Abstract

As the United States expands its carbon-free electricity generation, the country has built considerable amounts of onshore wind power, but has left offshore opportunities largely undeveloped. In fact, as the end of 2016, the U.S. had total wind generating capacity of 81.2 gigawatts (GW)[1]. The 30 megawatt (MW) Block Island Wind Farm[2] was the country's singular offshore wind project, accounting for less than a tenth of one percent of the total capacity.

Offshore wind provides several key advantages over onshore wind. First, and perhaps most obviously, there are vast amounts of open space in the ocean on which to build wind turbines (though care must still be taking in selecting the correct location, as this paper will discuss). Second, the wind over the ocean blows harder, and more consistently than on land[3]. Finally, 53% of the United States' population lives near the coasts[3], so concentrating energy production near these population centers shortens the distance needed to transport energy from its source.

This paper will describe a methodology for selecting the best location for an offshore wind farm off of the Virginia coast by considering the physical site characteristics, wind speeds, available federal lease parcels, distance to transmission interconnections and ports, and unsuitable areas that must be avoided.

Literature Review

"Continuous spatial modelling to analyse [sic] planning and economic consequences of offshore wind energy"[4]

In this article, Bernd Möller of Aalborg University in Denmark sets up a spatial methodology for analyzing suitability of offshore wind installations in Denmark. He extends a model that he co-developed in 2007 for siting of biomass energy plants, called "SCREAM" (Spatially Continuous Resource Economic Assessment Model). He breaks the analysis down to three broad categories of data, which he then joins to form a final spatial model.

The first category is a "wind power production calculator." This utilizes spatial weather forecast data to estimate wind speeds, as well as non-spatial data on wind turbine technology, which gives information on the turbine's energy output potential. The resulting combination of these two data layers is an isopleth showing power output potential by location.

The second data category in the SCREAM model is "levelized production costs" (LPC). This considers non-spatial inputs such as wind turbine size, projected number of turbines in the project, and the cost of capital. The model also factors in the spatially-dependent variables of water depth and distance to the shore, both of which affect construction and maintenance costs. The resulting LPC data layer provides the cost to produce electricity by location.

The third and final model category performs a spatial clipping operation to remove all areas that are undevelopable for either legal or practical reasons. This layer incorporates data on wildlife conservation areas, seabed geology, areas visible from land, undersea cables, pipelines, and shipping channels. The resulting output of this layers is a map of “conflict free areas.”

Möller takes these three data categories and combines them to form the aggregate SCREAM model for selecting optimal turbine placement sites.

“A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030” [5]

This report by the National Renewable Energy Laboratory (NREL) presents a comprehensive analysis of the economic factors associated with offshore wind development in the United States. Because the report examines the country as a whole, it incorporates location-dependent factors such as state laws and regulatory structures, capital and labor costs that are largely constant within a state. Therefore, these factors will not vary for sites within Virginia so can be set aside for purposes of this paper. The remaining spatial data can be divided into two broad categories: exclusion zones and continuous data, where the goal is find the locations that minimize costs and maximize energy production.

The NREL report aggregates 49 data layers to clip out the exclusion areas. These layers include environmental conservation areas, federal water lease blocks that are not available, shipping lanes, pipelines, undersea cables, and other existing structures.

The report uses the continuous spatial data to calculate a “net value” of income from electricity sales minus construction and operating expenses. Expenses are derived from ocean depth, distance from the nearest suitable port, distance to nearest energy grid interconnection point, and ocean meteorological conditions. The energy production is calculated from wind speed and direction.

The NREL report gives a broad picture of suitable wind turbine locations through the United States, like the Möller paper does for Denmark.

Methodology

We begin by importing the bathymetry data layer. This contains spatial information on the ocean depth. We also import the seabed geology table. This is a .csv file so our first operation will be to perform a join to link the seabed information to the locations in the bathymetry layer.

Offshore wind turbines are attached to base structures that are either anchored to the ocean floor, or located on floating platforms. The first geoprocessing step will be to perform a spatial query on the depth information and classify it into three groups: <30m, 30m-60m, and >60m. The first two groups require two different types of platform that are drilled into the ocean bed, while the third group utilizes a floating platform.

Similarly, the ocean floor composition dictates the type of piling used to anchor the turbine platform. Therefore, we will perform a second, aspatial query on the seabed geology type, and create groups. At this point, we will have a compound list of classifications with all possible combinations of the depth and seabed geology groupings.

Third, we import the wind speed data layer. The potential energy that a turbine can produce is proportional to the cube of wind speed so small changes in speed have very large impacts on the amount of electricity generated.[3] Since the data measurements are points, we perform a spatial interpolation to estimate the values at the un-sampled locations, and then generate an isopleth from this information.

The Bureau of Ocean Energy Management (BOEM) controls the use of federal waters for energy production and has divided the area into a grid of parcels available for lease. Therefore, the forth step is to import the layer of BOEM parcels off the Virginia coast and intersect this with our current data to keep only the parcels that are available.

Because the wind turbines must be linked to the electricity grid, the closer they are to an interconnection point on land, the cheaper they are to connect. Thus, the next layer we import is the map of transmission lines in the region, which are operated by PJM Interconnection. We use the connection point data to calculate the Euclidean distance to available BOEM parcels.

Likewise, proximity of turbines to ports reduces installation and maintenance costs. Our sixth data layer shows the locations of all ports in the U.S. As with the prior step, we calculate the Euclidean distance between the ports in Virginia and the available BOEM parcels.

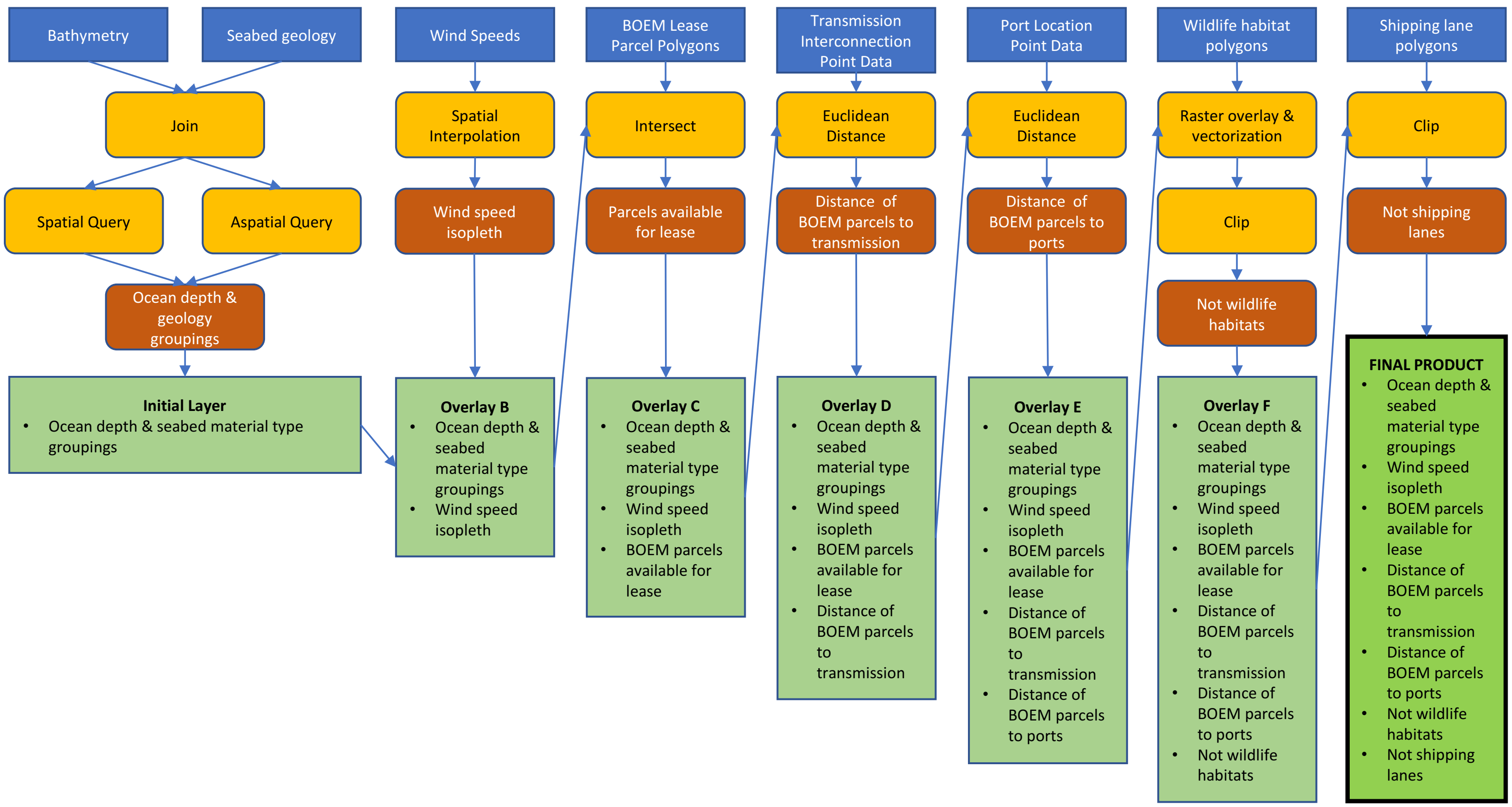
The last two data layers provide spatial data on parcels that cannot be used for turbines. The first of these contains wildlife habitats, bird migration paths, and other conservation areas. In reality, this is several raster and polygon datasets, but for the purposes of this assignment, we will treat them as one raster dataset, on which we will first perform a vectorization operation. The other dataset contains polygons of shipping lanes. With both layers, we perform a clip to remove conflicting areas that are unusable for wind development.

We are left with the final map that can be used to assess the available lease parcels most suitable for wind production.

Geospatial Layers List

1. Bathymetry (ocean depth)
    - Name: Ocean Basemap
    - Type: layer package (LPK)
    - Source: ESRI: https://www.arcgis.com/home/item.html?id=5ae9e138a17842688b0b79283a4353f6
    - Date: 8-Dec-2016 / Cost: Free
    - Other: may also be added as a base layer in ArcGIS
2. Seabed geology
    - Name: usSEABED
    - Type: csv
    - Source: United States Geological Survey (USGS): https://walrus.wr.usgs.gov/usseabed/data.html
    - Date: 2005 / Cost: Free
3. Wind speed data
    - Name: Wind NREL U.S. Offshore High Resolution
    - Type: shapefile
    - Source: National Renewable Energy Laboratory (NREL): https://maps.nrel.gov/swera/#/?aL=cHwSbr%255Bv%255D%3Dt&bL=groad&cE=0&lR=0&mC=40.21244%2C-91.625976&zL=4
    - Date: Unknown / Cost: Free
4. Bureau of Ocean Energy Management Available Lease Parcels
    - Name: BOEM Renewable Energy Shapefiles
    - Type: shapefile
    - Source: Bureau of Ocean Energy Management: https://www.boem.gov/Renewable-Energy-GIS-Data/
    - Date: 10-Apr-2017 / Cost: Free
5. Electricity Transmission Interconnection Points
    - Name: PJM System Map
    - Type: shapefile
    - Source: PJM Interconnection: http://www.pjm.com/library/maps.aspx
    - Date: Unknown / Cost: High (requires membership)
6. Ports
    - Name: Ports of the United States 201406
    - Type: shapefile
    - Source: United States Geological Survey (USGS): https://catalog.data.gov/dataset/usgs-small-scale-dataset-ports-of-the-united-states-201406-shapefile
    - Date: 01-Jun-2014 / Cost: Free
7. Wildlife habitats
    - Name: Mid-Atlantic Baseline Studies
    - Type: raster and shapefiles
    - Source: Biodiversity Research Institute
    - Date: 2012-14 / Cost: Free
8. Shipping route polygons
    - Name: Shipping Fairways, Lanes, Zones for US waters as of June 2013
    - Type: shapefile
    - Source: National Oceanic and Atmospheric Administration (NOAA): https://catalog.data.gov/dataset/shipping-fairways-lanes-and-zones-for-us-waters-as-of-june-2013
    - Date: 17-Jun-2013 / Cost: Free

<u>Geospatial Processing Methodology</u>



Sources

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[1] "Wind turbines provide more than 8% of U.S. generating capacity, more than any other renewable source." U.S. Energy Information Agency. Published 5/2/2017. https://www.eia.gov/todayinenergy/detail.php?id=31032#tab2. Accessed: 5/2/2017
[2] Block Island Wind Farm. Deep Water Wind, 2017. http://dwwind.com/project/block-island-wind-farm/. Accessed: 5/2/2017
[3] Offshore Wind Energy. Bureau of Ocean Energy Management. https://www.boem.gov/Renewable-Energy-Program/Renewable-Energy-Guide/Offshore-Wind-Energy.aspx. Accessed: 4/30/2017
[4] Möller, Bernd. "Continuous spatial modelling to analyse [sic] planning and economic consequences of offshore wind energy." *Energy Policy* 39 (2011): 511-517. Print.
[5] Beiter, Philipp, et al. "A Spatial-Economic Cost-Reduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030." National Renewable Energy Laboratory. September, 2016.