Offshore wind farm projects that require pre-construction financing cannot afford to rely on proxy data that are recorded at distant locations to characterize key design parameters present at the proposed site. Therefore, physical measurements that are specific to the project location must be obtained in order to inform the design basis, explore turbine suitability and estimate energy production. However, design and installation of offshore meteorological masts requires careful preparation and access to relatively large amounts of capital in the sensitive and uncertain initial phases of project planning. In this context the LiDAR measurement technique has emerged as a potentially attractive and economically competitive alternative to traditional offshore met masts.

LiDAR Measurement Fundamentals

The LiDAR probes a volume of the atmosphere by emitting electromagnetic radiation that illuminates natural aerosols and detects the scattered light that results from this interaction. Upon detection, the return signal is analyzed to determine its mean Doppler shifted frequency which is then used to obtain the line-of-sight wind velocity by \( v_f \). The vertical and horizontal wind speeds as well as the wind bearing are then obtained by applying a curve fit to the line-of-sight velocity data.

LiDAR and Offshore Wind Resource Assessment

The primary goals of a wind measurement program are to enable:

1. Accurate estimation of the power production potential and wind resource at the proposed site;
2. Definition of the wind conditions for the project;
3. Development of the site-specific cost estimates for the project.

Measurements from hub-height anemometry are the established industry standard for offshore project finance applications. With a carefully designed wind measurement program, these instruments can directly achieve the above goals. In cases where LiDAR is used as the primary measurement device for offshore applications, a comprehensive validation against conventional instruments should be implemented in order to assess the effects of the device measurement principles on the derived wind statistics.

LiDAR Validation for Offshore Measurement Applications

In order to maximize the value of LiDAR remote sensing measurements, a validation campaign should be performed before and possibly after deployment. The criteria tested as part of a well-executed validation campaign may consist of:

- Mean wind speed agreement within 2% of calibrated cup anemometer measurement in the majority of meteorological conditions;
- Data recovery rate in excess of 90% across the full wind speed range 0-20 m/s;
- Minimal time series disagreement with reference cup anemometer;
- Low or consistent bias as a function of measurement height;
- Continuous operation in a variety of environmental conditions.

Proper documentation of the validation campaign is necessary to ensure full measurement traceability of the LiDAR device.

Key Measurement Parameters for Offshore Wind Resource Assessment and Site Suitability

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean wind speed</td>
<td>Energy production estimate and turbine suitability</td>
</tr>
<tr>
<td>Wind direction</td>
<td>Frequency distribution characterization</td>
</tr>
<tr>
<td>Wind speed standard deviation*</td>
<td>Turbulence intensity used to inform wake loss</td>
</tr>
<tr>
<td>Extreme wind speed</td>
<td>Turbine loads calculations</td>
</tr>
<tr>
<td>Barometric pressure</td>
<td>Air density and seasonal/diurnal power production</td>
</tr>
</tbody>
</table>

LiDAR devices differ significantly in this respect due to inherent temporal and spatial averaging effects. The actual attenuation will vary from one device to another and more scatter is to be expected.

Conclusions

It is considered to be best practice to record critical wind data parameters at or near the proposed turbine hub-height with traditional meteorological equipment such as cup anemometers. However, for economic or logistical reasons, LiDAR instruments may be substituted for, or deployed in tandem with, a met mast provided they successfully complete a validation campaign. The campaign should be designed so that the effects of the device measurement principles on the derived wind statistics can be estimated with sufficient accuracy, and that corrections may be applied as necessary. The errors associated with this process however implies that greater uncertainty in the predicted wind conditions will result than would have with conventional instruments. The intrinsic redundancy of independent sensors as used on meteorological masts is considered to be an important factor when considering different wind measurement strategies at offshore sites and some sort of redundancy should be engineered in offshore measurement campaigns.