Energy Policy 96 (2016) 341–350

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Should we build wind farms close to load or invest in transmission to access better wind resources in remote areas? A case study in the MISO region

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HIGHLIGHTS

- We evaluate the economics of building wind farms in remote areas in MISO.
- We present a conceptual wind site selection model to meet 40 TWh of new wind.
- We use the model to compare remote windy sites to less windy ones closer to load.
- We show break-even transmission costs that would justify remote wind development.
- Comparing break-even values to historical costs, MN/IA sites are most economical.

ARTICLE INFO

Article history:
Received 9 January 2016
Received in revised form
28 May 2016
Accepted 3 June 2016

Keywords:
Wind power
Transmission
Variability
Decision making under uncertainty

ABSTRACT

Wind speeds in remote areas are sometimes very high, but transmission costs to access these locations can be prohibitive. We present a conceptual model to estimate the economics of accessing high quality wind resources in remote areas to comply with renewable energy policy targets, and apply the model to the Midwestern grid (MISO) as a case study. We assess the goal of providing 40 TWh of new wind generation while minimizing costs, and include temporal aspects of wind power (variability costs and correlation to market prices) as well as total wind power produced from different farms. We find that building wind farms in North/South Dakota (windiest states) compared to Illinois (less windy, but close to load) would only be economical if the incremental transmission costs to access them were below $360/kW of wind capacity (break-even value). Historically, the incremental transmission costs for wind development in North/South Dakota compared to in Illinois are about twice this value. However, the break-even incremental transmission cost for wind farms in Minnesota/Iowa (also windy states) is $250/kW, which is consistent with historical costs. We conclude that wind development in Minnesota/Iowa is likely more economical to meet MISO renewable targets compared to North/South Dakota or Illinois.

1. Introduction

Replacing conventional generation with wind power could reduce greenhouse gas (GHG) emissions and provide a sustainable, low-carbon source of energy. However, deciding where to build wind farms is not trivial. Many of the highest quality onshore wind resources in the United State (U.S.) are located in the Midwest, often in areas that are far away from load centers and that therefore require large transmission investments. An alternative to accessing these distant resources is to build farms closer to electricity consumers where wind power output may not be as high, but less transmission investment is needed. This paper provides a modeling framework that policymakers can use to inform where to build wind farms given these tradeoffs.

We focus on the Midwestern electricity grid, MISO (Midcontinent Independent System Operator), which spans 15 states. In 2012, 21% of total electricity sales were within Illinois, the most populous state in MISO. Including sales in the neighboring states of Missouri and Indiana, this percentage increases to 49%. In contrast, states that are more remote from major load centers such as North and South Dakota collectively account for only 4% of MISO's electricity sales[1] (U.S. Energy

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[1] For simplicity, we used total electricity sales within each state that is in MISO, even though some states are only partially in MISO. We did not include states within MISO's Southern region since they are outside the scope of our study's geographical focus.

http://dx.doi.org/10.1016/j.enpol.2016.06.011
0301-4215/

Table 1
Historical transmission costs per state (2014 $/kW of wind capacity).

	Percentile			# Observations in dataset
	25th	**50th**	**75th**	
IL	$22	$33	$115	29
IA	$55	$95	$180	20
MN	$50	$85	$158	51
SD	$267	$622	$727	29
ND	$264	$762	$1117	39

In the most recent queue database (MISO, 2013b) there were 338 wind farms with publically available transmission cost estimates in the states analyzed in this paper. Observations that recorded $0/kW in upgrades were excluded since these cases were for smaller projects and don't reflect the costs necessary to comply with 40 TWh of new wind generation. Some cost calculations in the queue dataset accounted for the recent Multi-Value transmission projects (MVP) in MISO, which are designed to reduce interconnection costs in MISO (MISO, 2012a). Sufficient data (sample > 20) for wind farms including MVP were only available for Iowa and Minnesota, which is not surprising since these states are the principle benefactors of the MVP projects. Thus the transmission cost estimates in this table for Iowa and Minnesota are derived from the subset of observations that included MVP projects (71 total); the other state cost estimates are derived from both MVP and non-MVP observations inclusive (97 total). The final dataset includes 168 different cost estimates (adjusted to 2014 $) from projects proposed between 2003 and 2013.

Information Administration, 2012). Compared to wind farms in North Dakota, Illinois wind farms tend to have lower transmission interconnection costs, as there is already a robust network of existing infrastructure (high voltage lines, substations, etc.). Based on data gathered from MISO's transmission interconnection queue, median transmission upgrade costs for new wind farms in Illinois are about $33/kilowatt (kW) of installed wind capacity, compared to $762/kW in North Dakota (see Table 1). This does not mean that North Dakota wind farms need to build dedicated, long-distance transmission lines into major load centers in Illinois, but it is likely more costly to upgrade the more limited transmission infrastructure in North Dakota compared to Illinois.

There may be benefits to building wind farms in remote areas if the total amount of power produced is larger than in closer locations and if it is produced at times when the electricity generated is more valuable. Consider again the example of North and South Dakota compared to Illinois. According to power output data of hypothetical wind farms from the National Renewable Energy Laboratory (NREL), North and South Dakota wind farms result in average capacity factors of 43% compared to 40% in Illinois ("Eastern Wind Interconnection and Transmission Study (EWITS)", 2012). At first glance this difference may appear small, but it accounts for a cost difference of $1.4 billion in upfront costs when trying to meet a wind generation target of 40 terawatt-hours (TWh) per year (equivalent to renewable targets in MISO), assuming that installed capital cost for wind farms are $1750/kW. Accessing higher capacity factor wind sites in remote areas could substantially reduce costs to meet policy goals, even if transmission upgrade costs for these sites are higher. Furthermore, the timing of wind power production is critical. Wind farms are most valuable when they produce during times of high energy demand, which corresponds to higher prices in energy markets, and a larger payment in capacity markets (in MISO, capacity payments for wind farms are based on the capacity factor of wind farms during peak load hours (MISO, 2013a)). Additionally, because wind power production is variable, other generators will have to ramp to fill in the gaps when wind speeds are low. Wind farms that require less ramping from other generators are therefore more valuable. Thus, when considering the temporal aspects of wind power, the problem of where to site wind farms (remote or local locations) becomes much less trivial than simply comparing capacity factors and transmission costs.

Hoppock and Patiño-Echeverri (2010) introduced a wind capacity expansion model to meet 10 TWh of new wind generation in MISO. They accounted for annual energy production at different wind farms as well as the transmission cost to access farms in distant locations such as Minnesota and Iowa. They find that given the high transmission cost to access more distant locations, it's more economical to build near lower-quality wind resources in Illinois. However, the authors also acknowledge that results depend on their transmission cost assumptions, which are based on limited data and may not reflect future costs. The transmission landscape is rapidly changing in the region, as demonstrated by the Multi Value Project portfolio, a $6.5 billion initiative that will increase transmission interconnectivity throughout MISO (MISO, 2012a). Therefore, as Hoppock and Patiño-Echeverri (2010) point out, it's very difficult to make static assumptions about transmission costs and arrive at strong conclusions.

Ultimately, the decision to build wind farms in a remote region depends on the difference in transmission upgrade costs between regions. In this study, we estimate the difference in transmission upgrade costs needed to justify the decision to site wind farms in lower-quality sites that are closer to load. We refer to this as the "break-even transmission cost premium" to access remote wind farms. If the difference in transmission costs across regions is below the break-even value, then it is more economical to build wind capacity in the remote region. We do not make strict assumptions about transmission costs, and instead provide break-even cost premium values that can be used by decision makers with information on true transmission costs. No paper to date has used this approach when considering siting decisions for wind development.

We use MISO as a case study given its ambitious renewable goals. We denote Illinois as the "local" region and Iowa/Minnesota (MN-IA) or North/South Dakota (ND-SD) as the "remote" regions. We assume that new wind capacity must be built in either the local or remote region (or both) to meet 40 TWh per year of additional wind generation in MISO. This goal is equivalent to complying with the Renewable Portfolio Standards (RPS) in Illinois, Minnesota, and Missouri.[2] These 40 TWh of wind generation correspond to about 5.7% of total load in MISO. There is currently about 40 TWh of existing wind in MISO so with the additional wind built in our analysis, this percentage would increase to 11.6% (MISO, 2015a, 2015b). We develop an optimization model that minimizes total wind installation and transmission costs to meet this target by selecting among a predetermined set of hypothetical wind farms. We account for each wind farm's energy value, capacity value, and the negative effects to dispatchable generators due to the variability in power output from the selected wind farms. No paper to date has included these temporal aspects of wind power production within a wind capacity expansion model. Finally, to calculate the "break-even transmission cost premium" to build wind farms in remote regions, we parameterize our transmission cost assumptions across different scenarios to see how the optimal solution changes (i.e., whether wind farms are built in Illinois versus MN-IA or ND-SD). We test how different assumptions affect these values in a comprehensive sensitivity analysis in Section 3.3.

This work contributes to the wind integration literature by presenting a conceptual framework for analyzing wind farm siting tradeoffs, and the numerical results reported here are meant as an approximation to study these tradeoffs in MISO. To demonstrate the usefulness of these results, we compare our estimates of "break-

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[2] RPS Targets (Database of State Incentives for Renewables and Efficiency (DSIRE), 2015) were compared to wind generation by state (U.S. Energy Information Administration, 2015) to estimate additionally required wind generation.