60	73.41	108.18
	15%	-64.45	-35.71	-1.93	37.72	84.17	138.50	201.97	275.99
	20%	-61.46	-2.21	67.44	149.18	244.94	356.96	487.81	640.42
	25%	-13.35	105.27	244.68	408.28	599.97	824.20	1,086.11	1,391.58
	30%	139.67	370.72	642.29	960.97	1,334.35	1,771.13	2,281.31	2,876.33
	35%	511.73	950.60	1,466.44	2,071.78	2,781.01	3,610.68	4,579.76	5,709.99
	40%	1,310.97	2,125.37	3,082.61	4,205.91	5,522.01	7,061.61	8,859.91	10,957.25

2027

Cumulative Installed Wind Capacity Growth	Electricity Price Growth Rate							
	-2%	-1%	0%	1%	2%	3%	4%	5%
5%	-39.63	-32.31	-23.53	-13.02	-0.46	14.53	32.38	53.59
10%	-58.88	-41.16	-19.91	5.53	35.93	72.20	115.40	166.76
15%	-74.28	-33.05	16.40	75.60	146.35	230.75	331.27	450.78
20%	-62.84	29.71	140.72	273.62	432.44	621.91	847.56	1,115.83
25%	32.18	233.21	474.31	762.96	1,107.91	1,519.42	2,009.51	2,592.19
30%	336.50	760.04	1,268.00	1,876.14	2,602.90	3,469.90	4,502.44	5,730.05
35%	1,109.98	1,977.55	3,018.08	4,263.80	5,752.50	7,528.47	9,643.54	12,158.21
40%	2,863.28	4,594.67	6,671.24	9,157.29	12,128.26	15,672.54	19,893.54	24,912.02

2030

Cumulative Installed Wind Capacity Growth	Electricity Price Growth Rate							
	-2%	-1%	0%	1%	2%	3%	4%	5%
5%	-39.63	-32.31	-23.53	-13.02	-0.46	14.53	32.38	53.59
10%	-58.88	-41.16	-19.91	5.53	35.93	72.20	115.40	166.76
15%	-74.28	-33.05	16.40	75.60	146.35	230.75	331.27	450.78
20%	-62.84	29.71	140.72	273.62	432.44	621.91	847.56	1,115.83
25%	32.18	233.21	474.31	762.96	1,107.91	1,519.42	2,009.51	2,592.19
30%	336.50	760.04	1,268.00	1,876.14	2,602.90	3,469.90	4,502.44	5,730.05
35%	1,109.98	1,977.55	3,018.08	4,263.80	5,752.50	7,528.47	9,643.54	12,158.21
40%	2,863.28	4,594.67	6,671.24	9,157.29	12,128.26	15,672.54	19,893.54	24,912.02