REMOTE SENSING IN WIND RESOURCE ASSESSMENT

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Presentation Outline

• Wind Resource Assessment Overview
• What is Remote Sensing
• Benefits/Challenges of Remote Sensing
  – As compared to industry-standard met masts with cup anemometers
• Common Uses for Remote Sensing
• Impact on Uncertainty
• Offshore Integration
Wind Resource Assessment (WRA) Overview

• **Goal**: Acquire sufficient information to reach an acceptably accurate, scientifically defensible, and financeable estimate of the long-term hub-height wind conditions (and corresponding energy production projections) within an area of interest.

• **Challenges**: Cost, schedule, and accuracy implications common to the industry, as well as site-specific environmental, engineering and permitting issues.

• **Approach**: Develop a comprehensive, site-specific meteorological monitoring campaign that integrates established approaches (*cup anemometers on met masts*) with innovative and/or enhanced methods (*remote sensing*) to satisfy project goals.
Standard WRA Monitoring Approach

• Consulting regional wind maps and local conditions, monitoring locations are chosen across a project area
• “Standard” measurement approach includes deployment of calibrated cup anemometers at multiple levels on a 60 m tilt-up tower
• Cost effective, well-understood, and accepted approach
• Certain sites merit the consideration of enhanced or alternative monitoring
  • Challenging permitting
  • Short-duration case studies
  • Unique flow conditions
What is Remote Sensing

- Remote Sensing: The acquisition of information about an object or phenomenon, without making physical contact with the object. (Wikipedia)
- Focus here on ground-based, profiling Sodar and Lidar
- Wind speeds and other characteristics measured by backscattering of sound (sodar) and laser (lidar) by changes in atmospheric turbulence (sodar) and atmospheric aerosols (lidar)

Sodar – Sound Detection and Ranging
- Acoustic based

Lidar – Light Detection and Ranging
- Laser Based
# Benefits/Challenges of Remote Sensing

## Benefits

- Many points of measurement (continuous shear profile)
- Measurement to and above hub height (200m+)
- Measures 3 components of wind
- Inflow angle can be derived
- No tower impacts on measurements

## Challenges

- Has not gained full industry acceptance yet (stand-alone)
- No measurement redundancy

### Sodar-Specific

- Potential for echoes from fixed structures/trees
- Potential for background sound interference
- Cannot measure during precip. events

### Lidar-Specific

- Challenges in complex terrain (terrain can affect anemometers, too)
- Scalar vs. Vector averages

- Relatively High cost (currently, but dropping)
- Needs a robust power source
- Historically requires more attention than towers
Current Uses for Remote Sensing

• Verify wind speed/shear profile above typical mast heights
• Measure full shear profile instead of discrete points
  – Particularly important across the rotor plane
• Short term deployments (mobile mast/round-robin)
  – Focus on flow case studies or conditions of interest
  – Can require seasonal correction
• Measure parameters for turbine suitability \( (u, \alpha, \rho, T, A, k) \)
  – Measure parameters as a function of height
• Post-construction turbine performance
  – Assess underperformance, verify power curve, wake measurements
• Near-term and Expected Future uses:
  – Full integration into wind flow models
  – Stand-alone wind resource assessment
  – Power curve testing and validation
  – Turbine control
Wind Speed Averages:

- Point: 10.1 m/s
- Line: 9.7 m/s
- Area: 9.9 m/s

- Hub-height wind speed not the full story!
- New International standards for power curve verification expected to include area calculations for speed and the use of remote sensing.
Shear changing with height

- Not all shear profiles are logarithmic
- Current assumption: hub height WS valid across rotor plane
- Logarithmic profile underestimates below and overestimates above hub height
- Other, less-typical profiles can have varying results
- Shear can lead to under/over performance – up to 2-3% long-term
- Unique conditions and transient events – low-level jets, strong wind veer – can impact short-term performance and equipment lifespan
- These parameters are hard or impossible to capture with a 60 m tower
Remote Sensing and Uncertainty Reduction

- Largest reduction seen in measuring shear profile – long-term remote sensing measurements can reduce this parameter to zero
- Can also reduce wind flow modeling uncertainty
- NRG/Leosphere Case Study (lidar):
  - Assumptions:
    - P50 = 2,800 hours
    - Capex = US$2 Mil/MW
    - Revenue = US$100/MWh
    - O&M = US$25/MWh
    - Lidar cost = US$90,000
    - Inflation = 2%
    - Project Period = 20 years
    - Interest Rate = 6%
    - Debt Period = 15 years

<table>
<thead>
<tr>
<th>WRAP w/o lidar</th>
<th>WRAP w/ lidar</th>
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<tbody>
<tr>
<td>Uncertainty = 15%</td>
<td>Uncertainty = 12%</td>
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<tr>
<td>P50 = 140.2 GWh/yr</td>
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<tr>
<td>P90 = 104.7 GWh/yr</td>
<td>P90 = 111.8 GWh/yr</td>
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<tr>
<td>IRR = 13.3%</td>
<td>IRR = 14.9%</td>
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<tr>
<td>Equity Investment = US$23 Mil</td>
<td>Equity Investment = US$16 Mil</td>
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Remote Sensing and Offshore Wind Monitoring

• **Important point**: Lidar can be a powerful tool in resource assessment, but it is still only one part of a comprehensive offshore site assessment plan comprised of robust measurement, modeling and analysis.

• **How** can lidar be employed in offshore wind monitoring?
  – Coastal Deployment
  – Offshore deployment on a fixed structure
    • With a tall tower
    • With a short tower
    • Stand alone
  – Offshore Deployment on a floating structure (buoy, barge)

• **What** are the benefits/risks of Lidar integration?
  – Enhanced data value
  – Potential cost and time saving on deployment
  – Uncertainty and acceptance of data record
Remote Sensing Summary

• Proven tool for measuring many wind characteristics without the use of a tall tower
  – Remote sensing has wide variety of pre- and post-construction applications

• Can add significant value to monitoring campaign, but cost and operational characteristics need to be considered
  – Mast: $30k - 55k;
  – Sodar: $40k - $70k;
  – Lidar: $165k - $250k

• ‘Bankability’ of remote sensing measurements in WRAs
  – Has come a long way; readily accepted under many circumstances
  – Stand-alone operation and complex terrain sites may require supplemental measurements or additional validation

• Impacts on uncertainty can be significant

• Several challenges to overcome, but future is bright