Distributed Wind Resource Assessment: State of the Industry

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National Renewable Energy Laboratory

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Abbreviations and Acronyms

CFD	computational fluid dynamics
CFSR	Climate Forecast System Reanalysis
DOE	U.S. Department of Energy
DWRA	Distributed Wind Resource Assessment
ERA-Interim	Re-Analysis Interim Model
IAV	inter-annual variability
kW	kilowatts
LCOE	levelized cost of energy
MCP	Measure-Correlate-Predict
MERRA	Modern-Era Retrospective Analysis for Research and Applications
NREL	National Renewable Energy Laboratory
NWP	numerical weather prediction
NWTC	National Wind Technology Center
OEM	original equipment manufacturer
WAsP	Wind Atlas Analysis and Application Program
WRF	Weather Research & Forecasting Model
WWPTO	Wind and Water Power Technologies Office

Executive Summary

The U.S. Department of Energy (DOE) Wind and Water Power Technologies Office (WWPTO) activities in wind technologies for distributed wind applications address the performance and reliability challenges associated with wind turbines installed in the distributed wind market segment by focusing on technology development, testing, certification, and manufacturing.

The WWPTO program goals in the distributed wind area are as follows:

The Wind Program aims to maximize stakeholder confidence in turbine performance and safety and improve project performance while reducing installed cost in order to be competitive with retail electric rates and other forms of distributed generation. The Wind Program's goals fall under one or both of the following focus areas:

- *Wind technology certification: Increase the number of small and medium wind turbine designs certified to performance and safety standards from a 2010 baseline of zero to 40 by 2020.*
- *Cost of energy: Reduce the levelized cost of energy (LCOE) of wind turbine technology used in distributed applications to be competitive with retail electricity rates and other sources of distributed generation.*[1]

In support of the WWPTO goals, researchers at DOE's National Renewable Energy Laboratory (NREL), National Wind Technology Center (NWTC) are investigating the Distributed Wind Resource Assessment (DWRA) process, which includes pre-construction energy estimation as well as turbine site suitability assessment. DWRA can have a direct impact on the Wind Program goals of maximizing stakeholder confidence in turbine performance and safety as well as reducing the LCOE. One of the major components of the LCOE equation is annual energy production. DWRA improvements can maximize the annual energy production, thereby lowering the overall LCOE and improving stakeholder confidence in the distributed wind technology sector by providing more accurate predictions of power production. Over the long term, one of the most significant benefits of a more defined DWRA process could be new turbine designs, tuned to site-specific characteristics that will help the distributed wind industry follow a similar trajectory to the low-wind-speed designs in the utility-scale wind industry. By understanding the wind resource better, the industry could install larger rotors, capture more energy, and as a result increase deployment while lowering the LCOE.

To elicit a better understanding of the challenges and needs associated with resource assessment activities within the distributed wind industry, NREL hosted a stakeholder workshop on June 18-19, 2015, following the Small Wind Installers Workshop in Stevens Point, Wisconsin. The workshop and a later survey were used to solicit insight on the wind resource assessment practices of the distributed wind industry. The primary goals of the workshop were to:

- Define the current state of the art of DWRA processes
- Identify R&D challenges and barriers

[1] http://energy.gov/eere/wind/distributed-wind

- Prioritize R&D challenges that, if solved, will provide a high return on investment for the distributed wind industry.

A full summary of the workshop, including the presentations, is available at http://en.openei.org/wiki/Distributed_Wind_Resource_Assessment_Workshop.

The following summarizes the key findings of the workshop and survey.

Define the Current State of the Art of DWRA Processes

- DWRA processes are varied due to the wide variation in distributed wind turbine project capital costs, timelines, and investment complexity.
- DWRA processes are mostly based on models or rules of thumb, with instruments being deployed only on larger projects (500 kilowatts [kW] +).
- DWRA costs are typically less than 1% of total project costs and rarely more than 3%.
- There is broad disagreement on the accuracy of DWRA methods, ranging from almost no error to 250%.
- Current DWRA processes largely exclude consideration of site-specific winds and turbine loading/suitability.
- There is minimal cross-over of the more mature utility-scale wind resource assessment approaches into DWRA processes.
- There are many needs within DWRA.
- One of the major themes present in the survey results was the wide range of responses across the distributed wind industry regarding methodologies, results, costs, timeline, and priorities. Some of this is due to the diverse nature of the industry. There is an enormous spread of turbine/project sizes, various project drivers, stakeholders, and configurations in the distributed wind industry, from single 1-kW machines on a private residence to multi-megawatt community wind farms. The tools used in these disparate scenarios are necessarily different, but industry recipients provided a wide range of responses even within specific turbine size classes. The amount of time and money that can be spent on a project is highly dependent on the size and configuration of the project as well as the risk appetite of the project stakeholders.

Identify R&D Challenges and Barriers

Through facilitated discussions, the following items were identified and then ranked in order of overall industry importance based on further industry expert feedback:

1. Limited access to public data [**Data Access**]

There is a dearth of easily accessible, publicly available, free or inexpensive modeled and observational data appropriate for use by the distributed wind industry. Having easy access to local data could help the distributed wind industry perform cost-effective and accurate resource and site assessments, as well as model validations.

2. Minimal data, methodologies, and guidelines available for resource and site assessment validation and benchmarking [**Validation & Benchmarking**]

The distributed wind industry lacks representative atmospheric and turbine performance data to validate and benchmark existing methodologies for predicting project performance and site suitability. New standard test cases and guidelines could include discussion of which tools, processes, and methodologies are appropriate for specific site conditions and the limitations of various approaches.

3. Lack of education and outreach opportunities for the DWRA industry [**Education & Outreach**]

There are limited opportunities for sharing resource assessment knowledge, such as webinars, workshops, and informational exchanges. There is also limited overlap and knowledge transfer between the established utility wind resource assessment and nascent DWRA sectors. Education and outreach could improve knowledge of distributed wind-focused site and resource assessment tools and methodologies. This could be instrumental in creating an industry informational commons, facilitating discussions around best practices, standardization, vocabulary, and more.

4. Lack of ways to access and incorporate site data for distributed wind projects [**Atmospheric Model Input Data**]

The distributed wind industry needs access to critical site information to facilitate atmospheric modeling, such as terrain, surface roughness, 3D buildings, and other surface features in a way that is affordable for the scale of distributed wind projects. Efficiencies could be gained from developing publically available data sets and tools to streamline the input of these data into the site assessment process.

5. Complexity and cost of Measure-Correlate-Predict (MCP) approaches result in a lack of multi-year resource information used in project assessments [**Measure-Correlate-Predict (MCP)**]

Current tools with embedded MCP approaches are currently too costly and time consuming for most DWRA applications. As a result, there is minimal characterization of year-to-year wind resource variability, including wind speeds, direction, turbulence, and other important factors that help provide high-quality assessments of long-term energy production. Underlying this is a lack of clear MCP methods for adoption and adaptation in DWRA applications.

6. Lack of robust methods for scaling wind data to typically lower hub heights for distributed wind projects [**Downscaling Methods**]

There is a general lack of validated, scientifically rigorous methodologies for downscaling modeled data, such as wind maps or coarse reanalysis/numerical weather prediction (NWP) data, which has resulted in myriad approaches to estimating hub-height data. Many of the typically used rules of thumb are based on “common wisdom” that is not backed by solid research, especially when applied to distributed wind applications. Developing industry standards for downscaling and reference wind parameters such as turbulence and shear would facilitate more accurate wind resource assessments at project sites.

7. Absence of standardization in DWRA methods [**Standardization**]

There is little agreement and documentation of industry standard methods, definitions, terms, and/or report templates for DWRA. This leads to challenges identifying performance issues and generating improved methods, which decrease confidence levels of funding and other organizations. This includes identification and calculation of common losses and uncertainties.

8. Minimal focus on turbine site suitability [**Site Suitability Assessment**]

There is minimal usage of site-specific wind loading analysis within the distributed wind industry. Developing cost-effective approaches for determining site winds and turbine loads could allow for more efficient and productive turbine designs. Refining and validating this approach could lead to significant performance and reliability enhancements similar to what the utility-wind sector has accomplished with low-wind-speed turbines.

9. Instrumentation, measurement systems, and data processing are too costly for many distributed wind projects [**Low-Cost Instrumentation**]

Due to the high cost and long time frames of measurement-based wind resource assessments, the industry often uses rule-of-thumb methods and simplified model-based approaches. This can lead to a high level of uncertainty in energy estimates. Development of or access to low-cost instrument-based assessments, including data processing, could increase the adoption of measurement-based approaches and lowered uncertainty in energy assessments.

Prioritize R&D Challenges that, If Solved, Will Provide a High Return on Investment for the Distributed Wind Industry

We asked participants to rank nine challenges that were identified through the workshop process based on the potential impact to the industry. Three questions were identical in format, but participants were asked to change their perspectives: according to the industry, according to their individual needs, or according to the role of the government. Although there was not a clear breakpoint in assessment of the challenges, the following top three priorities were identified as having a high priority in all of the relevant questions:

- Data Access
- Validation & Benchmarking
- Education & Outreach.

While clear priorities were identified, it should be noted that many of the challenges overlap and can potentially be addressed synergistically. Priorities will change as the distributed wind industry evolves its DWRA processes.

Conclusions

Below are practical activities for addressing the top three R&D challenges that, if solved, could have a high impact on the distributed wind industry; more details on activities for all nine challenges are described in Chapter 7.

- Data Access: Expand the availability of data accessible by the public

- Develop and populate a user-friendly data-sharing platform that provides access to publically available measurement data, such as:
  - State measurement program data
  - DOE anemometer loan program data
  - Other data collected by federal entities or links to that data.
- Develop and facilitate aggregation of and access to low-cost, long-term wind data sets, including site-specific NWP data.

- **Validation & Benchmarking:** Improve the validation and benchmarking of DWRA processes and modeling tools
  - Develop and support the implementation of long-term performance monitoring approaches
  - Implement a model validation process that would support independent or industry-based processes to understand the accuracy of existing models under a range of conditions
    - Develop validation datasets that highlight key DWRA-specific conditions
    - Implement a process to allow companies to validate or have their models validated by third-party experts.
  - Following benchmarking efforts, provide support to improve the accuracy of the models through activities such as:
    - Baseline methods against empirical datasets
    - Technical review of model elements
    - Support of model development/improvements.
  - Combine the results of multiple technical support efforts to provide better industry-wide guidance on modeling methodologies and appropriate assumptions.
- **Education & Outreach:** Expand education and outreach efforts within the DWRA community
  - Develop web-based DWRA content and sharing platform (OpenEI or other)
  - Aggregate key wind resource assessment lessons and practices from the utility sector and support the appropriate implementation into DWRA practices
  - Disseminate DWRA and appropriate utility wind resource assessment practices and information through industry-focused experience-sharing activities such as webinars, presentations, conferences, workshops, and Regional Resource Centers
  - Organize annual or bi-annual DWRA workshops to share experiences and expertise.

Informal discussions revealed that a venue bringing together DWRA professionals was deemed valuable in and of itself. No other industry venue focuses on DWRA, and participants placed high value on sharing experiences within the community. Even if no ongoing activities result from this assessment, all agreed that supporting an ongoing dialog among DWRA community members would be productive and help to improve the industry.

Finally, it should be noted that DWRA investments can yield positive results for the distributed wind industry. A turbine may be well designed and efforts may be expended to reduce deployment costs, but if it is sited improperly the performance will likely be less than desired. By improving the siting and prediction processes, we can positively impact the baseline distributed wind fleet performance across all projects.

Table of Contents

List of Figures

List of Tables

1 Introduction

This document provides a summary of the findings of the Distributed Wind Resource Assessment (DWRA) Workshop held on June 18-19, 2015. The workshop and a later survey were used to solicit insight on the wind resource assessment practices of the distributed wind industry. The U.S. Department of Energy (DOE) Wind and Water Power Technologies Office (WWPTO) funded this work under its distributed wind research, development, and testing activities. This document reviews the current methods used to assess the customer's wind resource, provides an overview of potential gaps and barriers to improving the methodologies, and then identifies which R&D challenges would have a high payoff if addressed.

2 Common Definitions

The DOE Wind Program defines distributed wind in terms of technology application, based on a wind plant's location relative to end use and power distribution infrastructure rather than [turbine or project] size. The Wind Program uses the following attributes to characterize wind systems as distributed:

- Proximity to end use: Wind turbines installed at or near the point of end use to meet onsite energy demand or support the operation of the existing distribution grid
- Point of interconnection: Wind turbines that are connected on the customer side of the meter, directly to the distribution grid, or are off-grid in a remote location[2]
- End use can include: on- or off-grid applications, including homes, farms and ranches, businesses, public and industrial facilities, etc.[3]

Wind resource assessment is the process of evaluating the operating atmospheric environment for a wind turbine and the relationship of the wind resource with turbine power production and loading. This process can include onsite measurements, wind maps, computational models such as linear models (e.g., Wind Atlas Analysis and Application Program, or WaSP), computational fluid dynamics (CFD), or numerical weather prediction (NWP) as foundational data products. It can also include empirical corrections based on expert judgment or site observation. The purpose of a wind resource assessment process is to develop a reasonable estimate of how much energy a particular wind site will produce and identify which turbines, based on design parameters, are best suited for the conditions at that location. Wind resource assessment is one distinct component of the site assessment process. Site assessors are generally concerned with estimating energy and site suitability as part of a larger process that includes equipment layout, permitting and zoning, financial incentive information, economics, and more.

2.1 General DWRA Considerations

The distributed wind market is broad and diverse with many turbine/project sizes, many project drivers, and many stakeholders. In order to generate an overarching discussion of the state of the industry for DWRA, some details may require further explanation outside of this document.

[2] http://energy.gov/eere/wind/distributed-wind

[3] *2014 Distributed Wind Market Report*: http://energy.gov/eere/wind/downloads/2014-distributed-wind-market-report

These topics include inter-annual variability, certified power curves, performance uncertainty, atmospheric performance drivers, financing structures, and more.

Distributed wind commercial processes and incentives currently prioritize installation over production. This is demonstrated by lack of distributed wind industry forums, infrastructure, documentation, and conferences specific to resource assessment, and by the absence of standard techniques for resource assessment and siting during the pre-construction process. Production and DWRA processes will become increasingly important for the industry to grow and attract new forms of capital or alternate incentive types (e.g., the Production Tax Credit).

3 DWRA Approaches

During the first part of the DWRA Workshop, representatives from companies presented and discussed their approaches to conducting DWRA. The intent was to not only share experiences across the industry but also to document the current approaches. The industry presentations demonstrated that there are many approaches for conducting a wind resource assessment at a potential distributed wind site. These approaches vary by levels of complexity, cost, and company engagement; however, there are two basic categories of wind resource assessment that are commonly used in the distributed wind space: models and onsite measurements. Each approach is discussed in detail in the next section. The responses we received during expert elicitation confirmed these findings. The most common tools used include wind maps, desktop spreadsheets, and desktop linear models.

These wind resource assessments are used to determine project viability, and the level of rigor used will help bound the cost estimates. Generally speaking, the industry is willing to spend around 1% of the total project cost on wind resource assessments, according to our expert elicitation. However, the numbers vary from <1% to 20%, and this is not entirely correlated with increasing project size. When asked how much they would be willing to spend for onsite measurements, industry members appeared to be comfortable paying up to around 10% of total project cost.

At present there is no systematic method used by the industry to validate the results of the assessments except when financial incentive fund managers require production information. In some cases, post-installation assessments are only completed if there is a large discrepancy between power generation by the turbine and predicted values, but this is performed on a case-by-case basis with limited direct efforts to insure the accuracy of future assessments.

There is also no industry-standardized methodology to document procedures, assumptions, or validation efforts. Generally there is a strong correlation between the level of effort in conducting the resource assessments and the size of the project, with smaller projects requiring low-cost, more automated or user-derived processes for at least initial project screening while larger projects can afford and require expanded efforts that would include onsite measurements.

3.1 Model-Based Approach

A model-based approach uses pre-existing datasets such as wind maps or re-analysis[4] data as an input for an energy assessment. This input is then modified for a specific turbine location using scaling[5] models, expert judgment, or rules of thumb to determine the impacts of site-specific conditions such as terrain, roughness, and obstacles. This approach does not include onsite measurements but can include a site visit for site assessment refinement purposes. The process is shown at a high level in Figure 1. There is a large degree of variability in this approach, from the simple use of publically available annual average wind speed estimates to detailed, site-specific physical modeling. This approach could also include the assessment of measured data from a nearby location to better understand local conditions.

The model-based approach is predicated on NWP models for the major data input. NWP can be defined as reanalysis data (Modern Era Retrospective-Analysis for Research and Applications [MERRA], ERA-Interim, and Climate Forecast System Reanalysis [CFSR]) or a finer-scale data product generated using the Weather Research & Forecasting (WRF) Model. The data from the NWP datasets are then used to create a static wind map or made available, typically for a fee, on a web-based portal. The outputs from these products are meteorological statistics such as annual average wind speed or wind speed and direction frequency distributions, temperature, and air density, respectively. These meteorological statistics are then corrected or scaled to the turbine height and location using a process called down-scaling that takes into account terrain, surface roughness, obstacles, and other local conditions. This down-scaling can be in the form of empirical rules of thumb or site-specific models such as WAsP or CFD. Finally, an energy prediction is formed using a wind turbine power curve or an annual energy production look-up table.

3.1.1 Level 1: Simple Approach

Project size: 1 kW to 49 kW

Cost: $500 or less per project

Approach: Static wind maps, gross approximation using annual average site wind speed

Duration: If used as part of a formal site assessment, an evaluation can be conducted in less than a week.

[4] Reanalysis refers to a family of data products that describe the long-term state of the global atmosphere. These data products are often used to initialize site-specific wind resource models. Examples are MERRA, ERA-Interim, CFSR, and National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis Project (NNRP); see https://reanalyses.org/ for more information.

[5] Scaling refers to the process in which measured or modeled data are adjusted using defined parameters to a different height above the ground. In simple terms, it is a process that uses the power law to adjust the reference height of data, typically downward to a lower altitude above ground for distributed wind applications; but in almost all cases, it is not a simple process. It should be noted that downscaling is typically used in the creation of all modeled data because NWP models calculate wind speeds at very high altitudes. Downscaling methods and models are typically business sensitive and therefore difficult to compare.

Current accuracy: Varies widely depending on vendor, project complexity, location, and input veracity but values of around +/- 50%, although not verified, are common outcomes.

Assumptions: Rayleigh Distribution, idealized losses, idealized turbine power curve, no inter-annual variability, no uncertainty, and no integrated directional sensitivity.

3.1.2 Level 2: Complex Approach

Project size: Varies depending on many factors, generally from 50 kW to somewhere between 500 kW and 750 kW

Cost: $2,000 or less per project

Approach: Automated using client-focused websites, includes more detailed site environmental characteristics, including frequency distribution of wind speed and wind direction, air density, etc.

Duration: 1 month or less to conduct assessment

Current accuracy: Varies widely depending on vendor, project complexity, location, and input veracity. Survey respondents suggested estimated accuracy between +/-20%, with extreme cases reported from -75% to 250%

Assumptions: Modeled frequency distribution, calculated losses, idealized turbine power curve, no inter-annual variability, and no uncertainty.

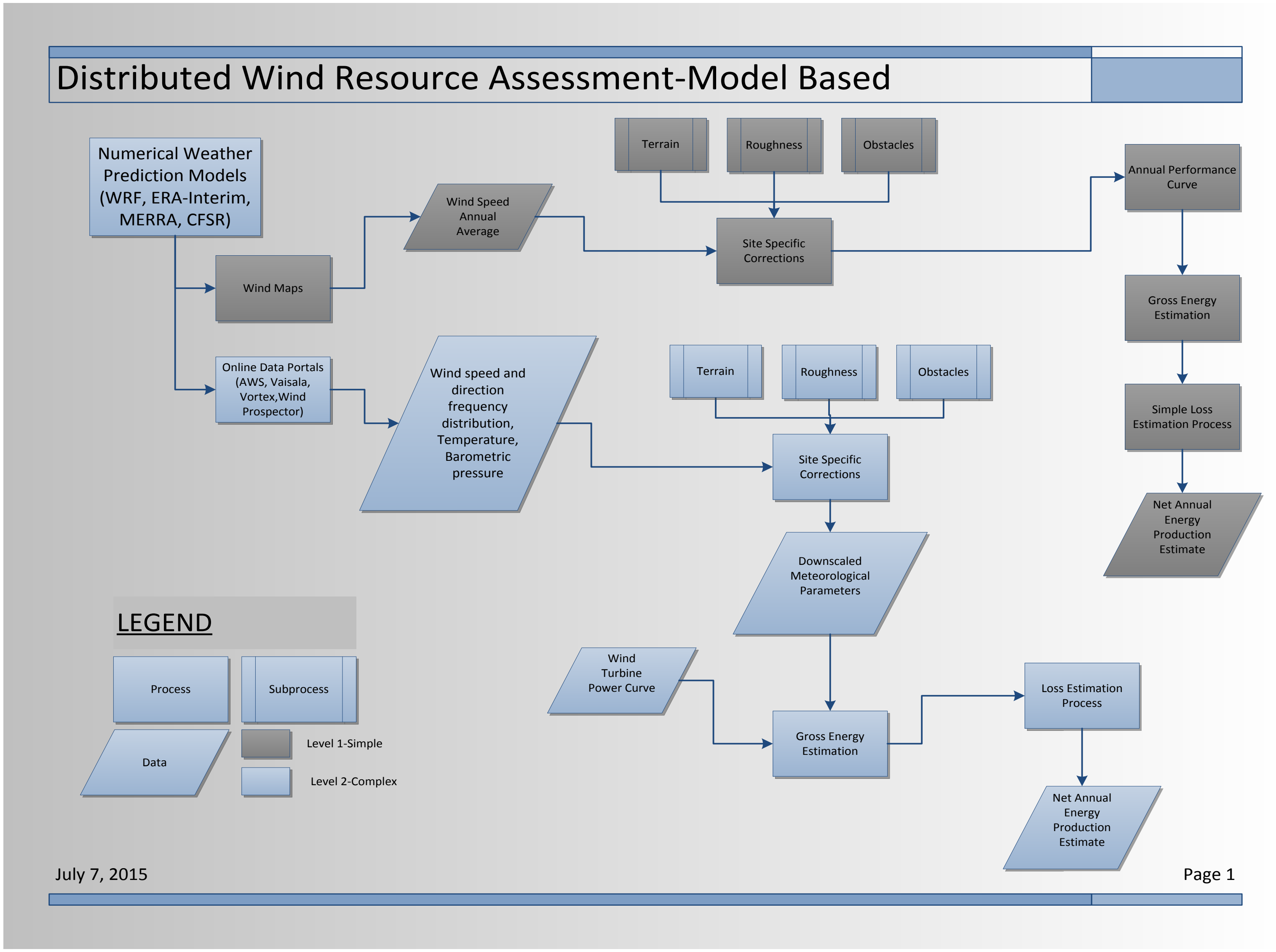

Figure 1. Distributed wind turbine wind resource assessment model-based approach

3.2 Measurement-Based Approach

Onsite measurements can also be combined with other model or analytical tools (aspects of the first approach) to perform higher-resolution assessments, reducing the overall uncertainty of the energy and site condition estimate. The onsite measurements can include meteorological towers or remote sensing devices. Generally speaking, larger projects tend to require onsite measurements to ensure that energy estimates are more accurate and likely to meet the projected energy output and therefore the economics of the selected turbine.

Figure 2 depicts a high-level overview of the resource assessment process for distributed wind projects with a commercial driver to better refine accuracy and uncertainty in energy estimates. The measurement-based approach is recognized across the industry as being more accurate for predicting energy production as well as site suitability. Instruments are, however, more expensive, and the process is more time consuming than traditional model-based approaches, which has led to limited uptake in the distributed wind sector.

The measurement-based approach generates its own site-specific wind statistics and largely eliminates the need for site-specific corrections accounting for terrain, surface roughness, and obstacles. There is typically an additional step known as Measure Correlate Predict (MCP) to adjust the relatively short-term measurements to a long-term representation of the wind statistics based on a modeled or other nearby, long-term reference wind measurement station. This long-term representation is then combined with the power curve to generate gross energy estimates, and these estimates are subsequently run through a loss and uncertainty estimation process to arrive at the net annual energy production and expected variability.

One of the least agreed-upon aspects of onsite measurements is when they should be used to measure the wind resource of a potential project. Opinions vary on the minimal size at which onsite measurements should be initiated, ranging from 50 kW to 750 kW, with outliers on both ends suggesting that onsite measurements are never realistic for distributed wind projects or are realistic only for projects greater than 750 kW. Increased site complexity is also a driver that leads to use of onsite measurement. Additional considerations noted during the discussion were the role of remote sensing as compared to tower-based measurement and how much time to allocate for onsite measurements to allow for MCP processes to provide high-quality results.

3.2.1 Level 3: 500 kW-750 kW and Up

Cost: $20,000 or more per project

Approach: Use of onsite instruments and advanced models to quantify long-term performance and uncertainty

Duration: 3 to 12 months minimum measurement time, 30 to 60 days modeling time

Current accuracy: Varies widely depending on vendor, project complexity, and input veracity. Survey results indicate accuracy in the +/- 20% range.

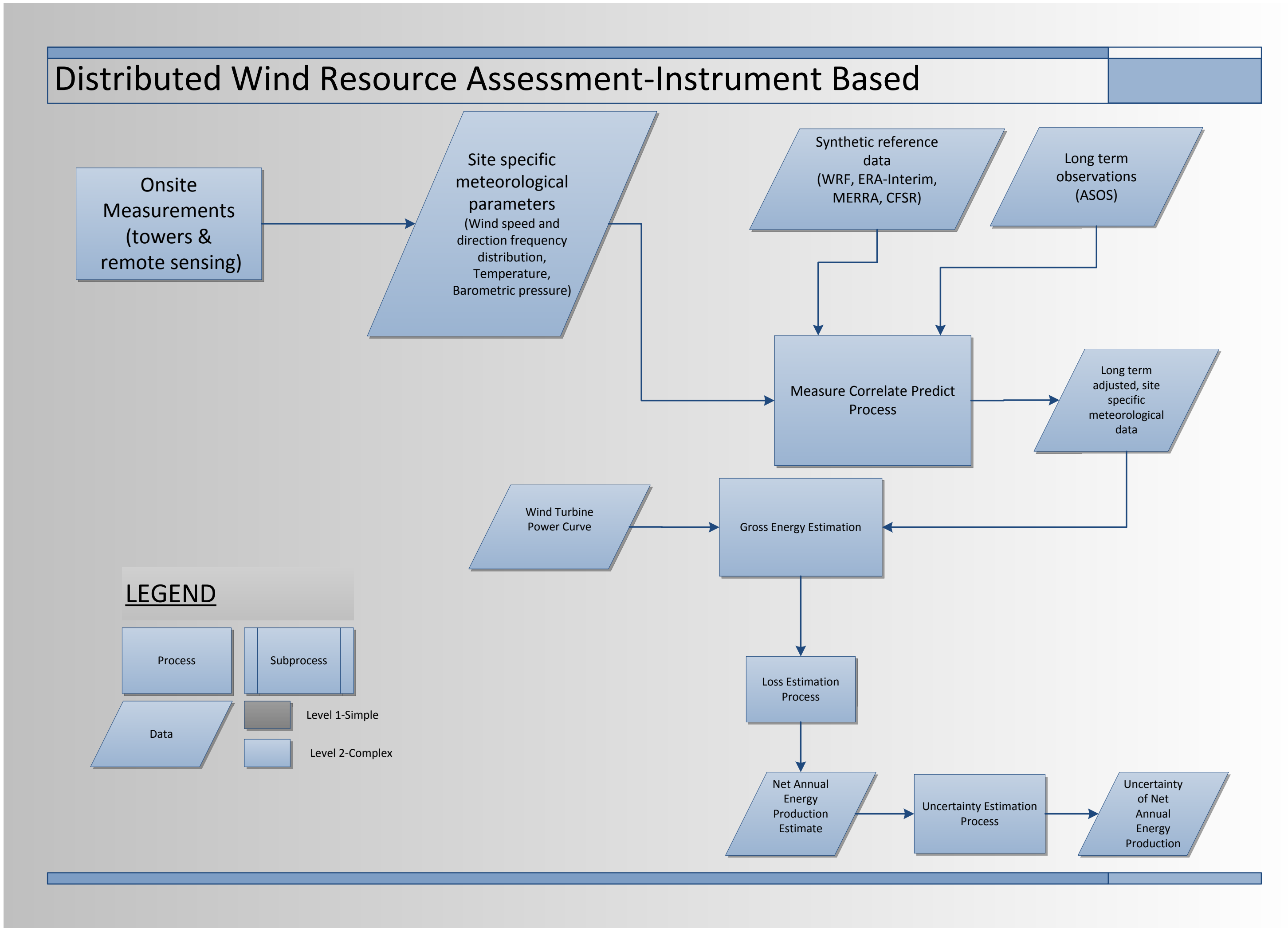

Figure 2. Distributed wind turbine wind resource assessment measurement-based approach

4 Potential to Reduce the Overall Cost of Deployed Distributed Wind Technologies

Several wind resource assessment aspects can impact the life-cycle cost of deployed distributed wind technologies. The following were identified and discussed during the workshop:

- Project costs can be reduced by developing faster, lower-cost site assessments while optimizing power performance estimates. A potential solution could include a reliable tiered screening methodology, with different methodologies available depending on the complexity level of the site under consideration. The objective would be to easily identify poor sites and eliminate them from consideration, minimizing expended resources.
- Improved consumer and stakeholder confidence in distributed wind systems could have secondary impacts that will lower costs, including:
    - Lowering the cost of capital and project financing by increasing the precision and accuracy of energy predictions
    - Expanding state or federal incentive support through improved and consistent project performance
    - Increasing the number of word-of-mouth sales based on better consumer experiences.
- Overall distributed wind fleet performance could be improved by improving performance prediction and decreasing the number of underperforming or short-lived turbines. Regardless of how well designed a turbine may be, if the project is sited improperly, the performance will likely be less than desired by stakeholders. By improving the siting and prediction process, there can be a positive impact to the baseline distributed wind fleet performance across all projects.
- Implementing more turbine-specific siting will allow the installation of turbines better tuned to specific sites as compared to the "one-size-fits-all" deployment model generally used by the small turbine industry. This approach follows the model implemented by the mid-size and larger turbine market in which several turbine models are offered on the same platform, allowing more aggressive designs to be installed at low-wind-speed/low-turbulence sites based on a high confidence in wind resource prediction. Most manufacturers in the distributed wind market currently design and build machines for worst-case deployment scenarios. The promise of better wind resource descriptions means that the industry can optimize turbines to be more productive by tailoring to site-specific winds.
- Refining resource assessment processes and employing site suitability analysis more consistently for distributed wind projects will contribute to reduced O&M costs as turbines are sited in locations that are less destructive to turbine components.

5 Current Challenges Identified by Workshop Participants

Following presentations on current industry wind resource assessment practices, a facilitated discussion identified key industry challenges and needs. The following nine areas were identified as gaps in the current understanding or availability of tools or knowledge to improve the resource assessment process for distributed wind systems. They are categorized as having major or minor impacts to the industry. It should be noted that although the discussion identified some needs or solutions to address the nine gaps identified, the listing should not be considered exhaustive.

Many of the ideas introduced below address several of the themes above, which are summarized in the following table.

Table 1. DWRA Gaps Summary

Improvement Opportunity	Cost of Assessment	Consumer or End User Confidence	Performance Estimation	Improving Characterization of Site Suitability	Level of Effort Required
Data Access	Major	Minor	Major	Major	Moderate
Validation & Benchmarking	Major	Major	Major	Major	Low
Education & Outreach	Major	Major	Major	Major	Low
Atmospheric Model Input Data	Major	Minor	Major	Minor	Low/Moderate
Measure-Correlate-Predict (MCP)	Minor	Minor	Major	Major	Low
Downscaling Methods	Minor	Minor	Major	Major	Moderate/High
Standardization	Minor	Major	Minor	Minor	Low
Site Suitability Assessment	Minor	Major	Major	Major	Moderate/High
Low-Cost Instrumentation	Minor	Major	Major	Major	High

5.1 Limited Access to Public Data [Data Access]

There is a dearth of easily accessible, publicly available, free or inexpensive modeled and observational data appropriate for use by the distributed wind industry. Having easy access to local data could help the distributed wind industry perform cost-effective and accurate resource and site assessments as well as model validations.

Needs:

- Better access to free reanalysis and/or NWP modeled datasets (i.e., 3Tier, AWS downscaled)
- Better access to wind map data that are scalable and contain the following:
    - Wind speed frequency distribution
    - Wind direction distribution
    - Barometric pressure, temperature, shear, turbulence intensity
    - Inter-annual variability (IAV).
- Better access to observational data such as historical or ongoing state or federal anemometer loan program data through a central data portal. Current data are hard to locate and are sometimes costly.

5.2 Minimal Data, Methodologies, and Guidelines Available for Resource and Site Assessment Validation and Benchmarking [Validation & Benchmarking]

The distributed wind industry lacks representative atmospheric and turbine performance data to validate and benchmark existing methodologies for predicting project performance and site suitability. New standard test cases and guidelines could include discussion of which tools, processes, and methodologies are appropriate for specific site conditions and the limitations of various approaches.

Needs:

- A way to validate existing models and understand their limitations and appropriate uses
- Improved and better-documented methodologies for MCP and IAV assessment, understanding under which conditions the different methodologies are most applicable
- Process and methodologies to conduct validation of the precision and accuracy of operational assessments
- Verification of the entire site assessment process, not just the models used to perform site assessment
- Assessment of power curves under operating conditions more consistent with distributed wind deployments.

As part of work efforts for other WWPTO-developed models, DOE/NREL incorporated three ways of conducting model assessment/verification: i) a model run-off to allow open market assessment and collaboration, ii) development of data sets people can use to publically validate codes, and iii) independent third-party model comparison/verification. These methods are not mutually exclusive.

5.3 Lack of Education and Outreach Opportunities for the DWRA Industry [Education & Outreach]

There are limited opportunities for sharing resource assessment knowledge such as webinars, workshops, DWRA collaborations (e.g., Gearbox Reliability Collaborative), and informational exchanges. There is also limited overlap and knowledge transfer between the established utility wind resource assessment and nascent DWRA sectors. Focus on education and outreach could improve knowledge of distributed wind-focused site and resource assessment tools and methodologies. This could be instrumental in creating an industry informational commons; facilitating discussions around best practices, standardization, and vocabulary; and more.

Needs:

- Better knowledge transfer between utility-scale and distributed wind sectors
- Collaborative best-practice development and documentation
- Training materials for all critical DWRA processes including scaling, IAV, use of certified power curves, uncertainty, etc.
- Common resource portal(s) to improve low-fee access and training to industry stakeholders
- More opportunities to connect and learn (e.g., webinars, workshops, informational exchanges).

5.4 Need Better Ways to Access and Incorporate Site Data for Distributed Wind Projects [Atmospheric Model Input Data]

The distributed wind industry needs access to critical site information to facilitate atmospheric modeling (e.g., terrain, surface roughness, 3D buildings, and other surface features) in a way that is affordable for the scale of distributed wind projects. Efficiencies could be gained from developing publically available data sets and tools to streamline the input of these data into the site assessment process.

Needs:

- Better ways to incorporate existing local data/information into the models
- Publically available data sets that provide additional critical information beyond what is currently available (wind speed, topography), such as 3D buildings, surface features, etc.
- Common model input or transition tools to allow models to operate seamlessly.

5.5 Complexity and Cost of MCP Approaches Result in a Lack of Multi-Year Resource Information Used in Project Assessments [Measure-Correlate-Predict (MCP)]

Current tools with embedded MCP approaches are currently too costly and time consuming for most DWRA applications. As a result, there is minimal characterization of year-to-year wind resource variability, including wind speeds, direction, turbulence, and other important factors that help provide high-quality assessments of long-term energy production. Underlying this is a lack of clear MCP methods for adoption and adaptation in DWRA applications.

Needs:

- Better characterization of year-to-year wind resource variability by region or location
- Clear MCP methods for adoption in DWRA applications
- Cost-effective tools to incorporate MCP approaches in DWRA applications.

5.6 Lack of Robust Methods for Scaling Wind Data to Typically Lower Hub Heights for Distributed Wind Projects [Downscaling Methods]

There is a general lack of validated, scientifically rigorous methodologies for downscaling modeled data such as wind maps or coarse reanalysis/NWP data, which has resulted in myriad approaches to estimating hub-height data. Many of the typical rules of thumb are based on "common wisdom" and are not backed by solid research, especially when applied to distributed wind applications. Developing industry standards for downscaling and reference wind parameters such as turbulence and shear would facilitate more accurate wind resource assessments at project sites.

Needs:

- Reference values for parameters such as shear, turbulence, boundary layers, roughness, and expected impacts of obstacles (could be rules of thumb, new tools, or quantitative guidance)
- Better understanding of (and statistics around) how much site-specific measured data are needed to develop high-confidence predictions for scaling parameters and how these might change depending on season, region, and general resource characteristics
- Standardized scaling approaches and methods; compare results from experts to help improve general understanding of downscaling
- CFD methodologies for understanding the wind resource characteristics for specific locations.

5.7 Absence of Standardization in DWRA Methods [Standardization]

There is little agreement and documentation of industry standard methods, definitions, terms, and/or report templates for DWRA, resulting in challenges identifying performance issues and generating improved methods, which in turn decreases confidence levels by funding and other organizations. Identifying and calculating common losses and uncertainties should be part of this effort.

Needs:

- Common reporting formats and/or templates

- Common loss framework and values including electrical losses, turbine and object wakes losses, etc.
- Common uncertainty framework.

5.8 Minimal Focus on Turbine Site Suitability [Site Suitability Assessment]

There is minimal usage of site-specific wind loading analysis within the distributed wind industry. Developing cost-effective approaches for determining site winds and turbine loads could allow for more efficient and productive turbine designs. Refining and validating this approach could lead to significant performance and reliability enhancements similar to what the utility wind sector has accomplished with low-wind-speed turbines.

Needs:

- Improved methods for identifying turbine technology that is suitable to survive site wind loads
- Cost-effective, onsite measurements to quantify parameters that affect turbine loads, such as turbulence, inflow angles, and extreme direction change.

5.9 Instrumentation, Measurement Systems, and Data Processing Are Too Costly for Many Distributed Wind Projects [Low-Cost Instrumentation]

Due to the high cost and long time frames of measurement-based wind resource assessments, the industry often uses rule-of-thumb methods and simplified model-based approaches. This can lead to a high level of uncertainty in energy estimates. Development of or access to low-cost instrument-based assessments, including data processing, could increase the adoption of measurement-based approaches and decrease the levels of uncertainty in energy assessments.

Needs:

- Low-cost measurements, including:
    - Equipment cost and the level of calibration required
    - Installation requirements, costs including the opportunity cost associated with additional site visits
    - Data collection, processing, and analysis.
- Central data analysis and quality control resource.

The cost/impact value argument must be better understood in order to determine what measurements mean for different markets and the potential impact that may justify the additional expense of onsite measurements. The value of onsite measurements must be quantified before the development of improved measurement systems will be impactful for DWRA.

6 Summary of Results from Expert Elicitation

NREL researchers undertook an additional expert elicitation to ensure that opinions from a wide variety of stakeholders, including those unable to attend the DWRA workshop, were represented in the findings of this report. The survey consisted of 16 questions, including participant background, end use of DWRA products, and key challenges for the industry. We received 23 responses from individuals across the industry, including consultants, academics, manufacturers, incentive fund managers, and representatives from non-profits and government agencies. We conducted the survey via SurveyMonkey over a 2-week period.

One of the major themes present in the survey results was the wide range of responses across the distributed wind industry regarding methodologies, results, costs, timeline, and priorities. Some of this wide range can be attributed to the diverse nature of the distributed wind industry: various turbine/project sizes, project drivers, stakeholders, and project configurations, from single 1-kW machines at a private residence to multi-megawatt community wind farms. The tools used in these disparate scenarios are necessarily different, but industry recipients provided a wide range of responses even within turbine size classes. The amount of time and money that can be spent on a project is highly dependent on the size and configuration of the project as well as the risk appetite of the project stakeholders.

The diversity of approaches and results spread for performing wind resource assessments underscore the need to conduct validation and benchmarking activities as well as develop standard reporting in the industry.

In Questions 13-15, the survey asked for a ranking of the nine priorities identified during the workshop (Section 5) based on three perspectives. The results from each question are summarized below. The questions asked were as follows:

- Question 13: Please rank the following in order of potential impact to the distributed wind industry.
- Question 14: Please rank the following according to your needs.
- Question 15: Please rank the following according to areas in which government participation would be most valuable.

These questions reflect the individual needs of the participants and highlight areas in which the recipients think DOE investments could be most effective and appropriate.

The results from each individual question are shown in Figures 3-5. Survey participants were asked to rank the nine priorities on a scale from 1 to 9, with 9 being the most impactful. The results were then summarized using the Borda Count Method.

Figure 3 shows participant priorities ranked according to the **potential impact to the distributed wind industry**. Several key themes emerge. While Education & Outreach and Data Access are clear priorities, the spread seems to indicate that all challenges are important and impactful to the distributed wind industry.

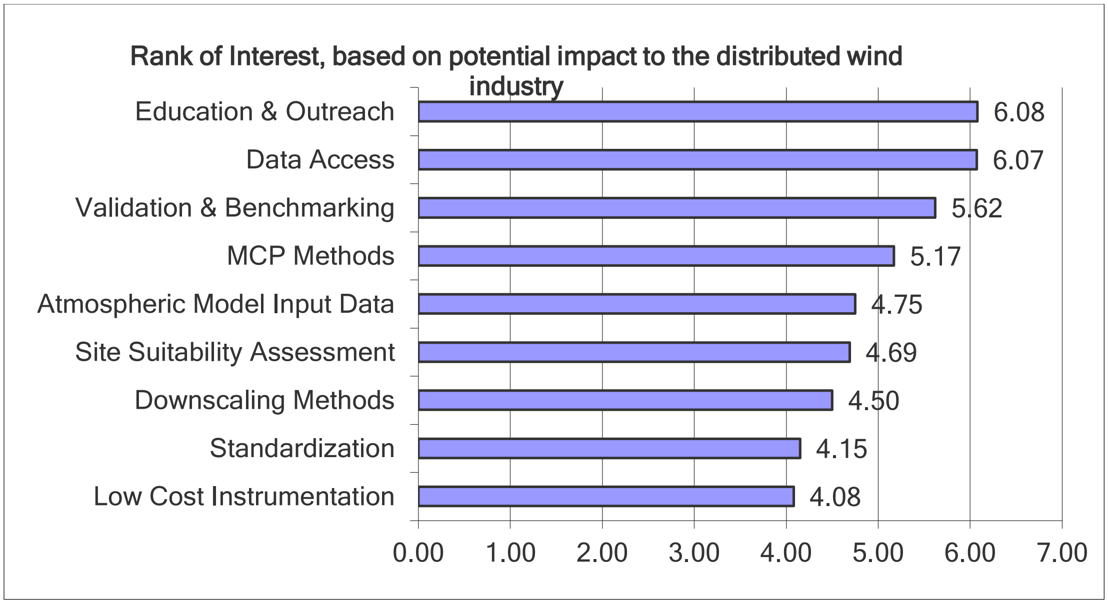

Figure 3: Ranking of industry priorities (according to the needs of the industry)

In terms of the **individual's needs**, the priorities are slightly different, although Data Access and MCP Methods are at the top of the list here too. From an individual perspective, there is a greater emphasis on site inputs and downscaling.

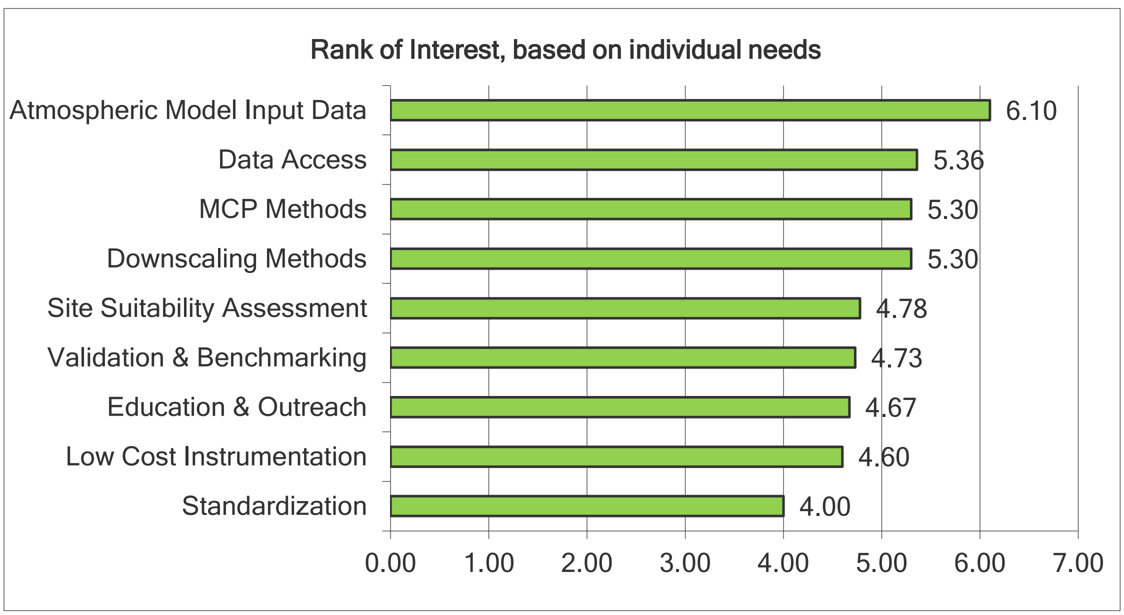

Figure 4: Ranking of industry priorities (according to individual needs)

For areas in which **government participation would be most valuable**, participants ranked Validation & Benchmarking highest, followed by a steady decline through Atmospheric Model Input Data, at which point the decline is steeper. It is interesting to note that Low-Cost Instrumentation is at the bottom of the list; however, one reason for the low ranking may be that participants view this aspect as a role for the industry, potentially with government funding support.

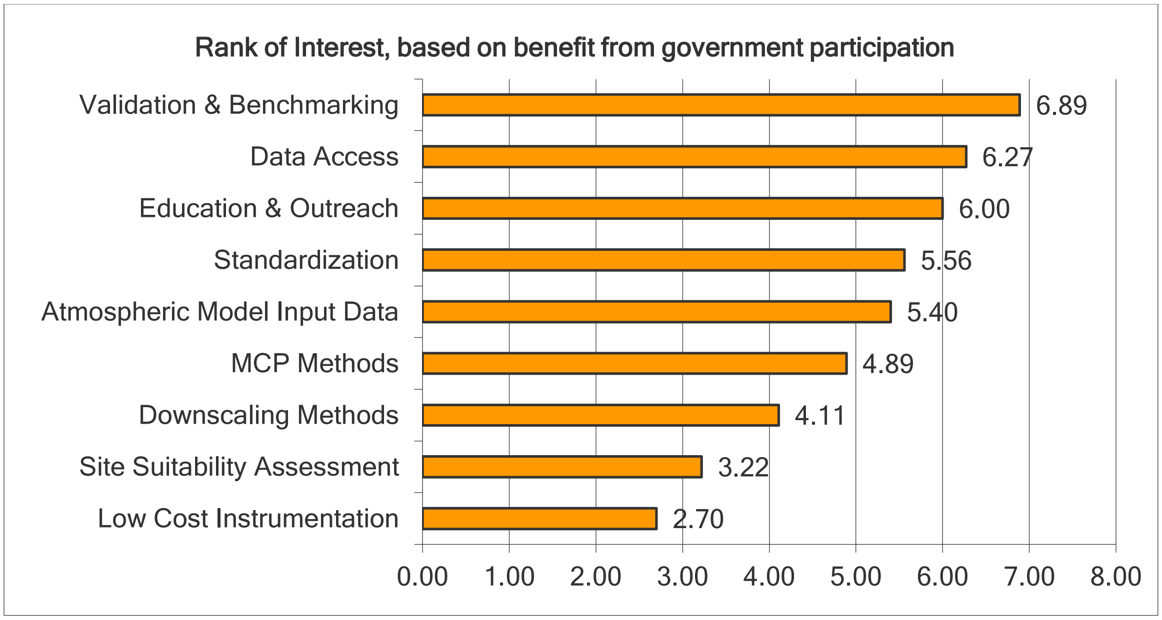

Figure 5: Ranking of industry priorities (according to potential benefit from government participation)

Although they are not in the same order, note that the top three priorities identified as having the greatest industry need and a clear government role overlap. In rank order obtained by summing the individual question results, the following likely represent the highest priorities of engagement:

- Validation & Benchmarking
- Data Access
- Education & Outreach.

It should be noted that the remaining two areas with high interest levels, MCP Methods and Atmospheric Model Input Data, also rank in the top half of the survey results to both questions so would be additional areas of concentration.

When combining the above with a review of the ranking based on individual needs, Data Access, MCP Methods, and Atmospheric Model Input Data are also highlighted as being important. Obtaining a better understanding of downscaling methods is also identified as a priority for individual companies but is not ranked as a high industry need or an activity with a strong governmental nexus.

Throughout this report, we have tried to highlight some of the emergent priorities. It is important to note that many of the other priorities may also require attention, and this idea is reinforced by the lack of significant break among the ranking of the identified priorities.

As with most of the survey results, there is overlap and synergy among the various industry priorities. For instance, the MCP and Downscaling Methods are issues that can be addressed through Education & Outreach and benchmarking.

7 Conclusions

Several rounds of expert elicitation provided NREL researchers with valuable insight into the current state of wind resource assessment in the distributed wind industry and how DOE efforts would be most effective in achieving two primary objectives: maximizing stakeholder confidence and reducing the LCOE for distributed wind technology. The nine areas of potential DWRA improvement can have minor or major impacts in both of these areas, as introduced in Table 1.

Stakeholder confidence will be maximized by creating reliable, well documented, and independently verified methodologies for performing wind resource assessments. Standard reporting from these activities can also aid stakeholders in comparing potential sites and/or technology options. It will be further boosted by facilitating knowledge-sharing opportunities through online portals and live events.

The LCOE will be lowered by improving the overall distributed wind fleet performance by generally improving performance prediction and decreasing the number of underperforming or short-lived turbines. Additionally, activities that address streamlining the inputs and DWRA process can reduce the cost of projects through the development of less time-consuming, lower-cost site assessments while optimizing power performance estimates.

7.1 Challenge Tiers

NREL researchers evaluated the stakeholder feedback in several ways, and ultimately the nine DWRA challenges tended to group into three major tiers. These tiers represent the urgency expressed by stakeholders surveyed as well as practical starting points for DWRA R&D activities. Tiers 1 and 2 should be considered the most immediate, with Tier 3 activities having a longer time horizon but also significant potential impact.

Tier 1 challenges are high priority for industry participants and correspond to foundational exercises that will lead to a better industry-wide understanding of the importance of DWRA and its associated challenges. Tier 1 challenges are likely to be well aligned with existing DOE activities and communication pathways such as OpenEI, WINDExchange, and A2e.

Tier 1 challenges are as follows:

- Limited access to public data [**Data Access**]
- Minimal data, methodologies, and guidelines available for resource and site assessment validation and benchmarking [**Validation & Benchmarking**]
- Lack of education and outreach opportunities for the DWRA industry [**Education & Outreach**].

Tier 2 challenges are medium priority for industry participants and correspond to individual pieces of the DWRA process. These can generally be considered R&D areas that would support the broader Tier 1 initiatives. As the industry evolves, we can expect the Tier 2 priorities to change with the advancement of DWRA techniques. Tier 2 challenges are as follows:

- Need better ways to electronically access and incorporate site data for distributed wind projects [**Atmospheric Model Input Data**]
- Complexity and cost of MCP approaches result in a lack of multi-year resource information being used in project assessments [**Measure-Correlate-Predict (MCP)**]
- Lack of robust methods for scaling wind data to typically lower hub heights for distributed wind projects [**Downscaling Methods**]
- Absence of standardization in DWRA methods [**Standardization**].

Tier 3 challenges are a lower priority for industry participants; however, due to the limited results spread, they should not be completely dismissed. In fact, if solved the Tier 3challenges potentially offer the most game-changing opportunities for the distributed wind industry. Generally the challenges in Tier 3 correlate within a longer time horizon for solving and adoption by industry. Again, Tier 3 challenges correspond to individual pieces of the DWRA process. These can be considered areas of R&D that would support the broader Tier 1 initiatives. As the industry evolves, we can expect the Tier 3 priorities to change with the advancement of DWRA techniques. Tier 3 challenges include:

- Minimal focus on turbine site suitability [**Site Suitability Assessment**]
- Instrumentation, measurement systems, and data processing are too costly for many distributed wind projects [**Low-Cost Instrumentation**].

7.2 Recommended Actions

Regardless of how well designed a turbine may be or efforts to reduce deployment costs, if it is sited improperly the performance will likely be less than desired by stakeholders. By improving the siting and prediction process, we can positively impact the baseline distributed wind fleet performance across all projects.

When we examine the practical activities that will address each of these issues, we see that all of the identified challenges overlap. Efforts made in the areas below will have the greatest impact on the industry if the challenges are solved. It should be understood that priorities will change as the distributed wind industry evolves its DWRA processes.

Activities that flow from these priorities could encompass the following:

7.2.1 Tier 1 Activities

- **Data Access:** Expand the availability of data accessible by the public
    - Develop and populate a user-friendly data-sharing platform that provides access to publically available measurement data, such as:
        - State measurement program data
        - DOE anemometer loan program data
        - Other data collected by federal entities or links to that data.
    - Develop and facilitate aggregation of and access to low-cost, long-term wind data sets, including site-specific NWP data.

- **Validation & Benchmarking:** Improve the validation and benchmarking of DWRA processes and modeling tools
    - Develop and support the implementation of long-term performance monitoring approaches
    - Implement a model validation process that would support independent or industry-based processes to understand the accuracy of existing models under a range of conditions
        - Develop validation datasets that highlight key DWRA-specific conditions
        - Implement a process to allow companies to validate or have their models validated by third-party experts.
    - Following benchmarking efforts, provide support to improve the accuracy of the models through activities such as:
        - Baseline methods against empirical datasets
        - Technical review of model elements
        - Support of model development/improvements.
    - Combine the results of multiple technical support efforts to provide better industry-wide guidance on modeling methodologies and appropriate assumptions.
- **Education & Outreach:** Expand education and outreach efforts within the DWRA community
    - Develop web-based DWRA content and sharing platform (OpenEI or other)
    - Aggregate key wind resource assessment lessons and practices from the utility sector and support the appropriate implementation into DWRA practices
    - Disseminate DWRA and appropriate utility wind resource assessment practices and information through industry-focused, experience-sharing activities such as webinars, presentations, conferences, workshops, and Regional Resource Centers
    - Organize annual or bi-annual DWRA workshops to share experiences and expertise.

7.2.2 Tier 2 Activities

- **Atmospheric Model Input Data**
    - Generate common list of required inputs and sources for DWRA models, publish through Education & Outreach pathways
        - U.S. Geological Survey surface roughness & terrain data
        - Reanalysis Datasets (MERRA, ERA-I, CFSR)
        - Constraints (environmental, airports, etc.).
    - Generate tools that can automate and/or streamline data gathering and input for DWRA processes
        - Automated code scripts (e.g., Python scripts)

        - Web based, geo-referenced tool for downloading input data sets (e.g., NREL's Wind Prospector).

- **Measure-Correlate-Predict (MCP)**
    - Baseline long-term IAV impacts by region or location (e.g., IAV wind maps)
    - Discuss utility-scale wind MCP methods in Education & Outreach Pathways
    - Develop new MCP techniques specific to DWRA process needs.
- **Downscaling Methods**
    - Survey existing downscaling approaches along with limitations and appropriate usage guidance
    - Update and experimentally validate many of the currently used industry rules of thumb (e.g., shear coefficients and relations to surface roughness) that have limited documented justification
    - Discuss utility-scale approaches for scaling atmospheric variables to height and location of interest
    - Update small wind site assessor guidelines with revised best practice information.
- **Standardization**
    - Document DWRA processes along with limitations and appropriate usage guidance
    - Discuss IEC 61400-15 approach to categorization of losses and uncertainties
    - Modify IEC 61400-15 categories for DWRA application space
    - Populate modified DWRA categories with Validation & Benchmarking information, IAV baselines, downscaling baselines, etc.
    - Engage in new revision of IEC 61400-2 as needed.

7.2.3 Tier 3 Activities

- Site Suitability Assessment
    - Identify performance and reliability implications of performing site-specific wind and turbine loading assessments
    - Generate new DRWA methods for site suitability assessment.
- **Low-Cost Instrumentation**
    - Develop ultra-low-cost instruments for onsite measurement
    - Develop methods to incorporate onsite measurements for faster, more cost-effective WRA processes (e.g., combine short-term measurements with MCP methods).

One point that should be noted in the summation of the workshop and its findings is the absence of discussion around siting models. Although this topic was not discussed in depth, the fact that it was not discussed is relevant. Industry participants indicated that they have access to a variety of siting models, mostly proprietary models, and they did not think that new siting modeling tools would support further industry growth. Of higher importance is the ability to augment those models with better downscaling approaches and/or perform validation exercises on public or in-house models.

Workshop participants also almost unanimously felt that although focused more on the challenges facing the industry, a venue that brings together the DWRA professionals was very valuable. Although built into the Education & Outreach key area, it was discussed informally that no other industry venue really focused on DWRA and that the value gained by sharing experiences within the community was very high. Even if nothing else results from this assessment, all agreed that supporting an ongoing dialog among members of the DWRA community would be productive and help improve the industry.

Glossary

downscaling	The method by which meteorological data is translated from the native height to the hub height of interest.
inter-annual variability	Inter-annual variability describes the tendency of site wind speed to vary from year to year.

Bibliography

Browers, Michael. 2012. *Wind Resource Assessment: A Practical Guide to Developing a Wind Project*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Orrell, Alice, and Nikolas Foster. 2015. *2014 Distributed Wind Market Report*. U.S. Department of Energy. Accessed June 2, 2016. http://energy.gov/sites/prod/files/2015/08/f25/2014-Distributed-Wind-Market-Report-8.7_0.pdf

Appendix: Workshop Participants

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