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Do onshore and offshore wind farm development patterns differ?

Peter Enevoldsen [a,*], Scott Victor Valentine [b]

[a] Center for Energy Technologies, Aarhus University, Denmark
[b] Lee Kuan Yew School of Public Policy, National University of Singapore, Singapore

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ABSTRACT

When developers are building wind farms offshore or onshore, are there notable characteristics that differentiate these projects? If so, what does this tell us about the nature of wind power development patterns? This study makes use of industry data from 44 wind farms, including 11 offshore wind farms, 19 onshore wind farms located in farmland and 14 wind farms located in forested areas with a total capacity of 1190 MW installed actual wind farms to test four hypotheses based on preconceptions identified in a literature review. Testing the validity of these preconceptions is important because if policymakers are to design policy to facilitate specific development patterns in a given nation, they need to be clear on what is working in the market. Our data suggest that, contrary to popular belief, offshore wind farms do not produce more energy per installed MW when compared to onshore wind farms. However, our data confirm that offshore wind farms produce more energy than onshore wind farms. We contend that this has less to do with superior wind quality in offshore sites than with scale differences. It appears that developers construct far larger offshore wind farms in order to presumably counteract the proportionally higher development costs associated with marine environments. One other remarkable finding associated with this study is that onshore wind turbines that are located in forested areas might be capable of matching the power production of offshore wind farms without incurring the additional costs associated with offshore projects.

Introduction

The sight of a wind turbine on the horizon has come to encapsulate what many perceive to be the initial stages of a transition to low carbon energy. There is good reason for this. Global wind power potential is enormous. In a 2005 study, Archer and Jacobson (2005) determined that capturing only 20% of technical potential using existing turbine technology “could satisfy 100% of the world's energy demand for all purposes (6995–10,177 Mtoe) and over seven times the world's electricity needs (1.6–1.8 TW)”. Another team of researchers from Harvard University and the VTT Technical Research Center in Finland estimated in 2009 that “a network of land-based 2.5-megawatt (MW) turbines restricted to non-forested, ice-free, nonurban areas operating at as little as 20% of their rated capacity could supply more than 40 times current worldwide consumption of electricity” and more than “5 times total global use of energy in all forms” (Lu et al., 2009).

During the past two decades, companies worldwide have begun to harness this untapped potential. Installed wind energy capacity has increased from less than 8000 MW in 1997 to more than 432,000 MW by the end of 2015 (IRENA, 2016). Moreover, the sector has established itself as a major source of new employment, topping 1 million workers in the sector for the first time in 2014 (IRENA, 2015) with an expected doubling to 2 million by 2030. Indeed, on a kilowatt hour basis, it has been estimated that wind power produces 55% more jobs than coal-fired power and natural gas-fired power; and 21% more jobs than nuclear power (WRI, 2010).

To date, the majority of wind power projects have been constructed onshore. As of the end of 2015, of the 432,000 MW of installed wind power capacity, 420,000 MW exists onshore (IRENA, 2016). The first onshore multi-megawatt wind turbines were installed in 1978 in Denmark (Gipe, 1995) and were primarily installed in farmlands – which permitted joint use projects that lower costs – and in close proximity the sea, to take advantage of stronger coastal wind profiles (Manwell et al., 2009; Troen and Petersen, 1989). However, as wind power projects have grown in concentration, so has social opposition with not-in-my-backyard (NIMBY) sentiments clearly on the rise (Valentine, 2011).

In response, many nations are adjusting policies to encourage offshore wind power development (Valentine, 2014). For almost a decade, planners have seen great potential in offshore wind energy and lauded such developments as a way to avoid both the high cost of acquiring onshore tracts of land and social opposition to further onshore

* Corresponding author at: Department of Business Development and Technology, BTECH Aarhus BSS, Aarhus University, Birk Centerpark 15, Denmark.
E-mail address: peteren@hih.au.dk (P. Enevoldsen).

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development (Ladenburg, 2009). Recent innovations in offshore foundations have made it possible to deploy wind turbines in deeper waters, enhancing global offshore wind potential (Adelaja et al., 2012). Consequently, offshore wind power capacity is on the rise, reaching 12,000 MW by the end of 2015 (IRENA, 2016). Offshore capacity is expected to increase rapidly in the coming years, especially in Europe (Young, 2015).

The pace of offshore development is highly contingent on the economics of any given offshore wind power project. Some research suggests that offshore wind farms exhibit cost advantages through less costly wind turbine materials because towers can be constructed at lower heights. However, most studies counter that offshore wind farms are more expensive to construct and maintain, due to the demand for larger fortified foundation structures, submarine cables and special vessels for transportation and installation (Bilgili et al., 2011). The general consensus is that offshore wind farms are still more costly than onshore options for generating energy. Yet, as perhaps a testament to market sentiments that offshore wind power projects present greater appeal due to lower risk of social opposition, one influential market report predicting low, central and high scenarios for installed wind energy in the EU in 2020, contends that offshore wind power will exhibit higher annual growth (%) than onshore wind power (EWEA, 2014).

The difficulties of earmarking suitable tracts of open land for onshore wind farms and the depressed rates of return for offshore wind projects have encouraged some wind project developers to search for non-traditional sites onshore. The increased tower heights of multi-megawatt wind turbines (Leung & Yang, 2012; Manwell et al., 2009) have made it possible to deploy wind farms in forested areas where land acquisition is cheaper and investment risks are lower because social opposition is expected to be lower due to increased distance to neighbors (Enevoldsen and Sovacool, 2016).

The reason why onshore wind farm development in forests merits special attention is because siting profiles differ markedly. The land use spectra for wind turbines in forested areas are different (Perks, 2010; Dai et al., 2015). Moreover, altered surface patterns cause shifts in wind profiles (Arnqvist, 2013; Dellwik et al., 2014), increasing turbulence and wind shear. Yet, from the existing literature there are indications that wind turbines deployed in forested areas are more likely to produce less electricity and have a shorter life span than other onshore wind farms (Enevoldsen, 2016). Nevertheless, studying onshore wind farms in forested areas is important because in some of the countries with high amounts of installed wind capacity, wind farms are increasingly being deployed in areas of managed forests, where owners are looking for extra income on land that cannot be used for food production (Enevoldsen, 2016).

Amidst this market flux with developments occurring within traditional onshore locations, in forested areas and in offshore sites, it merits investigating whether there any differences in development patterns. When developers are building wind farms offshore or onshore, are there notable characteristics that differentiate these projects? If so, what does this tell us about the nature of wind power development patterns? There are a number of preconceived notions. For example, a prominent assumption is that offshore wind farms will generate more energy per installed MW than onshore farms. But does this assumption hold true when one compares data from actual wind power developments? Testing the validity of these preconceptions is important because if policymakers are to design policy to support specific development strategies in a given nation, they need to be clear on what is working in the market.

This study makes use of data from actual wind farms to test four hypotheses based on preconceptions arising from a literature review. The data used for this study is based on 44 different wind farms, including 11 offshore wind farms with a total installed capacity of 3589 MW, 19 onshore wind farms located in farmland with a total installed capacity of 1395 MW and 14 wind farms located in forested areas with a total capacity of 1190 MW installed.

Research design, hypotheses and methodology

Research design

The methodology adopted for this study centers around access to data from operational wind farms. For this reason alone, this study represents an uncommon opportunity to gain insight into what is actually transpiring in the wind power market. As mentioned above, the data used in this study comes from 44 different wind farms: 11 offshore wind farms, 19 onshore wind farms located in farmland and 14 wind farms located in forested areas.

The offshore wind projects are mainly located in the European region, which is due to the fact that Europe is the continent with the most installed offshore wind power (GWEC, 2016). The onshore projects are spread all over the world and the wind projects in forested areas are mainly located in Northern Europe, as some of the leading countries in wind energy development has been forced to locate newer wind projects in such areas. There is a concern that our sample is subject to geographical bias due to the heavy representation of European wind farms; however, we contend that the global diffusion of wind power has resulted in development cost convergence, attenuating such concerns.

To make the sample of wind projects as robust as possible, no data were excluded. We used what we had accessed to. The name and exact location of the wind farms have been anonymized due to our confidentiality agreement with the data provider.

A literature study was undertaken to inform the development of four hypotheses. This involved a search of online academic databases. The search was directed through the following keywords: “Wind Energy,” “Wind”, “Onshore”, “Offshore” and “Wind Power” in combination with “Cost of energy”, ”Onshore”, “Forest”, “Offshore” and “Energy production”. The search produced an enormous amount of literature, which was further filtered to exclude irrelevant papers with little or no focus on the topic. In the end, we stopped our analysis after reading through 41 papers because these papers revealed four preconceptions related to development patterns of onshore and offshore wind farms that we felt merited analysis.

An important tenet of policymaking is that robust policy cannot be developed until the policy context and the needs of central stakeholders are well understood (Bardach, 2011). This is especially true when it comes to development policy which relies on market incentives to catalyze private sector investment. In development policy, robust policy anticipates industry needs and engenders an environment that resolves barriers to voluntary investment activity (Valentine, 2012). This study embraces the principle that understanding differences in wind farm development patterns yield insights into industry investment patterns which can influence investment activity. Simply put, by understanding how developers are currently structuring wind farm sites – both onshore and offshore – policymakers can then begin to understand what carrots, sticks or sermons are needed to achieve wind power diffusion (Bemelmans-Videc et al., 2003).

Four preconceptions and four hypotheses

Based on the literature review, we identified four preconceptions implied in the articles studied, which help to shed light on development patterns for different types of wind farms (onshore, offshore and onshore in forested areas). Verifying these preconceptions will hopefully help us to better understand wind power development patterns preferred by industry, or indeed in some cases patterns colored by policy.

The preconceptions and hypotheses are further introduced in Table 1.

Preconception 1: Stronger and more stable offshore winds enable more wind power production.

The rationale for this preconception is grounded in geophysics. First, comparatively strong coastal breezes are created by thermal variations caused by differences in rates of thermal retention between land and