Assessment of Delaware Offshore Wind Power

Amardeep Dhanju, Phillip Whitaker and Sandra Burton

Contributions from: Chad Tolman and Christina Jarvis
Supervised by: Dr. Willett Kempton and Dr. Richard Garvine

College of Marine Studies
University of Delaware

September 2005

Assessment of Delaware Offshore Wind Energy

I. Introduction & History of Windpower - Phillip Whitaker and Amardeep Dhanju

II. Delaware offshore wind energy – The Mapping Model – Amardeep Dhanju

III. Translation of historical buoy data into cash flow – Valuation Model - Phillip Whitaker

IV. Business Development Model - Sandra Burton

V. Avoided emissions – Chad Tolman

VI. Marine wildlife impact – Christina Jarvis

Appendix 1: Detailed description of data collection and processing for buoy 44009 wind and spot market electricity pricing in Southern Delaware – Phillip Whitaker

I. Introduction

The goal of many energy resource appraisals is straightforward: to value the resource in terms of money – what's it worth? Of course, that requires linking the resource to its market. To accomplish that this paper assesses the Delaware offshore wind energy resource by bringing together three elements: ***a mapping model, a valuation model, and a business development model.*** The mapping model makes a detailed examination of the developable offshore area out to 60 km - taking into account current technologies and competing uses of the ocean; the valuation model translates historical buoy records of wind data into electricity production and matches that figure with the corresponding real world pricing for electricity in the Southern Delaware spot market; and the business development model analyzes the value of this electricity in light of detailed development cost estimates. We have also appended a section to address two of the most common concerns related to development of offshore wind energy: one examines the avoided fossil fuel emissions that wind energy accomplish; and the other a summary of potential impacts to marine wildlife in the Delaware area.

First cut evaluation of offshore wind resources is accomplished most easily by taking the mean of the measured wind values available for the point closest to that being considered. This annual mean wind speed times the number of turbines that can be fit in the developable area provides the theoretical basis for determining resource size. The next question becomes is it an economically viable resource? To answer that is much more difficult. The Nantucket Sound project is planned as approximately 130 General Electric (GE) 3.6MW turbines and is projected to cost approximately $700,000,000 dollars. Attracting venture capital of this magnitude naturally requires a great deal of data that is site specific, methodically gathered, and tailored to provide the best possible answer to the questions affecting the risk level of the investment. In Horn's Rev, Denmark, three years worth of data from a meteorological tower was gathered and assessed before construction commenced. In Nantucket, a data tower was erected in 2002 and only in May of 2005 did formal efforts to obtain venture capital begin. Of course, this timing is a product of many factors; not merely accurate resource assessment. But several years' worth of tailored resource assessment is, and will remain, fundamental to securing financing for any utility scale wind project.

We recognized that other stakeholders such as coastal community governments might also wish to evaluate for themselves the amount and value of a wind regime that is under consideration as a possible source of energy. It goes without saying that if this resource were in the form of natural gas or fossil crude, communities affected by local resource extraction would not only be concerned about the environmental consequences of development, but also the potential of the resource for enhancing public wealth. This effort was undertaken to see if a methodology for reasonably accurate assessment could be pieced together that takes advantage of existing data. While there is no expectation that the historically archived wind data from buoys will fully satisfy the requirements of an investor, the method used here might provide those wishing to assess the potential of a particular site with a sound basis for the decision making such as policy initiatives or expending funds on the cost of permitting and more substantive information gathering.

We define, in as realistic a manner as possible, both state and federally controlled seafloor off the Delaware coast that is physically suitable for hosting wind turbines. Primary limitations considered were distance from the shore together with depth. Currently, technological and financial constraints limit construction of the turbines to areas with a depth of less than approximately 20 meters. National Oceanographic and Atmospheric Administration (NOAA) bathymetry data available for GIS mapping has (among others) gradients at 18.2 and 27.4 meters. Taking into consideration the growth curve of the wind industry over the past decade the decision was made to include as viable in our assessment areas down to the 27.4m level. Distance from shore is relevant not only as it relates to depth, but also as a factor in the costs of construction (distance required to run the transmission line for grid interconnect) and as a factor in the ongoing costs of maintenance. With more weight given to the depth consideration we decided to largely limit the scope of the analysis to a distance of 60km from shore. The exception to this was the wind mapping, which included wind data from NOAA buoy 44004 located approximately 370km east of Delaware's Indian River Inlet.

The discussion of the costs of current development recognizes we have been somewhat forward looking in including for consideration depths beyond present capability by restricting site consideration for cost analysis to areas that are within the present range.

History of Wind Power in U.S.

Wind power was the first renewable source of energy to be developed and used widely in the United States. The mechanical windmill was one of the two "high-technology" inventions (other was the barbed wire) of the late 1800's that allowed the pioneers to develop much of the western frontier. Between 1850 and 1970, over six million mostly small (1 horsepower or less) mechanical output wind machines were installed in United States. The primary use of these wind mills was to pump water for stock watering and farm home water needs. Large windmills, with rotors up to 18 meters in diameter were used to pump water for the stream railroad engines that provided the primary source of commercial transportation in areas were there were no navigable rivers.

Getting electricity from wind started in the late 19th century, when the "American" multi-blade windmill design was used for electric generation. The first use of a truly large windmill to generate electricity was a system build in Cleveland, Ohio in 1888 by Charles F. Brush. The Brush Machine was a post-mill with a multiple bladed picket fence rotor 17 meters in diameter, featuring a large tail hinged to turn the rotor out of the wind. The output of this windmill was modest 12 KW. By 1920, the two dominant rotor configurations (fan-type and sail) had both been tried and found to be inadequate for generating appreciable amounts of electricity. Further development of the wind generator electrical systems in United States was inspired by the design of airplane propellers and later by monoplane.

By the 1920's a market existed for the small scale wind turbines, especially in the rural mid-western states. With an output of 1-3 kW, these wind generators were first installed to provide lighting for farms and to charge batteries used to power small radio sets. Their use was extended to an entire array of direct current motor-drive appliances, including refrigerators, freezers, washing machines, and power tools. But as more appliances were powered by the early wind generators, more the intermittent nature of wind became a problem. The great depression brought with it New Deal programs such as the Rural Electrification Administration (REA). REA began subsidizing rural electric co-ops and electric transmission lines to the thinly populated (and unprofitable) areas of the mid-west; the same areas which were being served by wind power and soon the intermittent wind mills were no longer part of the landscape in the Midwest. This lends some irony to the present day debate regarding subsidies to recreate the wind power industry since the foundation that had developed by the 1930's was literally driven out of business by government policies favoring the construction of utility lines and fossil fuel power plants.

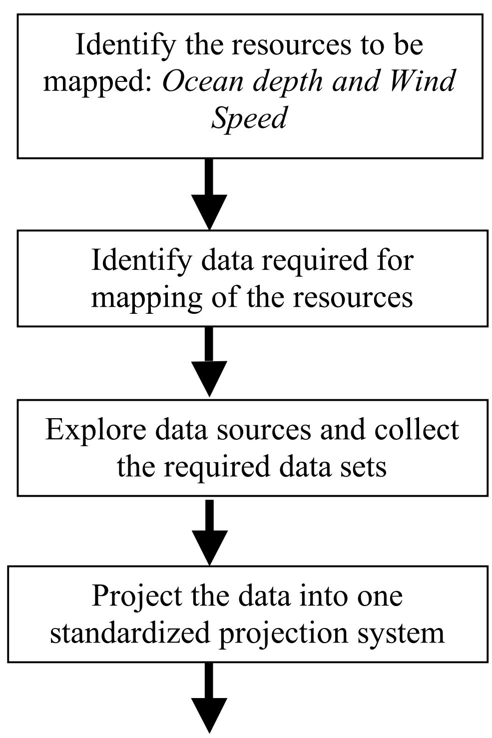
The development of utility-scale wind energy conversion systems was first undertaken in Russia in 1931 with the 100 kW Balaclava wind generator. This machine operated for about two years on the shore of the Caspian Sea, generating 200,000 kWh of electricity. Subsequent experimental wind plants in United States and other European countries showed that large scale wind turbines would work, but failed to result in a practical large wind turbine. The largest of the wind turbines designed and operated in this experimental phase was 1.25 MW Smith-Putnam model; installed in Vermont in 1941. The wind turbine load was too heavy for the materials of the day. In 1945, after only a few hundred hours of intermittent operation, one of the rotor blades broke off near the hub, apparently as a result of metal fatigue. Not surprising considering the huge loads that must have been generated on its rather fragile structure.

The revival of the wind industry in U.S. is a recent phenomenon, driven by federal investments in R&D, state incentives and technological advances in material's science contributing to the design of modern wind turbines and their blades. The introduction of strong and flexible composite materials has enabled the manufacture of large wind turbines, capable of harnessing large scale energy. The institution of favorable policies at the federal level with the PTC (production tax credit) and at the state level with RPS (Renewable Portfolio Standard) has provided the wind industry with much needed boost. Engineering efforts are now underway to tap the offshore wind resources, which are much larger in scale and magnitude than what is available on land.

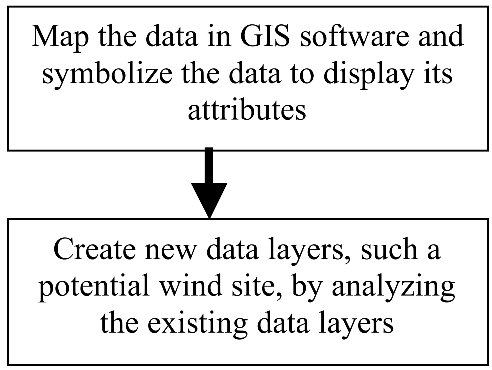
II. Delaware offshore wind energy – The Mapping Model

The assessment of Delaware offshore wind energy potential involves mapping two critical resources: wind speed and the area (of ocean floor and water column) available off the Delaware coast for setting up an offshore wind farm. The wind speed is a variable resource. With daily, monthly and seasonal variations, the mapping of this resource is based on probabilistic assumptions. The ocean depth and exclusionary zones on the other hand can be mapped with much higher accuracy. This section discusses the methodology used to map the wind potential off the coast of Delaware and marks out one possible site as being suitable for up to a 1.4GW (1400 MW) installed capacity wind farm. The electricity generation and consumption in Delaware stands at 3,390 MW[1], most of it generated by fossil fuel power plants in the State. An offshore wind farm with an installed capacity of 1 GW could displace almost one third of the state's fossil fuel electric generation, thus reducing large quantities of greenhouse gases, along with reductions in other pollutants such as sulfur dioxide, nitrogen oxide and toxins such as mercury. This particular assessment of the offshore wind potential in Delaware is divided into four sections. The first section accesses and maps the offshore data, the second section maps the land based geographic data and the third section does the same for wind data. The fourth section brings together the data from the first three sections into a single map project, and then maps the potential site for the development of a utility scale wind farm with an installed capacity in excess of 1 GW.

The following flow chart lists the steps involved in assessing the offshore wind resource and choose a potential wind site for the development of an offshore wind farm.



[1] Department of Energy Website: http://www.eia.doe.gov/cneaf/electricity/st_profiles/delaware.pdf



Part A: Accessing and Mapping Offshore Data

The first step in the assessment of the potential offshore wind energy is to map the resource area that can be potentially harnessed for setting up a wind farm or multiple wind farms. The calculation of such an area is dependent on two variables:

○ *Bathymetry:* As discussed earlier, the current technological and financial constraints limit construction of the turbines to areas with a depth of less than approximately 20m. National Oceanographic and Atmospheric Administration (NOAA) bathymetry data available for GIS mapping has (among others) gradients at 18.2 and 27.4 meters. Taking into consideration the growth curve of the wind industry over the past decade the decision was made to include areas to the depth of 27.4m level.

○ *Exclusion zones:* Such zones will include shipping lanes, marine wildlife sanctuaries and waste disposal sites among others. Due to the active or passive uses in the exclusionary zones, they will be excluded from the potential area for development of an offshore wind farm.

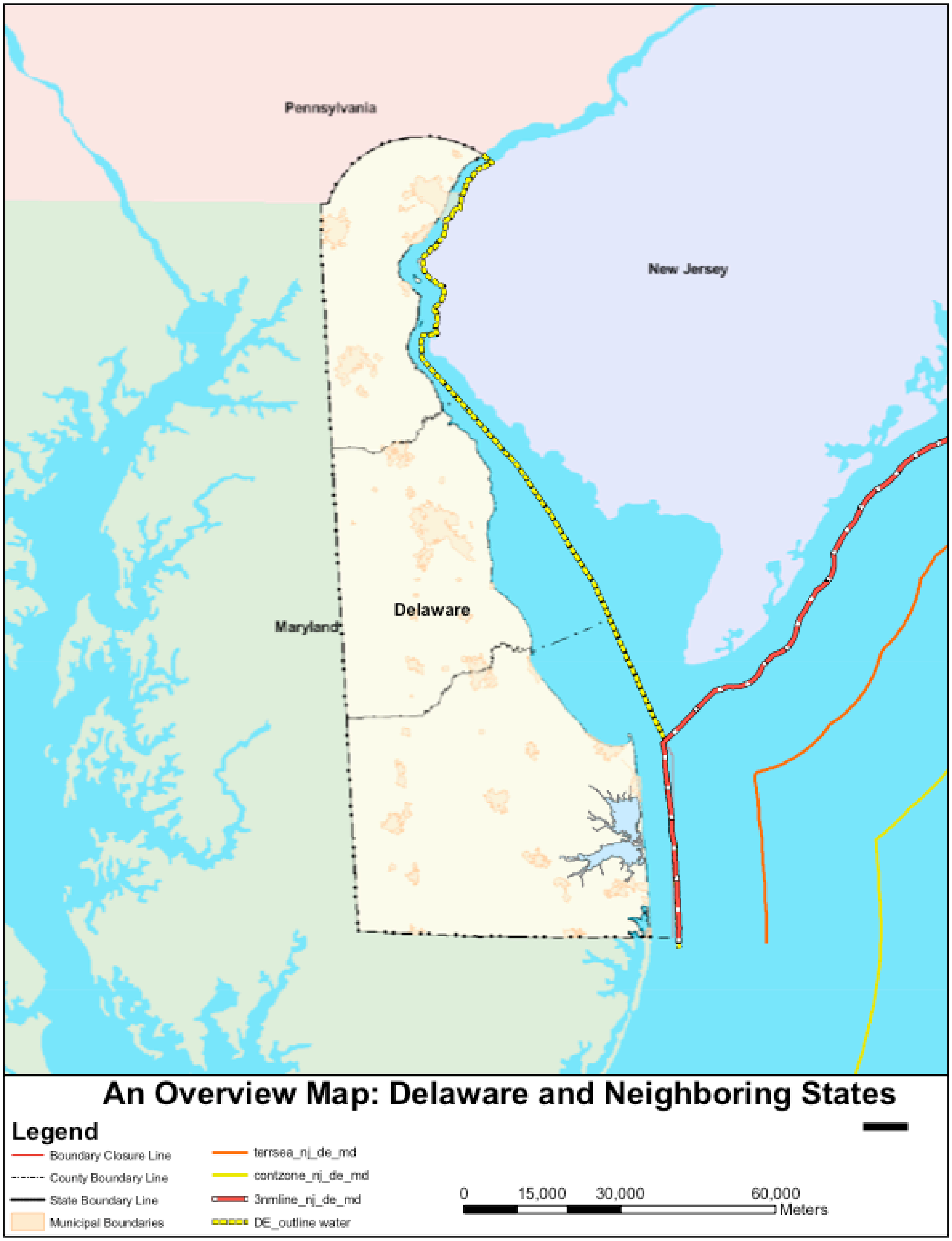
To map Bathymetry and Exclusion zones, data was drawn from two different sources: NOAA navigational charts and NOAA ENC Direct GIS data. The data is available in two different formats: raster dataset and vectors datasets. The vector format represents points, lines and polygons, while the raster format is made up of pixels.

1. Paper based NOAA Navigation Charts:

Introduction:

The first data source is a set of NOAA (National Ocean and Atmospheric Agency) navigation charts. The charts are available in the paper format. Two navigation charts were obtained from the map repository located at University of Delaware. These charts mapped two contiguous zones: the Delaware Bay and the Atlantic Ocean off the Delaware coast.

Map 1:


Pennsylvania
New Jersey
Delaware
Maryland
An Overview Map: Delaware and Neighboring States
Legend
Boundary Closure Line
County Boundary Line
State Boundary Line
Municipal Boundaries
terrsea_nj_de_md
contzone_nj_de_md
3nmline_nj_de_md
DE_outline water
0 15,000 30,000 60,000
Meters

The paper based NOAA navigation chart illustrated the following data:

○ Coast line of the states of Delaware and New Jersey.
○ Bathymetric contours marking water depth in feet.
○ Underwater features such as shoals and sloughs.
○ Shipping lanes, duly labeled.
○ Precautionary and exclusionary zones marked by sites such as chemical waste dumps, explosive dumping grounds and other such sites.
○ Special fishing areas such as oyster grounds.
○ Land based natural features such as rivers and lakes, and artificial features like roads, airports and tanks.

Creating a Digital Copy

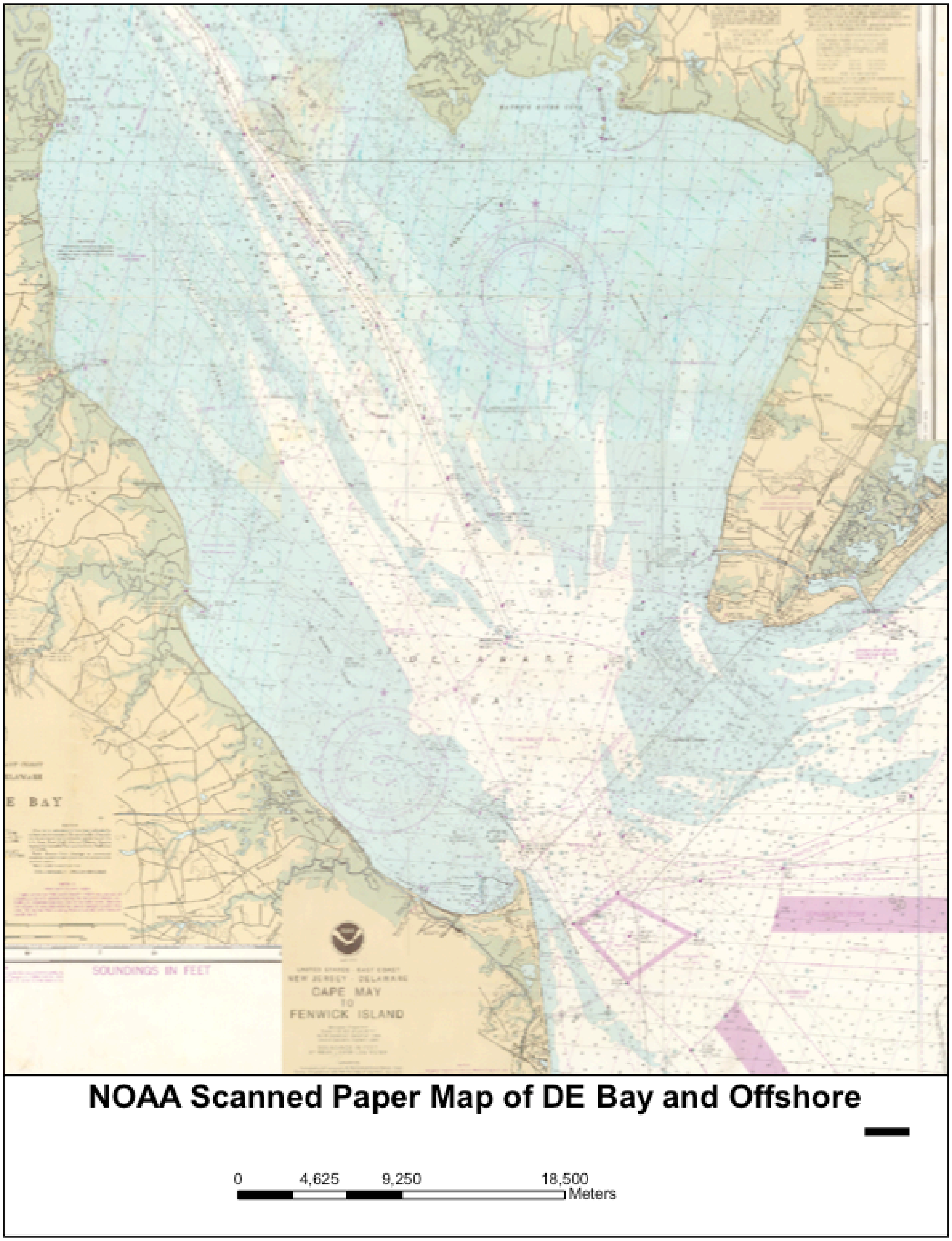
The two paper based nautical maps were scanned through an HP Designjet scanner, which facilitated the scanning of the oversized nautical charts. The scanner was set to a low resolution 150 bpi (bits per inch) to ensure a manageable file size. Even at this low resolution, the scanner quality was high with the fine bathymetric details clearly visible in the digital copy. The scanned digital copy was saved as a .jpg file. This .jpg file is a raster data format and thus can be imported into a GIS project as such. NOAA recently has made available digitally formatted copies of these paper maps. The digital copies can be downloaded as shapefile, which can then be added to a GIS project. A shapefile is a basic file storage unit for ArcGIS software. The next section will discus accessing and downloading these digital data file.

2. NOAA Spatial Data

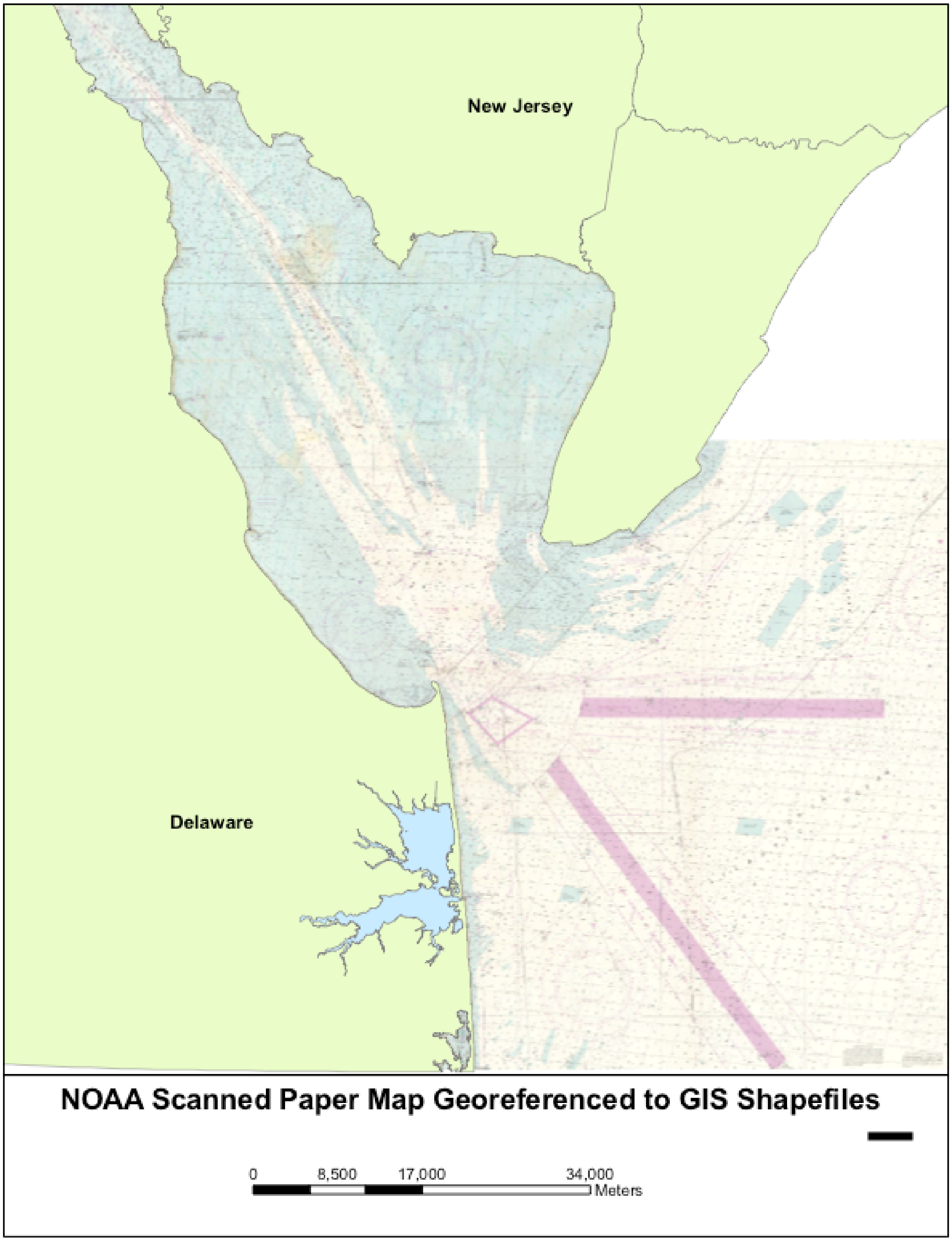
Introduction

Over the past decade many public agencies have invested significant resources to digitize the paper maps and provide the digital version for public access over the internet. One such effort is the NOAA ENC Direct spatial portal. This web portal provides comprehensive access to display, query, and download all available NOAA Spatial data. One of the datasets available in NOAA ENC Direct are the nautical charts of different coastal regions. These digital charts provide a detailed view of the natural and artificial features in coastal and marine environment, in GIS format. The data on this chart includes costal topography, bathymetry, landmarks, geographic place names and marine boundaries. Though much of the data available from ENC Direct is the same as that from scanned based NOAA navigational charts, both the formats offer unique advantages useful in the assessment of the study area. The scanned nautical charts are rich in detail, displaying the bathymetric data in feet. The shipping lanes and exclusionary zones are more clearly displayed and labeled in the paper format than in the electronic copy. On the other hand, with GIS data from ENC Direct it is possible to symbolize and map the bathymetric gradients (0-10 m) and display the bathymetric contours. Use of both data formats add up to offer a strong assessment of resources.

Map 2:


E BAY
SOUNDINGS IN FEET
NEW JERSEY - DELAWARE
CAPE MAY
TO
FENWICK ISLAND
DELAWARE
BAY
NOAA Scanned Paper Map of DE Bay and Offshore
0
4,625
9,250
18,500
Meters

Map 3:



New Jersey
Delaware
NOAA Scanned Paper Map Georeferenced to GIS Shapefiles
0
8,500
17,000
34,000
Meters

Extracting Data from ENC Direct

ENC Direct is an interactive data framework repository of spatial data. The data can be viewed and extracted as required. Bathymetry is the base map layer in the framework. Through the following steps the base map layer was extracted from the ENC Direct framework and added to a GIS project.

1. Under http://nauticalcharts.noaa.gov/csdl/ctp/encdirect_new.htm navigate to proceed to ENC Direct icon at the bottom of the page.
2. A Map Lab opens in a new window labeled 'ENC Direct'. This is an interactive display of different spatial layers.
3. The spatial layers are listed on the right, while the map in displayed in the center of the window.
4. Select the layers needed to be extracted, for this project is the:
   - Base Map
5. Click *Refresh Map* to display the 'Base map' layer.
6. Proceed to the 'area of interest' with the help of *pan, zoom in and zoom out* tools.
7. Once the 'area of interest' is in focus, proceed to *Extract Data icon.*
8. A new dialog window will open, displaying the layer to be extracted.
9. Click on the layers and click extract data button. And save the file in a folder.
10. The saved data is in a zip file format. Right link of the zip file to extract the data in a shapefile format. Once again, a shapefile is a basic file unit for an ArcGIS project.
11. The extracted shapefile is then added to an ArcGIS map document.
12. Once the base map layer with bathymetric data has been added to the ArcGIS project, the data is symbolized to display ocean depth gradient contours. For example depths between 0-10 meters will show in one color, while depths from 10- 20m is displayed in a different graded color. A map with bathymetric data in a color graded scheme will display the areas that can be potentially exploited for setting up an offshore wind farm.

Part B: Accessing and Mapping Land Based Geographic Data

Along with mapping and understanding of the offshore spatial data, it is also important to map the onshore spatial data to build a complete picture of the exploratory area. Coastal areas of Delaware and New Jersey were mapped for this project. Each state maintains its own spatial repository, from which the data was extracted and used.

1. **GIS data for Delaware from DataMIL**

The land based features for Delaware State were accessed and extracted from DataMIL, a GIS internet repository service for Delaware. The Delaware Data Mapping and

Integration Laboratory (DataMIL) is an interactive, online collaboratory established by the Delaware Geographic Data Committee (DGDC) to publicly make available spatial data. DataMIL services are available on the website http://datamil.udel.edu

Layers that were extracted for this project are:

1. State outline (line)
2. State outline (area)
3. Municipal boundary

The followings steps lay out the methodology to extract data from DataMIL:

1. Under http://datamil.udel.edu proceed to Map Lab.
2. Map Lab opens a new window 'Map Production Laboratory'. This is an interactive display of different spatial layers.
3. The spatial layers are listed on the right, while the map displayed is in the center of the window.
4. Select the layers needed to be extracted, which in this case are the
   a. State Outline
   b. Municipal Boundaries
5. Click *Refresh Map* to display the two layers.
6. Proceed the to the 'area of interest' with the help of *pan, zoom in and zoom out* tools.
7. Once the 'area of interest' is in focus, navigate to *Extract Data.*
8. A new dialog window will open displaying the three layers what are being extracted.
9. Click on the layers and click extract data button. Save the file in a folder.
10. The saved data will be in a zip file format. Right click on the zip file to extract the data in a shapefile format.
11. The extracted shapefile is then added to an ArcGIS map document.

2. GIS data for New Jersey

The GIS Data for New Jersey was extracted from New Jersey Geographic Information network. Much like the DataMIL, the NJ GIS Network is the official state portal for the spatial data. The service is available at https://njgin.state.nj.us

Data layers in NJ GIS Network that were extracted for this project are:

Boundaries

a. State outline (line)
b. State outline (area)
c. County boundary

The followings steps lay out the methodology to extract data from NJ GIS Network:

1. Under https://njgin.state.nj.us proceed to Data > Downloadable Data
2. It opens a new window 'NJ in Explorer' with a listing of spatial data links.

3. On the left, choose the theme ‘Admin and Political Boundaries’ and click on Start Search.
4. The search result will give a listing of data files, choose
    a. State Outline
    b. County boundary
5. Download the data as a zip file.
6. Right click of the zip file to extract the data in a shapefile format.
7. The extracted shapefile is then added to an ArcGIS map document.

Part C: Accessing Wind Data

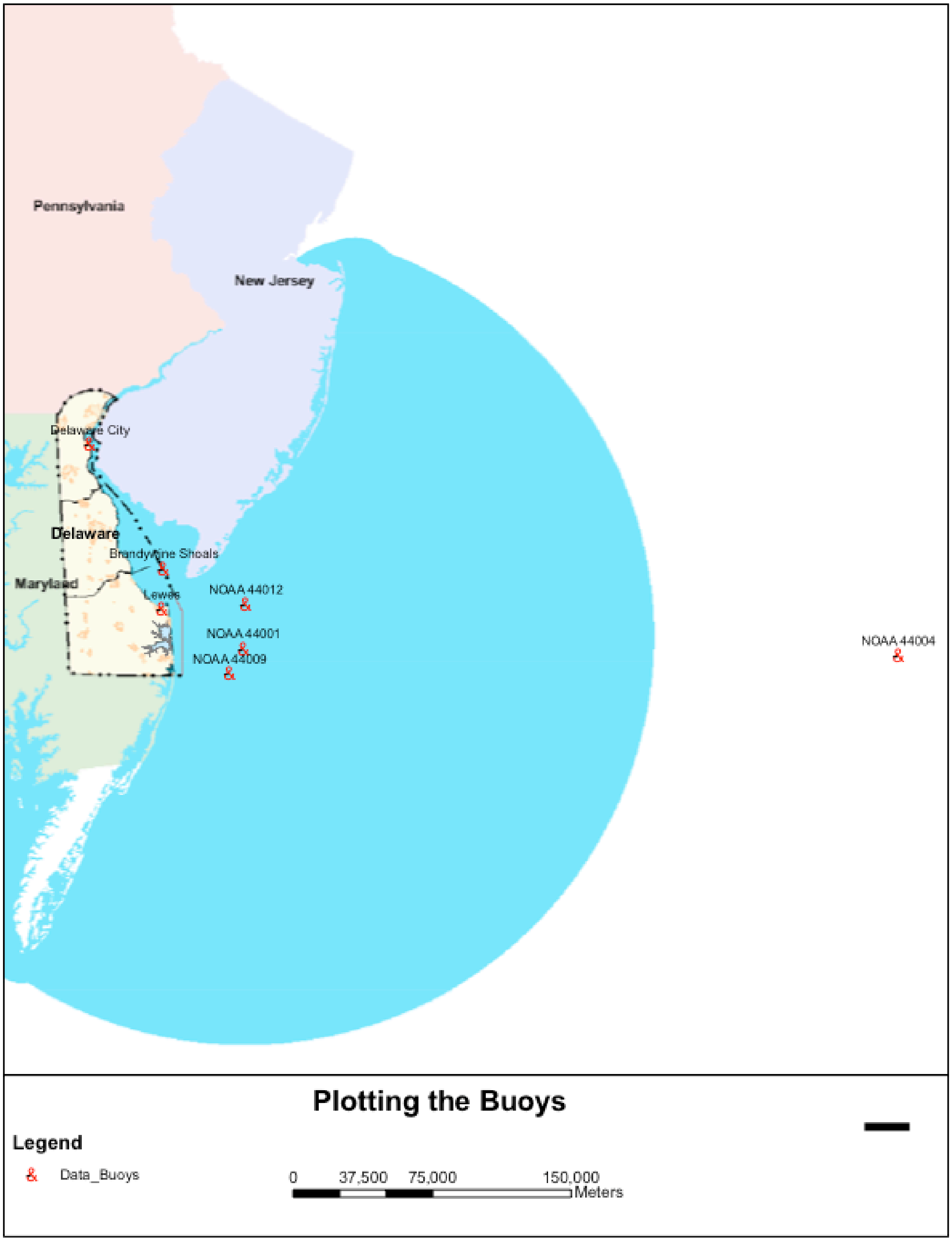
Buoy Data

Seven buoys were used for collecting data on the wind speed. Four of the buoys are located offshore, while three buoys are land based. The information on the buoys and the wind speed data from these buoys is available at National Buoy center (http://www.ndbc.noaa.gov). The first step in the buoy data was to plot the buoys on the GIS map. The latitude and longitude coordinates of the buoys were obtained from the website. A new shapefile was created and the longitude and the latitude were entered in the shapefile to create seven buoy points on a GIS map. The following table provides lists the latitude and longitude of the buoy points:

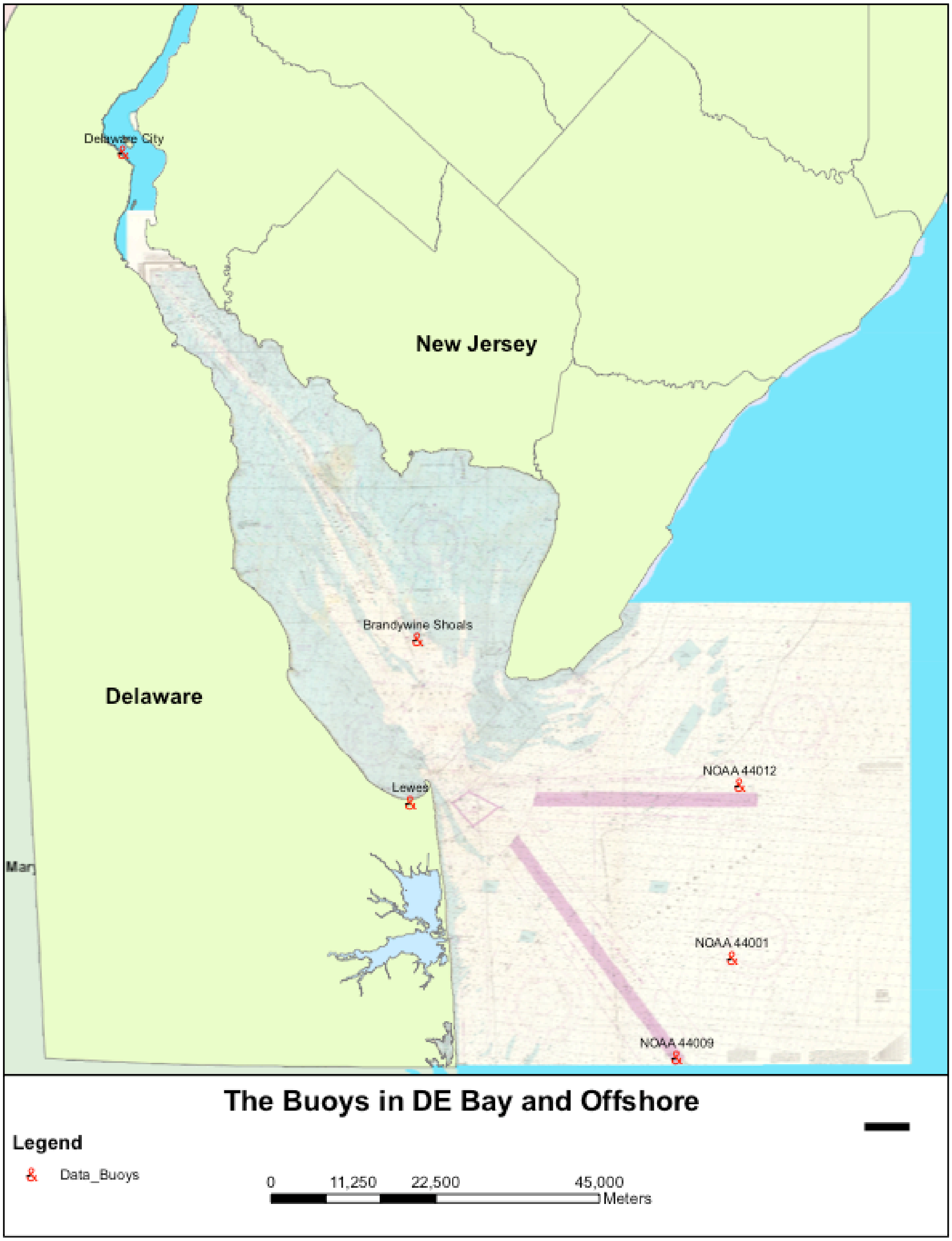
Table 1

Location ID	Anometer h/m	Latitude	Longitude
PORTS ID 8557380 LEWES	12.2	38° 46.9' N	75° 7.2' W
PORTS ID 8551762 DELAWARE CITY	6.4	39° 34.9' N	75° 35.3' W
PORTS ID 8555889 BRANDYWIND SHOALS	18.9	38° 59.2' N	75° 6.8' W
NOAA ID 44009	5	38° 27’ 49' N	74° 42’ 07' W
NOAA ID 44004	5	38° 28' 12” N	70° 33’ 35” W
NOAA ID 44012	13.8	38.8 N	74.6 W
NOAA ID 44001	5	38.7 N	73.6 W

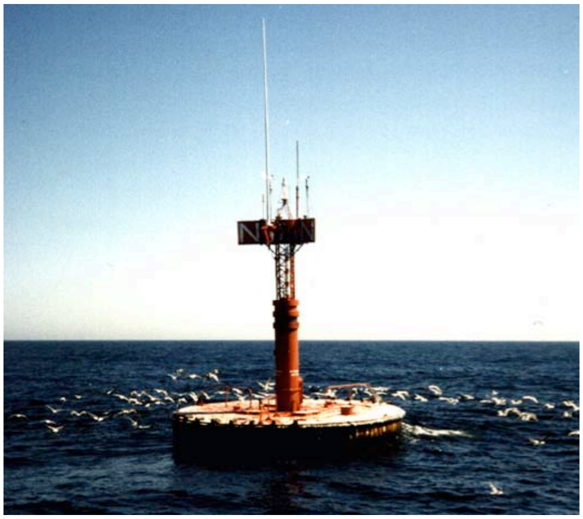
Map 4:


Pennsylvania
New Jersey
Delaware City
Delaware
Brandywine Shoals
Maryland
Lewes
NOAA 44012
NOAA 44001
NOAA 44009
NOAA 44004
Plotting the Buoys
Legend
Data_Buoys
0
37,500
75,000
150,000
Meters

Map 5:



Delaware City
New Jersey
Brandywine Shoals
Delaware
NOAA 44012
Lewes
Mar
NOAA 44001
NOAA 44009
The Buoys in DE Bay and Offshore
Legend
Data_Buoys
0
11,250
22,500
45,000
Meters



NOAA BUOY 44012

NOAA BUOY 44009

NOAA BUOY 44004 & 44001

Once the buoys had been plotted on a GIS map, the next step was to enter the wind speed data in the buoy shapefile. Thirteen columns were created, one for the annual average wind speed reading and twelve columns for each of the monthly readings. For each of the seven buoys, the wind data was entered. The next step is to interpolate the wind speed data between the buoys to illustrate different wind regimes in the Delaware Bay and off the Atlantic coast. The next section covers the mapping of the wind speed and all the other resources for which data has been collected until now.

Part D: Mapping an area for a Potential Offshore Wind Farm

Creating Maps:

In this step the data files collected will be added to an Arc GIS project to create a single resource map. From the map created, the potential area for creating a utility scale wind farm will be developed. ESRI ArcGIS software was used for the creation of the maps. The following steps lay out the mapping procedure:

1. Map Projection: Before mapping the data into the GIS software, it is important to check for the projections of the shapefiles. It is important that the shapefiles are in the same projection system to ensure that they overlay one on top of the other when they are added to the Arc GIS project. Since the area of concern is Delaware, we can project the shapefiles to UTM NAD 83 Zone-18 M projection.

2. Adding files: After correcting for the projection differences, the downloaded shapefiles are added to the ArcGIS project in Arc Map software. At this point, it is important to remember that the scanned NOAA paper navigation chart is a raster image with no geographical reference, when this file is added to the project, it will not overlay on the other shapefiles. The raster files will have to be geo-referenced in order to overlay on the other files.

The shapesfiles were added in the following order:

- Delaware Coast line
- New Jersey Coast Line
- Delaware area
- New Jersey counties
- 3 Mile nautical limit
- Territorial sea
- Contiguous zone
- Scanned NOAA navigational Chart (subsequently georeferenced to the other shapefiles)
- NOAA ENC Direct Base map with Bethymetric Data. This data was then symbolized to display graduated color scheme.
- Buoy points

3. Geo-referencing: It is a process of defining the position of geographical objects relative to a standard reference grid. The geographic object in question here is the raster data set representing the NOAA navigational chart. The raster file is added to the GIS project and then through the geo-referencing process the file is stretched to overlay the existing dataset.

4. Symbolizing the depth: The NOAA digital base map with bathymetric data is symbolized into a five class wind speed gradient:

Table 2

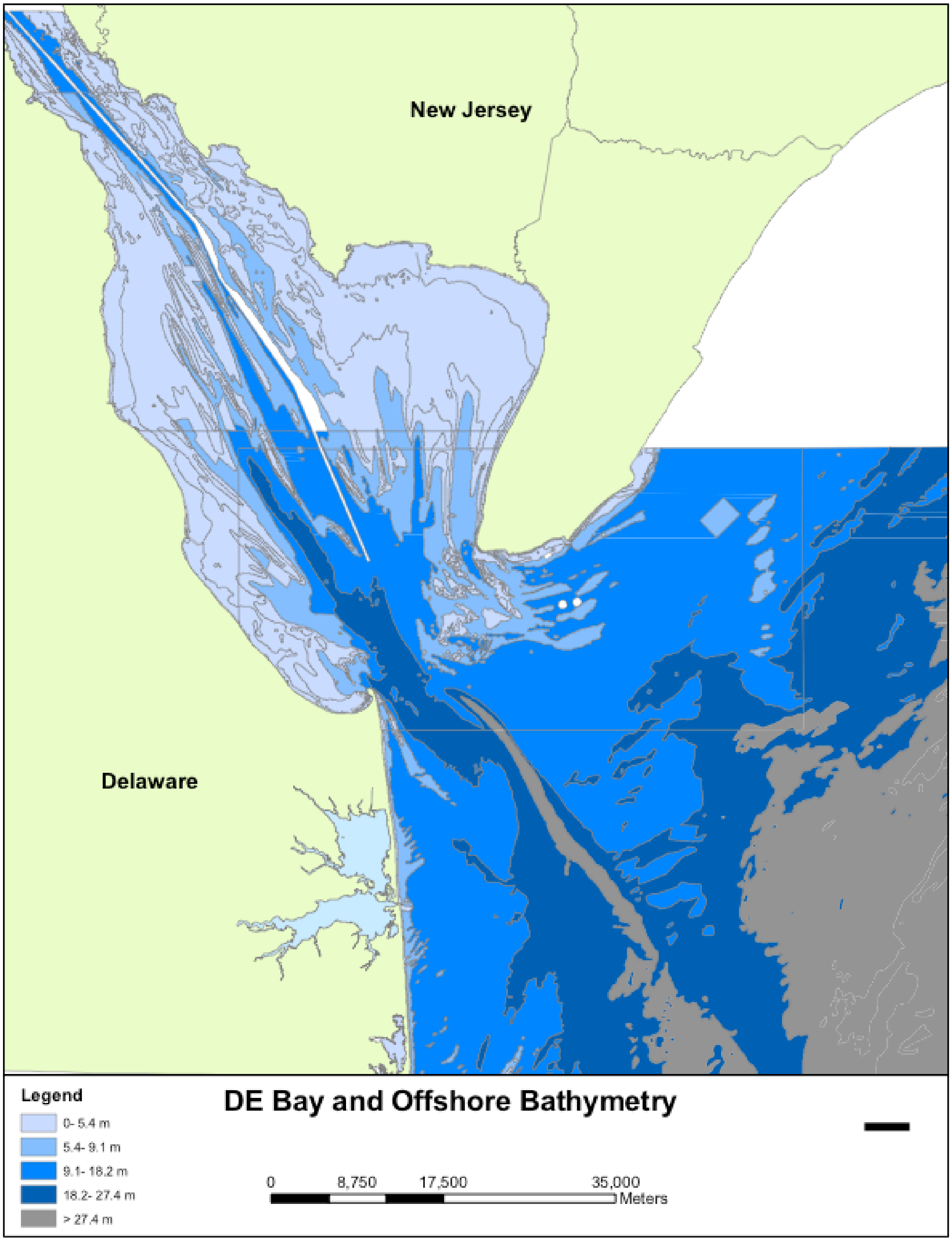
0- 5.4 m	**Class I**
5.4- 9.1 m	**Class II**
9.1- 18.2 m	**Class III**
18.2- 27.4 m	**Class IV**
> 27.4 m	**Class V**

The gradient classifications are then color shaded to illustrate the ranges. The development of offshore wind energy is presently limited to Class IV depths. Class V depths will be considered out of range for the development purposes in this project.

5. Defining the Exclusionary zones: Areas such as military sites, waste and chemical dumps and shipping lanes were defined and highlighted so that they can defined as exclusion zones. Some features like the waste dumps were highlighted in the existing shapefiles, while other features such as shipping lanes were specifically created from the scanned NOAA map.

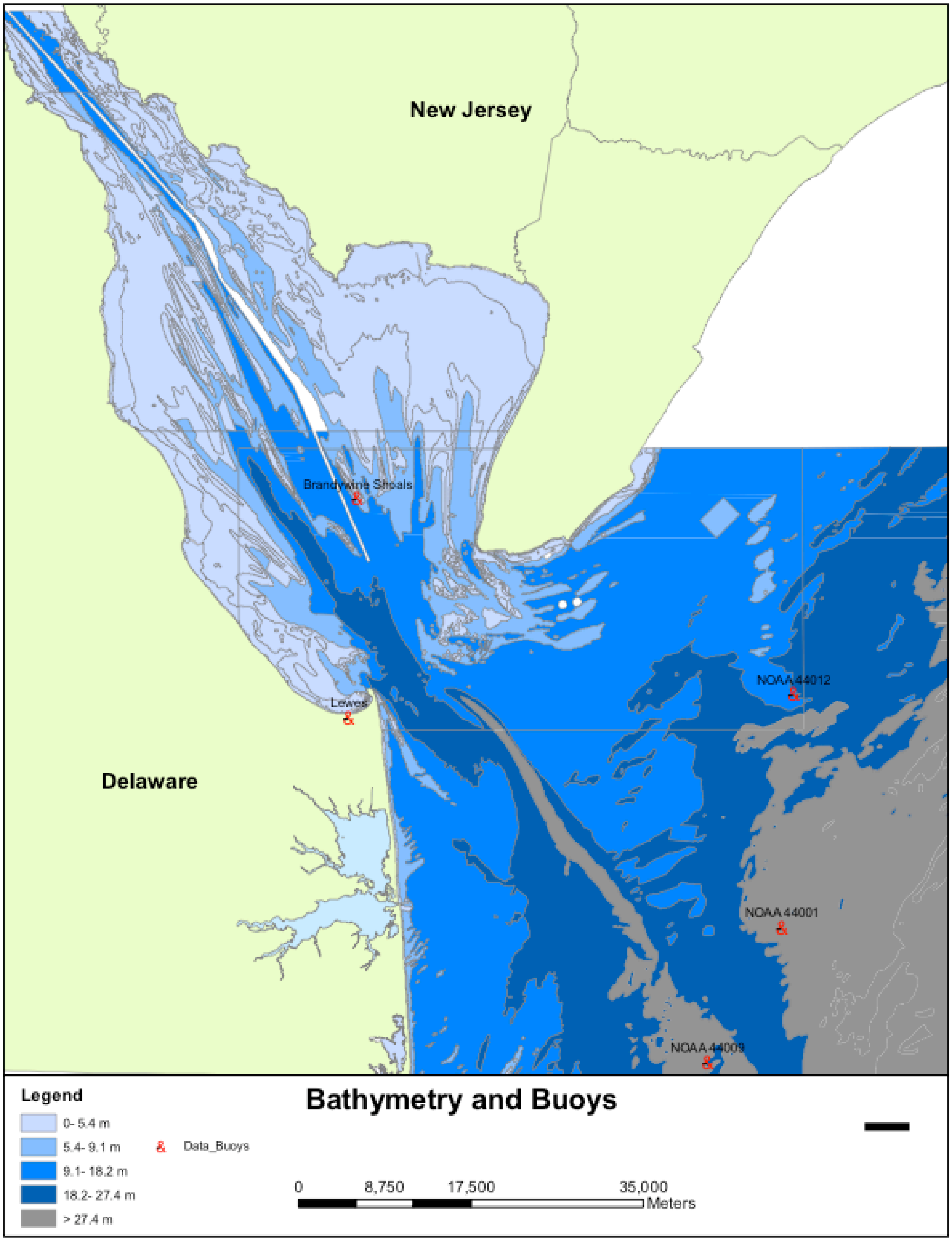
6. Creating the Potential Offshore Area: Considering the exclusionary zones and the depth limitation, three potential areas where identified for development of a utility scale offshore wind farm. Area-1 is located in the Delaware Bay, and Area-2 and Area-3 are located off the Atlantic coast. The areas were calculated using a Visual Basic script in ArcGIS.

Map 6:



New Jersey
Delaware
Legend
0- 5.4 m
5.4- 9.1 m
9.1- 18.2 m
18.2- 27.4 m
> 27.4 m
DE Bay and Offshore Bathymetry
0
8,750
17,500
35,000
Meters

Map 7:



New Jersey
Delaware
Brandywine Shoals
Lewes
NOAA 44012
NOAA 44001
NOAA 44009
Legend
0- 5.4 m
5.4- 9.1 m
9.1- 18.2 m
18.2- 27.4 m
> 27.4 m
Data_Buoys
Bathymetry and Buoys
0
8,750
17,500
35,000
Meters

Table 3

Delaware Bay	468 Sq km
Offshore Area-1	426 Sq km
Offshore Area-2	269 Sq km
Total Area	**1401 Sq km**

The next step in the process is to map the wind potential and select the most suitable area for the development of offshore wind energy.

7. Mapping the Offshore Wind Resource: The data from seven buoys were used for plotting the wind regime. Kriging method was used to interpolate the data between the points. Kriging is an interpolation technique for obtaining statistically unbiased estimates of spatial variation of known points such as surface elevations or yield measurements utilizing a set of control points. Since there were seven data points available for a relatively small area, it is expected that the distortions in interpolation were minimized. But the interpolation technique did not take into account the effect of land based natural features while calculating the wind speed. Thus the wind speed regime estimates from the interpolation would have a larger confidence interval for Atlantic offshore than for the Delaware Bay.

8. Assessing Delaware Offshore Wind Power Potential

Reconciling the bathymetric limitation and interpolated offshore wind resource, the following table provides an assessment of the Delaware Offshore wind power potential. The assessment is based on the available 3.6 MW GE offshore Wind Turbines. An average of 3 wind turbines can be installed per square KM. This derivation is based on the assumption that a minimum distance of 600 meters is recommended between the wind turbines of this size.

Table 4:

	Areas in Sq m	Areas in Square km	No. of 3.6 MW GE Turbines (approx)	Max Installed Capacity (MW)
Delaware Bay	468182346.76	468.18 sq km	1450	5222
Offshore Area-1	426194990.10	426.19 sq km	1320	4754
Offshore Area-2	269482707.70	269.48 sq km	834	3002
Total	1163860044.56 Sq km	1163.85 Sq km	3604	12978 MW

*At 0.33 capacity factor the output will be 4282.74 MW.

* The net installed capacity in DE is 3,390 MW. Source: www.eia.doe.gov Data year: 2002

* Offshore Area-1 is the area closer to DE shoreline, Offshore Area-2 is the area further off from DE shoreline.

[Note: The offshore areas in table 4 and table 5 vary due to difference in methods subscribed to calculate the areas. The variation is less then 10%]

8. Location of a Potential Wind Farm: The final step in this process is to map the location of a potential offshore wind site. The two layers mapped earlier, the wind speed layer and the bathymetric data layers were overlaid to find a location with high wind speeds in shallow water depths. From the mapping it was determined that the selected offshore area-1 is the best location for an offshore wind farm. Factors that influenced the choice of the location are:

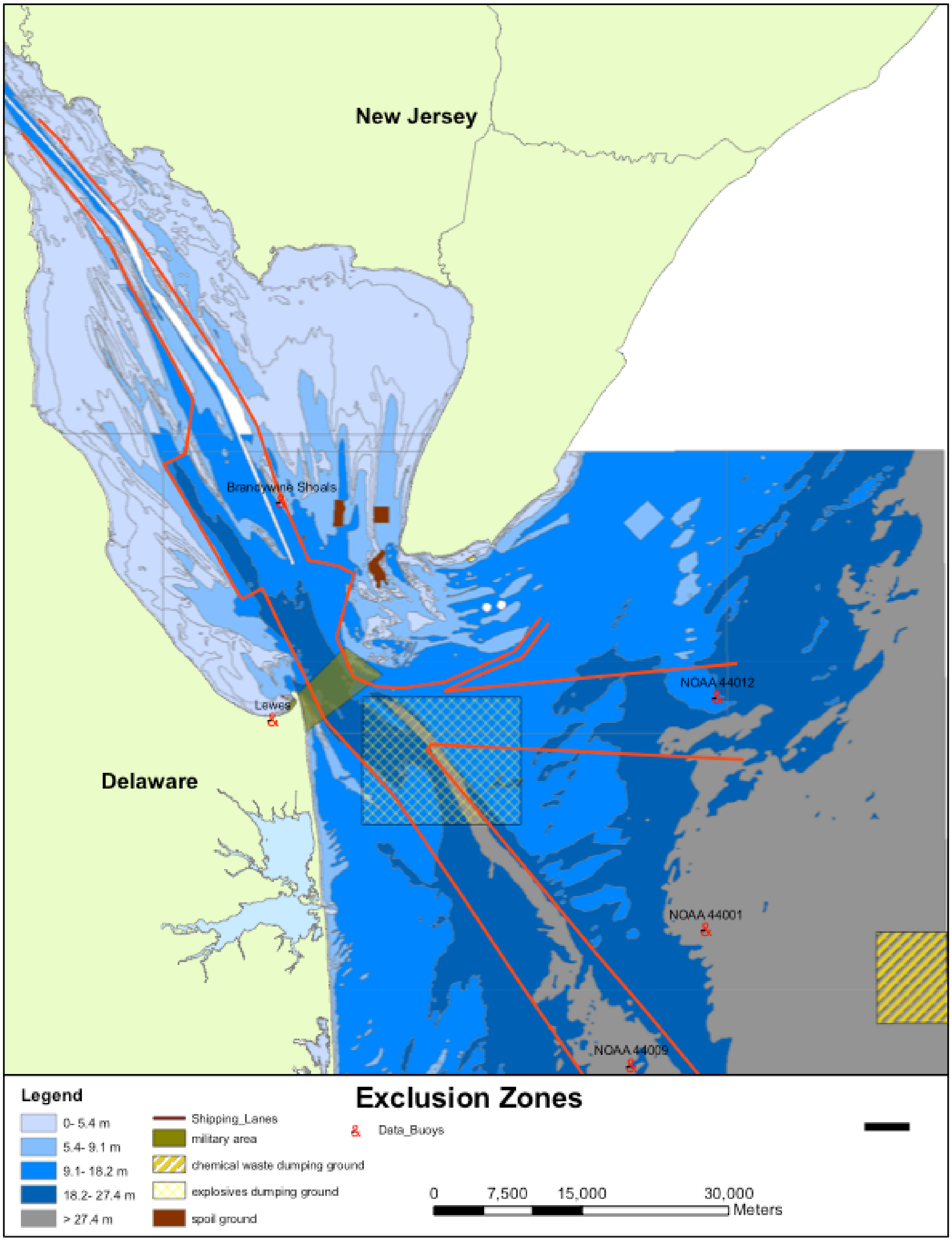
○ *Distance from shore:* The site is 7.5 km east of Fredrick Island Township. The distance will minimize the visual effect from the wind site, though such an effect will not be eliminated. The existing electric distribution facilities in the Town can be modified for accepting the power from the offshore farm.

○ *Cost of laying the power lines*: Such costs would be minimized by locating the wind farm closer to shore.

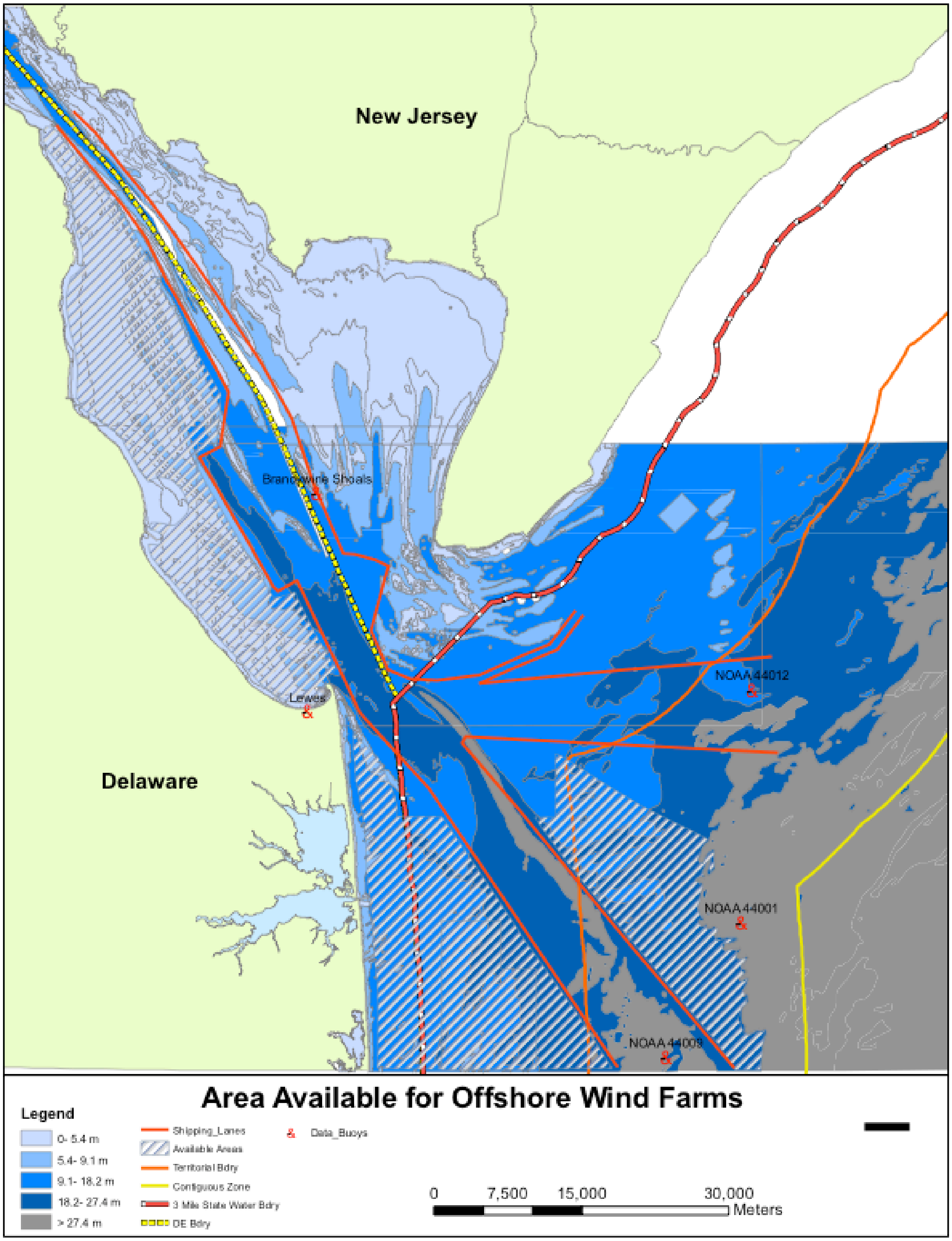
○ *Shipping lanes*: The electric cables from the site will not have to pass through the shipping lanes. This eliminates the possibility of accidental damage due to a ship wreck or any kind of accident.

○ *Area:* Availability of area at the chosen site to install around 400 wind turbines in the area.

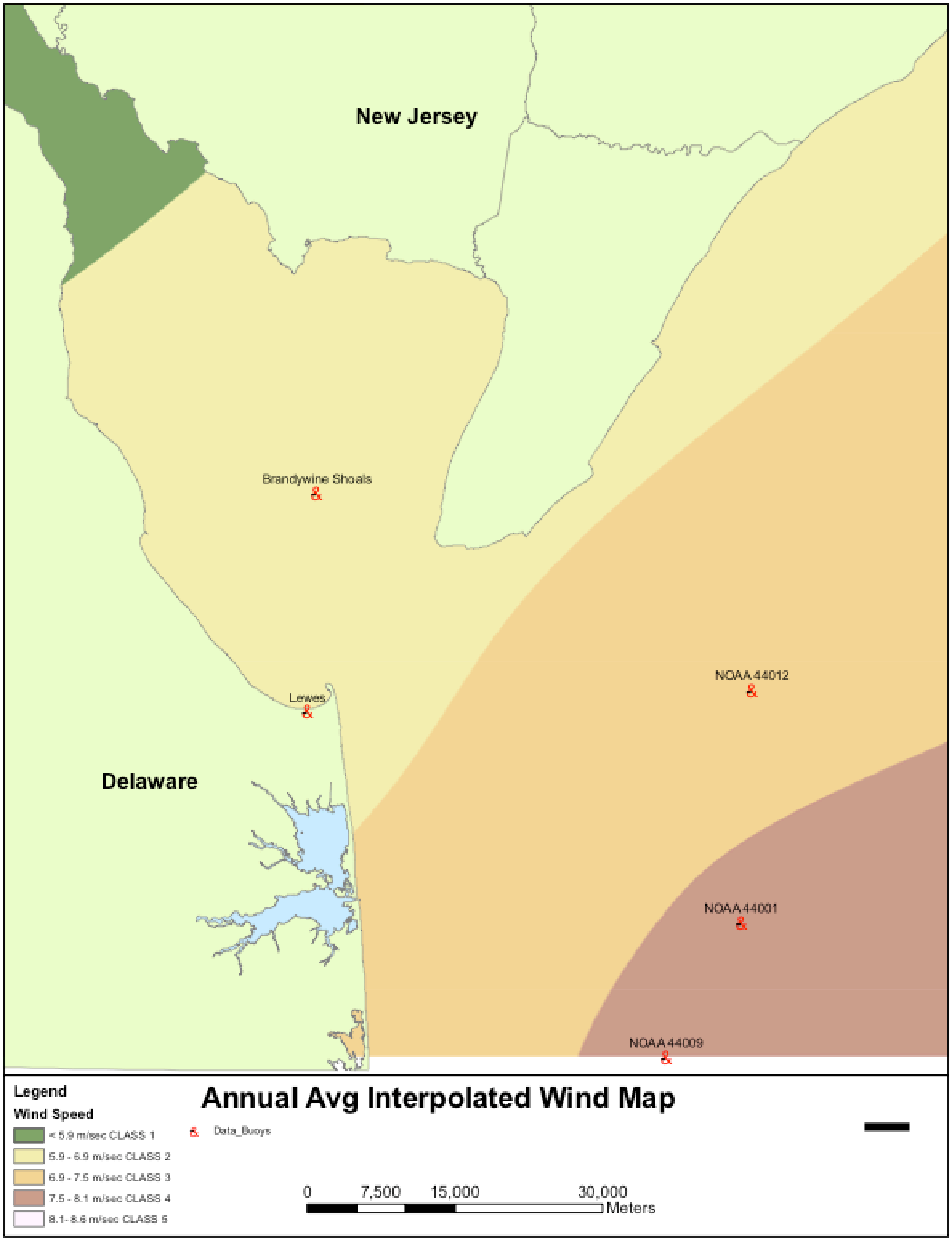
Map 8:


New Jersey
Brandywine Shoals
NOAA 44012
Lewes
Delaware
NOAA 44001
NOAA 44009
Legend
0- 5.4 m
5.4- 9.1 m
9.1- 18.2 m
18.2- 27.4 m
> 27.4 m
Shipping_Lanes
military area
chemical waste dumping ground
explosives dumping ground
spoil ground
Exclusion Zones
Data_Buoys
0
7,500
15,000
30,000
Meters

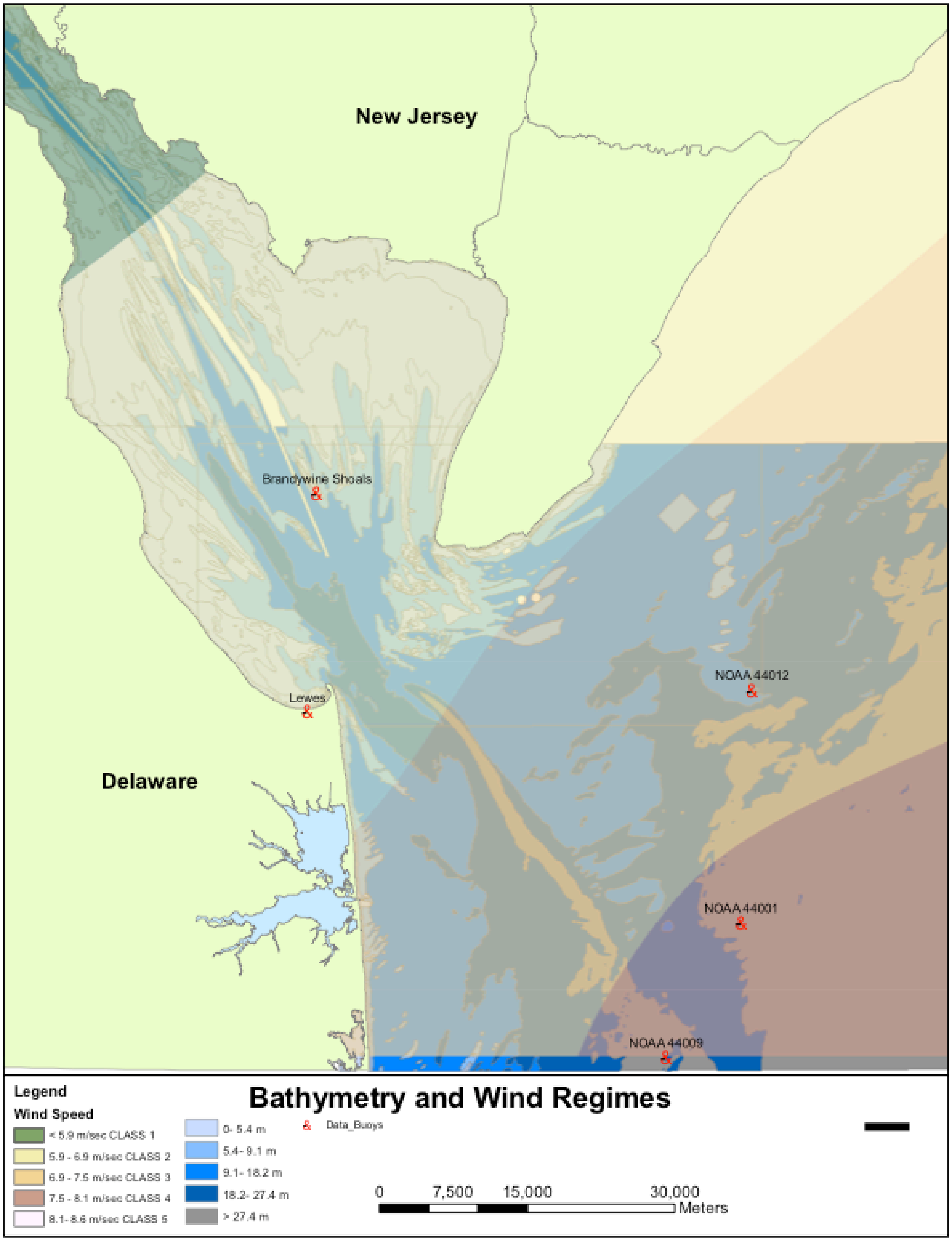
Map 9:


New Jersey
Delaware
Brandywine Shoals
Lewes
NOAA 44012
NOAA 44001
NOAA 44009
Area Available for Offshore Wind Farms
Legend
0- 5.4 m
5.4- 9.1 m
9.1- 18.2 m
18.2- 27.4 m
> 27.4 m
Shipping_Lanes
Available Areas
Territorial Bdry
Contiguous Zone
3 Mile State Water Bdry
DE Bdry
Data_Buoys
0 7,500 15,000 30,000
Meters

Map 10:

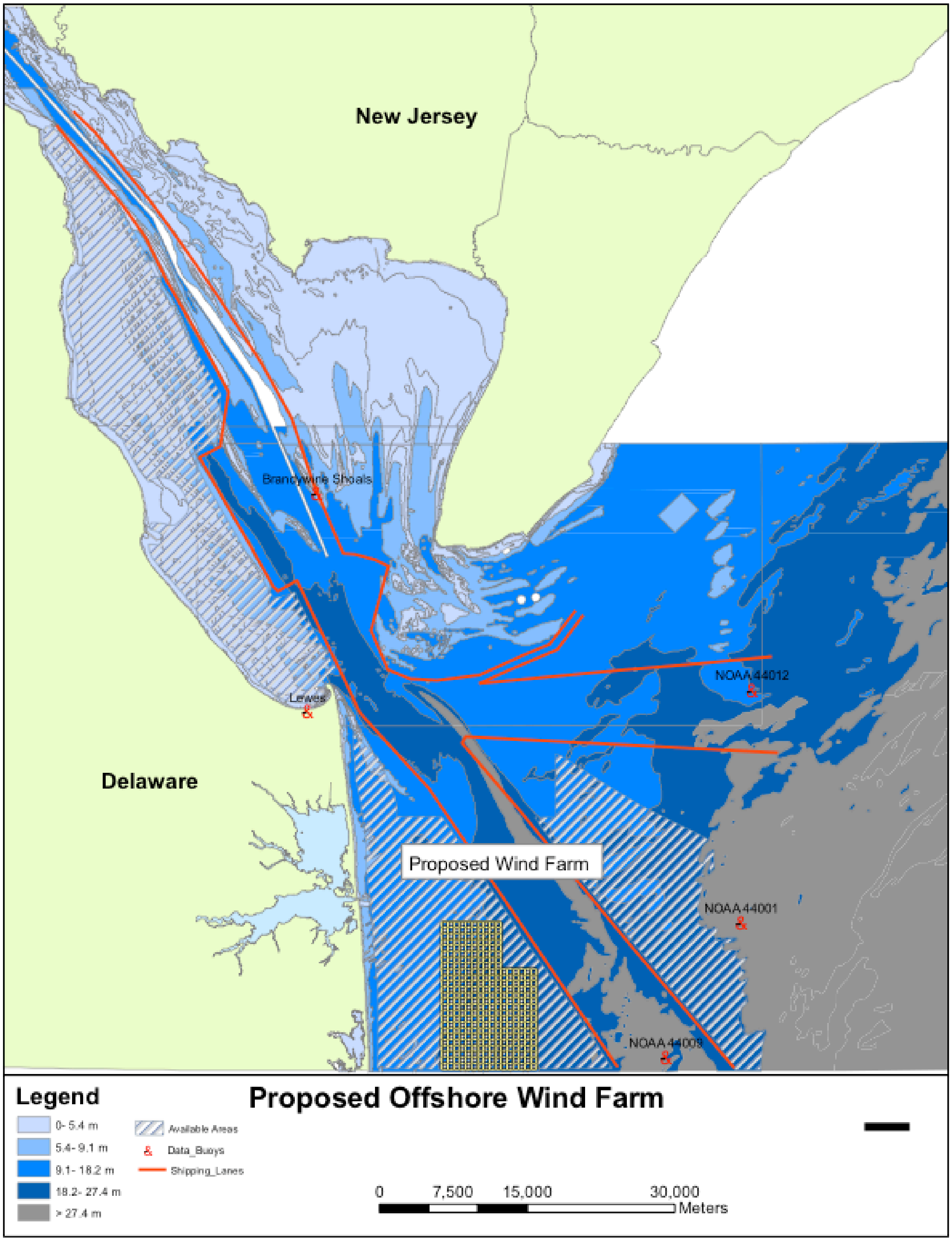

New Jersey
Brandywine Shoals
NOAA 44012
Lewes
Delaware
NOAA 44001
NOAA 44009
Legend
Wind Speed
< 5.9 m/sec CLASS 1
5.9 - 6.9 m/sec CLASS 2
6.9 - 7.5 m/sec CLASS 3
7.5 - 8.1 m/sec CLASS 4
8.1 - 8.6 m/sec CLASS 5
Annual Avg Interpolated Wind Map
Data_Buoys
0
7,500
15,000
30,000
Meters

Map 11:



New Jersey
Brandywine Shoals
NOAA 44012
Lewes
Delaware
NOAA 44001
NOAA 44009
Legend
Wind Speed
< 5.9 m/sec CLASS 1
5.9 - 6.9 m/sec CLASS 2
6.9 - 7.5 m/sec CLASS 3
7.5 - 8.1 m/sec CLASS 4
8.1- 8.6 m/sec CLASS 5
0- 5.4 m
5.4- 9.1 m
9.1- 18.2 m
18.2- 27.4 m
> 27.4 m
Data_Buoys
Bathymetry and Wind Regimes
0 7,500 15,000 30,000
Meters

Map 12:



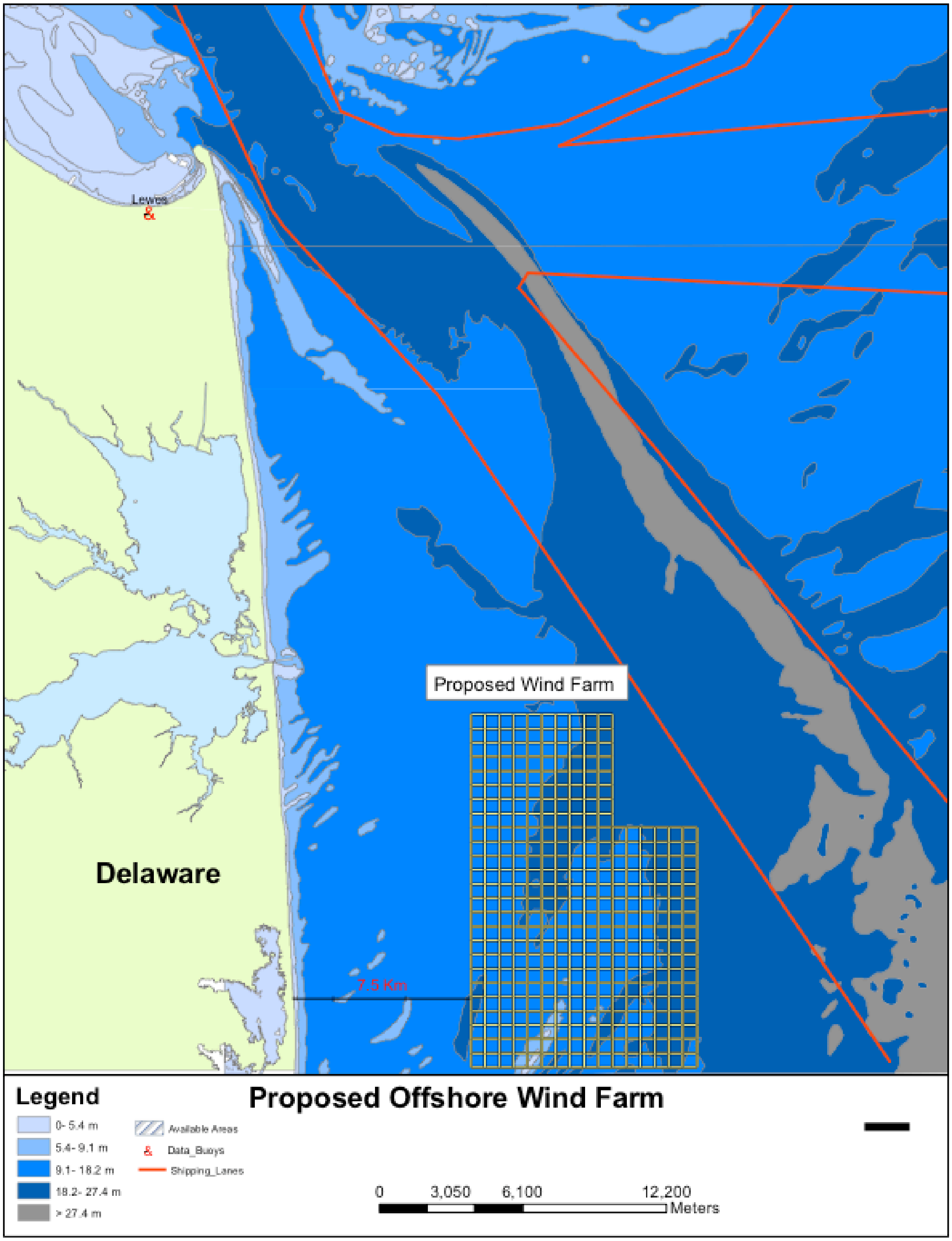
New Jersey
Brandywine Shoals
NOAA 44012
Lewes
Delaware
Proposed Wind Farm
NOAA 44001
NOAA 44009
Legend
Proposed Offshore Wind Farm
0- 5.4 m
5.4- 9.1 m
9.1- 18.2 m
18.2- 27.4 m
> 27.4 m
Available Areas
Data_Buoys
Shipping_Lanes
0 7,500 15,000 30,000
Meters

9. Creating a Grid:
An equal size square grid was created with 394 nodes for the placement of the wind mills. Each grid is a square of 600 X 600 m. At the chosen site 394 wind turbine can be installed with a spacing of 600 m between each of the wind turbine. With the use of 3.4 MW wind turbines, the total installed capacity of the proposed offshore wind site will be 1340 MW, enough power to displace one third of the existing fossil fuel based power plants in the state.

Conclusion:

Mapping the resource is the very first step in assessing the resource potential. The mapping techniques presented in this project can be undertaken in the academic setting using widely available hardware and software systems. With good quality Bathymetric and wind speed data, the maps can present a picture of the wind resource and the areas available for wind energy exploration. The next step in the effort is to value the energy from the proposed offshore wind farm at the market price.

Map 13:



Note: The area shown in this map is to illustrate the scale of an offshore utility wind project in relation to the entire area available. It does not correspond to any proposal known to the author nor is it meant to represent area discussed in the business development section.

III. Valuation model

This section makes a site-specific evaluation of historical wind data; translates that data into energy output, which is then related to the corresponding historical real world spot price for the electricity. First an appropriate NOAA offshore buoy was selected and its historical wind data was downloaded and treated to ensure a complete year of data existed (8760 hourly entries). Offshore wind turbine hub height was assumed to be 80 meters. The NOAA data was recorded at 5 meters so a conversion formula was applied to obtain an estimate for 80 meters. These estimated wind speeds were recorded in intervals of 1 hour. Each hourly reading was processed to derive the instant output from the General Electric 3.6 wind turbine; this instant output was assumed to be consistent over the wind reading's entire 1 hour period. Spot market pricing data from the local utility (PJM) for the same time frame was downloaded. This data is also recorded by PJM in hourly average readings. The power output and pricing data were then correlated to derive the actual value of the electricity that would have been produced.

Using proximity to the Delaware shore as the primary criteria we selected a specific buoy and visually reviewed several years' worth of data to evaluate the completeness of what was recorded. The choice of a buoy was easy: NOAA buoy 44009 is located only 34 km ESE of Indian River Inlet, Delaware; the year 2003 had the most-nearly whole data set. NOAA wind data for offshore buoys are recorded as an average of each 10 minute period. The standard format will read year, month, day, hour and ten-minute in space delimited text files. As the data is archived its volume is reduced to 1/6th of original bulk by converting it to hourly averages. (Note: data for land mounted buoys such as those ***in*** the Delaware and Chesapeake Bays are recorded at different intervals and in a different layout.) The conditions under which the buoys are required to perform are extremely hostile and the attention given their data recording role is, possibly due to economic necessity, somewhat limited. Therefore it is not unusual to find substantial gaps where readings are missing; as well as many cases where null values have been recorded.

The market area any Delaware offshore wind energy facility would feed into would most likely be the Southern Delaware area designated South Delaware Power Limited (DPL) - of the PJM Independent Service Operator (ISO). PJM stands for Pennsylvania, Jersey, Maryland, and is an *independent system operator* of a regional electrical grid that actually stretches over 17 states. All of their market data is available for internet download at http://www.pjm.com/markets/energy-market/real-time.html . PJM uses a pricing system (locational marginal pricing) where the price is set by the buyer's/seller's actual location within the transmission grid. This allows for effective market signaling but complicates the data analysis somewhat because it also results in wide variability in actual bid/sell price of electricity within PJM. Fortunately, the PJM data is aggregated into reports that include hourly averages over a collection of specific pricing points. In this case Delaware is divided into a number of these aggregated LMP points. As mentioned, the one of concern to us it the DPL South aggregate.

Selling industrial wind farm output into energy markets
The major drawback of wind energy is that (especially from the view of a culture used to the storage capability of fossil fuels) it lacks dependability. There are three basic strategies for marketing wind derived energy and they all reflect the intermittent aspect of wind in relation to conventional "dependable" energy sources. The first method is to store the wind energy in some form. There is much talk about hydrogen as a suitable vehicle for this storage medium, but the physics and chemistry of hydrogen make its ultimate adoption unlikely. A much more probable and economically viable means of storage has been described by University of Delaware Professor Willett Kempton in a strategy he terms "V2G" for vehicle to grid; in which the storage capacity of an electric vehicle fleet aids in compensating for winds intermittent nature. While the V2G concept makes economic sense and its implementation could serve to reduce or eliminate reliance on complex hydrocarbons as a source of transportation energy, it is still a notion in infancy and suffers from the same drawback as other less efficient wind energy storage plans. They all raise the price of wind energy beyond where it remains competitive with coal. As long as the environmental effects of fossil fuels are not priced into their consumption it will be difficult for wind with any type of storage to make headway on a strictly dollars and cents argument. With carbon trading looking like a probable part of the future landscape that may soon change; however it doesn't affect current economic comparisons in the United States.

That brings us to the idea of selling wind without storage and dealing with the prospect of market competitiveness. Our second option relies on the segment of the population that perceives a value in supporting clean energy. Green consumers have seen their beliefs reflected in policy instruments that create markets for renewable energy sources, including wind. Many states have set standards that require a certain amount of the electricity generated in their area of control to be from renewable sources. The Renewable Portfolio Standards (RPS) are a source of inspiration for marketing initiatives - such as those that identify consumers who agree to pay higher utility bills to offset the higher costs of clean energy. One of the more economical sources of the "green energy" required by RPS is a wind farm sited in a high wind area. The usual reliability requirements levied on those receiving long term contracts for the energy they produce (power purchase agreements or PPAs) are typically waived for wind energy facilities. Energy facility developers and operators are signed to long term contracts that pay a reasonable estimated return on investment to a bid contract. This is not entirely a subsidy since the lack of fuel costs means that the energy purchasing entity is trading strict reliability (which the grid can accept to a point) for a hedge against fuel price volatility. With this commitment in hand, obtaining capital follows the routine business model.

The third method, and is to sell the output on the spot energy market. This fully plays to the strength of wind energy against the weakness of fossil fuels. The fuel cost, as an item in the operating budget, is zero. The fuel cost constraint is one of the largest determinants of energy pricing and it is unlikely that offers to sell on the spot market would be less than the price of the particular fuel required. Wind, not experiencing this constraint, has the ability to bid into this market at its fuel cost, zero. This is possible because of the nature of the market which pays the full marginal price to all lower bidders. It is this market against which the energy that would have been produced by a GE 3.6 MW wind turbine, located at the location of buoy 44009 (see map) in 2003 was compared.

For a detailed description of the data collection and extrapolation process, see Appendix 2.

Discussion

This section has shown that a reasonably realistic assessment of the value of a wind resource is possible with resources that are readily available at the local public library's internet kiosk. The results are summarized in the table form below. The actual wind, wind turbine output and price data used in all calculations were hourly; and, since those data tables include 8760 rows, for brevity the results of those calculations are presented here as monthly averages.

Table 5

2003 production summary

	B	C	D	E	F	G	H
	SoDE$MWh	**ws 5m**	**ws 80m**	**hourly kW output**	**$/hr**	**SUM$**	**monthly kW hr**
January	49	8.6	11.2	2112	115	85298	1571023
February	52	7.9	10.1	1838	108	72892	1235238
March	54	5.7	7.3	1058	64	47687	787123
April	38	7.4	9.6	1419	57	40770	1021999
May	31	7.6	9.8	734	22	16694	546266
June	35	4.4	5.6	464	12	8366	334070
July	44	5.1	6.6	730	34	25621	543048
August	44	4.9	6.3	629	27	19747	467809
September	34	6.2	8	1160	38	27513	835213
October	31	6.9	8.9	1467	45	33613	1091715
November	31	6.5	8.4	1249	41	29847	899036
December	37	9.2	11.8	1544	61	45318	1148965
Annual sum:						**453366**	**10,481,505**

Column B: average spot market price at Indian River for given month in dollars per megawatt hour.
Column C: average recorded wind speed at 5 meters during given month. This is provided for reference only as all production calculations were based on recorded hourly readings.
Column D: average wind speed at 80 meters extrapolated from the 5m data.
Column E: average hourly output in kilowatts of GE 3.6 turbine during given month. These averages were calculated by averaging all hourly readings during the given month and dividing the total by the number of hours in that month. All production calculations were derived from recorded hourly readings.
Column F: average value of hourly production of 3.6 - derived from match between hourly wind data translated through the generator's production curve with those results tied to the corresponding electricity spot market. The averages presented here were then calculated by aggregating all hourly readings during the given month and dividing the total by the number of hours in that month.
Column G: total value of electricity produced during given month in dollars.
Column H: total number of kilowatt hours produced during given month.

In Map 13 we laid out an area of 126km^2 which accommodated 392 turbines at factory recommended spacing intervals; this 126:392 ratio, if applied to the entire 740 km^2 area evaluated, yields 2,294 turbines. We can use this to make an estimate of annual production and value of production for entire Delaware ocean resource (bays excluded) based on the mapping data provided:
2294 GE 3.6 MW turbines x $453,366 = **$1,040,021,604 / year**
2294 GE 3.6 MW turbines x 10,481,505KWh = **24,044,572,470kWh/year** or **24,044,572MWh/year** or **24,045GWh/year**

Note: The GE 3.6 MW wind turbine has an annual 100% production capacity of 31,536 MW/h. If we consider that our hypothetical turbine, located where NOAA buoy 44009 is would have produced 10,481 MW/h in 2003, we derive a capacity factor of 33%.

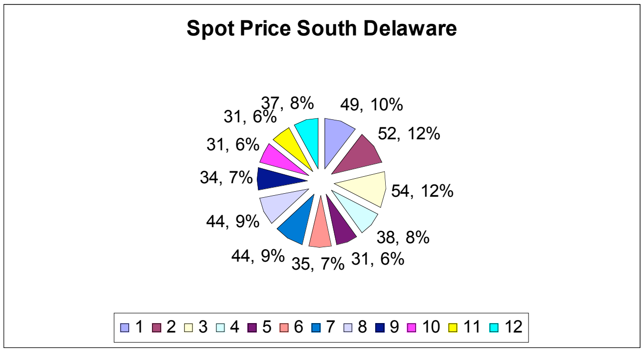
The first surprise this analysis produced was the sheer magnitude of the value of the resource. One billion dollars of potential sales per year adds a new dimension to appreciating the resource as an energy product.

The second finding was that electricity is not valued especially higher in the summer months than it is in the winter months. In the following analysis the assumption is taken that the spot market price is a general reflection of demand. This may or may not be true. Proceeding in the discussion as if it were we can see from the pie charts on the next page that the most significant variance from expectation is that the high winter prices of electricity and the high winter wind speed make the winter months very lucrative. Going into the analysis it was accepted wisdom that the value of electricity during summer is significantly higher that that during the winter. The period reviewed did not confirm that to be true. In fact, possibly due to use of electric home heating, the load curve could be characterized as flat. An expectation was that the higher summertime price could to some degree compensate the revenue stream for the reduced wind production during the summer.

What was observed was that prices during the summer months are high, as expected. However, the unexpectedly high prices during the winter months look to be combining with the greater winds to produce substantially more revenue that a fairly well informed, seat-of-the-pants analysis would have predicted.

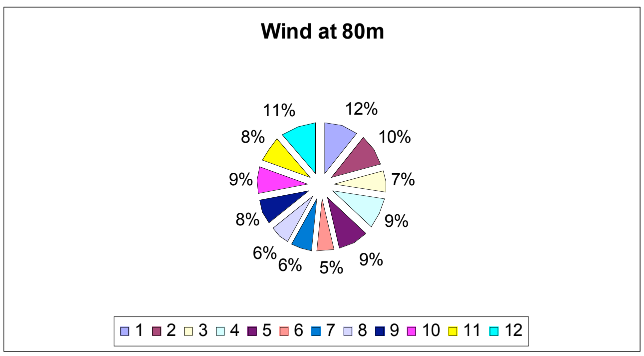
The analyzed buoy data is on the border between classes 3 and 4 winds. More detailed assessments of the wind regime and the predicted load of the region are called for. The age and pollution levels of the local Indian River coal fired plant; coupled with extremely rapid population shifts into the area make it likely that the future financial picture of the wind resource off the Delaware shore will only improve with time.

Graph 1

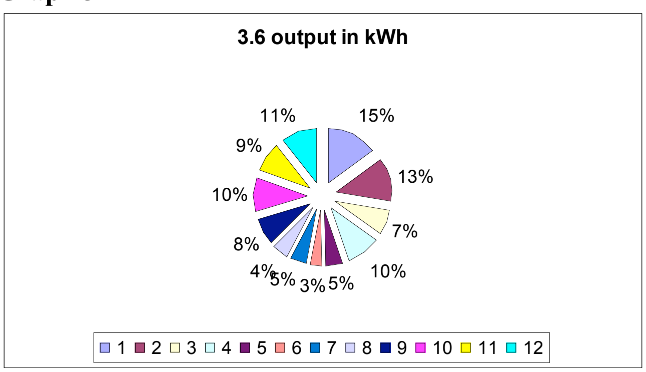


Above: Monthly average prices/MW in dollars. Demand is assumed to correlate to pricing and thus the percentage figure is as a part of the yearly total demand.

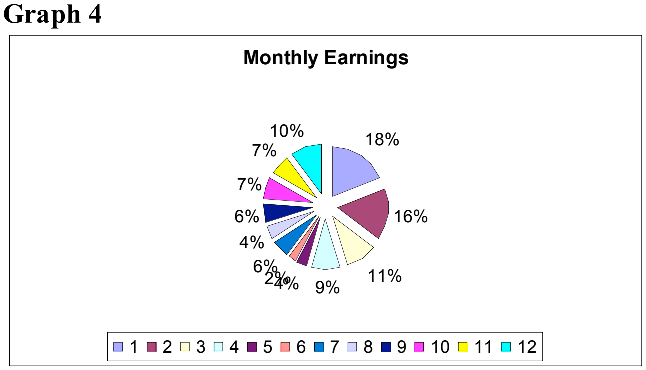
Graph 2



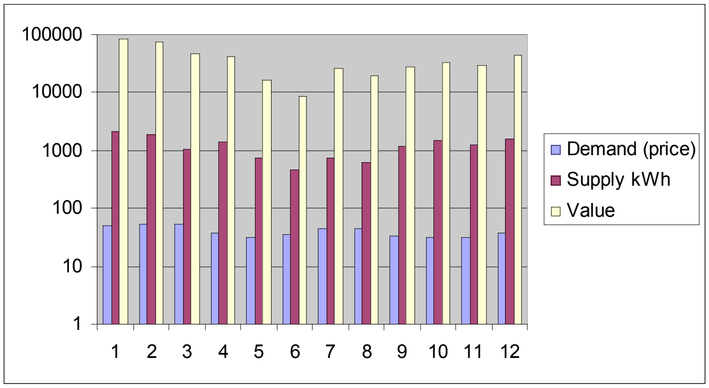
Graph 3



Graph 4



Graph 5
Note unexpectedly flat demand curve.



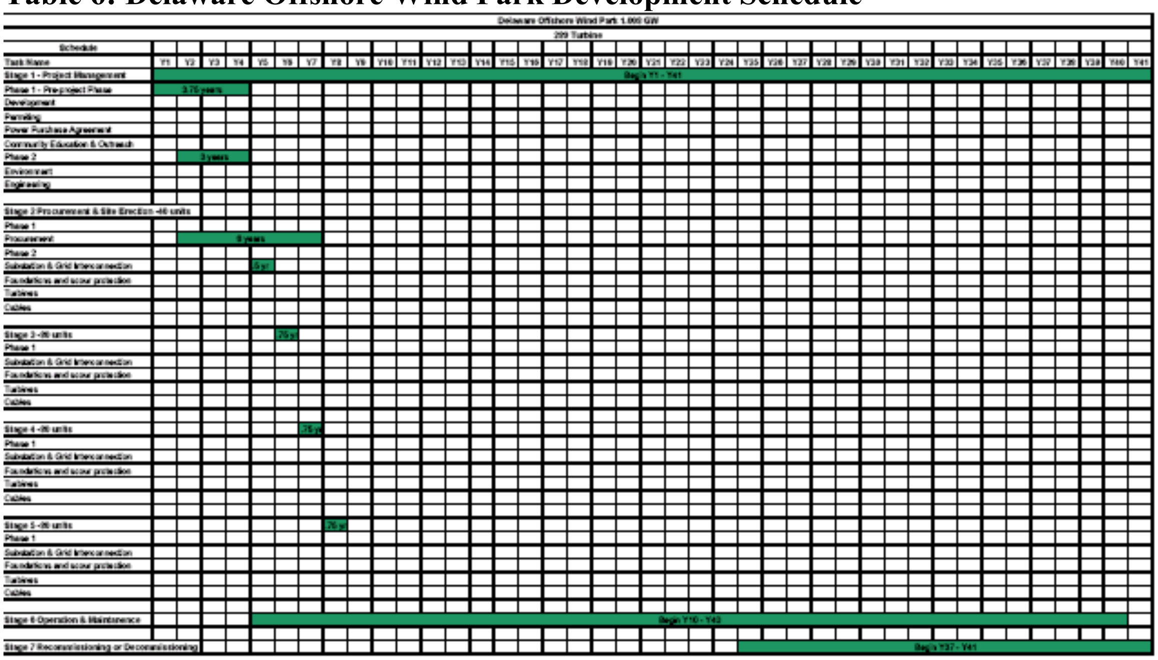
IV. Business Development Model

A critical element in any project is economic viability. Economics often represent the only barrier to widespread adoption of new technologies. This section discusses an Economic & Development Model that was designed to assess the feasibility of a one Gigawatt (1000 MW) wind park off the shore of Delaware under various scenarios.

As noted earlier, the Delaware Offshore Park would be located off the Indian River Inlet and consist of 280 GE Energy 3.6s turbines installed in 5 phases over the course of 5 years. Phase 1 construction would begin in year 5 after all permitting, site assessment, engineering and network upgrades were complete. Phase 1, consisting of the offshore substation and 40 units would come online in year 6 and begin producing revenue.

Phases 2 through 5 would be completed in years 6, 7, 8 and 9 with each phase producing power within one year. By the beginning of year 10, the Delaware Offshore Wind Park would be in full production generating an estimated 3.5 Gigawatt hours per year.[2]

Table 6: Delaware Offshore Wind Park Development Schedule



Assumptions

In the section below, the key economic assumption used in this scenario are described. These included the assumptions associated with costs, operation and maintenance, cost of capital, and revenue. As noted above, the project is divided into 5 stages aligning with the construction schedule experienced at Horns Rev. This schedule estimates complete installation within 5 years and the full production life of turbines of 30 years. The Operation and Maintenance budget begins in year 6 and increased with each completed stage.

---

[2] Based on the output calculated in Section III. Valuation Model of this paper.

Cost Assumptions
Although lower than mean estimated installed cost from European constructed and planned offshore projects ($1950 per kW), the scenario featured[3] uses the Cape Wind project cost of $1666 per kW to extrapolate the costs of the 1.008 GW park. Estimated at approximately $1.77 Billion, the total installed project costs are further broken down into cost components. As shown in Table 4.2 Range of Installed Costs, the cost of the offshore turbines are calculated at 45% of the total installed cost, the support structure and tower is estimated at 25% of the total cost, power collection and transmission is 21%, and installation and management makes up the remaining 9%.

Using a network upgrade estimate from Conectiv Power Delivery[4], this scenario estimates $102 Million in costs to upgrade the network for the injection of new generation. This estimate is extrapolated from a 750 MW estimate and may not reflect the real costs associated with a gigawatt facility.

Operation & Maintenance Assumptions
The operation and maintenance costs are a critical element in estimating the feasibility of any electricity generating facility. Unfortunately, the published estimates for offshore wind projects lend little confidence in estimating these variable costs. The published estimates range from 2¢/kWh of production to 25% of the cost of production as noted in from European projects. In the "Economic Impact Analysis of the Cape Wind Off-Shore Renewable Energy Project"[5], Global Insight estimates the total annual labor and non-labor O&M budget at $26.45M per year.

Using the Cape Wind Project O&M estimate above, the Delaware Office Shore Park estimates an annual O& M budget of $2.5 M for years 1 & 5, increasing from $6.3M in year 6 to $17.6 M by year 9, $21.4 for years 10-35 and gradually declining from $17.6M in year 36 to $2.5M in year 40. Beginning in year 37, the O & M budget includes $28.9M allowance for Decommissioning[6].

Table 7: Total Operation and Maintenance Budget

Operation & Maintanence Costs		
Labor	$	289,841,619
Spare Parts	$	230,555,833
Operations	$	79,047,714
Equipment	$	32,936,548
Facilities	$	26,349,238
Insurance	$	671,921,067
Decommissioning	$	144,920,810
Total	$	1,475,572,829

[3] Changing variables such as estimated cost per kW is a feature of this Economic & Development Model
[4] Conectiv Power Delivery Generation Interconnection Network Upgrade estimate for 750 MW into the Indian River 138 kV substation.
[5] Global Insight, Lexington, MA. April 2003. Economic Impact Analysis of the Cape Wind Off-Shore Renewable Energy Project.
[6] Assumed at 50% of original labor budget.

Table 8: Range of Installed Costs[7]

Costs by Cost Component			kW	MW	Total Cost per GW
	Cape Wind		**$1,666.00**	**$1,666,000**	**$ 1,666,000,000**
	Low		**$ 1,700.00**	**$1,700,000**	**$ 1,700,000,000**
	High		**$ 2,500.00**	**$2,500,000**	**$ 2,500,000,000**
	Mean		**$ 1,950.00**	**$1,950,000**	**$ 1,950,000,000**
Turbine Cost Data		**45%**	kW	MW	GW
	Cape Wind		$ 749.70	$ 749,700	$ 749,700,000
	low		$ 765.00	$ 765,000	$ 765,000,000
	high		$ 1,125.00	$ 1,125,000	$ 1,125,000,000
	Mean		$ 877.50	$ 877,500	$ 877,500,000
Support Structure & Tower Cost Data		**25%**			
	Cape Wind		$ 416.50	$ 416,500	$ 416,500,000
	low		$ 425.00	$ 425,000	$ 425,000,000
	high		$ 625.00	$ 625,000	$ 625,000,000
	Mean		$ 487.50	$ 487,500	$ 487,500,000
Power Collection Cost Data		**13%**			
	Cape Wind		$216.58	$ 216,580	$ 216,580,000
	low		$221.00	$ 221,000	$ 221,000,000
	high		$325.00	$ 325,000	$ 325,000,000
	Mean		$253.50	$ 253,500	$ 253,500,000
Power Transmission Cost Data		**8%**			
	Cape Wind		$133.28	$ 133,280	$ 133,280,000
	low		$136.00	$ 136,000	$ 136,000,000
	high		$200.00	$ 200,000	$ 200,000,000
	Mean		$156.00	$ 156,000	$ 156,000,000
Installation Cost Data		**7%**			
	Cape Wind		$116.62	$ 116,620	$ 116,620,000
	low		$119.00	$ 119,000	$ 119,000,000
	high		$175.00	$ 175,000	$ 175,000,000
	Mean		$136.50	$ 136,500	$ 136,500,000
Management Cost Data		**2%**			
	Cape Wind		$33.32	$ 33,320	$ 33,320,000
	low		$34.00	$ 34,000	$ 34,000,000
	high		$50.00	$ 50,000	$ 50,000,000
	Mean		$39.00	$ 39,000	$ 39,000,000
Delmarva Power Delivery Network Upgrade	Low		$ 77.17	$ 77,173	$ 77,173,333
	High		$ 102.21	$ 102,213	$ 102,213,333
				Total Cape Wind	$ 1,768,213,333

[7] Atlantic Renewable Energy Corporation, Richmond, VA; AWS Scientific, Inc., Albany, NY. December 2004. New Jersey Offshore Wind Energy: Feasibility Study

Cape Wind Project Web Site http://www.capewind.org/

Cost of Capital

Table 5 outlines the cost of money assumptions. Assuming a total project of $1.7 Billion and a 45% owner's equity, the annual debt service is estimated at $91.5 Million for 30 years. Assuming a risk free investment, the cost of capital is calculated on a (nominal) risk-free rate of interest, R_f[8]. The calculation assumes a 2% inflation rate and a 4% real risk free interest rate of 4% resulting in a 6.08% rate on the financed debt.

The Economic & Development Model allows the interest rate and percent of total assumptions to be changed automatically recalculating the debt service and reflecting it on the Cash Flow Worksheet. Although unlikely that a risk free scenario will exist, the Model is limited to calculating a risk-free scenario at this time.

Table 9: Finance Costs

Finance Costs	Amount		% of Tota	Nominal Rate(Rf)	Annual Debt Service	
Inflation (i)		2%				
Real Risk Free Interest Rate (rf)		4%				
Equity	$	795,696,000	45%	0%	$	-
Risk Free Interest Rate Loan (Rf=i+rf+(i*rf))	$	972,517,333	55%	6.08%	$	59,129,053.87
Total	**$**	**1,768,213,333**	**100%**	**6.08%**	**$**	**59,129,053.87**
		Annual	**Years**			**Total**
Debt Service	$	59,129,054	30		**$**	**1,773,871,616**
Principal	$	32,417,244	30		**$**	**972,517,333**
Total	**$**	**91,546,298**			**$**	**2,746,388,949**

Revenue

The revenue section of the Economic & Development Model allows for input changes to annual average price per unit (¢/kWh), rate of inflation percent per year and the production tax credit, shown below at 1.9¢/kWh. These input variables allow the user to improve the model results as better more reliable data becomes available. As information in these cells change, the Net Present Value and Internal Rate of Return for the project are also undated.

The total Projected Net Sales in kilowatt-hours is based on the installation of 340 - 3.6 MW turbines with a life of 30 years under the wind conditions described earlier in this paper. The value of the sales is estimated at 4.3 ¢/kWh, the spot market price at the Indian River Inlet previously calculated in this paper. As shown in Table 8, the total Cash In-Flow is $8.77 Billion which includes the 2.0% inflation rate per year[9] on the kWh value.

Also shown below is a one time $250,000 grant from the State of Delaware. This inflow appears in year 6 with the start of phase 1 and the first 40 turbines. The revenue reflects the maximum grant allowed for small wind turbines under the Delaware Green Energy Grant Program. The program specifies small projects; however the Technology

[8] This rate is generally reserved for projects with little risk and a high degree of certainty

[9] This is the same inflation rate used to calculate the no-risk interest rate. However, the project team notes that as wind energy is often traded on the spot market at its fuel price of zero, wind energy may actually deflate the cost of electricity.

Development Program has more flexibility and may consider this a viable project to support. In a project this large, a low interest or no interest loan from the State of Delaware may be more attractive.

Table 10: Revenue

	Annual Total
Projected Net Sales	$ 6,893,575,740
Annual Price Per Unit (kWh)	$ 0.043000000
Number of Units Sold kWh	108,993,024,000
Inflation	2.0%
Federal Production Tax Credits	$ 1,880,004,096
Value - Production Tax Credit	$ 0.019
Renewable Energy Credits	-
State of Delaware Grant	$ 250,000
Total Cash Inflow	$ 8,773,829,836

Findings

Under the scenario presented here, the project has a positive cash flow beginning in year 8, the Internal Rate of Return, calculating the rate of return that yields NPV=0, compares the rate with a firms (internal) rate of return. If the Internal Rate of Return (IRR) is greater than the cost of capital, then the firm usually selects the project.

Because projects with positive NPV imply above-normal discounted profits, firms generally invest in projects with a positive Net Present Value. In the scenario shown here, the NPV is negative.

Conclusion

Conditions in the model can be changed to determine what market conditions are needed to meet any given IRR or NPV. Variables such as increased production tax credit, low or no interest loans, inflation, spot market prices, equity to debt ratio, or the introduction of a Renewable Energy Portfolio Standard can all be altered in the model to build a scenario conducive to investment.

References

Atlantic Renewable Energy Corporation, Richmond, VA; AWS Scientific, Inc., Albany, NY. December 2004. New Jersey Offshore Wind Energy: Feasibility Study

Cape Wind Project Web Site http://www.capewind.org/

Delaware Energy Task Force Final Report to the Governor. December 2003. Bright Ideas for Delaware's Energy Future

Rothwell, Geoffrey & Thomas Gomez, 2003. Electricity Economics: Regulation and Deregulation, Institute of Electrical and Electronic Engineers, Inc.

GE Energy Web Site http://www.gepower.com/businesses/ge_wind_energy/en/index.htm

Global Insight, Lexington, MA. April 2003. Economic Impact Analysis of the Cape Wind Off-Shore Renewable Energy Project.

Horns Rev Wind project Web Site http://www.hornsrev.dk

Manwell, McGowan and Rogers, 2002, Wind Energy Explained: Theory, Design and Application. West Sussex: Wiley.

Off Shore Wind Energy Web Site: www.offshorewindenergy.org

PJM Interconnection Web Site http://www.pjm.com/about/overview.html

V. External Costs and Benefits

Part A: AVOIDED EMISSIONS OF CO_2, SO_2, AND NO_x

Generating electrical power from the wind, unlike power from fossil fuels, does not produce emissions of CO_2, SO_2, and NO_x.[10] The first of these is the principal cause of anthropogenic global warming,[2-3] while the last two contribute to acid raid, fine particulate matter, and, in the case of NO_x, to the formation of tropospheric ozone. In 2002, the last year for which we had emissions data, the net electrical generation in Delaware was 6.0×10^6 MWh (megawatt hours). The portfolio of energy sources is shown in Table 1.

Table 11
Portfolio of Energy Sources Used to Generate Electricity in Delaware in 2002

Energy Source	MWh	Percentage
Coal	3,463,565	57.7
Petroleum	949,696	15.8
Natural Gas	1,442,883	24.0
Other Gases	146,346	2.4
Other	0	0.0
Total	**6,002,490**	**100.0**

Table 12
Emissions Produced in Delaware in 2002 with 6.0×10^6 MWh of Electricity.
Table shows the emissions associated with this generation.
The last column shows the emissions on a per MWh basis, averaged over the energy portfolio used.

Emission	Amount (tons)	Amount (mt)	Emission/MWh
C as CO_2 [a]	1.6×10^6	1.5×10^6	0.25 mt/MWh
SO_2	33×10^3	30×10^3	5.0 kg/MWh
NO_x	12×10^3	11×10^3	1.8 kg/MWh

[a] **The amount of C as CO_2 was determined by multiplying the weight of CO_2 (5989 thousand short tons) by 12/44, the ratio of the atomic weight of C to the molecular weight of CO_2. The amount in metric tonnes (mt) was determined by multiplying the weight in short tons by 1.1.**

The amount of CO_2 produced along with the electricity generated from any fuel source can be determined from the chemical composition of the fuel, as shown in Table 9.

[10] Fossil fuels are used, and their emissions produced, in the manufacture, installation, and maintenance of wind machines and for that matter of the power plants used to generate electricity from other energy sources.

[2] IPCC, 2001. Intergovernmental Panel on Climate Change, **IPCC Third Assessment Report – Climate Change 2001**, Available on the web at: http//www.ipcc.ch.

[3] NAS, 2001. National Academy of Sciences, **Climate Change Science: An Analysis of Some Key Questions** (2001). Available on the web from the National Academy Press at: http://books.nap.edu/books/0309075742/html.

Table 13: Carbon as CO_2 Produced by Various Fuels Used to Generate Electricity

Fuel	Chemical Reaction[a]	Moles CO_2 /MJ[a]	Min gC /kWh[b]	Assumed Gen. Eff.	mt C /MWh[c]
Coal	$4(-CH-) + 5O2 = 4CO_2 + 2H_2O$	2.0	86	0.30	0.29
Petroleum	$2(-CH_2-) + 3O2 = 2CO_2 + 2H_2O$	1.6	69	0.30	0.23
Gas	$CH_4 + 2O_2 = CO_2 + 2H_2O$	1.2	52	0.45	0.12
Wind	na	0.0	0	na	0.00

[a] Chemical reactions and moles of CO_2 produced per megajoule of energy are from Table 1.4 (p.19) in T.G. Spiro and W. M. Stigliani, Chemistry of the Environment, Prentice Hall, Upper Saddle River, NJ, 1996.

[b] This is the minimum grams of carbon per kWh of electrical energy, if the heat were converted to electrical energy with 100% efficiency.

[c] This is the number of metric tonnes of carbon per MWh of electrical energy produced with the generating efficiencies (fractions of heat converted to electrical energy) shown.

The weighted average mass of carbon per MWh calculated using the last columns in Table 7 and Table 9 is 0.24 mt,[4] in good agreement with the value of 0.25 mt/MWh in Table 8; determined from the actual carbon emissions and electrical energy generated in Delaware in 2002.

[4] Since the chemical composition of the 'Other Gases' shown in Table 1 was not specified, we assumed that it behaved like petroleum in calculating the weighted average.

VI: POTENTIAL INTERACTIONS BETWEEN MARINE WILDLIFE SPECIES AND OFFSHORE WIND FACILITIES

The state of Delaware is truly a small wonder. The second smallest state in the nation, Delaware encompasses a mere 1,982 square miles of land, yet the richness and diversity of its natural resources belies its small size. Bordered by the Delaware River, the Delaware Bay, and the Atlantic Ocean, the state boasts 260 miles of shoreline (including inland bays), 25 miles of Atlantic Ocean coastline, two national wildlife refuges, a federally-designated national estuarine research reserve, a federally-designated national estuary, and a diverse array of saltwater and freshwater marshes, cypress swamps, barrier beaches, and inland bays. The Delaware Bay, part of the Environmental Protection Agency's National Estuary Program, is home to the largest horseshoe crab population in the world, and also serves as an important feeding ground for thousands of migratory shorebirds each spring (DNREC 2000). The waters off Delaware's Atlantic coast teem with valuable commercial and recreational fisheries, as well as abundant marine wildlife. Delaware's beaches attract over five million visitors annually, and tourism contributes almost 700 million dollars to Delaware's gross state product (pers. comm. with Mr. James Falk; 4/15/2004).

Marine Mammals

Marine mammals are of particular interest when considering potential interactions between wildlife and offshore wind developments, for several reasons. First, many marine mammals are very large in size (as compared to finfish and invertebrates discussed previously) and require large amounts of unimpeded ocean space in order to navigate the ocean freely. A large offshore wind farm may hinder the movements of migrating marine mammals, particularly those that use echolocation for navigational purposes. Should these marine mammals move away from the wind farm area in search of more open habitat, they may risk entering busy shipping lanes and thus be at risk for boat collisions. Increased boat collisions are a particular risk to species such as the highly endangered northern Atlantic right whale, which is known to migrate along the eastern Atlantic coast.

The effects of underwater noise on marine mammals are of special concern when assessing possible effects of an offshore wind facility. In particular, seismic explorations, pile ramming, and/or increased ship traffic may be expected to produce extensive noise during the exploration, construction, and operation phases. Pile ramming, for example, is thought to produce sounds greater than 205 decibels (dB). Some biological effects of low-frequency sounds on marine mammals include the masking of echolocation sounds used for finding food or for navigational purposes; disturbance of natural marine mammal behavior such as feeding or socializing; hearing damage; and physiological stress (Erbe and Farmer 2000). While literature on underwater noise specifically from offshore wind turbines and its effects on marine mammals is lacking, a European study on the effects of underwater acoustics from a simulated 2MW offshore wind turbine on seals and porpoises provides some insight into how marine mammals may be affected. The paper finds that porpoises and seals are capable of detecting low-frequency sounds emitted by offshore wind turbines. This finding is evidenced by the surfacing of both harbor seals and porpoises at a significantly greater distance from the simulated sound source when it was in operation than during control experiments. Porpoises were also found to have extended echolocation activity during the simulated operation of the wind turbine, indicating that they were aware of the noise and were exploring it with their biosonar. The study suggests that marine mammals may also suffer indirect effects of noise from a wind turbine, such as prey fish avoiding the sound source and the masking of marine mammals' mating and communication calls by the noise emitted from operating wind turbines (Koschinski et. al. 2003).

A limitation of the Koschinski et. al. study (2003) to this research project is, of course, the fact that harbour porpoises and harbour seals are not found in the waters off Delaware's coast. However, the study is valuable in that it is a first step towards assessing the possible effects that the rapidly-growing offshore wind industry may have on marine mammals. Further research is certainly required, including the potential for marine mammals to habituate or become desensitized to certain underwater sounds, a concept touched on briefly by Koschinski et. al. (2003) but not explored in great depth.

Literature on underwater noise from shipping vessels is more readily available than literature on underwater noise from offshore wind facilities. Since ships are thought to emit sounds at frequencies similar to offshore wind turbines, a thorough review of available literature on shipping noise and marine mammals may provide useful information when considering similar effects from offshore wind facilities, although such a review is beyond the scope of this research paper (Koschinski et. al. 2003).

Another potential adverse effect of offshore wind facilities on marine mammals is the creation of an electromagnetic field. An electromagnetic field is created by the generation and transmission of electricity through cables buried below the sea floor (Safewind 2004). Some marine mammals use the earth's magnetic field for navigation; an electromagnetic field created by offshore wind facilities may affect migration patterns of some marine mammals (Safewind 2004). However, the environmental impact assessment for Denmark's Rodsand offshore wind farm suggests that the magnetic field from a cable buried one meter below the sea floor is likely to be less than the earth's magnetic field and therefore is not expected to have any adverse effects, provided that all cables are properly buried at the appropriate depth (SEAS 2000).

Reptiles (Marine Turtles)

The potential interactions between an offshore wind facility and marine turtles are similar to those faced by marine mammals. Like some marine mammals, sea turtles are known to use the earth's magnetic field for navigational purposes, and therefore may be affected by the generation of an electromagnetic field at an offshore wind facility. The effects of low-frequency underwater noise (such as what may be expected during construction or operation phases) on sea turtles are unknown.

Although literature suggests that turtles are commonly found in shallow waters less than 50 feet in depth (NRC 1990), sea turtles are also known to be common visitors in bays and estuaries. Given marine turtles' apparent preference for shallow areas such as estuaries, and not open ocean waters where offshore wind facilities are likely to be found, it seems reasonable to conclude that interactions between turtles and offshore facilities are likely to be minimal (LIPA 2003). However, given that marine turtles are federally protected species, and given that they are spotted in Delaware's waters in the summer months, potential developers should consider potential effects on sea turtles, particularly if development is planned for summer months.

Birds

Collisions between birds and offshore wind turbines are difficult to assess, given the distance of offshore turbines from shore and the difficulty in recovering carcasses of birds in a marine environment. Additionally, the frequency and magnitude of impacts may vary based on turbine size, turbine speed, the migratory paths of birds, altitude of birds' flight paths, and presence of fish around the offshore turbine (which may tend to attract more birds to the area and thus possibly increase avian impacts) (EC 2001). Since there are very limited studies available on avian impacts from offshore turbines, the majority of information is drawn from studies conducted at land-based wind facilities, of which there are significantly more studies available.

Avian interactions with offshore wind turbines are most frequently in the form of collisions with the turbines themselves or with the turbine's rotor blades, and also from habitat disturbance. Collisions with land-based wind turbines have been extensively studied, and such studies may offer useful information when considering the potential effects of offshore turbines on birds. However, one should always keep in mind that land-based turbines are commonly situated on higher elevations than offshore turbines, such as ridges or peaks (where winds are stronger). Because these locations may be migratory pathways, these turbines may have a greater impact on birds than offshore wind turbines, which would be situated at sea level. A study conducted at a land-based wind farm in Tarifa, Spain concluded that birds were able to detect and avoid the presence of wind turbines (evidenced by a significant number of changes in flight direction when turbines were operating versus when they were not in operation). The same study also calculated a bird mortality rate of 0.03 birds per turbine per year, a figure that is well below the average number of bird mortalities from power lines (de Lucas, Janss, and Ferrer 2004). The authors of the study conclude that bird mortalities resulting from collisions with (land-based) wind turbines are much smaller than bird mortalities resulting from collisions with other sources, such as vehicles, buildings, windows, high-tension lines, and communications towers (de Lucas, Janss, and Ferrer 2004).

While no peer-reviewed literature on the effects of offshore wind facilities on birds is currently available (based on a literature search), European studies conducted on the subject do shed some light on the potential for collisions between birds and offshore turbines. The Tunø Knob offshore wind facility in the Netherlands conducted a study on the effects of the offshore facility on two species of sea ducks: the common eider and the black scooter. The study suggests that rotor noise and movement had no apparent negative effects on the distribution or abundance of the common eider. The study also found that common eiders tended to avoid flying or landing within 100 meters of the wind turbines, suggesting an "avoidance effect" of offshore wind farms on birds. The observed avoidance behavior of the ducks observed in the study suggests that offshore wind facilities may act as barriers to flight, an issue that should be considered if offshore facilities are proposed for development in migratory areas (Tingley 2003). While the Tunø Knob study is valuable in that is provides insight into a field where data is greatly lacking, care should be taken when extrapolating the results, as the study was limited to just two species (eiders and scooters), took place during only one season (winter) when no migration was occurring, and is based on a much smaller-scale offshore facility (ten turbines) than those that are currently being developed (Tingley 2003).

The potential for habitat disturbance is another possible effect of offshore wind facilities on birds. Habitat disturbance may be in the form of noise generated by an offshore turbine, such as the noise resulting from the flow of air over the rotor blades, noise from the ramming of the monopile foundation into the sea floor, or a low-frequency noise resulting from the vibration of the turbine itself. Noise disturbance may result in indirect habitat loss if birds avoid areas where noise is present, or if they are ousted from their feeding and roosting grounds (Tingley 2003 and EC 2001).

Another form of habitat disturbance is the physical barrier that multiple offshore turbines may pose to migrating birds. Uncertainty exists as to whether or not birds might fly through an offshore wind facility or circumvent a wind facility all together. Flying through a facility may result in increased collisions with rotor blades. While flying around a wind facility may reduce collisions between birds and rotor blades, such movement may also affect normal migratory routes and hinder birds from reaching their traditional feeding or roosting grounds. The flip side to this issue, of course, is the potential for the turbines themselves to create new perches, and thus new habitat, for migrating birds (Tingley 2003 and EC 2001). The potential for offshore wind turbines to act as barriers to flight may be of particular interest in Delaware, as the Delaware Bay serves as a stopover point and feeding ground for thousands of migratory birds each spring. Finally, although there have been some suggestions that birds may become desensitized or habituate to either the noise produced by offshore turbines or the barrier effect created by the turbines, this possibility has yet to be studied in great depth. Further refinement of bird impacts may be possible with data on flight altitudes of potentially impacted species; however, this is beyond the scope of the current project.

CUMULATIVE EFFECTS

Particular attention should be given to the cumulative effects that multiple turbines, and multiple offshore wind facilities, will have on marine wildlife. The effects of just one offshore facility on marine wildlife may seem insignificant; however – to provide an extreme example -- if the entire power generating capacity of the shallow waters off the east coast of the United States were realized (from Maine to Maryland, approximately 96 GW; see Kempton et. al. 2004 in prep.), this translates into approximately 28,000 3.6 MW wind turbines along the east coast! Obviously, this is an upper-limit estimate, and offshore wind development in this large of a scale will most likely never be fully realized. However, this value does provide a context in which to consider the potentially powerful cumulative effects of offshore wind facilities.

This point is clearly illustrated by a one-year study conducted by Thelander and Rugge (2000; as qtd. in Tingley 2003), which found an estimated 0.15 bird fatalities per turbine per year in the Altamont Pass wind facility in California, a seemingly low number. However, when this value is considered in the context of the 5000 operating turbines found at this site, one realizes that 750 birds are actually killed per year, including a high number of raptors. The lesson to be learned from this example is that the bird mortality levels (or any environmental impact) at one particular offshore site may not seem significant, but with the potential for development of multiple offshore sites along the east coast, the cumulative effects may be significant and should be thoroughly studied.

POTENTIAL MITIGATION METHODS

Several ideas have been proposed for mitigating the effects of wind turbines on wildlife, ranging from obvious to subtle; simple to complex (Tingley 2003). First and foremost (and perhaps the most obvious), a thorough understanding of which species of marine wildlife may be found in a given area, how these species use a given area (i.e., for migration, breeding, feeding, nesting, etc.), and how sensitive these species may be to disruptions to their habitat is of utmost importance when attempting to evaluate the impact of an offshore wind facility, and must be undertaken before any construction occurs. Clearly, it is much easier to relocate a potential offshore wind facility on paper before it has been built than after construction has already begun. Sites known to lie in important migratory pathways of birds or marine mammals should be relocated to areas that would pose a lower risk. Ocean areas that serve as breeding or feeding grounds for a particular species of marine wildlife – especially endangered or threatened marine species – should be avoided, or construction should be planned so as not to coincide with periods in species' life cycles when they may be especially vulnerable to disruptions.

Construction techniques are another way in which adverse impacts of offshore facilities may be reduced. The overall number of turbines, the size of the individual turbines, and the layout of the site are all factors that can be manipulated so as to avoid or mitigate harmful impacts. Fewer turbines overall may result in fewer bird collisions or less acoustical disturbance, although fewer turbines imply less energy production, a choice that may be unacceptable to developers or impractical given current energy demands (Tingley 2003). Larger individual turbines may be more visible to birds and thus reduce the risk of collisions (EC 2001). Shorter rows of turbines, rather than longer lines of turbines, may reduce the barrier effect discussed in the previous section, and allow birds to avoid collisions with turbines (de Lucas, Janss, and Ferrer 2004). Operationally, halting the operation of offshore turbines during times of low visibility or high migration activity may also reduce the impact on migratory species, avian or marine, although again, this choice may be unacceptable to developers or impractical given current energy demands (EC 2001).

Illuminating wind turbines with lights and painting rotor blades with bright colors are two suggestions for reducing avian impacts, although critics of these ideas point out that illuminating offshore wind towers may increase visibility from land, and may actually increase bird collisions by making the turbines more visible and more attractive to birds. A California study that investigated the effects of painting wind turbine rotor blades with ultraviolet paint as a way of reducing avian collisions found no significant correlation between the use of the paint and bird collisions with turbines (as qtd. in Tingley 2003).

There are several possible ways of mitigating the effects of noise on marine wildlife. Recall that noise is likely to be generated during the construction of offshore turbines (i.e., from pile-driving) and during operation (from the turbines themselves and from maintenance vessels such as boats and helicopters). Noise emitted during construction is expected to be short-term in duration, and therefore mitigation efforts may not be necessary. Noise emitted during operation and maintenance, however, is expected to be more long-term in duration and may have permanent effects; therefore, if further research predicts these effects are significant, mitigation efforts should be pursued (EC 2001). Suggestions for reducing noise include using low-noise vessels in and around offshore wind farms, and adjusting maintenance times (on a seasonal, daily, or even hourly basis) so as not to coincide with breeding, feeding, or migratory times (if possible). The use of bubble curtains to reduce or deflect underwater noise (especially during construction phases such as pile-ramming) is a technique that has been discussed in open literature, and has proven to be successful in lowering sound levels within the immediate vicinity of activity (Würsig, Greene, and Jefferson 2000). Finally, the effects of electromagnetic fields may be mitigated by ensuring that cables are buried at an appropriate depth (EC 2001).

Reference:

Beurskens, L.W.M. and M. de Noord. Offshore wind power developments: An overview of realizations and planned projects. ECN-C-03-058. July 2003.

Capewind.org. Accessed 3/1/2004. <http://www.capewind.org>.

Danish Institute for Fisheries Research, Department of Marine Fisheries. "Effects of marine wind farms on the distribution of fish, shellfish, and marine mammals in the Horns Rev areas." May 2000.

Delaware Department of Natural Resources and Environmental Control. Delaware Coastal Programs. 2000. Document No. 40-07/01/09/02.

Delaware Department of Natural Resources and Environmental Control. Delaware Reef Guide: 2004. 2004.

Delaware Department of Natural Resources and Environmental Control. "Endangered Species of Delaware." Updated 12/14/2001. Accessed 3/2/2004 <http://www.dnrec.state.de.us/fw/telist.htm>.

De Lucas, Manuel, Guyonne F.E. Janss, and Miguel Ferrer. "The effects of a wind farm on birds in a migration point: the Strait of Gibraltar." Biodiversity and Conservation. 13 (2004): 395-407.

Erbe, Christine and David M. Farmer. "A software model to estimate zones of impact on marine mammals around anthropogenic noise." Journal of the Acoustical Society of America. 108 (2000): 1327-1331.

European Commission (EC). Offshore Wind Energy: Ready to Power a Sustainable Europe. Final Report December 2001. NNE5-1999-562.

Fishbase.org. Accessed 4/2/2004. <http://www.fishbase.org>.

FocusonNature.com. Accessed 3/2/2004. <http://www.focusonnature.com>.

Kempton, Willett et. al. "The Offshore Wind Power Debate: Views from Cape Cod." Under review by Coastal Management 2004.

Koschinski, Sven et. al. "Behavioural reactions of free-ranging porpoises and seals to the noise of a simulated 2 MW windpower generator." Marine Ecology Progress Series. 265 (2003): 263-273.

Long Island Power Authority. Long Island's Offshore Wind Energy Development Potential: Phase 2 Siting Assessment. January 21, 2003.

McCauley, Robert D., Jane Fewtrell, and Arthur N. Popper. "High intensity anthropogenic sound damages fish ears." Journal of the Acoustical Society of America. 113 (2003): 638-642.

National Marine Fisheries Service. Fisheries Statistics and Economics Division, Silver Spring, MD. Personal communication 3/29/2004.

National Research Council. Decline of the Sea Turtles: Causes and Prevention. Washington, D.C: National Academy Press, 1990.

National Wind Coordinating Committee (NWCC). Permitting of Wind Energy Facilities: A Handbook. August 2002.

National Wind Coordinating Committee (NWCC). "Offshore Wind Developments in the United States: Report of the Wildlife Workgroup Meeting." November 18, 2003. Accessed 3/2/2004. <http://www.nationalwind.org>.

New Jersey Department of Fish and Wildlife. "Artificial Reef Program." Accessed 4/28/2004. <http://www.state.nj.us/dep/fgw/artreef.htm>.

Pasqualetti, Martin J., Paul Gipe, and Robert W. Righter, eds. Wind Power in View: Energy Landscapes in a Crowded World. San Diego: Academic Press, 2002.

Safewind Info. "Wind Farms, Wildlife, and the Environment." Accessed 3/2/2004. <http://www.safewind.info>.

SEAS. "Rǿdsand Offshore Wind Farm Environmental Impact Assessment, EIA Summary Report." 2000. Accessed 5/1/2004. <http://uk.nystedhavmoellepark.dk/>.

Tingley, Morgan Winn. "Effects of Offshore Wind Farms on Birds: "Cuisinarts of the Sky or Just Tilting at Windmills?" Diss. Harvard University, 2003.

U.S. Army Corps of Engineers New England District. "Comment Summary: Offshore wind energy generation projects proposed by Winergy, LLC." File Number 200201108. June 2003.

U.S. Environmental Protection Agency. "Wind Energy." State and Local Climate Change Program. January 2000. Accessed 4/7/2004. <http://www.yosemite.epa.gov>.

U.S. Fish and Wildlife Service, Northeast Region. "Endangered Species: State and County Listings." Accessed 3/29/2004. <http://www.northeast.fws.gov/Endangered>.

University of Delaware. "Sea Turtles Count on Delaware Bay." University of Delaware Sea Grant Reporter. Summer 2000. Accessed 4/23/2004. <http://www.ocean.udel.edu/publications/>.

Williams, Wendy. "Blowin' in the Wind: Offshore wind farms may prevent an energy crisis." The American Prospect (online). October 18, 2001. Accessed 3/30/2004. <http://www.prospect.org/print-friendly/webfeatures/2001/10/williams-we-10-18.html>.

Winergyllc.com. Accessed 3/1/2004. <http://www.winergyllc.com>.

Würsig, B., C.R. Greene Jr., and T.A. Jefferson. "Development of an air bubble curtain to reduce underwater noise of percussive piling." Marine Environmental Research. 49 (2000): 79-93.

Appendix 1

The process of data collection and extrapolation for wind and electricity prices in Southern Delaware:

Step 1

Downloading and treating the wind data.

- The selected data file was downloaded from the 44009 data page from the file >historical data>standard meteorological data [this is the hourly set] >2003 onto the PC program "notepad." http://www.ndbc.noaa.gov/station_page.php?station=44009

- The averaged monthly values were accessed from the same 44009 data page from the file >climatic summary>table. Download pdf document and extract the historical monthly averages. In the case of 44009 this covers the period from 1984-2001 and rated as being based on 133262 readings with 93.3% of the elements present.
- While the main, yearly data sets are stored in readings of meters per second, the averaged data is available only in knots. Upon downloading the averaged values in knots they were converted to meters/second by multiplying the speed by the factor 0.5144. Results were stored for later use.
- Using a simple locally developed UNIX program, the data was examined for missing elements and null values (their system defaults to 99) and when found the averaged value for that month from the summary table (in m/s) was inserted. The in house program also isolated the hourly data, with the corresponding time element and sent it to a separate file.
- Verification consisted of visually examining the data for overt anomalies and ensuring that the row count was 8760, the number of annual hours.
- Cut the yearly data into 12 monthly files in Notepad.
- The results were 12 monthly files of wind data ready for import into Excel.

Step 2

Downloading and treating the PJM market data.

- The selected data is filed on PJMHome>market>energy>realtime>monthlyrealtime data page. Twelve separate monthly files including data for all PJM markets in 2003 were downloaded and stored locally from http://www.pjm.com/markets/energy-market/real-time.html

- Another in-house UNIX program was used to examine the PJM data for missing values, none were found. The program was also instructed to sort the South DPL data lines from the rest and to send them to another file for compilation. Each resulting monthly file contained 24 hourly averaged price values for each day of the month. The data were visually examined for the appropriate number of rows and columns and by looking for overt, anomalous values. None were found.
- The results were 12 monthly PJM price data files ready for import to Excel.

Next, an Excel spread sheet was prepared to receive the data. In order to translate the buoy data into dollars that data had to first be adjusted to reflect the approximate 80m hub height of the GE

3.6 turbine. While there are a number of reasons an offshore developer might base their selection of a turbine on, such as warranty term or an included maintenance agreement, we selected it because it has the highest productivity per installation of any turbine currently on the market. It should be noted, however, that German manufacturer REpower, is currently testing their model 5M. This is a 5MW machine and interpretation of this analysis could be significantly altered by a substitution. Data is not yet available for the output curve of the 5M so a comparison analysis must wait.

The recorded anometer readings for buoy 44009 were taken at 5m elevation. This needed to be converted to speeds at 80m. There are a number of methods to extrapolate buoy data to hub height and all of them have weaknesses. A comprehensive discussion of the alternatives is available from recent work by Archer and Jacobson (2005). Only one of the methods was used in this exercise, and that was a simplified Log Law conversion supplied in unpublished notes by Prof. Richard Garvine of the University of Delaware:

Formula 1

$$R \equiv u_2 / u_1 = \frac{\log(z_2 / z_0)}{\log(z_1 / z_0)}$$

Where R = wind velocity at desired hub height, in this case a generic 80m was used;
U_1 = wind velocity at the lower height;
U_2 = wind velocity at desired hub height of 80m;
Z_0 = the surface roughness, ocean surface roughness varies from a maximum of 4mm to a minimum of .006mm. A moderate value of .035mm was assumed in all calculations. The formula is in meters so the notation is 0.00035mm.
Z_1 = lower height in meters
Z_2 = upper height in meters

Step 3
For Excel going from the 5m values to the 80m values would be written as follows. All information contained within the < > symbols is descriptive and neither the < > symbols nor the words should be transcribed:

Formula 2
=<value in m/s for 5m wind speed, this is normally a spreadsheet cell referent>*(log(80/.00035)/(log(5/.00035)))

The cell referent for this formula pointed to the downloaded and processed 5m wind data.

Step 4
The power output of the 80m wind was derived by using Excel to calculate a best fit polynomial to the power output curve on the GE website. A more precise calculation can be obtained by using Matlab to perform the same function. More precision is possible with the Matlab because the image is scanned in and data points are matched with a precision the researcher’s eye cannot match. However, the fit of the curve used had an R^2 value of .997 and was verified by informed peers; it is presumed to be adequate to the task at hand. The formula derived could clearly be

improved as it results in extremely small negative values at initial startup speed for the turbine. These small negative values are assumed to be of little significance and no attempt has been made to compensate for their presence.

The 3.6 begins production at wind speeds of 3.5 m/s and follows the output curve to a maximum production capacity of 3600kW at 14m/s and produces a constant 3600kW at speeds above 14m/s until 27m/s, when safety cutoffs engages in and drop production to zero at higher speeds. This was accounted for by configuring the Excel formula to read 0 for all values below 3.4; to plot values between 3.5 and 14 with the derived polynomial; to read all values between 15 and 27 as 3600; and to read all values above 27 as zero. This is an example of the Excel formula with an arbitrary letter/number referent included. This referent should point to the cell with the desired w/s at 80m which was the output of step 3.

Formula 3
=IF(AND(0 <= E2, E2<=3.4),0,IF(AND(3.4 < E2,E2 <= 14),-2.2428*E2*E2*E2+82.057*E2*E2-513.93*E2+890.84,IF(AND(14< E2, E2<=E2),3600,IF(E2 > 27,0)))) .

Step 5
A cell was prepared to multiply the output of step 4 with the PJM data. The 3.6 output was in kilowatts and the pricing data was in megawatts so output is divided by 1000 to adjust. The output divided by 1000 was multiplied by the price per/MW/h result.
Example: =D6/1000*D3

Step 6
Monthly results of XX, XX and XXXX were formatted to be both summed and averaged.
See table for results.

Summary:
At this point there are 3 columns left open and ready to receive the PJM price data with dates.
There is a column left open and ready to receive the 5m wind speed data.
There is a column prepared with a formula (referent pointed at the 5m cell) to convert the 5m wind speed to wind speed at 80m.
There is a column prepared with a formula (referent pointed at the 80m cell) to convert it to 3.6 output.
There is a column prepared with a formula pointing to the 3.6 output to convert kW to MW and multiply the result with the value in the PJM price data cell.

There are cells prepared to average the results of all these calculations.
There are cells prepared to both average and sum the final dollar values representing the 3.6 output.

Step 7
Repeat process 11 more times, once for each month of the year. Copying initial format onto separate spreadsheets is highly recommended.
Import the PJM price data – by month.
Import the 5m wind data – by month