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Investment cost and view damage cost of siting an offshore wind farm: A spatial analysis of Lake Michigan

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ABSTRACT

Investment and view damage costs are important determinants in siting locations for offshore wind farms (OWF) in the Lake Michigan region. This study is limited to the Michigan state boundary for the OWF sites and viewshed impacts. Investment cost depends on the depth and distance to shore of the farm. View damage cost depends on household density and consumer willingness to pay to avoid the visual disamenity of wind turbines. Both these costs are dependent on the geographic location and are summed to create an aggregate cost. Using ArcGIS, the OWF siting locations were mapped, with spatial analysis revealing the northern region of the lake at the minimum aggregate cost. The view damage cost contributes at most 68%, but on average 7%, to the aggregate cost. The aggregate levelized cost of energy (LCOE) ranges from 183 to 368 $/MWh (average of 256 $/MWh). The view damage LCOE contribution to the aggregate LCOE is 3% on average and 46% at most. View damage impact is the dominating factor only around a small shoreline region (due to large impacted populations). A series of maps are presented that highlight the investment and view damage tradeoffs which can inform OWF siting in Lake Michigan.

1. Introduction

Wind energy is becoming one of the fastest growing renewable energy technologies with 45 GW of wind power added globally in 2012, which represented 15.9% of the world's total capacity additions [1]. Over 1.1 GW (2.4%) of the 45 GW increase was from offshore wind power [2]. For the United States, 13 GW of wind power was added in 2012, none of which came from offshore wind power sources [3].

The U.S. Department of Energy has invested $227 million in offshore wind projects and research since 2011 [3]. These development projects range from the East Coast (where there is minimal space for onshore wind potential, but high demand for energy), the Gulf of Mexico (where there are many ports available for constructing large offshore wind structures, and Oregon (where the technology of floating wind turbine foundations can make offshore wind a reality for this deep coast area) [3]. These unique constraints and benefits highlight the many opportunities for innovation in supporting offshore wind in the U.S. In the Great Lakes, there are significant benefits due to shallow lake depths and high wind speeds close to the power demand areas. However, there are also disadvantages and constraints such as strong local opposition, ice effects on turbine and foundation structures, and existing policy and environmental regulations for Lake development.

Since none of the Great Lakes offshore wind energy potential is currently under development, this paper looks at the tradeoffs in siting offshore wind farm (OWF) locations in the Lake Michigan region. Specifically, it focuses on the Michigan governed portion of Lake Michigan. The resulting framework can be used to inform future development. Typical siting practices used by project developers look solely at maximizing the energy generation capabilities (high wind speeds) and minimizing the project costs (low depths) while abiding by the local laws/regulations. They then rely on public outreach and community engagement to address any social objections throughout the process [4]. In this case, the viewshed is not considered a separate cost, but rather a factor to be aware of. While other studies analyzed OWF siting through different influences such as: economic valuation terms (Korean peninsula [5]), social viewshed impacts (Delaware [6]), or spatial GIS integration (Greece [7]), similar analyses have not been done in Lake Michigan. Moreover, this paper looks at the view damage cost as a separate tradeoff with equal consideration as power generation or economic costs.

Abbreviations: LCOE, levelized cost of energy; O&M, operations and maintenance; OWF, offshore wind farm(s); WTA, willing(ness) to accept; WTP, willing(ness) to pay.

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One example of a siting assessment is the Report of the Michigan Great Lakes Wind Council, which defines favorable and unfavorable Michigan locations based on existing uses, state and federal laws, and environmentally excluded areas [8]. The results of this are presented in Fig. 1. An example of a proposed project was Scandia Wind's Aegir Project, which proposed placing two 500 MW wind farms 4–6 miles off the coast of Muskegon and Ottawa counties in Lake Michigan [9]. However, the local residents believed the turbines would dramatically alter the view and be detrimental to their way of life, so they voted against the installation thereby leading to project cancellation [10]. The project would have had significant societal benefits such as over 3000 new (temporary) jobs and cleaner air quality due to displacing polluting energy sources [9]. Ultimately, perception of the view damage cost ended up derailing the project. View damage cost characterization will need to be incorporated sufficiently into current siting practices to make OWF projects successful in the Great Lakes.

This paper develops a spatial modeling framework to quantify tradeoffs between investment cost and view damage cost in OWF development in the Lake Michigan region. These costs will also be levelized by the power generation to provide comparable cost of energy results throughout the region. This analysis will enable quantitative consideration of viewshed in OWF siting and also allow a comparison of its importance relative to investment cost. This spatial assessment will be similar to the maps from the Great Lakes Wind Council report with the final results visually portrayed as a series of maps categorizing the investment cost, view damage cost, and the summation of those costs (defined as aggregate cost) [8]. This siting location analysis will also show whether investment cost or view damage cost is more influential in determining the lowest cost siting locations. This analysis can also inform potential policy changes in the state of Michigan.

2. Methodology

For this analysis, ArcGIS was used to compute and display the investment cost, view damage cost, and wind power generation as spatial models used in offshore wind turbine siting in Lake Michigan. The investment model and view damage model represent the calculated cost, while the wind power generation model represents the power generation. In the models, sites defined by geographic location (latitude and longitude) are analyzed to determine the minimum cost location which are influenced by several factors. Geographical data such as bathymetry (lake depth), land elevation, and spatial data contribute to the investment and view damage models [11]. Additional census factors include household count data by county and land use data analyzed with the viewshed survey data for the view damage cost model formulation [12]. Data on wind speeds are combined with the power generation curves as the factors used to create the wind power generation model [13].

The models also include assumptions (fixed parameters independent of location) to define the model scope. Each model consists of 100 3 MW Vestas V112 turbines (300 MW OWF) oriented as a 10×10 grid with the spacing of 4 diameter lengths from north to south and 7 diameter lengths from west to east [14] [15]. This layout is a standard placement to minimize wake effects [16] (wind turbulence of one turbine affecting the downwind turbine) assuming the direct wind flow direction would come from west to east, which is the predominant wind direction in the winter when the winds are the strongest in Lake Michigan [17]. This model focuses on the spatial derivation of costs and minimizing these costs, so typical siting constraints such as shipping lanes and migratory pathways are not modeled. This allows decision makers to view unconstrained results, and it may serve to influence broader policy initiatives.

The sections below describe how the data are used to model investment cost, view damage cost, and wind power generation. The modules defining the factors and processes used to create the models are in Appendix A.

2.1. Investment cost modeling

The investment cost model is based on a similar model developed by Dicorato, which included installation, port, and

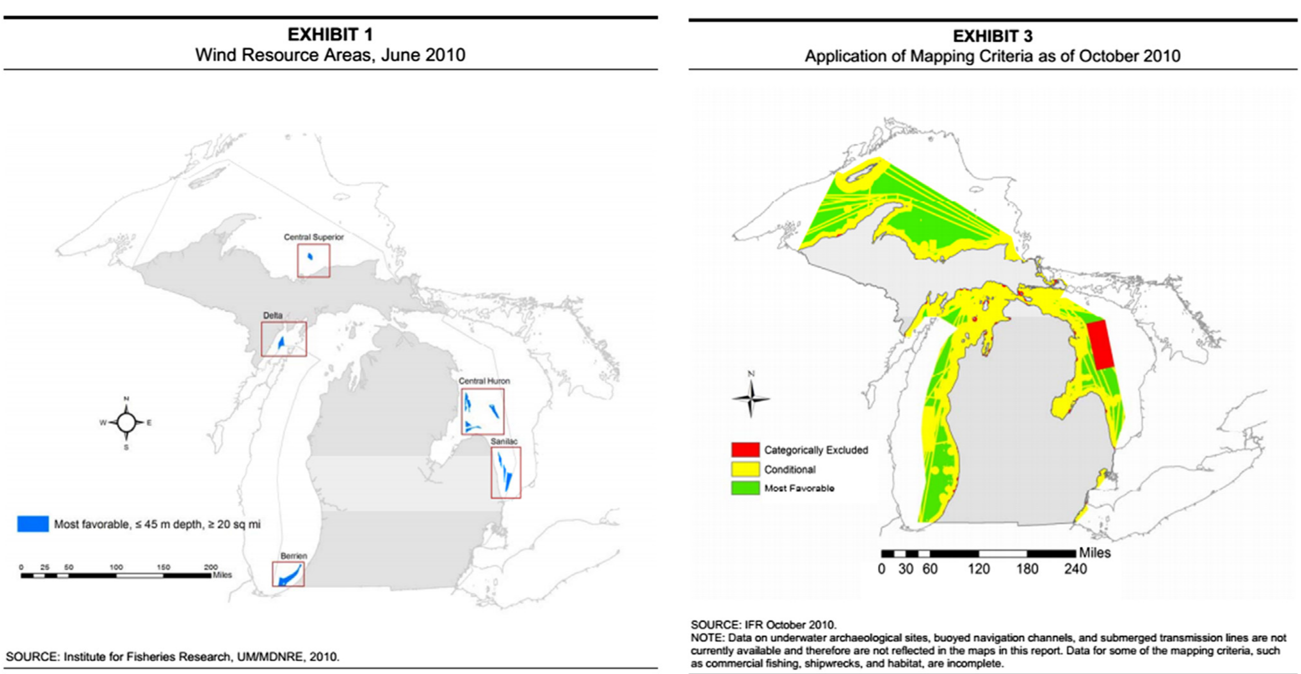

Fig. 1. Lake Michigan offshore wind siting representing favorable locations ≤45 m depth, ≥20 sq mile (52 sq km) and defined as “categorically excluded, conditional, and most favorable” (figures from Klepinger [8]).