399MW Offshore Wind: Lake Michigan Powers Wisconsin and Iowa Sustainably

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Abstract

Northern Arizona Universities Project Development team for the 2024 Collegiate Wind Competition sponsored by the Department of Energy seeks to develop an offshore wind farm within the constraints of Lake Michigan. The purpose of this project is to address the needs for renewable energy production to combat and replace fossil fuel power plants that prove to have significant effects to the environment. This hypothetical offshore wind farm utilizes 42 Vestas V174-9.5MW turbines for a nameplate capacity of 399MW. Major design considerations were:

- Environmental and public impacts and mitigation
- Grid integration
- Financial analysis
- Overtaking the transmission capacity of a retiring fossil fuel power plan, Edgewater Generating Station

The details of the proposed offshore windfarm follows:

- Located 25 miles east of Sheboygan's shoreline
- Requires 2 offshore substations and 1 onshore substation
- Generates 2.1 million MWh annually.

The integration of this hypothetical offshore wind farm is expected to increase the 8.1% of utility scale net electricity generation of renewable energy for the state of Wisconsin to 33.4% and decrease fossil fuels from 75.4% to 56.2%. Additionally, Iowa is expected to increase renewable energy production from 67.2% to 75.7% and decrease fossil fuel production from 32.6% to 24.1%

DOE Competition Requirement

- Assess wind farm development opportunities within the Great Lakes and create a development plan along with a bid price of the specified leasing area.
- In depth research for site-characteristics
- Offshore wind farm designs consideration includes: wind turbine selection, transmission infrastructure, construction and operation plans, and surveying and instillation plans.
- Incorporate one other generation, storage, or end-use technology as part of a hybrid power plant.
- Conduct a cost-of-energy and cash flow analysis for a 20 year project that includes: initial capital costs, operating expenses, energy production, levelized cost of energy, and a power purchase agreement.

Siting

NAU Wind Jacks Offshore Wind farm (dark blue marker) pursued Lake Michigan with an emphasis of locating the base of operation in Sheboygan, WI (gold marker). This allows the team to replace the transmission capacity that will be lost due to the retirement of Edgewater Coal-Fire Generating Station. In terms of lake activity and shipping lanes, this location is the less dense compared to the rest of the lake. Noise pollution and bird migration are key environmental impacts that can easy be avoided by shutting the plant down during seasonal migration.

Figure 1 - Location

Transmission Infrastructure

By replacing the transmission capacity from Edgewater Generating Station, the team will be able to partner with Alliant Energy, the utility company that will purchase the generated electricity and distribute it to their customers. The current 345 kV transmission lines will distribute the teams 399 MW to approximately 1 million customers spanning from Wisconsin to Iowa. This will ultimately increase the Utility-Scale Net Electricity Generation of Renewable Energy of Wisconsin by 25.3% and 8.54% in Iowa. Consequently, this will decrease the total share of fossil fuels by 21.3% in Wisconsin and 8.19% in Iowa. This all thanks to the 2 circuit design of the offshore wind farm, 1 offshore substation, and 2 on shore substations.

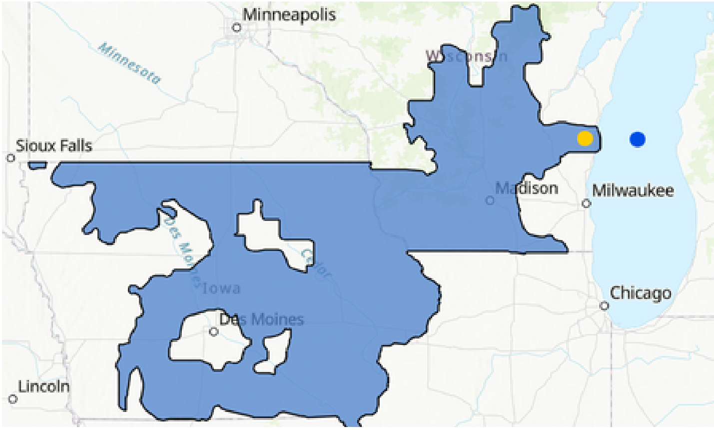

Figure 2 - Alliant Energy Service Grid

Leasing Block

The following is the design constraints of the selected leasing area in Lake Michigan:

- Total area of 22 sq. miles
- 25 miles east of the Sheboygan, WI shoreline

It is to be expected that the bid price for this lease block is approximately $8.72 Million USD.

Figure 3 - Leasing Block Dimensions and Location

Market Prediction for Levelized Cost of Energy

For an offshore wind farm that has a nameplate capacity of 399MW, the Levelized Cost of Energy for the year of development, 2030, is ¢8.71/kWh [3]

Power Purchase Agreement

100% of the generated electricity from NAU Wind Jacks Offshore Wind Farm will be sold to Alliant Energy at ¢18.1/kWh for the state of Wisconsin and ¢9.87/kWh for the state of Iowa over the course of the 20 year operation life cycle.

Engineering and Client Requirements

Client Requirements

- 20 Year Lifespan
- Siting Selection
- Technology Selection
- Development and Technical Integration Plans
- Financing Plan
- Annual Energy Production

Engineering Requirements

- Leasing Block Area
- Levelized Cost of Energy
- Capital and Operational Expenditures
- Wind Data
- Site Bathymetry
- Power Grid Utility Line Connections
- Port Infrastructure

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SAM and JEDI

- The combined use of SAM and JEDI allowed a thorough initial financial analysis. Through SAM, the team found a Levelized Cost of Energy of 14.55¢/kWh. Through JEDI the team found that the break-even point is 20 years.
- Comparing these results to the DOE 2023 Offshore Market Report, the team has room to improve design and analysis [3].

Farm Layout

- 42 Vestas V174-9.5MW turbines
- Nameplate capacity of 399MW
- 6 x 7 grid with 900 m between columns and 1400 m between rows
- Grid is 5 degrees off horizontal for wind adjustment

Figure 4 - Farm Layout

Methods

- Wind power plant feasibility assessed with three programs.
- Furow is designed for wind farm development and handles data for wind resource, turbine, and site, to create a thorough prediction of power output performance to allow for design optimization.
- The System Advisor Model (SAM) and Jobs and Economic Development Impact Model (JEDI) are designed to consider the capital expenditures and operational expenditures of a wind power plant in order to determine if the power plant is projected to be profitable.

Furow - Wind Farm Power Output Analysis

- Wind resource data was acquired from the National Renewable Energy Laboratory for the latitude and longitude (43.75,-87.15) of the proposed site [2].
- A power curve for a 10MW offshore turbine with similar height and operational windspeeds was scaled to represent the selected V174-9.5MW turbines.
- Energy loss estimations were generated for glaze icing under conditions for temperatures between -6.7°C and 0.1°C and relative humidity above 90%.
- Furow calculated power output and farm performance using the above inputs with the eddy-wake viscosity model to account for turbulence and wind degradation.
- Outputs include energy production of 2.1 Million MWh, array efficiency of 94.4% and a Capacity Factor of 48.1.

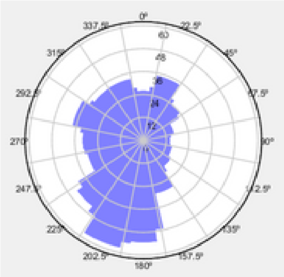

Figure 5 - Energy Generation

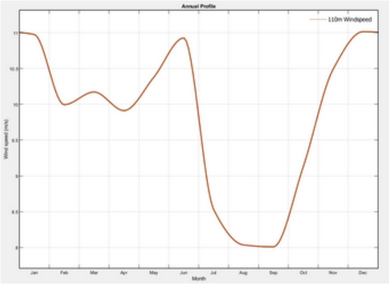

Figure 6 - Annual Wind Resource

Conclusion

- The design of this hypothetical wind farm has the potential to generate 2.1 Million MegaWatt hours in a year.
- Initial financial analysis results in a Levelized Cost of Energy (LCOE) of 14.55¢/kWh
- The Power Purchase Agreement for this LCOE is 18.1¢/kWh for the state of Wisconsin and 9.87¢/kWh for the state of Iowa
- The power plant is set to reach profit at year 20.

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U.S. DEPARTMENT OF ENERGY furow NREL NATIONAL RENEWABLE ENERGY LABORATORY ArcGIS ENERGY CLUB

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