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Ecological and economic cost-benefit analysis of offshore wind energy

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ABSTRACT

Wind energy has experienced dramatic growth over the past decade. A small fraction of this growth has occurred offshore, but as the best wind resources become developed onshore, there is increasing interest in the development of offshore winds. Like any form of power production, offshore wind energy has both positive and negative impacts. The potential negative impacts have stimulated a great deal of opposition to the first offshore wind power proposals in the U.S. and have delayed the development of the first offshore wind farm in the U.S. Here we discuss the costs and benefits of offshore wind relative to onshore wind power and conventional electricity production. We review cost estimates for offshore wind power and compare these to estimates for onshore wind and conventional power. We develop empirical cost functions for offshore wind based on publicly reported projects from 2000 to 2008, and describe the limitations of the analysis. We use this analysis to inform a discussion of the tradeoffs between conventional, onshore and offshore wind energy usage.

1. Introduction

Over the past 10 years, the onshore wind industry in the U.S. has grown dramatically and as a result developers, citizens and the U.S. Congress have expressed interest in the development of an offshore wind industry. Several companies have developed plans for offshore wind projects and the U.S. Mineral Management Service (MMS) is in the process of reviewing these applications and developing regulations for the industry while the state of Texas has already leased lands for at least one and possibly several additional offshore wind farms. Lawmakers, government agencies, corporations, non-governmental organizations and private individuals are deciding whether or not to support or participate in the development of an offshore wind industry, and the relative level of support or encouragement to give this new industry. In making these decisions, stakeholders will have to balance the ecological costs and benefits of offshore wind against its economic costs and compare to offshore wind energy's most realistic competitors. The decision is complex and requires balancing local and global environmental issues, historical conservation and economic costs.

Offshore wind energy competes with both onshore wind energy and conventional fossil-fueled electricity. Onshore wind power and natural gas fired power are the two fastest growing segments of the electricity market. Coal power is the largest current producer of electricity in the U.S. Offshore wind will thus displace either coal, natural gas or onshore wind.

Given the uncertainties associated with global climate change, it is difficult to compare the societal costs and benefits of wind energy to fossil-fueled energy. However, one way to develop a first-order comparison of these costs would be include the costs of market based carbon offsets in the costs of conventional electricity. This assumes that the costs of carbon emission credits accurately reflect their ecological value which would occur if carbon credits actually represent a reduction of the specified amount of carbon dioxide from the atmosphere.

It is perhaps less difficult to compare the costs of onshore and offshore wind energy since they both have similar carbon emissions. In this case, one could simply compare the economic and ecological costs of onshore and offshore wind.

There are several reasons why developers or lawmakers might prefer offshore wind power over fossil-fueled power or onshore wind power. Offshore wind power could be less expensive than its competitors, either at a local or national scale, it could have the potential to be less expensive than its competitors, or it could have less severe social and environmental impacts than its competitors.

In this paper, we seek to address the question, "Is investment in offshore wind power preferred over investments in fossil-fueled or onshore wind power?" We focus primarily on coal-fired power as representative of fossil-fueled power since it is the dominant source of electricity in the U.S. and it is both inexpensive and a major source of greenhouse gases.

We begin with an overview of the commonly expressed criticisms and benefits of offshore wind power. We discuss cost models for offshore wind power and compare them to onshore wind power and conventional power. We also discuss the factors that lead to higher costs through a first-order empirical cost function and

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discuss how these costs can be decreased. We discuss the environmental impacts of offshore wind power and how these factors can be mitigated. We end the paper with the conclusions of the analysis.

2. Criticisms of offshore wind power

There have been a number of criticisms on offshore wind power in the U.S., mostly associated with the Cape Wind project (Table 1, [1,2]). The environmental impacts are discussed in more detail below, the rest of the concerns are discussed here.

2.1. Navigational safety

Any structure placed in federal water must receive a permit from the Army Corps of Engineers (ACE). The ACE, through the Rivers and Harbors Act (RHA), has the authority to regulate obstructions to navigation in federal waters. The ACE considers a multitude of factors in making RHA decisions, however, their primary responsibility is protecting navigation, therefore they are unlikely to permit offshore wind projects that pose serious threat to U.S. shipping lanes. However, densely spaced wind turbines could provide a problem for recreational boats and small fishing vessels attempting to navigate through a wind farm. Typically, turbines in a wind farm are spaced 500–1000 m apart and have blades that at their lowest point are at least 20 m above the water. Small boats should therefore have no problem navigating among these turbine in good weather, however, some critics of the Cape Wind project have pointed out that the coast of Massachusetts is infamous for bad weather and shipwrecks. This is likely to be the case in many places in which offshore turbines are particularly profitable (i.e. areas with high winds).

2.2. Federal subsidies

Opponents of offshore wind projects claim that offshore wind power is not economically viable without federal "subsidies", by which they mean federal tax credits for renewable energy. The federal Production Tax Credit (PTC) gives a tax credit of $0.02/kW h of produced electricity for the first ten years of production from any renewable source, including wind.[1] Opponents of the PTC argue that its original purpose was to help the renewable energy industry become established and because it originally became law in 1992, it should now be allowed to expire. In fact, the PTC did expire in 2000, 2002 and 2004 and is currently set to expire at the end of 2008. Interestingly, the pattern of wind capacity growth in the U.S. seems to closely follow the expiration of the PTC [3]. In each of the years in which the PTC was allowed to expire, the growth in wind capacity slowed markedly. Given the relatively unfavorable economics of offshore wind, it is reasonable to suggest that offshore wind energy projects will need the continuation of the Production Tax Credit (PTC) in order to be competitive.

2.3. Aesthetics

Opponents to wind power claim that wind turbines mar the landscape or seascape. This is especially an issue for the Cape Wind project in which local activists are concerned about the views from historic landmarks. There are some aesthetic issues that are beyond the scope of analytic tools, however, the effects of wind farms on property values has been analyzed. Sterzinger et al. [4] analyzed property values in the viewshed of onshore wind turbines and found that in eight out of ten cases the property values in the viewshed increased faster than the values in control sites. Furthermore, in nine of ten cases the rate of property value increase rose after the placement of the wind farm. Thus, there is no empirical evidence to suggest that wind farms negatively influence property values.

In Denmark, Ladeenburg and Dubgaard [5] estimated the willingness of citizens to pay for moving turbines further from shore. They found that respondents were willing to pay 46, 96 and 122 Euros per year per household in order to move a theoretical wind farm to 12, 18 or 50 km away from the coast, relative to an 8 km baseline [5]. Huaghton et al. [6] conducted a similar study on Cape Cod and found that 22% of respondents were willing to pay, on average, a onetime cost of $286 for windmills to not be built, while 9% were willing to pay an average of $112 for windmills to be built. The average net willingness to pay per person was $75. These data suggest that on average the public views offshore wind turbines as visual disamentities, at least before they are built.

2.4. Cost and risk

The offshore environment is significantly more uncertain and difficult than onshore, and thus, more costly and risky. The offshore environment involves personnel traveling to and from offshore turbines; this increases equipment and time costs as well as insurance costs due to increased risks. Offshore work involves increased risks of storms which affect the amount of time available for maintenance and installation which in turn influence capital and operation costs. Offshore environments are corrosive to electrical and structural equipment and require turbines to be marinized with cathodic and humidity protection. Capital expenditures for offshore wind projects depend on marine vessel dayrates which are unpredictable, and offshore foundations require more steel for jackets and pilings than onshore foundations.

2.5. Unpredictable power

One of the most substantive criticisms of wind power is that it is unable to provide constant, predictable power to the grid. The electricity grid is designed to send a constant AC load to consumers and it relies on large power plants producing predictable and steady electricity. Wind energy is not steady and varies on the scale of minutes, hours, days and months and the changes in wind power output are difficult to predict ahead of time [7]. Therefore, integrating wind power into the electricity grid will require backup systems (especially natural gas fired power plants) that can respond quickly to changing production from wind farms [8]. This increases the total national cost of electricity. The DOE has estimated that the supply up to 20% of the nation's electrical use from wind power would cost up to $5/MW h in integration costs [9].

3. Benefits of offshore wind power

Offshore wind power shares all of the same benefits of onshore wind power relative to conventional power sources (Table 1). Most notably, wind power has very low carbon emissions over its lifecycle, as well as negligible emissions of mercury, nitrous oxides and sulfur oxides. Wind power does not use fuel and is therefore freed from the price volatility associated with electricity generated from oil, natural gas, biomass, nuclear and coal. Wind power does not rely on large sources of freshwater as conventional sources of power do [9]. In the near term, offshore wind power will be more expensive than onshore wind power, however, there are several benefits of offshore wind power that are not shared by onshore wind; these benefits may or may not justify the additional costs.

[1] For example, if a 400 MW wind farm has a capacity factor of 50%, then it would produce about 1.7 billion kW h of electricity annually, and would qualify for 35 million dollars in tax credits each year for the first ten years of its operational life.