An assessment of the possibility of wind farm development in the Pacific Ocean near Japan

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Why offshore in Japan?

**Rural area (Hokkaido, Tohoku)**
- Large wind penetration
- Good wind
- Enough Land for WF
- Relatively low demand

**Urban area (Tokyo)**
- Small wind penetration
- Not very good wind
- Not enough land for WF
- Large demand

Offshore wind energy near urban area will promote further wind penetration in Japan.

To develop the offshore wind energy, *the assessment of offshore wind potential is very important.*
Existing studies in Japan

- Nagai et al.
  Estimated wind energy potential for the area 3km from the coastline using measurement data at lighthouses and WAsP.
  - Measured wind speed at lighthouse does not represent the offshore wind characteristics
  - The distance of 3km from the coastline is not enough

- Fujii et al.
  Estimated wind energy potential for whole the EEZ of Japan using satellite image data.
  - The accuracy of the wind speed prediction is unknown.
  - Social and economical criteria are not considered appropriately
Summery of the Problems

- Lack of offshore measurement around Japan
  - Offshore wind characteristic is unknown
  - Verification of wind climate assessment method cannot be done

- Economical and social criteria are not appropriately considered
  - Need some different kind of geographic data
  - Provide Several scenarios
Outline of this study

- Perform the measurement at offshore site
  - To investigate the offshore wind characteristic
  - To obtain verification data for wind climate assessment methods

- Propose wind climate assessment method based on mesoscale modeling
  - Verify the proposed method by the measurement data
  - Investigate the spatial distribution of wind characteristic around the sea area near Tokyo

- Investigate the offshore wind energy potential
  - Consider several scenarios related to economical and social restrictions
  - Estimate the available potential for each scenario
1. Measurement
The site

The measurements were carried out at two sites and results were compared.

Measurement instruments

- Explosion-proof anemometer was used
  - 10 min averaged wind speed/direction
  - 10 min. max/min wind speed,
  - 10 min. standard deviation of wind speed

Obtained data were transferred to the Lab. by mobile phone
Mean Wind Speed

Assuming the power law, wind speed at 70m was estimated from the measurement. ($\alpha=0.1$ for offshore, 0.2 for onshore)

- High wind speed in winter
- Much higher wind speed at offshore site
- Annual mean wind speed is:
  - 7.4 m/s (offshore)
  - 4.3 m/s (onshore)
Energy Density

- Most of the energy density exists in the prevailing wind directions, i.e., NW, S.
- Energy density at offshore is much larger than that at the onshore site.

- Offshore: 561.2 W/m²
- Onshore: 119.5 W/m²
The turbulence intensity is much lower at the offshore site.

In winter, the turbulence intensity is stronger at the offshore site.
For all the wind speed class, turbulence intensity is smaller than IEC-61400 turbulence class C.

The turbulence intensity depends on the wind direction.
The Difference of Turbulence Intensity

- The difference of turbulence intensity between measured and IEC^37km
- Measurement site

- For westerly wind direction, turbulence intensity is larger
- This is due to the effect of land especially mountains

The difference of turbulence intensity between measured and IEC
2. Offshore wind climate assessment
Mesoscale Model

To estimation the wind climate, mesoscale model was used

Advantage:

• As it considers the thermal effect, hub height wind speed can be calculated considering the effect of the stratification
• The spatial variation of the flow field can be obtained

Regional Atmospheric Modeling System

• Navier-Stokes equation
• Convective parameterization
• Radiation parameterization
• Soil and vegetation parameterization
• Parallel Computation
• ECMWF Analysis data as boundary and initial condition
• 100m landuse and 50m DEM
Computation settings

- Three domains were set so that the coast of the supply area of Tokyo Electric Power Company was included.
- Computation was carried out for one year.
- Two horizontal component of the wind speed at 70m a.s.l. for whole the domain was obtained by vertical interpolation.
Verification of the mesoscale model

Calculated wind speed at the measurement site was compared with the measurement

Annual mean wind Speed: Measurement 7.4m/s; RAMS 7.1m/s

Prediction error is 4.1 %
Wind Rose

wind rose at Iwaki platform for natural gas mining

North westerly in winter, southerly in summer

Good agreement with the measurement
• Annual mean wind speed increases as the distance from the coastline increases
• Even though the distance from the coastline is same, wind speed differs considerably depending on the site
• Although the distance from the coastline is same, wind speed differs considerably especially near the coastline.

• At the offing of Choshi, wind speed is strong even near the shore.
3. Estimation of offshore wind potential
Offshore wind energy potential

Assuming that 2.4MW wind turbines are placed with the interval of 8D x 8D, wind energy potential along the coast of the supply area of TEPCO, 50km from the coastline was estimated.

Area where potential was estimated

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roted Power</td>
<td>2.4MW</td>
</tr>
<tr>
<td>Hub Height</td>
<td>70m</td>
</tr>
<tr>
<td>Rotor Diameter</td>
<td>92m</td>
</tr>
<tr>
<td>Power Regulation</td>
<td>Pitch</td>
</tr>
<tr>
<td>Cut-in wind Speed</td>
<td>3.0m/s</td>
</tr>
<tr>
<td>Cut-out wind Speed</td>
<td>25.0m/s</td>
</tr>
<tr>
<td>Interval</td>
<td>8D x 8D</td>
</tr>
</tbody>
</table>
Total potential 287 TWh/year

Almost equal to the annual demand for Tokyo Electric Power Company 2005

- Not all of those potential can be exploited due to economical and social restrictions.

NEXT, we propose several scenarios, and estimate the potential.
Criteria 1: Water Depth

Two scenarios were considered regarding the water depth

1. Only bottom-mounted foundation can be used
   - Area with water depth up to 20m can be used

2. Both bottom-mounted and floating foundation is used
   - Area with water depth up to 500m can be used
Criteria 2: Prohibited area

Three scenarios were considered regarding the area where the development of wind farm is prohibited

1. No restriction
   - All the area can be used

2. Social restriction
   - Areas with fishery right, national parks and ports cannot be used

3. Social restriction + landscape
   - + area within 10km from the coastline cannot be used
Three scenarios were considered regarding the expected capability factor of the wind farm:

- For onshore wind farm at least 20% of the capability factor is required.
- For offshore wind farm, the construction cost and the maintenance cost would be more expensive.
- Thus, in this study, capability factor of 25%, 30%, and 35% are considered as criteria.
Energy Potential (Scenario 1)

Only Bottom-mounted
No Restriction

<table>
<thead>
<tr>
<th>CF</th>
<th>TWh/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 25%</td>
<td>11.51</td>
</tr>
<tr>
<td>Over 30%</td>
<td>7.98</td>
</tr>
<tr>
<td>Over 35%</td>
<td>1.84</td>
</tr>
</tbody>
</table>

0.6 to 4.0% of the Annual demand of TEPCO
Energy Potential (Scenario 2)

Only Bottom-mounted Social Restriction

<table>
<thead>
<tr>
<th>CF</th>
<th>TWh/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 25%</td>
<td>4.71</td>
</tr>
<tr>
<td>Over 30%</td>
<td>3.98</td>
</tr>
<tr>
<td>Over 35%</td>
<td>1.16</td>
</tr>
</tbody>
</table>

0.4 to 1.6% of the Annual demand of TEPCO
Energy Potential (Scenario 3)

Only Bottom-mounted Social Restriction & Landscape Restriction

<table>
<thead>
<tr>
<th>CF</th>
<th>TWh/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 25%</td>
<td>0.21</td>
</tr>
<tr>
<td>Over 30%</td>
<td>0.21</td>
</tr>
<tr>
<td>Over 35%</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Only 0.07% of the Annual demand of TEPCO
Energy Potential (Scenario 4)

Bottom-mounted & Floating
No Restriction

<table>
<thead>
<tr>
<th>CF</th>
<th>TWh/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 25%</td>
<td>150.42</td>
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<tr>
<td>Over 30%</td>
<td>133.42</td>
</tr>
<tr>
<td>Over 35%</td>
<td>93.53</td>
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</table>

32.6 to 52.4% of the Annual demand of TEPCO
Energy Potential (Scenario 5)

Bottom-mounted & Floating
Social Restriction

<table>
<thead>
<tr>
<th>CF</th>
<th>TWh/y</th>
</tr>
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<tbody>
<tr>
<td>Over 25%</td>
<td>129.14</td>
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<tr>
<td>Over 30%</td>
<td>118.55</td>
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<td>Over 35%</td>
<td>87.76</td>
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</table>

30.58 to 45.0% of Annual demand of TEPCO
Energy Potential (Scenario 6)

Bottom-mounted & Floating
Social Restriction & Landscape Restriction

<table>
<thead>
<tr>
<th>CF</th>
<th>TWh/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 25%</td>
<td>107.56</td>
</tr>
<tr>
<td>Over 30%</td>
<td>100.59</td>
</tr>
<tr>
<td>Over 35%</td>
<td>80.40</td>
</tr>
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</table>

28.0 to 37.5% of the Annual demand of TEPCO
Offshore measurement was performed at the top of the tower of a natural gas platform. (94m above sea level, 37km from the coastline)

An offshore wind climate assessment method with mesoscale modeling was proposed. The prediction error of annual mean wind speed by this method was 4.1%.

All the wind energy potential along the suburb of Tokyo area 50km from the coastline is almost equal to the annual demand for Tokyo Electric Power Company.

If only the bottom mounted foundation can be used, the wind energy potential in this area varies from 0.21 to 11.51 TWh/year.

If floating foundation can be used, the potential varies from 80.40 to 150.42 TWh/year.
Thank You!

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