Policy Recommendations to Develop Offshore Wind Power in the United States

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Table of Contents

I. Executive Summary……………………………………….…………3

II. Overview of Offshore Wind Power Industry…………………..…………4

III. Cost-Benefit Analysis……………………………………………………8

Economic Cost and Benefits…………………………………………..9

Social Externalities ……………………………………………………… 24

IV. Policies…………………………………………………………………… 28

Chinese Renewable Energy Policies...……………………………………… 28

U.S. and E.U. Policies ……………………………………………………. 31

V. Conclusion …………………………………………………………….36

VI. Appendices……………………………………………………………... 39

VII. References ……………………………………………………………….. 42

Executive Summary

Over the course of the past twenty years, many countries have begun to emphasize the necessity of generating a substantial wedge of their total energy consumption from renewable resources such as solar, wind, and hydro power. This policy trend has been taking place across nations in the European Union and in East Asia, including China. Recently, the American Wind Energy Association (AWEA), in conjunction with the United States Department of Energy, put forth the “20% Wind by 2030 Scenario” report, which advocated for a policy target that hinges on 3.6%, or 54 GW, of all American electricity being generated by off-shore wind farms . Additionally, the construction of offshore farms are seen as an excellent approach to harvesting wind energy in close proximity to major metropolitan areas, most of which are situated along America's coasts.

Despite the Department of Energy's policy targets and its benefits, the U.S. still lacks any operational large-scale offshore wind farms and most efforts to construct farms are limited. The cause for this lethargic growth of the offshore wind industry is the high capital costs and energy policies that do not sufficiently incentivize grid companies to guarantee a steady revenue stream post-construction.

However, the policy targets are not out of reach, as is demonstrated by the success of the mature European markets and the astronomical growth in the Chinese market**.** The primary differences between the American and other markets are the government policies used to provide necessary incentives to render offshore wind farms sufficiently profitable. Therefore, the purpose of our study is twofold: To analyze the feasibility of developing a strong American offshore wind

industry via a comprehensive cost and benefit analysis from both the business perspective and the societal perspective; and to examine the effects of existing policies from abroad on the profitability of offshore wind farms in the United States.

Overview of Offshore Wind Power Industry

Of all renewable energy technologies, wind energy has one of the most favorable combinations of resource and cost. Global wind resource is vast, and energy costs are cheaper than many other renewable technologies. Also, wind power emits no Carbon Dioxide or other harmful emissions that contribute to climate change, ground-level pollution or public health issues. Hence, wind energy can help meet multiple state and national goals, including reducing energy imports, reducing air pollution and greenhouse gas emissions which cause climate change by displacing fossil fueled power generation, and meeting renewable electricity standards.

According to the 2009 World Wind Energy Report, the worldwide capacity of wind-powered generators reached around 159,213 Megawatts, around 2% of total electricity consumption. Although wind power comprises a relatively small fraction of worldwide energy production, it is also the fastest-growing energy industry: the same report states that wind power capacity has consistently grown in the past five years with an average rate of 3%, which means that it has been doubling every three years.[1]

The main markets driving this significant growth are Asia, North America and Europe, each of which installed more than 10 GW of new wind capacity in 2009. In 2009 the world's largest market was China, which nearly doubling its wind generation capacity from 12.1 GW in 2008 to 25.1 GW at the end of 2009 with new capacity additions of 13 GW. There are 85 countries participating in wind power production, with more than 10,080 wind farms in operation.

The United States is the leading producer of wind energy, followed by China and Germany. In 2009, US installed an additional 9,922 Megawatts, or 26.5% of total production of wind power, achieving a total capacity of 35,159 Megawatts. This was the second largest wind power installation of the year, only to be surpassed by China.[2]

Wind power industry is expected to maintain its high growth rate for the next decade. BTM Consult, one of the leading consultancy companies in wind power, predicted in its 2009 annual report that on the global level wind power capacity will continue to grow at an average growth rate 13.5% in the next five years, resulting in a total global capacity of 447GW by 2014. This report also expects that wind power will maintain an average growth rate of 12.1% in the following five year period as well, reaching a cumulative capacity of 1,000GW by 2019, and producing 8.4% of total electricity consumption.[3]

The global build rate of offshore wind has shown strong growth over the past few years. However, offshore wind capacity remains a minor fraction of world wind power industry. As of October 2010, 3.16GW, or 1.2% of total wind energy, is being produced offshore. Offshore wind turbines are operating in 10 European countries, with more than 830 wind turbines installed in 39 offshore wind farms in waters off Belgium, Denmark, Finland, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom. In addition, there are minor installations in China and Japan. Almost all of the 2300 MW of installed capacity has been built on shallow waters (less than 30 meters deep). [4]

As of September 2009, there were more than 100GW of offshore wind projects proposed or under development in Europe. Projections by BTM Consult show that in the medium term offshore wind capacity will reach a total of 75 GW worldwide by 2020. So far almost all deployment has taken place in Northern Europe, a situation expected to continue for another five years. Beyond 2015 a significant contribution will come from China, with the US making a more modest input.

Currently United States does not have any operating offshore wind power plants, but there have been a number of proposals for building offshore wind farms. About 20 projects representing more than 2,000 MW of capacity are in the planning and permitting process. Most of these activities are in the Northeast and Mid-Atlantic regions, although projects are being considered along the Great Lakes, the Gulf of Mexico, and the Pacific Coast, as well. The deep waters off the West Coast, however, pose a technology challenge for the near term.

Most notably, after 9 years in the permitting process, the Cape Wind project off of Massachusetts was offered the first commercial lease by the Department of Interior in April 2010. The Cape Wind project proposes America’s first offshore wind farm on Horseshoe Shoal in Nantucket Sound. This project plans to install 130 wind turbines to produce up to 420 megawatts of electricity, which will supply three quarters of electricity for the entire Nantucket, Cape Cod and Martha’s Vineyard area. The location of the project is apt considering that energy consumption is concentrated in coastal regions. Of the 48 contiguous states, 28 have a coastal boundary and those states consume 78 percent of the nation’s electricity, and many states have enough offshore wind potential to meet 100 percent of their electricity needs.[5]

When completed, the Cape Wind project will contribute to the US’s goal of expanding the wind power sector. The Department of Energy (DOE) issued a report in 2008 that found that the United States could produce 20 percent of its electricity from wind by 2030. To reach this level, 293 GW of wind energy would need to be added, including 50GW of offshore wind.

Offshore wind power has several notable advantages over onshore wind power. Onshore wind resources are usually built in large masses of empty land, usually far away from large cities. Therefore, onshore wind power usually involves large transmission costs to the population centers. On the other hand, most potential offshore wind sites are relatively close to major urban load centers where energy costs are high and land for onshore wind development is limited.

Moreover, offshore winds are generally stronger and more consistent than onshore wind. As a result, turbines can operate at their maximum capacity for a longer period of time, and the constancy reduces wear on wind turbines and reduces the need for maintenance or backup energy sources. Construction of wind turbines on the sea reduces a significant portion of construction costs, and the transportation of enormous equipments for the turbine is much easier on the sea. Therefore, it is possible to build wind turbines that have the capacity of around 5 MW, while most onshore wind turbines have a capacity ranging from 1.5 MW to 2.5 MW.

Most of the newly available offshore wind power sites are in deeper water, further from the coast. Therefore, in order to have a mature offshore industry, there must be further technological developments in the areas of foundations, access, wind farm electrics, transportation and erection. The technological challenges include the design of new turbines in the 5-10 MW bracket and the need for major improvements in the logistics of installation and operation & maintenance. In addition, it is important to better understand where the wind blows best; and ports will need to be expanded in order to handle huge turbines and the vessels that transport them; job-specific marine vessels will also need to be built.

The remaining challenge for offshore wind power is to make it competitive with traditional electricity generation technologies. This means that the cost of electricity will have to be reduced by some 30% over the next few years. This will require increased market penetration and public acceptance as well as improved technology. Finally, the project approval process needs to be made more efficient, with greater state and federal cooperation.[6]

However, some progress is already being made towards developing an offshore wind power industry. Google recently agreed to spend $200 million on a transmission system for offshore wind along the Mid-Atlantic coast, and Department of Interior Secretary, Ken Salazar, recently signed the nation's first offshore wind power lease at Cape Wind, paving the way for the initial steps in the development of a US offshore wind power industry.[7]

Cost-benefit Analysis

As stated earlier, there are no offshore wind farms in operation in the United States thus far and all the offshore wind projects are still staggering at proposal stage. The lagged growth of offshore wind power industry in the United States can be ascribed to several major reasons: offshore wind is a very costly energy source compared to the traditional fossil fuels; and the policies implemented by U.S. government is not adequate to offset the high cost and spark interest in the private sector.

A comprehensive cost and benefit analysis we are providing in our study will help policy makers to gauge the worthiness to develop offshore wind in the United States as well as identify the amount of subsidies from the government needed to make offshore wind business viable.

The analysis will start from quantifying the costs and benefits from the business perspective under the assumption of no government subsidy. Section 1 focus on the economic costs and benefits associated with the development of offshore wind. As will be presented in

Section 1, the benefits, from an offshore wind business owner's point of view, will solely come from the sales of electricity generated by wind, while the costs will include the initial capital cost to build a wind farm, annual operation and maintenance costs, etc.

Understanding that the adoption of offshore wind as a source for electricity will bring non-business related benefits and costs to the society as a whole, we find it is extremely important to address the social externalities associated with offshore wind. For example, in comparison with coal, wind power in general emits no carbon dioxide or other toxic gases. On the other hand, the existences of offshore wind turbines in the near-shore area might be deemed as visually unpleasant by the local residents. In Section 2, we will provide a quantitative examination of the quantifiable social externalities and a qualitative analysis on the uneasily quantifiable costs and benefits.

Section 1: Economic Cost and Benefits

Offshore wind projects are analyzed in terms of their initial installed capital cost (ICC) as well as their life-cycle costs, also known as the levelized cost of energy (LCOE). Cost projections of either type for the U.S. market are difficult because of the many regulatory and technical uncertainties and the lack of U.S. market experience. Although the European market is based on a more developed supporting infrastructure and substantially different regulatory, policy, and physical environments, preliminary analysis of that experience provides some potentially useful insight. As in the case of land-based projects, the ICC for offshore wind power has been increasing over time. Costs jumped approximately 55% between 2005 and 2007, leading to an estimated average capital investment of $4,250 per kWh for an offshore wind project in 2010. The wind turbine itself contributes 44% of this total. In general, capital costs are expected to increase with distance from land and water depth, and decrease as the size of a project increases, as a result of economies of scale. As the technology matures, prices are expected to decline.[8]

The LCOE calculations, or the cost of energy produced over the anticipated 20-year life of a project, are based on a range of factors, many of which are currently unknown and must be projected.

In our analysis of the economic cost and benefit, we will compare the LCOE with the average selling price of wind power to figure out the gap between cost and benefit in business terms.

1.1 Initial capital cost

Unlike the traditional fossil fuel plants, for the wind farms, 75% of the total cost for energy is related to the upfront costs such as the cost of turbines, installation, grid connection and so on.[9] Overall, wind power projects are a lot more capital-intensive than other energy sources. The rest of the section will analyze each cost component within the realm of capital cost and their respective evolving trends.

1.1.1 Cost of turbine

Most of the offshore wind turbine models currently in operation are derived from land-based wind turbine models. Despite the same basic functionalities, offshore turbine requires additional features such as counter-corrosion, tide-resistance, to cope with the severe oceanic conditions. Besides the add-on features, the sizes of offshore wind turbines also differ from the onshore models. Most of the offshore turbines being used in European countries fall into the range of 2.5MW to 3.5MW, as opposed to the dominating 1.5MW model in offshore wind farms.[10] Also the larger sizes of offshore wind turbines are well-supported by the considerable size and lifting capacities of marine shopping as opposed to land-based transportation.

Most of the offshore wind farm projects by far are located in the shallow water zones that are with less than 30-meter water depth. The only two deepwater offshore windmills are located in Norway and Italy and they are still at the experimental stage. The trend for the future is to tap into the deepwater areas, which provide higher wind speed with less aesthetic unpleasantness caused by turbines. A research report by the National Renewable Energy Laboratory pointed out that due to the extraordinary high cost of support structure and transmission line for deepwater projects, each individual offshore turbine located in the deepwater area must have the size of 5MW or bigger to be cost-effective.[11]

Based on the conditions mentioned above, we decided to create two cost projection models that are respectively pertinent to shallow water wind farms and deep water deep farms. In the shallow water model, we will use the 3MW turbine model that reflects the current industry standards. In the deep water model, for the reasons mentioned above, we will use the 5MW turbine model.

In terms of the actual cost of turbines, we are going to use the data from two different sources for the two models. L. Fingersh's wind turbine design cost and scaling model paper has a very detailed cost breakdown for offshore 3MW turbine denominated in 2005 dollar [See Appendix I]. This is the basis of our turbine cost estimate for the shallow water mode. On the other hand, W. Musial's future for offshore wind energy in the United States is one of the few literatures that estimate the cost on the cutting-edge 5MW deepwater turbine [See Appendix II]. We are going to use this source as the basis for our turbine cost estimate.

Another major factor, which must be included in our projections of offshore wind turbine cost, is the production learning curve. It is based on the fact that increased production volume results in improvements in manufacturing, assembly, and installation techniques, which in turn lower the per-unit costs. Higher volumes mean costs from suppliers are also reduced. The International Energy Agency estimates that learning curve cost reductions for wind turbines are 18% per doubling of installed capacity. In a 2002 study Milborrow determined using worldwide production data that wind turbine prices have been declining at a rate of 15.3%.[12] This same study indicates lower rates of 12.4% for an individual supplier. Milborrow forecasts that larger machines and improved production techniques will cause an onshore wind turbine's cost to fall by 15% for every doubling of global installed capacity – and historically doubling has occurred about every 2.88 years. Milborrow contends that if these trends continue, costs will fall about 40% by 2012. However, in the offshore wind power sector, due to the short industry history, we were not able to retrieve a price decline trend specifically pertinent to offshore wind turbines. Therefore, we decided to use the low end of the onshore wind technology learning curve, which is 10% price decrease every year, as the assumption for our base case. The high end of the onshore wind technology learning curve, which is a 15% price drop every year as predicted by Milborrow, will be adopted as the bull case in our study.

1.1.2 Support Structure

Present-day offshore wind power plants are located in very shallow water of 5 m to 12 m. Offshore wind development has been limited to waters shallower than 30 m in the North and Baltic Seas. At depths less than 30 m, the established monopile foundation technologies can be deployed without significant R&D effort.[13] For many European countries, such as Denmark, the Netherlands, Germany, and the United Kingdom, these shallow water sites appear to be abundant, and should allow offshore wind installations to proliferate rapidly in the near term. In the United States, approximately 500 MW of shallow water development is underway, but to date, no installations have been permitted.

In order to capture the abundant wind resources in deepwater areas, a more sophisticated subsea support structure needs to be developed to counter the severe oceanic conditions in the deepwater areas, such as extremely high wind speed, tides, and corrosion. A lot of research reports pointed out that the concept of floating platforms, which have been widely used in deepwater oil drilling, can be adopted for deepwater offshore windmills as well. Currently, there are only two prototype floating platforms in operation. The first one was designed by Blue H technology and started operation in 2008 to support a 0.8MW turbine in the sea close to Southeast Italy. It was then decommissioned one year later after completing a year of planned tests and data gathering. The other one, commissioned in September 2009, was the first floating support structure for large-capacity turbine. It was installed in the North Sea off of Norway with a 2.3MW turbine mounted on the platform. Since the current operational floating platforms are only in the experimental stage, it's hard for us to assume these technologies as the industry standard going forward. Also, because of the business confidentiality of these technology developers, we were not able to obtain detailed cost breakdown data pertinent to these technologies. Instead, we chose to look at the theoretical models proposed by researchers in academia. The currently available research reports mainly focused on two floating platform configurations, one designed by the National Renewable Energy Laboratory called NREL TLP concept and the other one designed under a European Union-funded study called Dutch Tri-Floater concept. Since the Dutch Tri-Floater concept was included as the conservative case in a cost analysis report done by NREL[14], we are going to cite the cost range provided by the paper, which is $2.88 to $6.50 million for one 5MW turbine. The major variable for the cost range was the steel price assumption. In the high estimate, the steel price was assumed to be $2/lb while in the low estimate, the steel price was assumed to be 1.1/lb. The midpoint of the range, $4.69

million, is going to be used as the baseline cost estimate for support structure in our model. Similar to the wind turbines, the cost of offshore platform will also experience a substantial learning curve once the mass commercial production starts. However, due to the lack of commercial production of this new technology, the precise estimation of the learning curve is not available yet. In our model, we assumed that it is the same as the learning of monopile structure.

1.1.3 Transmission system

Offshore wind farms require a special type of cable that transmits the electricity generated by the turbines to the on-shore grid system. Data for the shallow water model are retrieved from the NREL's Wind Turbine Design Cost and Scaling Model[15], which entails the assumption that the wind turbines are situated 5 miles from the shore with the water depth of 10 meters.

On the other hand, since there has been visually no wind farms in regular operation in the deepwater areas with water depth higher than 30 meters, the cost estimation for the deep water model based on W. Musial's (2004)[16] in our model is extremely rough. W. Musial pointed out that the costs of the transmission system for deepwater cases will be much higher due to the greater distance from the shore and greater oceanic turbulence that requires more durable cable materials. We are going to make our estimation based on the analysis done by W. Musial (2004), which is one of the few literature that gives specific forecast on the cost of deepwater projects. Taking into account the annual learning curve of 10% and the inflation adjustment of 150%, we calculated the cost of transmission system for 2010 installation projects based on the 2006 installation figure provided by W. Musial, which is $1,942,000 for a 5MW turbine with assumed water depth 600 feet.

1.1.4 Miscellaneous cost

The miscellaneous part of the initial capital cost includes everything else that needs upfront investment and doesn't belong to the turbine, support structure or transmission system. In breaking down the miscellaneous cost, we follow the guideline provided by the L. Fingersh (2006), which offers detailed formulas to calculate every single cost component (the multiplier factors in the formulas are all denominated in 2003 dollars, so inflation adjustment is needed in order to calculate the actual costs for projects that are installed in 2010. The inflation adjustment rules also follow the standards given by L. Fingersh (2006). The miscellaneous initial capital cost in our model includes:

1. *Transportation*: there are two elements of transporting There are two elements of transporting an offshore wind turbine. One element is to get the turbine components to the port staging and assembly area. The second is to get the assembled turbine to the installation site. This second of these cost elements is covered in the offshore installation cost

Offshore transportation cost factor $/kW = 1.581E-5 * machine rating 2- 0.0375 * machine rating + 54.7

Offshore transportation cost = machine rating * cost factor above

2. *Port and staging equipment*: Offshore wind installations require unique facilities to install and maintain operation. Special ships and barges are needed for installing piles, setting towers and turbines, laying underwater electrical lines, and providing ongoing servicing.

Port and staging equipment = 20 * machine rating

3. *Offshore Turbine Installation*

Offshore turbine installation = 100 * machine rating

4. *Offshore permits, engineering, and site assessment*

Offshore electrical interface and connection cost = 260 * machine rating

5. *Personnel access equipment: Wind turbines located offshore must be accessed from marine vessels, small boats, or helicopters for servicing.*

Offshore permits, engineering, and site assessment cost = 37 * machine rating

6. *Scour protection*

Personal access equipment = $60,000 /turbine (regardless of turbine rating)

1.2 Variable cost--Operation and Maintenance

After reviewing the most current literature on the O&M cost of offshore, we found that ￡16/MWh with is the most commonly used estimation for O&M cost. Therefore, in our models, we are also going to adopt this convention. The conversion from British pound to US dollar is based on the exchange rate as of December 6th 2010.

1.3 Discount factor—financing cost

In order to calculate the LCOE (Levelized Cost of Energy), the initial capital cost number needs to be annualized over the life expectancy of the projects, which in our model is assumed to be 20 years. According to the annuity formula, the annualized capital cost is calculated as such: initial capital cost/ [Σ1/(1+r)t] (t denotes the number of years and r denotes the discount rate).

The challenge for now is figure out the discount rate, which is the same as the financing cost for our projects. The significant part of the financing cost is based on the perception of financial risk and project uncertainties. These risk perceptions could potentially be lowered through research on virtually all of the factors that make up the LCOE for offshore wind, but the larger impacts will come from confidence built on deployment experience.

Project risk can be broken down into the uncertainty surrounding regulatory and permitting issues, the risks associated with construction and installation, and the operational risks that are associated with accurate energy production and long-term reliability. Risk and uncertainty may dissipate as the industry matures, but today the process remains immature. Risk reduction can have as big of an impact on the LCOE cost of an offshore wind project as the reduction in capital expenses.

Due to the large variance in the regulatory environments and operational profiles of offshore wind projects within the United States, it's hard for us to pin down one figure that perfectly represents the financing cost for offshore wind projects across the nation. Instead, we chose to narrow down to a range of 7% to 25% for the financing cost based on the disclosure in the research report. A 7% discount rate is commonly used by the U.S. Department of Energy (DOE) as reference for the comparison of renewable energy generation technologies; the California Energy Commission (2003) uses a 16% discount rate as a standard assumption for merchant (nonutility) project developers. According to NREL conversations with private equity financiers, a 100% equity investment in renewable energy technologies with no operational history in the United States requires a return on equity between 25% and 35%. A discount rate greater than 25% is likely to be cost-prohibitive. [17]

In our model, we use 25% as the financing cost in the most conservative case and 7% in the most optimistic case.

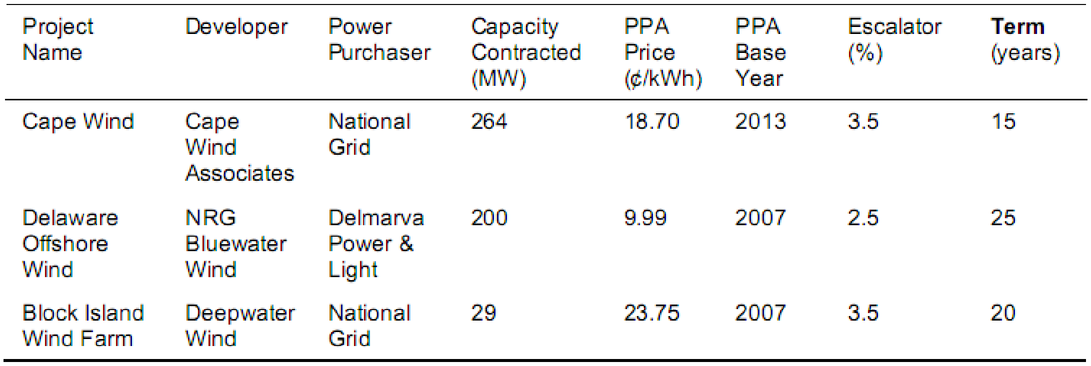
1.4 Capacity factor

The capacity factor (CF) of wind power is the ratio of average delivered power to theoretical maximum power. Although geographical location determines in great part the capacity factor of a wind farm, it is also a matter of turbine design. Indeed, a large rotor combined with a small generator will take advantage of just about any wind and achieve an artificially high CF, obviously at the cost of a low yearly energy output. Most of the literature on capacity factors is in fact composed of studies trying to either identify optimal turbine designs for particular places or create different sorts of computational models with wind speed as a variable input to predict capacity factor. However, N. Boccard pointed out that there is a significant gap between estimated value and realized value for wind capacity factor. While 35% is the capacity factor number used by the majority of the cost estimation models in the literature, the average realized capacity factor of European wind farms was only 21% from 2003 to 2008. [18]According to NREL's 2009 wind technology overview, the actual realized capacity factor for U.S. wind farms on average was 24% in 1999, 34% in 2008 and back to 30% in 2009. Despite the fact that capacity factor should increase over time due to the improved technology, the actual capacity factor contained within the range of 20% to 35% over the past two decades. In our model, we are going to use the 20% capacity factor as the baseline and 35% as the bull case. A sensitivity table is going to be run to test how the fluctuation of capacity factor affects the costs of wind.

1.5 Summary of economic cost-benefit analysis

After inputting all the aforementioned variables in our model, we figured out the Levelized Cost of Energy for both the shallow water and deep water models. Comparing the cost of energy for wind against the sales price of electricity generated by wind, we can get a good picture whether the offshore wind power industry is profitable by itself. The table 1.0 presents the sale price of wind power contracted between the proposed offshore wind projects and the U.S. government. The costs that we calculated in the bull case of the shallow water model were well below the sales price disclosed by the Power Price Agreements. That is to say, if cost control is done properly that all the variables can meet the targets as we set in the bull case, then offshore wind is a quite profitable industry. However, in all other cases of our model, we see the costs overrun the sales price, especially in the deepwater models where initial capital investment is a lot more intensive than shallow water models In the next section, we are going to look into the social externalities associated with the built of offshore wind farms, particularly the reduction of carbon emission.

Table 1.0: Announced Power Price Agreement (PPA) for U.S. projects under Development



Project Name	Developer	Power Purchaser	Capacity Contracted (MW)	PPA Price (¢/kWh)	PPA Base Year	Escalator (%)	**Term** (years)
Cape Wind	Cape Wind Associates	National Grid	264	18.70	2013	3.5	15
Delaware Offshore Wind	NRG Bluewater Wind	Delmarva Power & Light	200	9.99	2007	2.5	25
Block Island Wind Farm	Deepwater Wind	National Grid	29	23.75	2007	3.5	20

Shallow Water Wind Cost of Energy Estimate Base Case (Unit:$, unless ot

Assumptions	
Turbine Size (MW)	3
Technology learning curve:	10%
Water Depth	<30m
Support Structure	Monopile
Year of Installation	2010
Life Expectancy of the project (years)	20
Capacity Factor	20%
Financing cost	25%

Breakdown of Initial Capital Cost	
Turbine Capital Cost [1]	2,655,237
Support Structure	1,096,343
Electrical transmission [2]	911,323
Miscellaneous (including all the following items)	1,248,463
Transportation	276,546
Port and staging equipment	72,827
Turbine installation	365,120
Permits, Engineering, Site Assessment	117,114
Personal access equipment	62,986
Scour protection	200,767
Surety bond (De-commissioning, 3% of Initial Cost of Capital)	173,210
Initial Capital Cost	5,911,365

Levelized Cost of Energy (LCOE)

	2010	*2015*	*2020*	*2025*	*2030*
Annualized ICC	1,495,078.39	1,495,078.39	1,495,078.39	1,495,078.39	1,495,078.39
Annual O&M Cost [3]	63,072.00	37,243.39	21,991.85	12,985.97	7,668.08
Annual Energy Production (MWh)	5256	5256	5256	5256	5256
LCOE ($/KWh)	0.2965	0.2915	0.2886	0.2869	0.2859

Note: 1. Original number in L. Fingersh's paper was $2,698,000 in 2005 dollar. Inflation and learning curve adjustments have been made
2.Assume the distance from the shore is 5 miles and the water depth is 10 m
3. Assume the O&M cost is $12/MWh in 2010

Shallow Water Wind Cost of Energy Estimate Bull Case (Unit:$, unless otherwise n

Assumptions	
Turbine Size (MW)	3
Technology learning curve:	15%
Water Depth	<30m
Support Structure	Monopile
Year of Installation	2010
Life Expectancy of the project (years)	20
Capacity Factor	35%
Financing cost	7%

Breakdown of Initial Capital Cost	
Turbine Capital Cost [1]	2,112,559
Support Structure	872,272
Electrical transmission [2]	725,067
Miscellaneous (including all the following items)	1,009,299
Transportation	220,026
Port and staging equipment	57,943
Turbine installation	290,496
Permits, Engineering, Site Assessment	93,178
Personal access equipment	50,113
Scour protection	159,734
Surety bond (De-commissioning, 3% of Initial Cost of Capital)	137,810
Initial Capital Cost	4,719,198

Levelized Cost of Energy (LCOE)					
	2010	*2015*	*2020*	*2025*	*2030*
Annualized ICC	445,458.86	445,458.86	445,458.86	445,458.86	445,458.86
Annual O&M Cost [3]	110,376.00	48,974.42	21,730.21	9,641.81	4,278.12
Annual Energy Production (MWh)	9198	9198	9198	9198	9198
LCOE ($/KWh)	0.0604	0.0538	0.0508	0.0495	0.0489

Note: 1. Original number in L. Fingersh's paper was $2,698,000 in 2005 dollar. Inflation and learning curve adjustments have been made

2.Assume the distance from the shore is 5 miles and the water depth is 10 m

3. Assume the O&M cost is $12/MWh in 2010

Deep Water Wind Cost of Energy Estimate Base Case (Unit:$, unless otherwise

Assumptions	
Turbine Size (MW)	5
Technology learning curve:	10%
Water Depth	>30m
Support Structure	Floating
Year of Installation	2010
Life Expectancy of the project (years)	20
Capacity Factor	20%
Financing cost	25%

Breakdown of Initial Capital Cost	
Turbine Capital Cost [1]	3,333,611
Support Structure	4,527,090
Electrical transmission [2]	1,911,219
Miscellaneous (including all the following items)	7,250,625
Transportation	1,053,750
Port and staging equipment	277,500
Turbine installation	1,391,250
Permits, Engineering, Site Assessment	446,250
Personal access equipment	240,000
Scour protection	765,000
Surety bond (De-commissioning, 3% of Initial Cost of Capital)	660,000
Initial Capital Cost	25,533,818

Levelized Cost of Energy (LCOE)					
	2010	*2015*	*2020*	*2025*	*2030*
Annualized ICC	6,457,909.22	6,457,909.22	6,457,909.22	6,457,909.22	6,457,909.22
Annual O&M Cost [3]	105,120.00	62,072.31	36,653.08	21,643.28	12,780.14
Annual Energy Production (MWh)	8760	8760	8760	8760	8760
LCOE ($/KWh)	0.7492	0.7443	0.7414	0.7397	0.7387

Note: 1. Original number in W. Musial 2004 report was $3,387,300. learning curve and inflationg adjustments are made

2. Based on the 2006 projection given by W. Musial after adjusting for inflation and learning curve; assuming the water depth is 600

3. Assume the O&M cost is $12/MWh in 2010

Deep Water Wind Cost of Energy Estimate Base Case (Unit:$, unless otherwise noted)

Assumptions	
Turbine Size (MW)	5
Technology learning curve:	15%
Water Depth	>30m
Support Structure	Floating
Year of Installation	2010
Life Expectancy of the project (years)	20
Capacity Factor	35%
Financing cost	7%

Breakdown of Initial Capital Cost	
Turbine Capital Cost [1]	3,333,611
Support Structure	4,527,090
Electrical transmission	1,520,604
Miscellaneous (including all the following items)	7,250,625
Transportation	1,053,750
Port and staging equipment	277,500
Turbine installation	1,391,250
Permits, Engineering, Site Assessment	446,250
Personal access equipment	240,000
Scour protection	765,000
Surety bond (De-commissioning, 3% of Initial Cost of Capital)	660,000
Initial Capital Cost	25,533,818

Levelized Cost of Energy (LCOE)					
	2010	*2015*	*2020*	*2025*	*2030*
Annualized ICC	2,410,211.82	2,410,211.82	2,410,211.82	2,410,211.82	2,410,211.82
Annual O&M Cost [3]	183,960.00	81,624.03	36,217.02	16,069.68	7,130.20
Annual Energy Production (MWh)	15330	15330	15330	15330	15330
LCOE ($/KWh)	0.1692	0.1625	0.1596	0.1583	0.1577

Note: 1. Original number in W. Musial 2004 report was $3,387,300. learning curve and inflationg adjustments are made

2. Based on the 2006 projection given by W. Musial after adjusting for inflation and learning curve; assuming the water depth is 600 feet

3. Assume the O&M cost is $12/MWh in 2010

Section 2: Social externalities

2.1 Impacts on carbon emission

Another frequently used argument for the need to develop a wind-energy industry is the extent to which it can cut back carbon emissions. However there is some debate on this topic, and some experts' contest that after the emissions associated with constructing and maintaining an offshore wind-farm the decrease in emissions is negligible. We believe that this cut is still worth analyzing since coal power plants incur high emissions during construction as well.

In our analysis we evaluated the range of CO2 emissions from a fully operational coal power plant that would be eliminated if an off-shore wind farm replaced it. To calculate the volume of CO2 emitted we used the following assumptions: Commercial coal has 70% carbon content; only 40% of the energy released by coal is turned into electricity; 1 unit of carbon yields 3.667 units of CO2; 2460 kWh are produced from one ton of coal.[19]

Using this data we identified the total CO2 emissions per MW and the savings from cutting that volume of emissions. The value of a ton of CO2 emissions can be quantified using estimates from various environmental organizations and the current trading price on the European market. The range of values is from $10 to $14. This data is reflected in the following table.

Assumptions	
Percentage of carbon in per ton of commerical coal	70%
CO2 emitted by per ton of carbon (ton)	3.66
Electricity yielded by per ton of coal burnt (Kwh)	2460
Price of per ton of CO2 (Base Case) ($)	10
Price of per ton of CO2 (Bull Case) ($)	14
CO2 savings from wind power (Base Case) ($/KWh)	0.010
CO2 savings from wind power (Bull Case) ($/KWh)	0.015

2.2 Impacts on wildlife

As wind energy develops into an increasingly important and dominant sector, its environmental impacts include the not only the potential to displace or offset carbon emission but also adverse effects such as wildlife fatality and aesthetic intrusion on the landscape. Wind turbines are linked to wildlife, especially birds, largely because “wind current most beneficial for producing wind energy also happen to be the ones that billions of birds use to migrate across the US”.[20] Before examining the aforementioned impacts of wind turbines on the environment, it needs to be noted that, since wind turbines still remain relatively new technology, studies and research on their environmental costs are still ongoing. Moreover, the data on the impact on wildlife is relatively limited, and it is difficult to quantify the impact since “scientific literature on the effects of wind farms on wildlife population is scant”.[21] Additionally, wind turbine-caused wildlife mortality estimates are often “highly uncertain and prone to biases” partly due to searcher detection error and scavenger removal of carcasses.[22]

Findings differ from farm to farm, but migratory and resident bird and bat fatalities have been recorded at various wind energy facilities. These fatalities are caused both directly and indirectly by wind turbines. Direct impacts refer to fatalities resulting from birds and bats being killed directly by collisions with wind turbine rotors and monopoles. Indirect impacts often refer to disruptions of foraging behavior, breeding activities, and migratory patterns resulting from alterations in landscapes. Both direct and indirect impacts lead to increased mortality, alterations in the availability of food, roost and nest resources, increased risk of predation, and potentially altered demographics, genetic structure, and population viability.[23]

In researching such impacts on the avian population, the primary emphasis has been to quantify collision mortality with wind turbines. According to research conducted mainly in the

United States and the Europe, “bird collisions range from 0 collisions/turbine/year up to >30.0 collisions/turbine/year. The variability is partly due to a number of different factors including layout design of the wind farm and specific characteristics of turbines, weather conditions, and topography, as well as the specific bird species and numbers of birds using the site and their behavior.

Habitat alteration or disturbance resulting from wind turbines is a function of the size and numbers of turbines that are constructed on the development site. For example, vast wind energy development such as the APWRA in California which consists of several thousands of turbines “can result in habitat disturbance from areas modified for turbine pads alone if sensitive plant communities or habitats critical to the life cycle of specific wildlife species are impacted. Additional electrical transmission lines that need to be erected for large wind farms, road networks within the wind farms, and other infrastructure development associated with large wind energy development could pose further threat to wildlife population. Electrical transmission lines, for example, represent significant collision and electrocution risk to birds .

Although many reports concur that wind turbines can have negative impacts on the wildlife, many have also indicated that the impacts of wind farm developments on bird populations as well as other wildlife populations generally insignificant for most species. Although the impact on wildlife is often limited, and wind turbines pose no threat at the population level, it is important to understand the potential risk from wind energy developments.

2.3 Aesthetic impact

Environmental concerns of wind energy developments include visual impact of wind turbines. Visibility is often a primary reason for concern about wind energy projects.[24] In a report that examines the benefits and costs of the Cape Wind project, a proposal to construct

US's first offshore wind farm in Nantucket Sound, the visual impact of wind turbines are quantified through a projected fall in property values. Through surveys, the report concluded that because "some valuation of the natural beauty of the region is assumed to be embedded in the property value of Cape Cod homes" the presence of the wind farm "raises the distinct possibility that the presence of windmills might reduce property values on Cape Cod". According to the report, on average, home owners believe that the windmill project will reduce property values by 4.0% and that those with waterfront property believe that it will lose 10.9% of its value. In total, property holders in the six towns believed that the total loss in property values directly as a result of the offshore wind farm to be over $1.3 billion. The report argues that with the decline in property values, property tax revenues would fall, as well. Similar survey with real estate professionals operating in the area gave results that further showed that the property value would decline as a result of the wind farm. Realtors believe that 44% of prospective buyers are unaware of the windmill proposal, which helps explain why the windmill project has had little concrete effect on the real estate market so far. 49% of those surveyed anticipate property values to decline if the wind farm were to be built, and the mean of the responses was loss of 4.6%. The findings from the survey indicate that the visual impact of the wind turbines is one of the sources of criticisms about wind energy development. [25]

Although there is no way to entirely eliminate visibility of wind turbines on the landscape, there are ways to minimize the obtrusiveness of the structures. Some maintain that providing "visual unity" is the "single, most important consideration".[26] Within a wind farm, consistency in the type of turbine structure, turbine color, surface finishes, spacing, number of blades, and spinning direction of the rotors minimize visual interruption. Consistency and uniformity will minimize project visibility in sensitive areas with high open spaces. Going forward, wind farms will have to adhere to guidelines that minimize their visual conspicuousness and obtrusiveness.

2.4 Summary of social externalities

According to our calculation, the social benefit of reducing carbon emission, in terms of dollar value, is \$0.01/KWh to \$0.015/KWh. The positive social externality brought by offshore wind is clear. However, if the government evaluates the social externalities at a monetary value exactly the same as our range of \$0.01/KWh to \$0.015/KWh and the makes subsidies of the same amount, the cost of the wind power sector is still going to overrun the benefits from a commercial perspective. In the next section, we are going to look at the policies related to offshore wind power in different countries, especially E.U. and China, and study how those industry leaders address social externalities and make the offshore wind power industry viable.

Policies

Section 1: Chinese Renewable Energy Policies

The first country we chose to examine was China because it was comparable to the USA both in the long-term potential and current state of its wind power industry. Much like America, China has the ability to harness between 700 and 1200 GW of wind energy 750 GW of which is in the form of off-shore wind energy.[27] The key difference is that unlike America, China has managed to create an environment that is extremely favorable to potential investors.

Unlike Europe, which has had over a decade of commitment to achieving renewable energy targets, the Chinese renewable energy market has only emerged recently. Their recent entry has not, however, prevented the Chinese from achieving rapid expansion – the market has seen a quadrupling of total wind farm capacity for several years. Furthermore, in 2010 China showcased its first fully operational 100MW off-shore wind farm at the Shanghai Donghai Bridge and has already begun the construction of several similar farms along its Eastern coastline.[28] In total, the government forecasts that up to 32,800MW will come directly from off-shore wind power by 2020.[29]

The policies that will support the growth of the Chinese off-shore wind market are similar to the policies employed over the last decade to generate growth in the land-based wind market. The policies have been so successful that they not only help China meet its targets, but generally cause it to overshoot them. For example, although the 11th Five-Year Plan called for a total wind farm capacity of 10GW by 2010, China surpassed this target and hit a total installed capacity of 12GW in 2008.[30] This trend demonstrates the success of the incentive structure put forth by the Chinese government under the Renewable Energy Law and subsequent amendments. The incentives used break down into two major categories which are worth exploring: Bidding process and feed-in tariffs; Creation of special funds and tax exemptions.

1.1 Bidding Process and feed-in tariffs

As was established in a previous section on tangible costs, one of the main barriers to entry is the relatively high cost of producing electricity from wind farms. The high costs associated with the production of electricity are then transferred to the grid companies, and ultimately the end user. Naturally, in a country with abundant coal resources and a finite grid capacity wind farms would struggle to find transmission companies willing to purchase their output. To overcome this issue, the Chinese government has set up a uniform price for purchasing wind power across four regions and required grid companies to purchase a majority of the electricity produced by wind farms in their area. Additionally, to slightly deflate wind power prices for large-scale plants they have also instituted a bidding system which adds a free-market element to the industry.

The aforementioned price levels are determined through a feasibility study carried out by the government which identifies the price that is necessary for a wind farm to effectively compete with other local power sources. This price ranges from 0.51-0.61 yuan/kWh, which is almost double the 0.34 yuan/kWh price of coal. Additionally, the government has implemented a bidding system for concessions to build large-scale wind farms. The bidding process imposes restrictions on bidders that guarantee the efficient and timely construction of proposed wind farms, while also allowing bidders to specify a price at which they would sell their electricity to the grid companies. By allowing the free-market to play a role this policy deflated prices to the range of 0.38-0.55 yuan/kWh.[31]

Recently, the Renewable Energy Law has been supplemented with amendments that go further in guaranteeing that a wind farm's production will be wholly purchased by local grid companies at a specified price. Although legislation titled the Mandatory Connection Policy sought to guarantee prior to 2009, the unpredictably rapid expansion of the wind power industry led to grid companies being unable to provide the necessary infrastructure to service wind farms. The amended law reinforced the MCP, and threatens heavy monetary fines on any grid company that is not purchasing all energy provided by local wind farms. [32]

1.2 Special Funds and Tax Exemptions

In addition to enacting policies that guarantee steady revenue streams to wind farms, the Chinese government also set up a Renewable Energy Development Fund and a series of tax breaks that benefit not only the wind farms, but also turbine suppliers and grid companies.

The Renewable Energy Development Fund's primary purpose is to help grid companies cope with the costs of providing necessary infrastructure to service renewable energy plants, wind farms included. Essentially, by collecting a surcharge from all consumers, the REDF accumulates a large sum of money which it then redistributes to the grid companies according to need.[33] Given China's uneven distribution of wealth between the East and West, this provides a way to direct wealth to the development of underdeveloped western provinces.

The tax breaks serve primarily to cut down shipping costs, help grid companies cope with elevated cost burdens, and promote the construction of wind farms in hard-to-reach areas.

Section 2: U.S. and E.U. policies

2.1 Production Tax Credit (PTC) & Options

The primary incentive that the U.S. government provides for advancement of the renewable energy sector is the federal renewable energy production tax credit (PTC), established under the Energy Policy Act of 1992. Wind, as the largest producer of renewable energy, has the greatest impact on the federal budget. For wind, it provides a credit at the rate of 1.5 cents/kilowatt-hour, which is adjusted annually for inflation, for electricity that is wind-generated and sold by the taxpayer to an unrelated party during the taxable year. Currently, the PTC for wind energy stands at an income tax credit of 2.1 cents/kilowatt-hour, the value of which is subtracted from the business taxes a wind-producer would pay.[34][35] The credit mostly applies to electricity generated from utility-scale wind turbines/wind plants intended for wholesale, during the first 10 years of operation.

Even though the American Recovery and Reinvestment Act (ARRA) in 2009 has renewed the PTC through a three-year extension until December 31, 2012, the allowance for uncertainty and lapse in continuation of this vital federal incentive has had potent negative effects on the wind industry. It has not only been renewed and expanded numerous times, most recently in October 2008 and February 2009, but it has been allowed to lapse in three years: 1999, 2001 and 2003.[36] The direct results are palpable, as can be seen in Appendix III. In the years immediately following the temporary continuations of the PTC, the annual wind energy capacities dropped significantly. The wind industry notes that a longer and more certain term for the federal tax subsidy is needed to provide a stable financial environment for the industry as well as allow reduced costs. While the U.S. has become the world's largest wind energy producer, the vacillating status of the PTC has impeded its progress. For example, when awaiting the word from Congress regarding the extension of the tax credit in 2008, AWEA Executive Director Swisher stated that "current figures hide a dire reality: the pipeline of investment for 2009 has been on hold for months…because of the uncertainty about the production tax credit."[37] It has also caused a rush to complete projects by the end of 2008, before the expiration – the result being increased risks and costs which will eventually trickled down to the customers. The level at which the domestic investment in wind turbines and their component manufacturing facilities have been growing was threatened as well by the uncertainty in the policy's extension. The relatively short-term nature of the PTC also prevents larger quantity orders for wind turbines, which would have been instrumental in reducing costs. As the PTC is the most important federal financial incentive promoting the investment in and deployment of wind power technologies, the U.S. needs to rapidly extend the tax credit, or better yet, maintain a more permanent stance on such a policy.

The wind industry, including the offshore wind industry, has been given a large boost by the ARRA. The incentives have been significantly increased with the extended and enhanced PTC, ITC (investment tax credit), and newly available cash grant. Developers can choose to receive, instead of the PTC, an ITC – a non-refundable tax credit equal to 30% of a qualified wind facility's qualifying costs – which can then be converted to an equivalent Treasury cash grant. The option to choose between the different types of subsidies is advantageous as it allows wind producers to maximize the benefits, tailored to their specific needs and preferences. The U.S. Department of Energy funded the report "PTC, ITC, or Cash Grant?"[38] The analysis was done on two fronts: quantitative and qualitative.

To compare the value of electing the PTC or the ITC/equivalent cash grant on the quantitative level, a cash flow model is used to determine the relative financial value of each incentive based on installed project costs and expected capacity factor. As the ITC and cash grant are of equal financial value, in theory the cash grant results would be the same as those for the ITC. Results for wind projects with installed costs ranging from $1,500/kWh to $2,500/kWh and capacity factors from 25% to 45% showed that the PTC provides more value than the ITC in approximately two-thirds of the cases. It is intuitive that projects that cost less than $1,500/kWh will likely gain more from the PTC and those that cost more than $2,500/kWh will receive more value from the ITC. These extreme cost cases aside, capacity factor is the more important determinant. Appendix III shows the findings favoring the PTC at a 7.5 nominal discount rate.[39] A lower discount rate would make the PTC look even more attractive as future PTCs would not be discounted as heavily; the ITC is realized in year one of operations (although it vests linearly over a five-year period).

Qualitative reasons have to be taken into consideration as well, especially when the quantitative difference is small. Seven factors have been identified: (1) the option to elect an equivalent cash grant, (2) performance risk, (3) tax credit appetite, (4) liquidity, (5) subsidized energy financing, (6) power sale requirement, and (7) owner/operator requirement. The first factor involves the intrinsic value of cash. Especially in difficult financial environments, developers may find the cash grant more attractive than the tax credits, even more so if the cash grant will allow access to less-expensive debt or equity capital. Secondly, the PTC is dependent on project performance unlike the ITC and cash grant. If a project under-performs, the ITC will give more value and some project owners would prefer the certainty of the ITC over the higher expected value of ITC with its inherent performance risk. Thirdly, a project must be assured of having a tax base sufficient to fully absorb the tax benefits over a decade with the 10-year PTC to make it a worthwhile choice, a long-term projection that may be uncomfortable for some tax investors. The ITC on the other hand does not require such a forecast for tax appetite as the full credit is realized in the first year; however a relatively larger tax base is required in the beginning to take complete advantage of the ITC. The cash grant would make tax credit appetite and tax equity investors a less important factor. As for liquidity, the ITC and cash grant are relatively more illiquid as an investment as they are realized in one year and vest linearly over five years. But a project choosing PTC can be sold at any time with the transferable benefits to new buyers. Subsidized energy financing comes in due to the fact that before the ARRA was enacted, both the PTC and ITC were reduced proportionally by the amount of a project's installed costs financed by government-sponsored low-interest loan programs, but the ARRA removed this penalty for the ITC only. Thus, a project that can secure this subsided energy financing could very well be better off choosing the ITC or cash grant. The power sale requirement factor favors the more widely applicable ITC which does not impose such a restriction, whereas to be PTC-eligible, the wind power generated must be sold to an unrelated third party. Lastly, to claim the PTC, the project owner must also operate it, effectively ruling out lease financing. The ITC, however, opens the way for different leasing structures with no requirement for the owner and operator to be the same entity.

With the likely scenario that most projects would fall in the middle of the range for installed costs and capacity factor, where the difference in value between choosing the PTC or ITC is modest, qualitative considerations may have a heavier bearing on the decision. All qualitative factors except liquidity favor the ITC for wind, suggesting that wind projects generally would benefit more from electing the ITC and that it's reasonable to assume that the cash grant would be chosen in lieu of the ITC itself. In the end, the choice is made dependent on an individual basis. The point is that the increased incentives and their flexibility now offered by the government are essential to the growth of the wind industry. They should not be allowed to lapse as have been done in the past, especially given that the U.S.'s wind industry lags behind compared with that of other countries such as the European Union.

2.2 Renewable Portfolio Standard

State renewable portfolio standard (RPS) requirements are another driver for offshore wind. They ensure a growing percentage of electricity is from renewable sources, like wind power, and are most successful when used in combination with the tax credit. Mandatory RPS currently exists in 30 states and 6 more states have renewable portfolio goals, though RPS does not at a national level.[40] The U.S. should be taking the federal equivalent of the RPS into consideration (which would be know as RES, renewable electricity standard), as the European Union has in its Renewable Energy Directive which contains legally binding national targets. For 2020, the EU has mandated an overall 20% renewable energy objective, equipped with given indicative trajectories for the Member States to follow (for example: by 2011-12 they should reach 20% of the target, and by 2017-18 they should be 65% of the way to their goals).[41] With similar standards in place, the U.S. energy sector will be more likely to turn to relatively untapped sources such as offshore wind to meet the set targets.

2.3 Cap & Trade

Another incentive to induce growth in the wind industry by making wind more cost-competitive is curbing carbon emissions. There has been growing interest in the offshore wind industry as findings have shown the enormous potential for energy in this sector. The European Union has an emission trading scheme (ETS), putting a cost on emitting CO_2, while the U.S. is debating whether or not to impose cap and trade policies. The Waxman-Markey bill is up for consideration in the Senate and is the "first time either house of Congress had approved a bill meant to curb the heat-trapping gases scientists have linked to climate change." The EU ETS has gone through several stages, first handing out allocations then turning to auctioning of permits to the power sector for emitting CO_2. The U.S. can learn from the EU system already in place, learn from prior mistakes, and make improved regulations. Setting a limit for pollution would encourage advancements in renewable energy, such as offshore wind with huge untapped potential.

Conclusion

Our cost-benefit analysis highlights the typical scenario that most potential offshore wind farm investors face – an overly expensive foray into a new market, which will not yield a reliable revenue stream. However, from the statistics that we found in the cost-benefit analysis, in the bull case of the shallow water model, the cost $0.06/KWh is actually well below the sales prices of wind power contracted for the two biggest shallow water projects in the U.S., which are $0.1/KWh and $0.187/KWh respectively. Considering that our bull case entails the most optimistic assumptions about technology advancement, financing cost and capacity factor, the actual cost of any wind farm under development will most likely dwell on the break-even point.

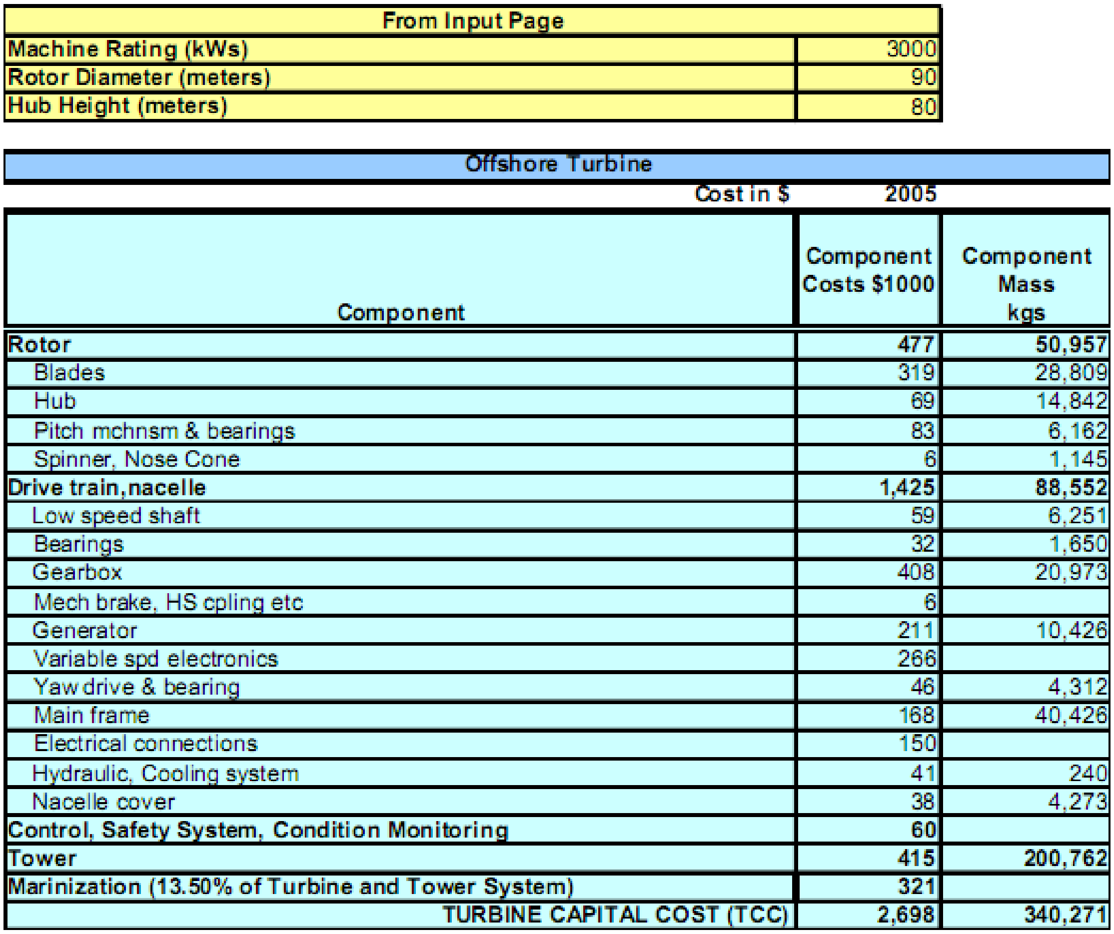
However, other countries around the globe have faced similar challenges when nurturing a fledgling wind power industry and overcome them using efficient and pragmatic policies. Although not all of the policies that we have observed are applicable in the United States, the majority are worthy of consideration and can push American investments in offshore wind farms out of the red. Unfortunately, the policies we currently observe in the U.S. are not adequate enough to help the off-shore wind industry become a viable source of energy.

The PTC, with its options to convert to the ITC and cash grant, is integral in promoting the industry's growth and thus should be made more permanent. The uncertainty of such a subsidy from the government destabilizes the wind sector as a whole and impedes its progress. Following the footsteps of the EU with their legally binding renewable energy targets, the U.S. should also consider a federal Renewable Electricity Standard as well as making more renewable standards in the U.S. binding instead of voluntary. Putting a cost on carbon emissions through a means like the EU ETS could make wind energy more cost-competitive with conventional energy sources such as coal. From our examination of the Chinese policy, both the Feed-in Tariffs and the Bidding Concession policies seem highly fruitful for an underdeveloped market. While both of these policies guarantee a steady future revenue stream at a rate which meets feasibility requirements, the Bidding Concession policy also legally binds the investors to see their projects through several checkpoints and quality checks. This alleviates one of the key problems that the American market has faced in recent years – unreliable construction schedules, which not only slow progress but discourage would-be investors. The Feed-In Tariff policy, on the other hand, only tackles the issue of setting a price that will be above the rate necessary for breaking even. The EU has had success with their feed-in tariffs, requiring utilities to buy clean energy, as well.

Moving forward, it is imperative to watch the political climate and market conditions as the American government considers implementing any of these policies. However, without pushing forward timely and decisive legislation the American government will be unable to catch up to its global rivals in tapping into an emerging source of renewable energy. This will only lead to losses in potential economic, environmental, and energy security benefits for the nation as a whole.

Appendix I

Cost breakdown of 3MW offshore wind turbine model



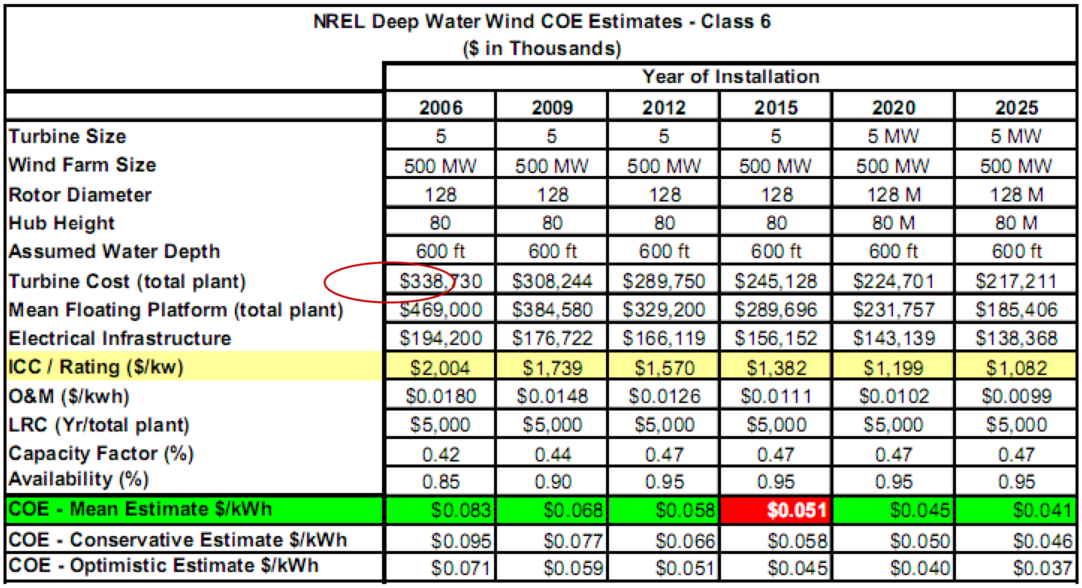
From Input Page	
Machine Rating (kWs)	3000
Rotor Diameter (meters)	90
Hub Height (meters)	80

Offshore Turbine

Cost in $ 2005

Component	Component Costs $1000	Component Mass kgs
Rotor	**477**	**50,957**
Blades	319	28,809
Hub	69	14,842
Pitch mchnsm & bearings	83	6,162
Spinner, Nose Cone	6	1,145
Drive train,nacelle	**1,425**	**88,552**
Low speed shaft	59	6,251
Bearings	32	1,650
Gearbox	408	20,973
Mech brake, HS cpling etc	6	
Generator	211	10,426
Variable spd electronics	266	
Yaw drive & bearing	46	4,312
Main frame	168	40,426
Electrical connections	150	
Hydraulic, Cooling system	41	240
Nacelle cover	38	4,273
Control, Safety System, Condition Monitoring	**60**	
Tower	**415**	**200,762**
Marinization (13.50% of Turbine and Tower System)	**321**	
TURBINE CAPITAL COST (TCC)	**2,698**	**340,271**

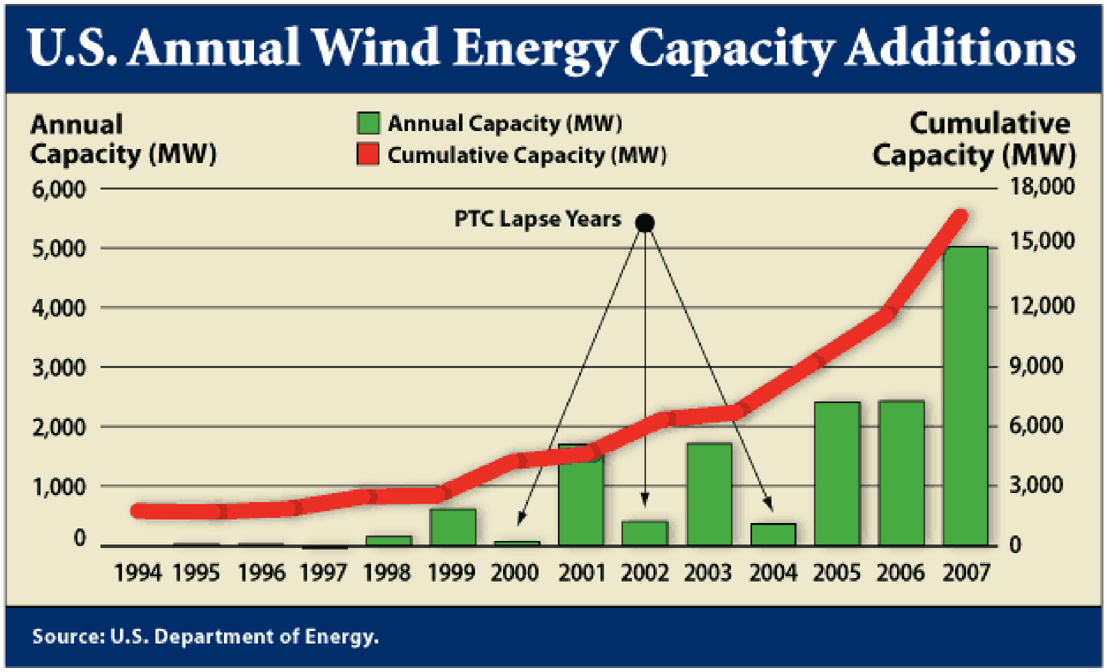
Appendix II



NREL Deep Water Wind COE Estimates - Class 6
($ in Thousands)

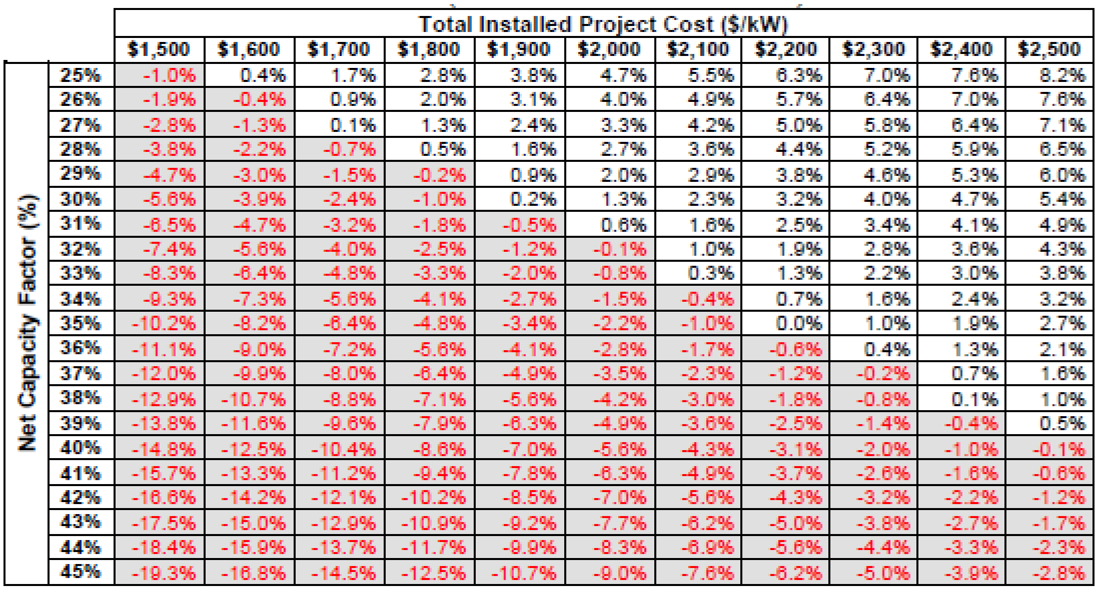
	Year of Installation					
	2006	**2009**	**2012**	**2015**	**2020**	**2025**
Turbine Size	5	5	5	5	5 MW	5 MW
Wind Farm Size	500 MW	500 MW	500 MW	500 MW	500 MW	500 MW
Rotor Diameter	128	128	128	128	128 M	128 M
Hub Height	80	80	80	80	80 M	80 M
Assumed Water Depth	600 ft	600 ft	600 ft	600 ft	600 ft	600 ft
Turbine Cost (total plant)	$338,730	$308,244	$289,750	$245,128	$224,701	$217,211
Mean Floating Platform (total plant)	$469,000	$384,580	$329,200	$289,696	$231,757	$185,406
Electrical Infrastructure	$194,200	$176,722	$166,119	$156,152	$143,139	$138,368
ICC / Rating ($/kw)	$2,004	$1,739	$1,570	$1,382	$1,199	$1,082
O&M ($/kwh)	$0.0180	$0.0148	$0.0126	$0.0111	$0.0102	$0.0099
LRC (Yr/total plant)	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Capacity Factor (%)	0.42	0.44	0.47	0.47	0.47	0.47
Availability (%)	0.85	0.90	0.95	0.95	0.95	0.95
COE - Mean Estimate $/kWh	$0.083	$0.068	$0.058	**$0.051**	$0.045	$0.041
COE - Conservative Estimate $/kWh	$0.095	$0.077	$0.066	$0.058	$0.050	$0.046
COE - Optimistic Estimate $/kWh	$0.071	$0.059	$0.051	$0.045	$0.040	$0.037

Appendix III



U.S. Annual Wind Energy Capacity Additions

Source: U.S. Department of Energy.



Net Capacity Factor (%)	Total Installed Project Cost ($/kW)										
	$1,500	$1,600	$1,700	$1,800	$1,900	$2,000	$2,100	$2,200	$2,300	$2,400	$2,500
25%	-1.0%	0.4%	1.7%	2.8%	3.8%	4.7%	5.5%	6.3%	7.0%	7.6%	8.2%
26%	-1.9%	-0.4%	0.9%	2.0%	3.1%	4.0%	4.9%	5.7%	6.4%	7.0%	7.6%
27%	-2.8%	-1.3%	0.1%	1.3%	2.4%	3.3%	4.2%	5.0%	5.8%	6.4%	7.1%
28%	-3.8%	-2.2%	-0.7%	0.5%	1.6%	2.7%	3.6%	4.4%	5.2%	5.9%	6.5%
29%	-4.7%	-3.0%	-1.5%	-0.2%	0.9%	2.0%	2.9%	3.8%	4.6%	5.3%	6.0%
30%	-5.6%	-3.9%	-2.4%	-1.0%	0.2%	1.3%	2.3%	3.2%	4.0%	4.7%	5.4%
31%	-6.5%	-4.7%	-3.2%	-1.8%	-0.5%	0.6%	1.6%	2.5%	3.4%	4.1%	4.9%
32%	-7.4%	-5.6%	-4.0%	-2.5%	-1.2%	-0.1%	1.0%	1.9%	2.8%	3.6%	4.3%
33%	-8.3%	-6.4%	-4.8%	-3.3%	-2.0%	-0.8%	0.3%	1.3%	2.2%	3.0%	3.8%
34%	-9.3%	-7.3%	-5.6%	-4.1%	-2.7%	-1.5%	-0.4%	0.7%	1.6%	2.4%	3.2%
35%	-10.2%	-8.2%	-6.4%	-4.8%	-3.4%	-2.2%	-1.0%	0.0%	1.0%	1.9%	2.7%
36%	-11.1%	-9.0%	-7.2%	-5.6%	-4.1%	-2.8%	-1.7%	-0.6%	0.4%	1.3%	2.1%
37%	-12.0%	-9.9%	-8.0%	-6.4%	-4.9%	-3.5%	-2.3%	-1.2%	-0.2%	0.7%	1.6%
38%	-12.9%	-10.7%	-8.8%	-7.1%	-5.6%	-4.2%	-3.0%	-1.8%	-0.8%	0.1%	1.0%
39%	-13.8%	-11.6%	-9.6%	-7.9%	-6.3%	-4.9%	-3.6%	-2.5%	-1.4%	-0.4%	0.5%
40%	-14.8%	-12.5%	-10.4%	-8.6%	-7.0%	-5.6%	-4.3%	-3.1%	-2.0%	-1.0%	-0.1%
41%	-15.7%	-13.3%	-11.2%	-9.4%	-7.8%	-6.3%	-4.9%	-3.7%	-2.6%	-1.6%	-0.6%
42%	-16.6%	-14.2%	-12.1%	-10.2%	-8.5%	-7.0%	-5.6%	-4.3%	-3.2%	-2.2%	-1.2%
43%	-17.5%	-15.0%	-12.9%	-10.9%	-9.2%	-7.7%	-6.2%	-5.0%	-3.8%	-2.7%	-1.7%
44%	-18.4%	-15.9%	-13.7%	-11.7%	-9.9%	-8.3%	-6.9%	-5.6%	-4.4%	-3.3%	-2.3%
45%	-19.3%	-16.8%	-14.5%	-12.5%	-10.7%	-9.0%	-7.6%	-6.2%	-5.0%	-3.9%	-2.8%

Positive (and unshaded) means the ITC (or equivalent cash grant) provides more value
Negative (and shaded) means the PTC provides more value

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