Offshore Wind Power Location Assessment of Rhode Island Sound

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Abstract

Offshore wind power is experiencing exponential growth in the United States, and the assessment of potential areas is a crucial step in erecting a farm. This paper outlines the methods involved in completing a full assessment of the Rhode Island sound and can be used when doing offshore assessments of similar areas.

Measured point data was collected by NDBC buoys BUZM3 and 44097 every ten minutes dating from January 2010 to June 2012 and mean wind speeds were calculated. A turbine count was calculated assuming 0.54 km2 per turbine. An available area analysis yielded the max potential area, and from that max power output was established. The area analysis was done with the NOAA Marine Cadastre program and took shipping lanes, sand borrow areas, and visual exclusion into consideration. A total area of 963.04 km2 was found meaning a max turbine count of 520 and the average yearly power output was 1,780 megawatts.

A full analysis of the Rhode Island sound was completed and could be used to determine the viability of an offshore wind farm in the area. The potential for renewable energy in the US is highlighted in this paper.

1. Introduction

In this paper a methodology for assessing the viability of an offshore wind farm in the Rhode Island Sound will be discussed. The steps include available area mapping, power production calculation, and turbine count. The raw data was collected by National Data Buoy Center buoys BUZM3 and 44097. The final max power output was calculated and can be used in a market evaluation for the area.

2. Review of Literature

Large wind power farms are one of the fastest growing industries in the country especially along the eastern and western coasts and the Great Plains (Snyder et al, 2008). Wind power may in time replace oil and fossil fuels as a reliable source of electricity. Assessing a location for wind power involves assessing the many factors that go into a successful wind farm, from average wind speeds to popular opinion. The US outer continental shelf may have the greatest potential of all areas in the United States (Sawyer et al, 2010). Wind power could have a great contribution to reducing our dependence on fossil fuels while reducing total nationwide emissions by nearly 1,000,000 tons (Sawyer et al, 2010). Cape Cod's "Cape Wind" wind farm is the first offshore wind farm of its scale, with 130 3.6 MW ratings, producing up to 420 MW of renewable energy. This will pave the way for more wind farms on the outer continental shelf.

There are many elements that contribute to power generation from wind. While wind speed is extremely important, consistency is also a vital factor to producing electricity. Because electricity moves from the turbine to a household almost instantly, steady winds are the only winds that can be effectively used in power generation. This is one of the reasons fast, stable winds off the ocean are considered the ideal for wind power. This is very apparent in the wind field over the Outer Continental Shelf (OCS)(Garvine et al, 2008). The major factor holding back wind power today is building costs and wind power's biggest adversary, wind variability. Because the wind doesn't always blow, electricity is not always produced. However, this can be remedied, to an extent.

Variability is the largest hindrance for most renewable energy sources such as wind, solar, and wave power. There have been many studies to try and reduce variability so these technologies can be viable as sources of energy. One method that has been extensively researched is the combination of different sources of energy to reduce variability (Snyder et al, 2008). For example, combing an offshore wind farm and wave powered generators would create a more even flow of electricity. The less consistent winds produce more energy overall, but with much more variability than steady waves. This type of electricity generation can work with other sources of electricity. Natural gas generators and solar power can work well with onshore farms (Zhao et al, 2009). A second method that may become popular in the future is the combination of farms at different locations (Lu et al, 2007, Kempton et al, 2010). This has been shown to extremely reduce variability; up to 87% of the variability of one non-connected farm was eliminated when connected with three other farms in separate locations with different wind patterns (Apt et al, 2010).

Wind power is almost entirely green. However, construction emissions and co-located generators are the main sources of emissions (Katzenstein et al, 2008). When natural gas generators are co-located with wind turbines, the variability that has to be covered by the generator is the source of CO2 and NOX gasses. However, the lack of emissions from the turbines covers this and leaves the electricity generation with low variability and low emissions. There are other detrimental aspects of wind power that must be worked around, one being the killing of migratory birds that fly around the turbines (Kikuchi et al, 2009). Their deaths aren't caused by direct contact with the blade, but the pressure drops caused by the turbines can rupture the birds' chests. This is only really a problem with birds that migrate through zones in which wind turbines are placed. Knowing when and where the birds migrate and then building in other areas while birds are migrating is the easiest way to avoid the problem (Kikuchi et al. 2009). Marine life and interference with fishing areas can also be a drawback for offshore farms if not properly prepared for (Dhanju et al, 2008). However, the base of towers can be used to stimulate coral reef growth if erected in the correct faction, and when the towers are spaced apart enough they do not interfere with fishing locations (Dhanju et al, 2008).

Wind power interest has boomed in the last decade because of environmental concerns, its immense potential and, importantly, the rising cost of fossil fuel (Bolinger et al, 2008). Wind power is a source of energy that will never run out, making it a very attractive commodity. It also can be very lucrative when variability is reduced and there are no major losses from other factors such as transport and grid failures (Bolinger et al, 2008). A theoretical 500 MW farm has been shown to have a cost of energy of $54/MWh, which is lower than the national average of $58/MW h and very close to the less environmentally friendly coal, at $49/MW h (Snyder et al, 2009, Apt et al, 2009). Before any farms can be put up, a location must be assessed for viability of power output, acceptance of the local population, and other factors regarding the location (Dhanju et al, 2008). In offshore locations, many of these factors could include exclusion zones, shipping lanes, migratory bird routes, bathymetry, and of course wind speed. When an area is deemed viable, the possible annual revenue is assessed based on wind speeds, turbine height, and the amount of time the farm could be active if not all year. Wind speed and regularity are the most important factors when assessing a location (Dhanju et al 2008).

The National Buoy Data Centers (NBDC) buoys are often used when recording wind speed for the OCS and the US Middle Atlantic Bridge (MAB). In a study of the MAB, 18 years of hourly data were analyzed and turbine height data was found using a wind height methodology (Garvine et al, 2008). After wind speed and regularity have been assessed, other factors must also be considered when evaluating a location: Mapping of the area is vital to determine exclusion zones when using ocean floor based towers', this data is used to determine the available water sheet area and count of turbines. The final step when calculating power production involves the area's market value based on the closest electric grid node. Also, when considering location it is important to determine public opinion, especially if the farm would be in sight from the shore. (Dhanju et al, 2007)

3. Research Objective

A full wind power assessment of the Rhode Island Sound was conducted using mean wind speed data recorded every 10 minutes for the past three years, with minor data inconsistencies. The data was recorded using National Data buoy Center (NDBC) data collection buoys with anemometers at varying heights. Two buoys were used in this assessment: buoy station BUZM3 and buoy 44097. Once the mean wind speed was found, an extrapolation equation was used to determine hub height wind speeds, for this study, the pre-determined hub height was 80m. The mean wind speed at hub height would then be used to determine the max kW output per turbine.

The next step after determining max electrical output was to use mapping programs to discover the total available area over which turbines could theoretically be placed. This step, known as available area mapping, was done using the National Oceanic and Atmospheric Administration's (NOAA) Multipurpose Marine Cadastre Program.

The research objectives of this assessment were to fully understand the viability for a wind farm in the Rhode Island Sound area. All major factors were taken into account to find the max area, the mean wind speed, and the economic impact on the local power grid.

4. Methods

5. Available Area Mapping

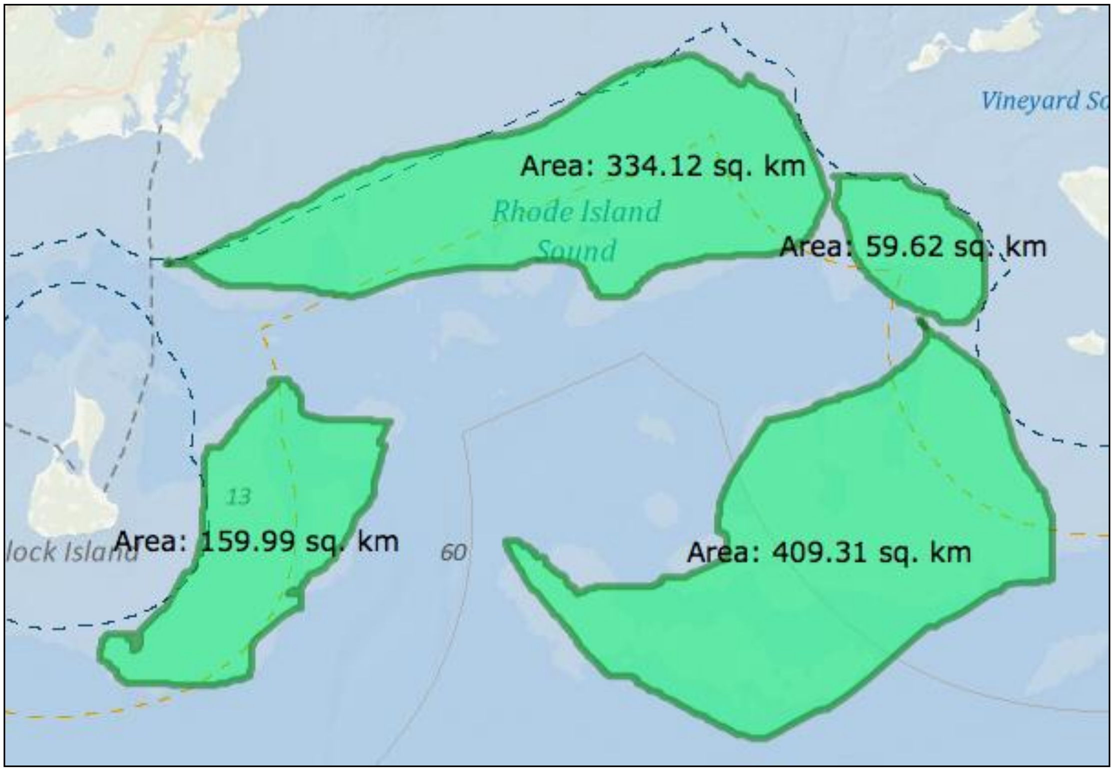
5.1 Bathymetry

The first step of the study is to find the max possible area that can sustain a turbine farm. For this study, waters deeper than 30m were excluded and areas within 3.5 kM of shore were excluded. The area was mapped using the Multipurpose Marine Cadastre program the area was mapped. (See Fig. 1)

The 30m depth was chosen for the exclusion analysis because our theoretical turbines are 80m high and can be built in waters 30m deep and shallower. This excludes all areas within 1 km of land to minimize possible visual impact and conflict with local residents. This would hypothetically be up for debate in the area, but for this test the 1km exclusion was used.

Other exclusion analysis includes shipping lanes, bird zones, and military exclusion zones, which were found to be minimal. These factors have been deemed insignificant and will not be used in the final calculation for available area.

Fig. 1: Map of the Rhode Island Sound: 963.04 total area – from 0m to 30m in Rhode Island Sound



6. Power Production

The use of measured point wind data was used because of the uniformity of the ocean. Widespread buoys were acceptable due to the lack of terrain change on the ocean, where as in a hilly or wooded area many more, much closer anemometers would have to be used. Buoy station BUZM3 is located 1.3 km South East of the Rhode Island Sound, technically being placed in Buzzards Bay, MA. This station's anemometer was at a height of 24.8m above sea level. Buoy 44097 is located roughly 5 km south of the Rhode Island Sound and had an anemometer at 5m above sea level. (See Fig. 2)

Fig. 2: Buoy locations and height

Location ID	Anemometer Height	Latitude (N)	Longitude (W)
NOAA ID 44097	5 m	40°58'52"	71°7'1"
NOAA BUZM3	24.8 m	41°23'48"	71°2'0"

Fig. 3: Average yearly Buoy wind speed

Buoy (year)	Average buoy height wind speed (m/s)	Average extrapolated wind speed (80m) (m/s)	Average generated electricity (kW)
BUZM3 (2010)	7.9	8.8	3656.8
BUZM3 (2011)	7.4	8.4	3307.3
BUZM3 (2012)	7.5	8.4	3268.2
44097 (2010)	7.0	9.2	3656.8
44097 (2011)	6.4	8.5	3312.9
44097 (2012)	6.4	8.5	3353.9

The data used in this assessment ranges from January 2010 to June 2012. The data is nearly constant with buoy BUZM3; however, there is a three-month gap from September 2011 to November 2011 with buoy 44097. Figure 2 shows non-extrapolated and extrapolated speeds as well as the calculated kilowatt generation for each month.

These numbers, in conjunction with the max turbine count, can be used to conclude the total power output for the entirety of the Rhode Island sound. The location can be presented as a single number, which can also be used for market value assessments, which will not be discussed in this paper.

Fig. 4: Average monthly electrical output data for 2011 from buoy BUZM3

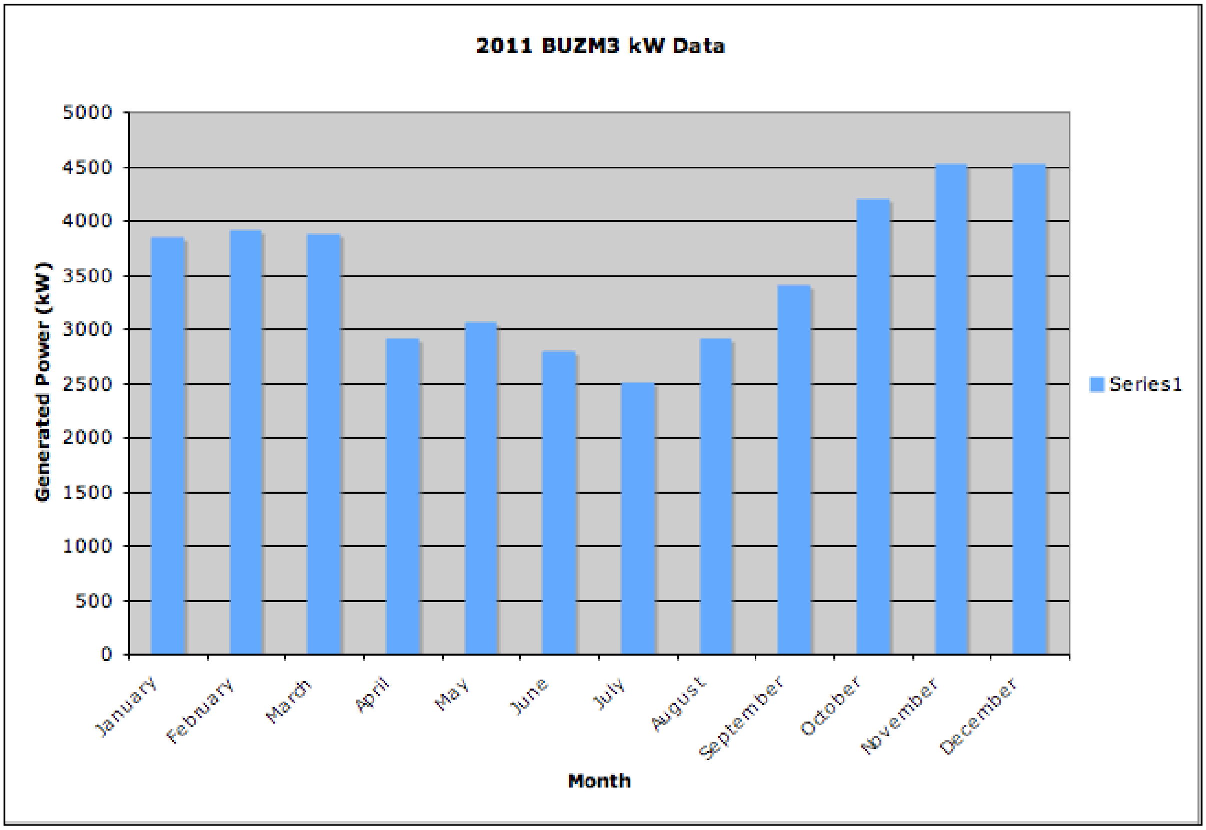
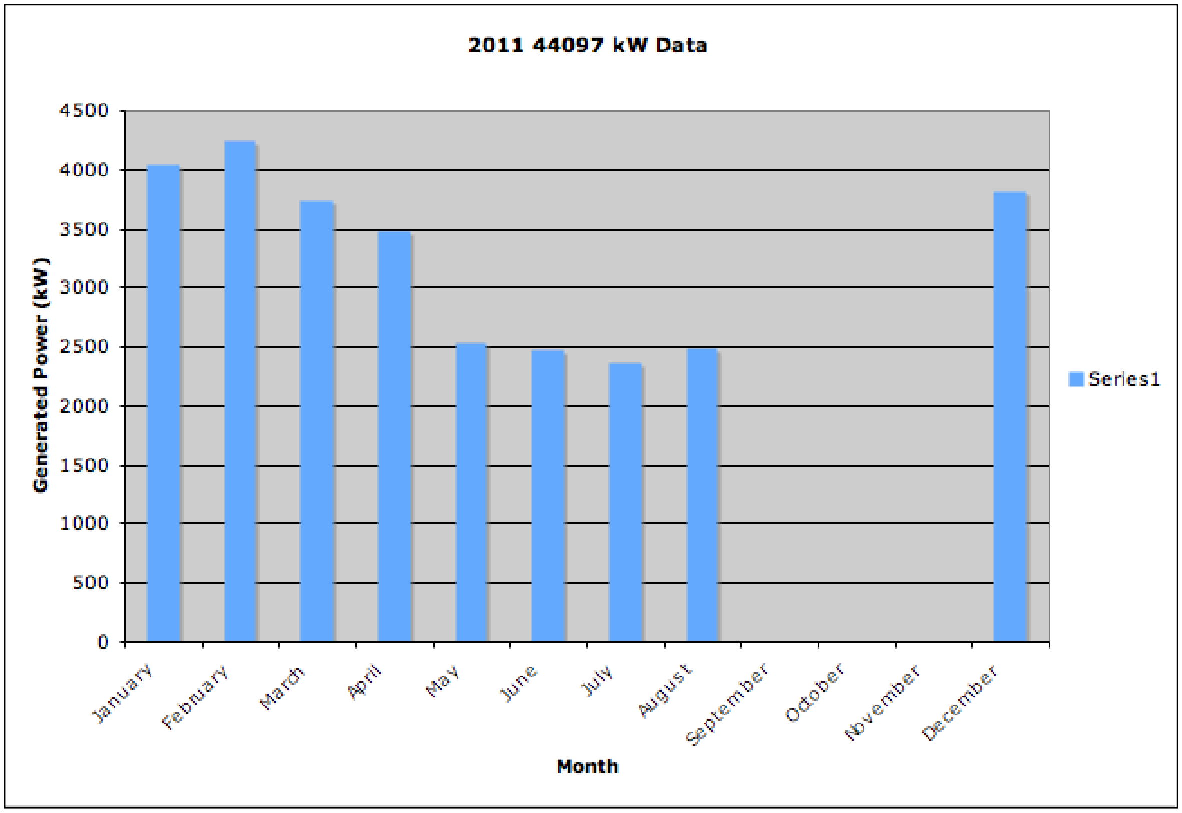


Fig. 5: Average monthly electrical output data for 2011 from buoy 44097



Figures (4) and (5) show the averages for each buoy in 2011 alone, to show the variation from month to month. All data was averaged from data point taken every ten minutes then collapsed down monthly data. Yearly averages were also calculated and shown in figure (3).

6.1 Extrapolation from buoy height to hub height (buoy selection)

The data collected by the buoys is only partially sufficient when doing a commercial assessment of an area due to the fact that the anemometers are at different heights than the potential turbines. For this study, all wind speed averages will be found at 80m. Using the formula shown in Fig 5, the wind speed can be calculated based on mean speeds found at anemometer height. These calculations are exceptionally accurate due to the flat nature of the ocean, where wind blocks such as hills or trees are not present. In figure (6) R= wind velocity at the desired hub height, u_1 is wind velocity at the lower height and u_2 is the velocity at the higher height. Z_0 is the average surface roughness (assumed 0.00035), while Z_1 is lower height and Z_2 is the higher height in meters.

Fig. 6

$$R = \frac{u_2}{u_1} = \frac{\log(Z_2/Z_0)}{\log(Z_1/Z_0)},$$

Then, once mean hub height speed is found, the formula shown in figure (3) can be used to determine the max electrical (kW) output of a single turbine. The mean wind speeds are hub height however are not always consistent and short term variation occurs, but this study was done by compressing 10 minute data down to monthly averages for ease of calculation. P_w represents the aggregate power generated, D is the rotor diameter and U is the average wind speed.

Fig. 7

$$\overline{P}_{\mathrm{w}} = \rho \left(\frac{2}{3} D\right)^2 \overline{U}^3$$

In this study, the theoretical turbine has a diameter of 111 m.

The extrapolation of 24.8m to 80m with an assumed surface roughness of .000035 was 1.124252418805807. Comparatively, the extrapolation for the 5m anemometer was found to be 1.319. Simply multiplying the buoy height mean wind speeds by these numbers would give the hub height speeds.

6.2 Turbine Count

The max power output is determined using the max possible turbine count. To find how many turbines could be possibly erected in our area, we use a spacing factor. To conclude this number we must look at inter-turbine spacing and how wake effects affect power output; with more turbines in a small area, turbine count rises but power-per-turbine falls. When the space between each turbine is increased, turbine count falls but individual power production for each turbine rises. It is generally accepted that no more than 10% wake loss is reasonable. For the GE 3.6 s with a 104 m blade, the array spacing corresponds to 0.54km^2 for each turbine. Knowing that the total area for the Rhode Island Sound is 963.04 km^2, the max turbine count can be calculated to be 1,784 turbines.

Using the max turbine count of 1,780, and [the monthly averages shown in figure (3), the yearly max power output can be calculated. The average yearly kilowatt generation per turbine from 2010 to July 2012 was found to be 3425.9 kW. Knowing this, the total max electrical output of the Rhode Island sound is approximately 6,112,000 kW, or 6,112 MW per year.

7. Conclusion

This paper outline the methods used to determine the max power output of the Rhode Island sound based on 10-minute data collected from National Data Buoy Center buoys BUZM3 and 44097. These two buoys were selected based on their close proximity to the Rhode Island Sound and their distance from land. By finding the total available area in the Rhode Island Sound then using the measured point data to determine the average wind speed, the max electrical output of each turbine and therefore the total location could be shown. Using this data, a full market analysis could be done to find the plausibility of a successful wind farm in the area. The final yearly output based on averages from January 2010 to July 2012, with minor gaps was found to be roughly 6,112 Megawatts of power.

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