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Tall towers, long blades and manifest destiny: The migration of land-based wind from the Great Plains to the thirteen colonies

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HIGHLIGHTS

- Analyzes siting constraints for wind turbines with tall towers & long blades.
- Interdisciplinary analysis of siting geology, meteorology, economics and land use.
- Economic feasibility analysis of identified sites performed.
- LCOE and pay-back period vary due to site and economic assumptions.
- It is economically feasible to develop wind project in low wind regimes.

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ABSTRACT

Until recently, it was not economically feasible to install wind turbines in many locations, including in large portions of the states that border the Atlantic Ocean in the United States, due to the low wind speeds. Newer designs allow turbines to be deployed at higher hub heights (> 100 m) where wind speeds are greater, and come with longer blades, allowing them to produce significantly more energy at lower wind speeds. We undertake a case study, using rural Sussex County, Delaware, US, to study their economic feasibility. We take an interdisciplinary approach, move beyond theory and general models, and consider micro-scale wind resources (the primary driver of revenue); local site geology, which influences project feasibility and foundation cost; local transmission constraints and expenses related to transmission and connection to the existing electrical grid; local values attributable to the environmental attributes of wind power; operation and maintenance costs (including insurance and replacement parts); land use and zoning considerations, including setbacks from roads, structures and airports; taxes; and rents/royalties. We find the base case levelized cost of energy (LCOE) to be ~$70/MWh (before accounting for the federal production tax credit) based on a 25 year-life of a wind turbine. Sensitivity analyses are undertaken around project life, project finance, the discount rate, and wind speed.

1. Introduction

Wind power is thought to have reached the “next generation,” where the technology is mature and economically affordable [1]. Between 2000 and 2010 the wind industry was in a “spend more get more” period, whereas beginning in 2010 transitioned into a “spend same get more” period Liebreich in [2]. In the past seven years, the average cost of land-based wind has decreased by 35% worldwide [1]. Wind power sales prices in the United States (US) are at an all-time low, resulting it wind power being economically competitive despite low natural gas prices [3]. Installed project costs have dropped an average of $640/kW since 2010 [3]. The cheapest Power Purchase Agreements (PPA) have fallen from $69/Megawatt-hour (MWh) in 2009 to just under $20/MWh in 2016 [3]. Wind-power price decreases are largely the result of the use of longer blades, higher towers (where there are greater wind speeds), and better information technology [2] leading to improved capacity factors. In the early 2000s, capacity factors barely reached 20%, whereas now they reach above 30%, with some even in the high 40’s [2]. Looking to the future, the cost of land-based wind is expected to drop by another 41% by 2040, mostly due to improved capacity factors (as compared to say improved logistics, lower O & M costs and cheaper material costs) [4].

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Lofty renewable energy goals make new wind farms a critical climate “stabilization wedge” [5]. In 2015, 8598 MW of new wind capacity was added in the US, accounting for 41% of electric-generating capacity additions [3]. The US is expected to add around 2.5 GW of wind power per year between now and 2020 [6]. Bloomberg New Energy Finance [4] estimates that zero-emission energy sources could contribute up to 60% of installed capacity by 2040.

Presently, the US east coast (along with the deep south), as compared to the rest of the continental US, has little wind power production. As of the end of 2016, the thirteen states that border the Atlantic Ocean[1] cumulatively have 3286 MW of installed capacity, comprising approximately 4% of the US’ installed wind power capacity of 82,183 MW [7]. However, almost all of that installed capacity is found in two states—New York and Maine—which together have 2728 MW of installed capacity [7]. In addition, in early 2017, a commercial-scale wind project was commissioned in the southeast—the Amazon Wind Farm US East—with 104 wind turbines (208 MW) spanning two North Carolina counties [8].

A main contributing factor to the low levels of installed capacity are the widely spread low wind speeds. At 80 m, wind speeds in multiple east coast states are between 4.0 m/s and 6.0 m/s. In comparison, wind speeds on the US Great Plains average around 8.5 m/s and can routinely reach 10 m/s AWS [9]. Due to the rapid expansion of wind power installations in the past two decades, many viable high wind speed sites have already been developed, and in other areas, such as the eastern and southeastern portions of the United States, high wind speeds are for the most part lacking. If jurisdictions wish to meet future energy demands and renewable energy goals and do so locally, they will need to consider a suite of options including solar, offshore wind power and low wind speed land-based sites.

A main concern in developing low wind speed areas is economic feasibility. New “advanced” wind turbines, which are marked by having high hub heights and large rotor diameters, are a potential solution. Not only are these machines able to produce significant power in low wind speed areas given the swept area of the blades, but they are also considered to deliver more constant electricity compared to earlier wind turbine models [10]. Delivering electricity at a more constant rate can facilitate integration and result in an increase in economic value of the power produced. Other benefits of new turbine designs include increased wholesale value of bulk power produced and a reduction in forecast errors and grid costs [10]. Yet, despite improvements in capacity factors as turbines with higher hub heights and larger rotor diameters have been brought to market, questions remain over whether or not it would be economically viable to develop low wind sites.

Those questions were partially answered by the United States Department of Energy (DOE) in 2015. Examining continental-scale data, DOE suggested that it might be economically-feasible to develop wind projects along the east coast of the United States given estimated capacity factors for wind turbines with hub heights positioned at 110–140 m and the relationship between the levelized cost of energy (LCOE) and hub-height [11]. An analysis of basic factors such as available land, and micro data on wind speeds and geology is a necessary next step to determine whether it is feasible to develop wind farms along the east coast of the United States and other low wind areas.

Assessing the potential energy and revenue stream of a specific turbine at given low wind speed site using micro-scale wind speed data is a vital step in planning a wind farm project [12]. Although the authors there discuss methods for analyzing a turbine’s performance at different types of sites, they do not use a specific place as a case study. In terms of economics, Capellaro [13] discusses a method to predict the value of wind power subject to pure market prices, as well as different types of potential financial support, but ultimately is more focused on how wind generation relates to local market electricity prices than on price of power production per se. Moreover, while underscoring the importance of micro data, Capellaro uses average hourly European regional EPEX spot market prices over the course of one month to develop his model rather than prices that can vary locally.

More generally, a review of the literature as a whole has not revealed any published study that has used site-specific data to make direct observations on the potential economic output of a low wind speed site either in the eastern United States or elsewhere for that matter, resulting in a gap in understanding. Johansson and Thorson [14], Johansson et al. [15], and Molly et al. [16] each provide results suggesting that wind turbines with lower specific power could be economically beneficial in areas of low wind speed. However, all three studies use theory and models, as opposed to site-specific data, with Johansson and Thorson [14] calling for a future study that includes wind speed data at the micro-scale to improve modeling. This study thus contributes to, advances and moves beyond the literature in several respects. Although the study reported here is not a modeling exercise per se, it is at least a partial answer to their call and adds significantly to the body of knowledge regarding costs and value of wind power in low wind regimes. Indeed, not only does present study employ site-specific micro wind data to determine energy output and to estimate pay back periods, but it integrates micro-scale geologic, land-use and transmission data, local wholesale prices for electricity, and local values attributable to the environmental attributes of wind power into the wind power cost and value models generated. Moreover, it does so by bringing together researchers with expertise in meteorology, geology, policy analysis, land use planning, and policy analysis. As such, it moves considerably beyond theory to application, and provides a needed interdisciplinary approach, which for the most part is lacking in energy research, and in that regard is novel.

Although development of low wind sites cannot solve all of societies ills, it can help states meet their clean energy goals, displace fossil fuel generation and its un-priced environmental, health and climate effects, contribute to stable electricity rates, produce economic development and create jobs, and provide an indigenous, local source of electricity. Detailed, site-specific analyses serve to bridge the gap that exists between the theory of low wind speed area development and actual implementation by developers. Indeed, land areas might otherwise languish in a site development “valley of death,” which may be as deep and pernicious as those witnessed in the energy technology sector between research and development and the market, resulting in the “loss” of all the aforementioned benefits.

In order to evaluate DOE’s proposition using site-specific data, we evaluated a relatively rural county in the United States—Sussex County, Delaware—as a case study. Delaware is among nine states along the east coast of the United States that have 0–100 MW of installed wind capacity. Table 1. Currently, Delaware only has 2 MW installed capacity, which comes from a single, one-turbine project that has been operating in Lewes, Delaware since 2010 [17]. Delaware is the 40th ranked state in installed capacity and has no wind power under construction [7,18]. This is in contrast to the California, where the modern wind power revolution began and which has 5656 MW; Texas, with the largest installed capacity of more than 20,000 MW, and Iowa, with the largest share (36.6%) of instate generation [7,18].

Utility-scale projects could be desirable in states such as Delaware given that Delaware’s Renewable Portfolio Standard (RPS) law mandates that a minimum percentage of the electricity supply be generated from renewable sources such as wind power—a percentage that increases each year. Additionally, in-state generation can contribute to a state’s economy.

A crucial component of wind project financing is the production tax credit (PTC).[2] The PTC is a tax credit for the production of electricity, and is used as a federal incentive to provide financial support for wind

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[1] The thirteen colonies did not include Florida. Also, at the time of the American Revolution Maine was part of the Massachusetts Bay Colony only becoming a separate state in 1820 as part of the Missouri Compromise. The thirteen colonies also included Pennsylvania, which has an additional 1369 MW of installed capacity [3].

[2] A related tax credit is the investment tax credit (ITC), which pertains to the percentage of capital costs a business is allowed to deduct from its taxes. However, since the ITC is only available to small wind turbines up to 100 kW, often referred to as residential wind turbines [19], we do not consider it as an option in the cost estimation.