Wind Resource Modeling and Turbine Energy Estimation of Two Coastal Sites in Virginia

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Outline

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- Model Construction
  - Topographic Map
  - Data Processing
  - Mapping the Wind Resource
  - Turbine Energy Estimation
- Results
  - Suffolk
  - CBBT
- Conclusions
## Project Overview

### Location of Station
- **Newport News**
  - **Latitude**: 36.96323
  - **Longitude**: -76.41172
- **Monter-Merrimac Bridge Tunnel**
  - **Latitude**: 36.94533
  - **Longitude**: -76.40375
- **Chesapeake Bay Bridge Tunnel Third Island**
  - **Latitude**: 37.03652
  - **Longitude**: -76.07666

### Site Modeled
- Suffolk
- Suffolk
- Chesapeake Bay Bridge Tunnel

### Turbine Used
- Vestas V112-3.0 MW
- Vestas V112-3.0 MW
- NREL 5.0 MW Reference Turbine

### Height of anemometers(s)
- 50.9 meters; 85 meters; 97 meters
- 12.2 meters
- 16 meters

### Range of dataset
- September 2006 – November 2007
- June 2005 – December 2010
- June 2005 – December 2010

### Timestamp
- 10 minutes
- 5 minutes
- 5 minutes

### Number of Model Runs
- 3 (one for each height)
- 9 (annual and eight sub-seasons)
- 9 (annual and eight sub-seasons)

### Model Validation
- Yes
- Yes
- No
Model Construction – Topographic Map

Global Mapper 13
- Topographic map
- Orography (contours)
- Terrain (roughness)
- Digital vector map exported to WAsP

<table>
<thead>
<tr>
<th>Roughness Length (m)</th>
<th>Terrain Surface Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Open Water Areas</td>
</tr>
<tr>
<td>0.0005</td>
<td>Smooth Bare Soils</td>
</tr>
<tr>
<td>0.001</td>
<td>Wetlands</td>
</tr>
<tr>
<td>0.005</td>
<td>Woody Wetlands</td>
</tr>
<tr>
<td>0.01</td>
<td>Grassland</td>
</tr>
<tr>
<td>0.05</td>
<td>Farmland</td>
</tr>
<tr>
<td>0.2</td>
<td>Shrubs and Bushes</td>
</tr>
<tr>
<td>0.5</td>
<td>Forest</td>
</tr>
<tr>
<td>0.6</td>
<td>Open Urban Areas</td>
</tr>
<tr>
<td>0.75</td>
<td>Urban Areas</td>
</tr>
<tr>
<td>1</td>
<td>Dense Urban Areas</td>
</tr>
</tbody>
</table>
Model Construction – Data Processing

WindFarmer MCP+ Module
- Data ‘cleaning’
- Wind roses
- Export ‘cleaned’ wind data as a WAsP observed wind climate file
The Power in Wind

Wind Speed:
As wind speed increases, power increases by a factor of 3.

\[ P = \frac{1}{2} \rho A v^3 \]

Example:
Consider two sites. One site with a wind speed of 10 mph and another site with a wind speed of 12 mph.

\[ P_2 = \left(\frac{12}{10}\right)^3 P_1 \]
\[ P_2 = 1.73P_1 \]

There is only a 20% increase in wind speed, but a 73% increase in available power between the sites.

Model Construction – Mapping the Wind Resource

WAsP
- Load vector map, wind climate data, mast location into WAsP
- Map verification
- Wind atlas
- Wind resource grid
**Model Construction – Turbine Energy Estimation**

**WindFarmer**
- Industry standard software for turbine/wind farm energy estimates.
- All data and layers developed previously used (including wind resource grid)
- Turbine location and power curve inserted.
- Turbine expected energy production can now be estimated.

**Assumptions and Uncertainties**
- No output losses
- Anemometer uncertainty – 2%
- Horizontal extrapolation ≈ 5-10%
- Vertical extrapolation ≈ 5-20%
- Wind flow model – model validation
Results - Suffolk

Newport News
- Capacity factor ≈ 27.1-29.2%
- Net yield ≈ 7.1-7.7 GWh
- Uncertainty ≈ 25.3-31.0%

MMBT
- Capacity factor ≈ 22.4%
- Net yield ≈ 5.89 GWh
- Uncertainty ≈ 30.5%

MMBT Sub-seasons
- Best Sub-season: 3 (28.1%)
- Worst Sub-season: 5 (14.6%)

Probability distributions show significant variations in the AEP expectations from the MMBT and Newport News datasets.
### Results - CBBT

<table>
<thead>
<tr>
<th></th>
<th>Annual</th>
<th>Sub-season 1</th>
<th>Sub-season 2</th>
<th>Sub-season 3</th>
<th>Sub-season 4</th>
<th>Sub-season 5</th>
<th>Sub-season 6</th>
<th>Sub-season 7</th>
<th>Sub-season 8</th>
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<tbody>
<tr>
<td><strong>Capacity Factor (%)</strong></td>
<td>31.9</td>
<td>40.4</td>
<td>40.2</td>
<td>33.4</td>
<td>23.67</td>
<td>31.9</td>
<td>27.90</td>
<td>40.1</td>
<td>40.3</td>
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<tr>
<td><strong>Net yield during period (GWh)</strong></td>
<td>13.98</td>
<td>2.21</td>
<td>2.20</td>
<td>1.83</td>
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<td>2.20</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Total Uncertainty (%)</strong></th>
<th>1 year</th>
<th>10 years</th>
<th>20 years</th>
<th>1 year</th>
<th>10 years</th>
<th>20 years</th>
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<td>26.28</td>
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<td>23.18</td>
<td>23.12</td>
<td>3.28</td>
<td>0.54</td>
<td>0.51</td>
</tr>
</tbody>
</table>

- **Capacity Factor** – 31.9%
- **Net Yield (central)** – 13.98 GWh/year
- **Uncertainty** ≈ 25%
- **Best sub-season**: 1 (40.4%)  
- **Worst Sub-season**: 4 (23.67%)  

10 and 20 year outlooks reduce uncertainty and improve the shape of the distribution.
Conclusions

• Results indicate that both test demonstration sites may be suitable for energy production.

• High degree of uncertainty
  • Vertical shear
  • Seasonal variation – attempt to address through sub-season analysis
  • Some important factors were not considered in this analysis (for example wind flow model for CBBT)

• Analysis conducted with data from a single anemometer – two or more vertically separated anemometers ideal.

• Anemometer uncertainty and vertical spacing between anemometers on a tower crucial to reducing the uncertainty.

• Alternative method - method of least squares (LES) to estimate vertical wind profile.