Wind Energy Resource Assessment: Information Production, Uses, and Value – Survey Report

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Summary

High-quality information about the wind resource at candidate wind farm sites is essential to continue to guide the rapid growth of wind energy in the United States and around the world. In the effort to produce better information through improved wind resource assessment (WRA) methods, input from people within the industry who produce and use this information is key. During the summer of 2013, researchers at the National Center for Atmospheric Research, with funding from NASA Research Opportunities in Space and Environmental Sciences Grant No. NNX10AB30G, conducted an online survey of WRA experts (both *producers* and *users* of WRA information) to learn about current practices, priorities, and informational needs. A central focus of this survey was on the current and potential role of NASA's Earth Science datasets, and WRA techniques developed using these datasets, in improving wind resource information for the wind industry. Key findings from this survey include:

- Wind resource assessments are produced by a variety of actors, including wind energy developers, consultants, and energy utilities, using several different methods and data sources. Over a third of WRA producers in our sample had used the National Aeronautics and Space Administration's Modern Era Retrospective Analysis for Research and Applications (NASA MERRA) dataset. MERRA users cited many perceived benefits of this dataset, with its public availability foremost in this list. Among those who had not used the MERRA dataset, many said they had not heard of this dataset, while several others said that they simply did not use methods that required reanalysis data.
- Use of wind resource assessments also spans a wide range of different organizations across multiple sectors of the wind industry. Among WRA users, we found relatively low "name recognition" for the MERRA dataset: that is, less than half of the users had an opinion about whether use of MERRA would increase or decrease the quality of an assessment. The factor that was most frequently associated with high-quality WRA information was validation of the methods using on-site production data.
- Respondents viewed overprediction in wind resource assessments as an ongoing problem for the wind energy industry. Causes of overprediction cited by respondents included modeling and data issues, as well as the incentives of different actors (developers and consultants). Consequences of overprediction included financial impacts for owners and investors as well as longer-term reputational impacts for the industry.
- Respondents overwhelmingly thought that quantifying the uncertainty in wind resource assessments would be valuable, though they also cited several barriers to its use in the wind energy development process, including a lack of understanding of the uncertainty results and difficulties in overcoming existing practices across the industry.
- Respondents were asked how they would allocate research and development funds to improve the quality of wind-related information available to guide wind energy development decisions. Results show a general consensus on the importance of improving WRA methods, but respondents differed in the value they place on other research areas including uncertainty quantification.

Respondents' consensus about the need for high quality site data as well as improved methods for using that data to produce wind resource estimates should help to guide future efforts to serve this community's needs. In particular, while MERRA is highly regarded by those who have used it, our results suggest a need to increase knowledge of this data source among WRA producers, perhaps through training modules, as well as informing WRA users about the contributions that MERRA has made to producing better wind resource estimates.

I. Introduction

Wind energy produces more electricity in the US than any renewable energy source other than hydropower, and the wind energy industry is growing at a fast rate. Development of each new wind energy project is a multi-phase process that requires a number of different information sources at each phase (see Figure 1). Particularly in the early phases of development, information about the wind resource – how much wind energy would be produced at different candidate wind farm locations – is a key input into site selection decisions. Particularly in Phases II and III, the purpose of a wind resource assessment (WRA) is to provide this information.

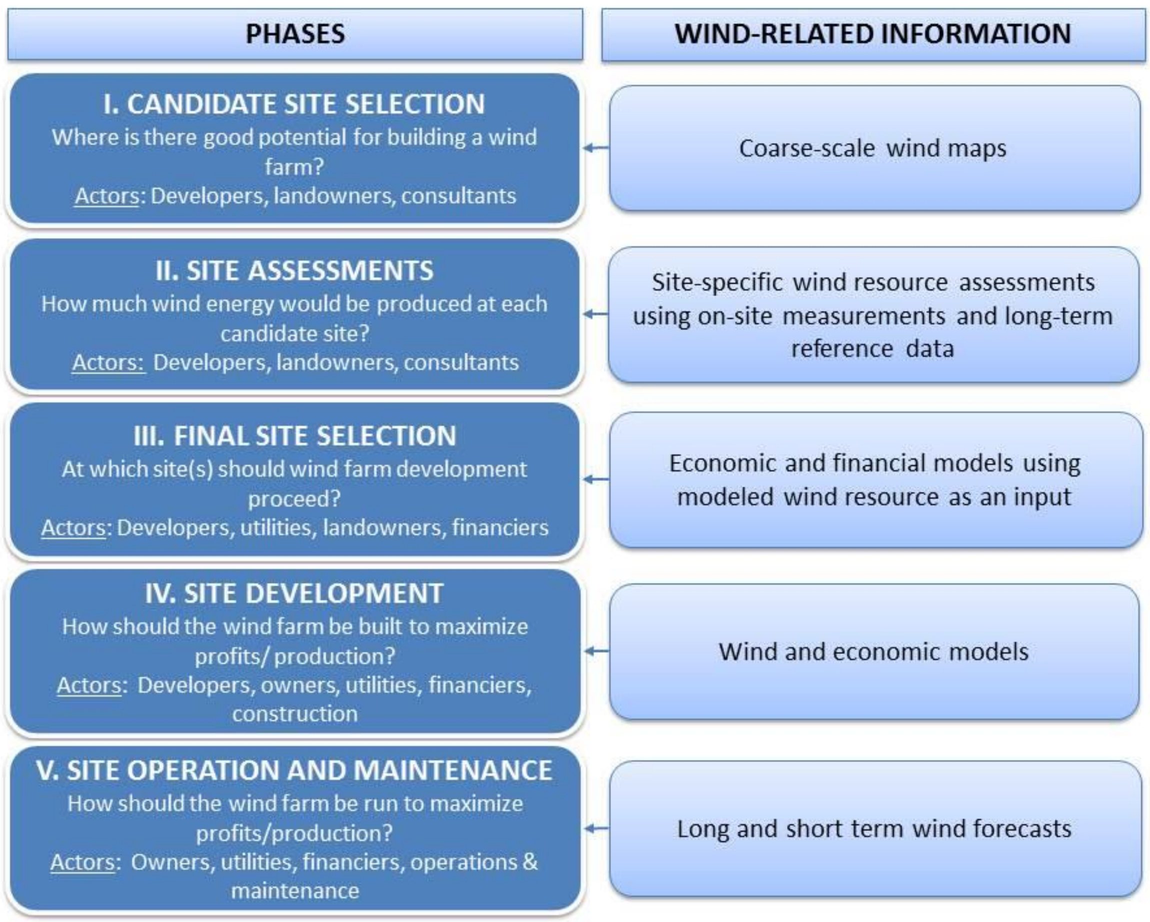


Figure 1: The wind energy development process and information needs

Ongoing research efforts at the National Center for Atmospheric Research (NCAR) are aimed at improving WRA methods in order to provide better information to support wind energy development. Specifically, some researchers are developing techniques that combine on-site observations with global-scale long-term reanalysis datasets such as the National Aeronautics and Space Administration's Modern Era Retrospective Analysis for Research and Applications, also known as the NASA MERRA reanalysis dataset. These new methods offer several potential improvements over existing methods, including increased accuracy and reliable uncertainty estimation.

Efforts to generate improved wind resource methods can be informed by an understanding of the informational needs of individuals and organizations in the wind industry who use these assessments to shape wind energy development decisions. Knowing how this information is currently produced and used in the wind energy development process, understanding industry members' perspectives on current problems and challenges in the wind resource assessment process, and gathering opinions on possible solutions to those challenges can help to better serve the wind industry's informational needs.

II. Survey Objectives

During the summer of 2013, researchers at NCAR conducted an online survey to assess the potential value of improvements in WRA methods. More specifically, we wanted to collect data from a number of actors who are involved in both *producing* wind resource assessments and *using* these assessments to inform decisions related to wind energy development. The overall goal of this survey effort was to assess current practices (related to both production and use of WRA), as well as opinions about challenges and obstacles in the WRA process and potential solutions to these challenges.   Our specific objectives were:

1. To assess what methods WRA producers currently use to conduct these assessments, including the data sources that are used;
2. To specifically assess use of the NASA MERRA dataset in WRA, including opinions about its strengths and weaknesses;
3. To examine WRA users' perceptions regarding the quality of WRA and how this is affected by different factors;
4. To gather opinions about the causes, consequences, and potential solutions for the problem of overprediction in wind resource assessments;
5. To measure attitudes toward WRA methods that provide more precise quantification of uncertainty in their wind resource estimates; and
6. To assess respondents' priorities for research and development efforts aimed at improving the quality of wind resource information that is available to inform wind energy development decisions.

III. Methods

Survey Development

The online survey was developed over a period of several months through a systematic process. First, our research team met several times to discuss the wind resource assessment process and to define key questions related to production and use of information generated through this process. We reviewed published and "gray" literature and websites on wind resource assessments and wind energy development as well as the "value of information" approach. Next, we conducted a series of semi-structured interviews with nine industry experts, and also conducted a short in-person survey with an additional seven experts at the American Wind Energy Association Conference in Chicago. These efforts represented a separate qualitative data collection effort aimed at assessing the role of WRA in wind energy development and probing informational needs within this process. In addition, these interviews served as a backdrop for the development of the online survey.

Based on these preliminary activities, we drafted an initial set of survey questions and reviewed it internally, as well as circulating it for feedback from many of the experts we had previously interviewed. Next, the survey was programmed into an online survey software program (Qualtrics), and an additional round of pretesting was conducted to get feedback on both the content of the questions (e.g., which response options to include), and the survey's flow, clarity, and presentation.

Recruitment of Participants

Our target group of respondents for this survey included individuals involved in the wind energy development process with experience either producing or using wind resource assessments. Ideally, our survey could have been administered to a random sample of ALL individuals who fulfilled these criteria. However, no comprehensive database of this population (including their contact information) exists (to our knowledge). Given this constraint, we did our best to identify as many WRA producers and users as possible through several means. First, we got referrals for both individuals and organizations we should contact through our interview process. Second, we compiled a list of major and minor wind energy developers and wind energy consulting firms. To do this, we used online data sources listing wind energy production by different firms, as well as a contacts database from the American Wind Energy Association (AWEA) conference. For each of these organizations, we identified possible individuals to contact again using online sources and the AWEA database, and then sent emails to these contacts introducing our study and requesting contact information for the individual(s) within the organization who were most familiar with wind resource assessments (production or use). We also requested and obtained an email list from a workshop held by the Utility Variable-generation Integration Group (UVIG). In total, our survey contact list included about 200 individuals.

A survey invitation email was sent to all 200 of these potential respondents. The email contained a description of the study, a link to the online survey, and language explaining that participation was voluntary and that all responses would be reported anonymously. Reminder emails were sent one, two, and (in some cases) three weeks after the initial invitation.

We are careful to emphasize that our sample is essentially a convenience sample: as mentioned above, we were not able to randomly select respondents from a known list of "wind energy resource assessment producers and users." For this reason, our sample cannot be viewed as representative of the industry as a whole, and we cannot extrapolate our results beyond the specific group of respondents who participated in the survey.

All aspects of our survey procedure were reviewed by the Human Subjects Committee at the National Center for Atmospheric Research to ensure that proper confidentiality was maintained and that other ethical issues were attended to.

IV. Results

Respondents

Out of the approximately 200 individuals that we invited to take the survey, we received 45 complete responses and an additional 11 incomplete responses containing varying amounts of useable data. Thus, our overall response rate was between 23% (complete responses) and 28% (complete and incomplete responses).

Table 1: Characteristics of respondents and their organizations

Variable	Number	%
Organization Type		
Energy utility	15	27%
Wind energy development company	11	20%
Consulting firm	8	14%
Research organization	7	13%
Manufacturing company	5	9%
Non-profit	2	4%
Software company	2	4%
Government	2	4%
Technical due diligence firm	1	2%
Other/multiple/did not provide	3	5%
Number of years at current organization		
Less than one year	5	9%
1-5 years	28	50%
6-10 years	15	27%
More than 10 years	8	14%
Number of years in wind-related field		
Less than one year	0	0%
1-5 years	16	29%
6-10 years	25	45%
More than 10 years	15	27%
Regions in which organization works		
US	41	73%
North America	30	54%
Central America	15	27%
South America	18	32%
Europe	26	46%
Africa	13	23%
Middle East	10	18%
South Asia	11	20%
East Asia	15	27%
Southeast Asia	12	21%
Australia/South Pacific	12	21%

Note: Percentages in this table are out of 55 respondents with at least partially completed surveys.

Characteristics of the survey respondents and their organizations are summarized in Table 1. As we had hoped, our respondents span a range of different types of organizations that are involved in some way in wind energy development and, more specifically, wind resource assessment. More than a quarter of respondents work for energy utilities, while another fifth represent wind energy development companies. Consulting firms, research organizations, and manufacturing companies each comprise at least 10% of the sample, while non-profits, software companies, government, and technical due diligence firms are also represented. The survey also asked respondents which specific organization they worked for; 43 of the 55 respondents provided their organizations' names, and in total 34 different organizations were listed. (There were only 5 organizations that had multiple respondents complete the survey.) Taken together, these results give us confidence that our survey results, while not statistically representative of the entire industry, do include a diversity of opinions and experiences from across the industry rather than representing a single organization or organization type.

Respondents also span a range of experience levels, both in terms of the number of years they have worked for their current organization and in terms of the time they have spent working in a wind-related field. Less than 10% of respondents have been at their current organization for less than a year, but in total nearly 60% of respondents have less than five years of experience at their current firm. However, all respondents have been working in a wind-related field for more than a year, and more than two thirds of respondents have at least five years of wind-related experience. Finally, the sample also includes quite a bit of geographical diversity in terms of the regions in which respondents' organizations conduct work related to wind development. While the sample of organizations that we recruited was comprised almost entirely of organizations based in the US, and close to ¾ of respondents indicated that their organizations conducts work in this country, our results show that these firms also work in a wide variety of locations throughout the world.

Table 2: Respondents' and organizations' involvement in different phases of wind energy development

Phases of the wind energy development process	Organization is involved in this phase		Respondent is most familiar with this phase	
	Number	%	Number	%
Site selection/prospecting	35	63%	24	43%
Wind resource assessment	44	79%	47	84%
Environmental impact assessments	21	38%	7	13%
Community outreach & engagement	28	50%	7	13%
Financing	18	32%	3	5%
Technical due diligence	32	57%	19	34%
Power purchase agreements	24	43%	13	23%
Transmission/ interconnection	27	48%	12	21%
Manufacturing	7	13%	3	5%
Construction	18	32%	3	5%
Operations & maintenance	36	64%	16	29%
Other	11	20%	9	16%

Since the main objective of our survey was to assess the value of improving wind resource assessments, our intention was to recruit a group of respondents who could provide knowledgeable responses on this subject based on some prior experience either producing or using these assessments. Tables 2 and 3 provide information on the background and experience of the respondents and the organizations they worked for. Table 2 shows results from two survey questions that ask the respondent which phases of the wind energy development process *their organization* is involved in, as well as which phases *they themselves* are most familiar with. Reflecting our selection process, the phase that is most represented in both columns is wind resource assessment: 79% of respondents indicated that their organizations are involved in this phase, and 84% of respondents indicated that this was one of the phases they are most familiar with. However, this table also shows that the organizations and, to a lesser extent, the individuals surveyed also have involvement in several other phases of wind energy development, such as site selection and prospecting and technical due diligence.

Table 3 looks more specifically at both production and use of wind resource assessments. Respondents were first asked whether or not their organization was involved in conducting or producing wind resource assessments. If the respondent said yes to this question, she was then asked if she personally conducted these assessments. A similar series of questions was then asked for use of wind resource assessments. Results indicate that almost 2/3 of respondents' organizations are involved in WRA production, while ¾ said WRA results are used within their organization. One third of respondents said they currently produce WRA, while another 15% have produced these assessments in the past. A larger proportion of respondents said they use WRA either currently (54%) or in the past (13%). Overall, almost ¾ of the total sample of respondents who started the survey have some direct experience with WRA. Thus, we were fairly successful in identifying our target group of respondents.

Table 3: Respondents' experience with production and use of wind resource assessment

Experience with Wind Resource Assessment	Number	Percentage
Organization CONDUCTS or PRODUCES wind resource assessments	35	63%
Respondent's experience with wind resource assessment PRODUCTION		
Currently conducts wind resource assessments	19	34%
Has conducted wind resource assessments in the past	9	16%
Has never conducted wind resource assessments / did not respond	28	50%
Organization USES, REVIEWS, or EVALUATES wind resource assessments	41	75%
Respondent's experience with wind resource assessment USE		
Currently uses wind resource assessments	30	54%
Has used wind resource assessments in the past	7	13%
Conducts assessments for others but does not use assessments	4	7%
Has never used wind resource assessments / did not respond	15	27%
Respondent has any experience (past or current) with wind resource assessment	41	73%

Production of Wind Resource Assessments

Table 4 shows how the 28 individuals in our sample who either currently or previously conducted wind resource assessments are distributed between different segments of the wind industry. The largest contingent (36%) worked from wind energy development companies, while energy utilities and consulting firms each comprise nearly a fifth of the sample. This table also indicates that more than 90% of the respondents that work for development companies are involved in producing wind resource assessments. In contrast, about a third of the energy utility respondents are WRA producers.

Table 4: Organization type for wind resource assessment producers

Variable	Number of respondents	% of producer sample by organization category	% of respondents in category who produce assessments
Organization Type			
Energy utility	5	18%	33%
Wind energy development company	10	36%	91%
Consulting firm	5	18%	63%
Research organization	3	11%	43%
Manufacturing company	1	4%	20%
Non-profit	0	0%	0%
Software company	1	4%	50%
Government	0	0%	0%
Technical due diligence firm	1	4%	100%
Other/multiple/did not provide	1	4%	33%

For this group of respondents who indicated prior experience with WRA production, the online survey displayed follow-up questions about why and how these assessments were produced. Table 5 summarizes responses about the purposes of WRA production. The majority of respondents said that assessments are used within their own organization to inform project development. The second most common use is for research purposes (for example, research and development into new WRA techniques) while about a third of respondents said their organization sells WRAs to other parties and about a quarter said their assessments are provided to other users for free.

Table 5: Reasons for producing wind resource assessments

Reason for producing assessments	Number	%
Used "in-house" to inform project development	22	63%
Produced for research purposes	16	46%
Provided to other users (e.g., developers) for a fee	12	33%
Provided to other users (e.g., developers) for free	8	23%
Other	3	9%

Note: Percentages in this table are out of 35 respondents who said their organization produced wind resource assessments.

Respondents were also asked to estimate how many wind resource assessments they had been involved in conducting over the past year. Twenty two respondents provided numerical responses, with a range of 0 to 60 (mean =15, median =6). One respondent indicated that s/he does not conduct assessments personally, but manages a team that conducts about 200 per year.

WRA Methods Used by Producers

Several additional survey questions focused on the methods and data sources the respondent has used to conduct his/her assessments. Methods are tallied in Table 6. Two-thirds of respondents said they have used "measure-correlate-predict" (MCP) methods, while nearly as many listed "statistical methods." The WAsP software (Version 10 or earlier) has been used by just over half of the respondents who conducted these assessments.[1] A little less than half of these producers have also used dynamical downscaling methods, computational fluid dynamics, and hybrid approaches that combined two or more techniques. These results make it clear that a wide variety of methods are used by these respondents to conduct wind resource assessments. Table 6 also shows the total number of methods that were named by each respondent. Of the 27 individuals who said they had conducted wind resource assessments in the past, almost 90% said they have used two or more of the methods listed in the survey.

Table 6: Methods used by respondents to conduct wind resource assessments

	Number of responses	%
Method		
Statistical methods	17	63%
Measure-correlate-predict (MCP) methods	19	70%
Wind Atlas Analysis and Application Program (WAsP) - Version 10 or earlier	15	56%
Wind Atlas Analysis and Application Program (WAsP) - Version 11	4	15%
Dynamical Downscaling, including Numerical Weather Prediction, WRF, MM5, others	13	48%
Computational Fluid Dynamics (CFD)	12	44%
Hybrid methods combining two or more techniques	13	48%
Other	3	11%
Number of methods used		
1	3	11%
2-4	17	63%
5 or more	7	26%

Note: Percentages in this table are out of 27 respondents who answered these questions.

Subsequent questions were intended to shed light on why respondents would choose one method over another. One set of questions asked respondents to rate, on a scale of one to five, the importance of several factors in shaping decisions about which method(s) or technique(s) to use for a particular

[1] At the suggestion of one of the experts who pretested our survey, we separated WaSP 10 or earlier from WaSP 11. According to this expert, Version 11 introduced computational fluid dynamics (CFD), whereas earlier versions used less sophisticated methods.

assessment. Table 7 summarizes the "importance score" for the six factors that were listed in the survey. This is the average rating for each factor on the five point scale, where one is "Not at all important" and five is "Very important." Table 7 also shows the percentage of respondents who rated each factor as "Important" or "Very important." Results indicate that the factors that are most highly rated are data availability and requirements, and site characteristics. All of the other factors are also rated fairly highly overall (i.e., more than half of respondents said each of these factors is "important" or "very important"). However, the factor that received the lowest ranking is the end user's familiarity or experience with the method(s) used to conduct the assessment.

Table 7: Importance of factors in decision about which method(s) or technique(s) to use for a wind resource assessment

Factor	Importance score	% rating factor as "important" or "very important"
Data availability and requirements	4.69	88%
Site characteristics (e.g., complexity of terrain)	4.48	92%
Results of validation or intercomparison studies showing accuracy of method compared to others	4.29	76%
Computational requirements of method (e.g., computing time, need for supercomputer)	3.70	56%
Own familiarity/ past experience with method	3.80	68%
Familiarity/ past experience with method among end users (e.g., clients)	3.40	52%

Note: Percentages in this table are out of 25 respondents who answered this question.

We also asked respondents an open-ended question about whether there are any other factors that influence their choice of wind resource assessment methods. The text responses given by the 5 respondents who answered this question are presented in Table 8.

Table 8: Text responses to the question: "Are there any other factors that play an important role in your choice of wind resource assessment methods?

Previous investment in software by my company means I will be highly likely to use them in the future.
Labor cost to produce, reliability/defensibility of methods, and familiarity with certain tools (i.e. accuracy of any given tool or method is highly dependent upon the expertise of the user)
The single most important factor is whether or not it can it be used as a basis for project finance.
The primary factor is reducing uncertainty in the assessment, so choosing data, methodologies, and models that offer the most accurate predictions.
Duration of data availability, averaging period of data.
Performance and ease of use.

These survey results corroborated information we had gathered in interviews with WRA experts vis-à-vis the importance of site characteristics in influencing what method(s) would be used to conduct a particular assessment. To shed more light on this topic, the survey presented respondents with two different scenarios in which a developer is looking at building a 100 MW wind farm. The scenarios described the location and the data available for each proposed site, and then asked the respondent to indicate which method(s) they would use to produce a WRA for that site. These scenarios are summarized in Table 9, and a comparison of responses under the two scenarios is presented in Figure 2. Scenario A describes a site with simple terrain, relatively abundant on-site data, and multiple nearby reference stations. Scenario B is a site with complex terrain, less on-site data, and a single reference station. Looking at Figure 1, the main difference in methods between Scenario A and Scenario B is a slight shift away from statistical methods, MCP, and WAsP, and a fairly large increase in the use of dynamical downscaling, CFD, and hybrid methods for the more complex site.

Table 9: Comparison of two hypothetical WRA production scenarios presented to respondents

	Scenario A	Scenario B
Location	Kansas	Colorado
Terrain	Simple	Complex
Number of tall (60 m) met towers on site	2	1
Length of on-site data record	3 years	1 year
Number of reference stations within 80 miles of site with hourly data for past 10 years	3	1

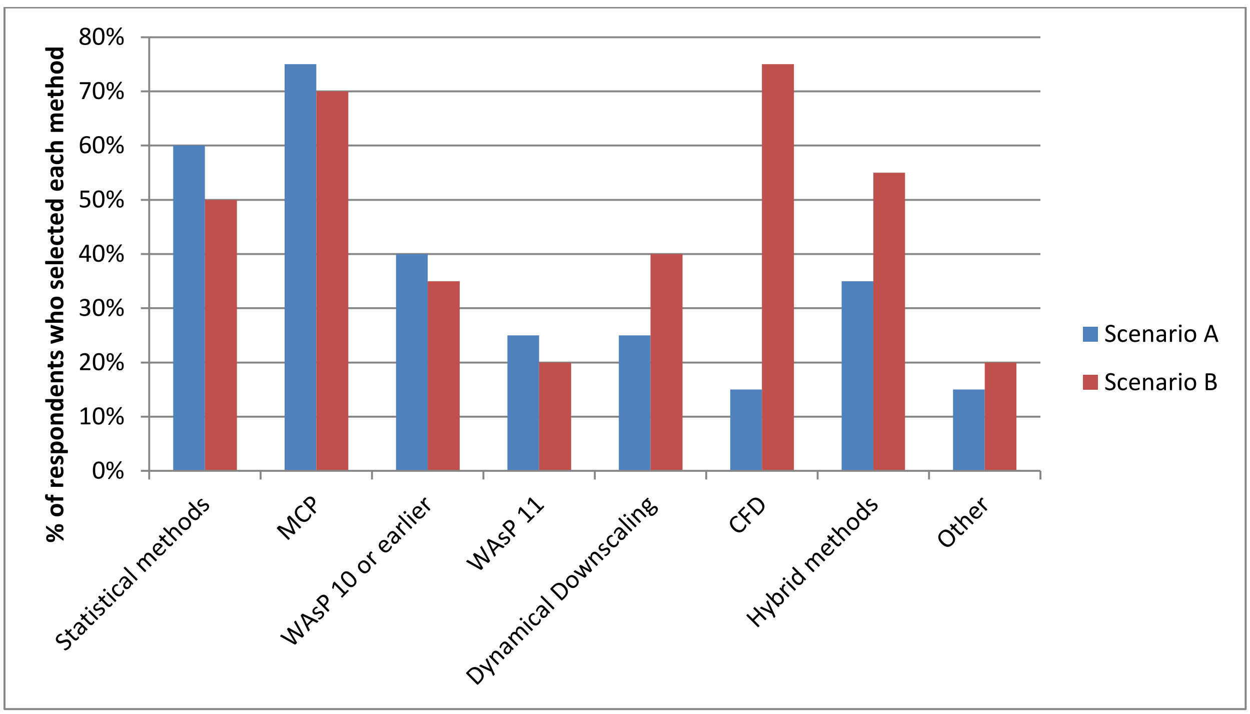


Figure 2: Comparison of methods respondents said they would use to conduct a WRA for Scenarios A and B (described in Table 9)

Data sources, including MERRA

We also asked respondents about the data sources they used in the wind resource assessments they had conducted. For each data source that the respondent used, we asked whether the respondent's organization produces or collects those data itself, whether these data are provided by another source (such as a client), or whether the data come from both internal and external sources. These results are tallied in Table 10. Results indicate that WRA producers use data from a variety of sources. The one data source that is used by all producers is on-site met tower measurements. Most respondents (81%) also use long-term reference station data, while use of wind resource maps, remote sensing data, and climate reanalysis dataset is slightly lower at about 60% for each of these sources. We can also examine the total number of sources each respondent indicated that s/he uses: results show that only one respondent said s/he relies on a single source (on-site measurements), while 23 of the 26 WRA producers use three or more data sources.

The origins of these data sources also vary. The source that is most often produced internally is remote sensing data, while respondents said they rely on external sources most often for long-term climate reanalysis datasets. Wind resource maps, on-site measurements, and long-term reference station measurements tend to come from a combination of internal and external sources.

Table 10: Data sources used by wind resource assessment producers and the origins of these data

Data Source	# (%) of respondents using source	# (%) of users who get data from:		
		own organization (internal)	other source (external)	internal and external sources
Wind resource maps	16 (59%)	2 (13%)	7 (44%)	7 (44%)
On-site measurements from meteorological towers	27 (100%)	11 (41%)	5 (19%)	11 (41%)
Remote sensing data (e.g., lidar, sodar)	15 (58%)	9 (60%)	1 (7%)	5 (33%)
Long-term meteorological data from weather stations near the site	22 (81%)	2 (10%)	8 (38%)	11 (52%)
Long-term climate reanalysis datasets	15 (56%)	2 (13%)	8 (53%)	5 (33%)

Note: In the first column, percentages are out of 27 respondents who answered this question. In subsequent columns, the number in the first column is the denominator.

Given the focus of our study, we were particularly interested in respondents' use of long-term climate reanalysis datasets in general, and the NASA MERRA dataset specifically. The preceding results indicate that just under 60% of the WRA producers in our sample have used any long-term reanalysis dataset in the past. Subsequent questions specifically addressed use of MERRA. Respondents were presented with the following background information:

> NASA's "Modern Era Retrospective Analysis for Research and Applications," also known as NASA MERRA, is one of the global atmospheric reanalysis products that is publically available. Other examples of atmospheric reanalyses include the NCEP-NCAR Reanalysis, and the ERA-Interim Reanalysis.

The survey then asked whether the respondent had ever used the NASA MERRA dataset. Ten of the 27 WRA producers responded affirmatively, while the remaining 17 respondents said they had not used

MERRA or were not sure. Follow-up questions were then directed at both users and non-users of the NASA MERRA dataset (see Table 11).

Table 11: Use of the NASA MERRA climate reanalysis dataset by WRA producers

	Frequency	%
Ever used MERRA (N=26):		
Yes	10	37%
No	12	44%
Don't know/not sure	5	19%
For producers than have used MERRA (N=10):		
Benefits of using MERRA		
Publicly available	10	100%
Spatial resolution	6	60%
High correlation with site data	6	60%
Ease of access and use	6	60%
Temporal resolution	5	50%
Reliability of updates to data	4	40%
Vertical resolution	3	30%
Available file formats	3	30%
How does MERRA compare to other reanalysis datasets?		
Less useful than other datasets	0	0%
Depending on site, MERRA is sometimes better and sometimes worse	6	60%
More useful than other datasets	2	20%
Don't know/not sure	2	20%
For producers that have not used MERRA (N=12):		
Reason for not using MERRA		
Never heard of it	6	50%
Use methods that don't require reanalysis data	4	33%
Heard of it but lack experience using it	3	25%
Unsure of the quality of MERRA relative to alternatives	2	17%
Use other reanalysis datasets that are better than MERRA	0	0%
What would make you more likely to use MERRA in the future?		
Making MERRA available in ASCII format at user-specified sites	4	33%
Faster access and download of data files	2	17%
Reports on data quality	1	8%

For the 10 respondents that said they had used MERRA in the past, we first asked for an estimate of the number of assessments they had produced over the past year that had used the MERRA dataset. Responses range from one to 60, with a mean of 12.7 and a median of 7.5. In total, these ten respondents have collectively produced 127 WRAs using the NASA MERRA dataset over the past year. Since we also asked producers about the *total* number of assessments they had conducted over the past year, we can estimate the fraction of these assessments that each respondent produced using MERRA. As a percentage of the total number of assessments they conducted in the past year, assessments using MERRA comprise between 4% and 100% of respondents' WRAs, with a mean of 51% and a median of 47%. Thus, on average, the respondents who said they use the MERRA dataset tend to rely on this data source about half of the time.

We then asked the MERRA user group to indicate what they see as the main benefits of using this reanalysis dataset. Responses are tallied in Table 11. All 10 MERRA users indicate that being publicly available is one of MERRA's benefits. Sixty percent of respondents also selected the dataset's spatial resolution, high correlation with site data, and ease of access and use. We also asked respondents how MERRA compares with other reanalysis datasets. None of the 10 MERRA users said that MERRA is less useful than other reanalysis datasets for conducting wind resource assessments. The majority of respondents indicated that MERRA's usefulness varies across sites, with the dataset sometimes outperforming and sometimes underperforming alternative data sources.

We also asked these respondents to describe any problems or issues they have had using MERRA. Two respondents mentioned poor correlations to site data in some cases (for example, in mountain passes). One respondent is concerned about "shifted seasonal trends" in the dataset, while another said that the "update (via WindPRO) can lag up to 2 months behind current data," and another respondent said the dataset is "a bit coarse." Finally, one respondent said that the surface temperature data is "highly suspect."

For the 12 WRA producers that have *not* used NASA MERRA previously, we asked why they have not used this dataset. Six respondents indicated that they had not heard of MERRA, while another four said they rely on methods that do not use reanalysis datasets. Three respondents said they have heard of MERRA but lack experience using it, and two respondents said they are unsure of MERRA's quality relative to alternative reanalysis datasets. None of these producers claimed to use a reanalysis dataset that they thought outperformed MERRA. Finally, we asked these respondents what could be done to make it more likely that they would use MERRA in the future. Four respondents indicated that they would like to see MERRA data made available in ASCII format at user-specified sites, while an additional two respondents requested faster access and download of data files. One respondent wrote in a response saying that s/he would like to see reports on MERRA's data quality.

Costs

A final category of questions we posed to wind resource assessment producers involved the costs of producing and providing these assessments and the factors that influence those costs. Unfortunately, the sample of individuals who provided answers to these cost-related questions was relatively small. Only 12 of our respondents indicated that their organization sells wind resource assessments to other users, and one of these respondents was not personally involved in producing wind resource assessments. Of the 11 remaining respondents who could provide information on costs from the perspective of producers who sell WRAs, only 7 provided data on a subsequent survey question that asked about factors influencing the cost of an assessment that would be sold to a client. For each factor, respondents rated the effect on costs using a five point scale, where 1 = "Greatly decreases cost" and 5 = "Greatly increases cost." Thus, average scores above 3 indicate an overall opinion that that factor would increase the cost of the assessment, while a score below 3 would indicate that the factor would decrease the assessment's cost.

Scores for six factors included in the survey are summarized in Table 12, along with a tally of the number of respondents who said each factor would decrease costs, have no effect, or increase costs. The factor that received the highest score is a client's requirement that the WRA be completed in a very short time frame. All but one respondent indicated that this would *greatly* increase the assessment's cost. Complex terrain was also judged to increase cost by all respondents. High computational requirements and lack of comparable reference stations were each judged to increase costs by all but one respondent. Respondents are split between thinking that use of reanalysis data would have no effect on costs or increase costs. Regarding a large quantity of on-site data, two respondents thought this would decrease costs while three thought this factor would increase costs and one said it would have no effect.

Table 12: Factors influencing the cost of a wind resource assessment sold to a client

Factor	Cost effect score	# of respondents who said factor would… Decrease cost	Have no effect	Increase cost
The client needs the assessment to be completed within two weeks	4.85	0	0	7
The site has complex terrain	4.14	0	0	7
The assessment has high computational requirements	4.00	0	1	6
There are very few comparable reference stations in close proximity to the site	3.85	0	1	6
The assessment uses reanalysis data	3.42	0	4	3
The site has a large amount of high-quality on-site met tower measurements	3.29	2	1	3

Finally, we asked respondents that produced WRA for sale to provide a range of costs that their organization charges for a single site assessment. As above, the number of responses to this question is small: only five respondents provided a cost range. In addition, in the hypothetical WRA production scenarios summarized in Table 9 above, we asked respondents who sold WRAs to estimate how much their organization would charge for these hypothetical assessments. The same five respondents provided information in response to these questions. This set of cost estimates is presented in Table 13.

Overall, the cost of actual assessments varies greatly: between $0 and $400,000. The hypothetical scenarios provide more of an "apples to apples" comparison since respondents are starting with the same initial descriptions in making their cost estimates. Still, we see that cost estimates do vary quite a bit: for Scenario A, the range is from $7,500 to $30,000, while for Scenario B estimates range from $9,000 to $35,000. Four of the five respondents indicated that the assessment for Scenario B would be more costly than for Scenario A.

Table 13: WRA cost estimates given by producers who sell assessments

Respondent	Costs of Single-Site WRAs Sold by Organization in Past Year		Estimated Costs of Hypothetical Assessments (see Table 7)		
	Minimum	Maximum	Scenario A	Scenario B	B minus A
1	$5,000	$30,000	$15,000	$18,000	$3,000
2	$0	$100,000	$30,000	$35,000	$5,000
3	$15,000	$70,000	$30,000	$25,000	-$5,000
4	$3,000	$15,000	$7,500	$9,000	$1,500
5	$10,000	$400,000	$8,000	$15,000	$7,000
Average	$6,600	$123,000	$18,100	$20,400	$2,300

Use of Wind Resource Assessments

Our survey sample includes 37 individuals who either currently used WRA as part of their job or had done so in the past. As with the producers, it is useful to examine how this user group is distributed across different types of organizations. Table 14 shows that the largest group of users in our sample comes from wind energy development companies, and that ALL of the survey respondents in this organizational category said that they use wind resource assessments. (Note that all but one of these respondents also produced WRAs.) Energy utilities and consulting firms are also well represented in this sample, with other users coming from a wide variety of different sectors.

Table 14: Organization type for users of wind resource assessments

Variable	Number of respondents	% of user sample by organization category	% of respondents in category who use assessments
Organization Type			
Energy utility	9	24%	60%
Wind energy development company	11	30%	100%
Consulting firm	5	14%	63%
Research organization	4	11%	57%
Manufacturing company	2	5%	40%
Non-profit	2	5%	100%
Software company	1	3%	50%
Government	2	5%	100%
Technical due diligence firm	0	0%	0%
Other/multiple/did not provide	1	3%	33%

Follow-up questions that our survey directed to this group of users included perceptions about factors that influence the quality of a wind resource assessment, as well as questions about the use of “third party” wind resource assessments (i.e., assessments obtained from other organizations).

Perceived Quality of Wind Resource Assessments

We were interested in learning about WRA users' perceptions of some of the methods and approaches that are used to produce these assessments. In particular, we wanted to know whether users thought that various WRA approaches would lead to higher or lower quality assessments. For a set of four WRA approaches, we asked the respondent to rate whether using this approach would DECREASE or INCREASE the quality of that assessment in their opinion. The approaches we examined were use of the NASA MERRA dataset in producing the assessment, use of the WAsP software program, use of a method that had produced more accurate results than alternative methods in a recent (hypothetical) intercomparison study conducted by the European Wind Energy Association (EWEA), and use of computational fluid dynamics (CFD) in producing the assessment. Figure 3 shows four pie charts corresponding to each of these four factors. Each chart displays the proportion of the WRA users who judged each factor to: 1) decrease the quality of the assessment; 2) have no effect on the quality of the assessment; 3) increase the quality of the assessment; or 4) have an unknown impact on assessment quality (respondent did not know).

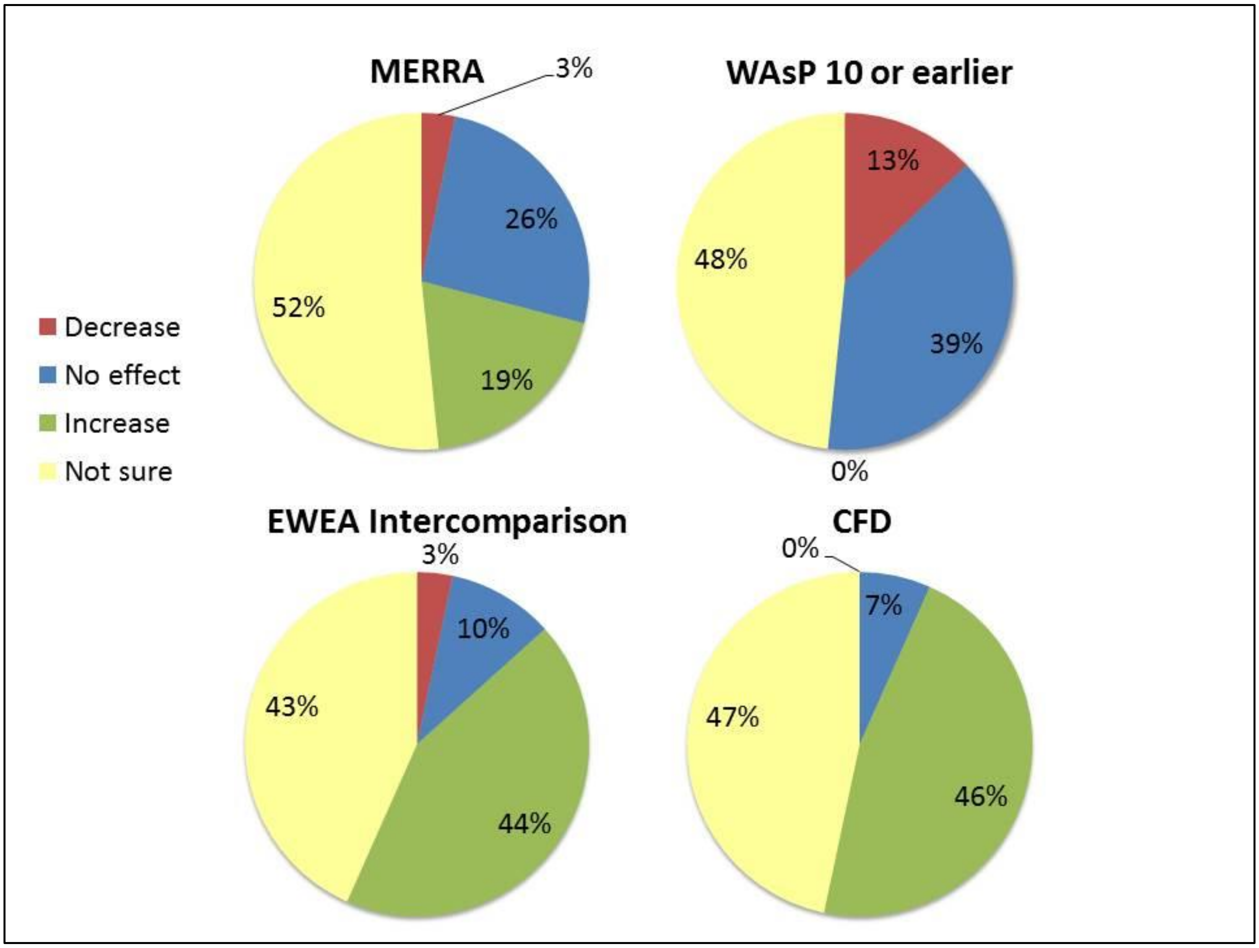


Figure 3: Wind resource assessment users' perceptions of how different characteristics affect the quality of an assessment

One clear finding from these data is that close to half of the WRA users said they do not know what effect each factor would have on the quality of a wind resource assessment. This may indicate that these users are not familiar with each of these specific characteristics of a wind resource assessment. Among respondents who did express an opinion on the quality impact of each of these factors, the factor that was judged to *increase* quality the most was use of computational fluid dynamics (CFD). Being told that the method used to produce the assessment had performed well in an EWEA intercomparison study also had a positive impact on perceived quality. Looking specifically at MERRA, a very small proportion (3%) saw use of MERRA as *decreasing* the quality of a WRA, while about a quarter of respondents said this would not affect perceived quality and nearly 20% of users said MERRA would increase the quality of a wind resource assessment. Overall, it appears that most of the WRA users that took this survey were not familiar enough with MERRA to have an opinion about its impact on WRA quality. This may be due to the fact that MERRA is a relatively new dataset; it has been operational since 2008.

Respondents were also asked the open-ended question: “Can you tell me what features of practices most strongly influence your opinion about the quality of a wind resource assessment?” Twenty four respondents provided text responses to this question. These responses were analyzed for common themes and are summarized in Table 15. The two themes that were mentioned most frequently involved steps taken to verify the accuracy of an assessment through comparisons with actual wind or production data, and comments related to the quality and/or quantity of the on-site measurements used as inputs into the WRA. There were also several comments related to the modeling methods used and the appropriateness of these methods given the site characteristics and/or data inputs. Four responses mentioned that it is important to know who is conducting the assessment, particularly with respect to their expertise and past record of results. The quality of the long-term record was also mentioned four times, and an additional three respondents emphasized the importance of a strong correlation between on-site measurements and the long-term reference data. Three respondents mentioned “consistency” of results, while two respondents said that reporting uncertainty and/or error in the model estimates is essential. One respondent said that the transparency of the methods used to conduct the assessment is important. Finally, one respondent objected to the survey question on the grounds that we did not provide a baseline against which “quality” should be judged.

Table 15: Factors affecting WRA users perceptions of WRA quality

Quality Factor	# Mentioning Factor	% Mentioning Factor	Examples of Text Responses Mentioning Factor
Accuracy / Validation with actual site data or production	7	29%	*I feel comfortable with the quality when operational data verifies the assessment on several look-back analyses we've done.*
Quality / quantity of on-site measurements	7	29%	*The inclusion of more observed data gives me much more confidence as well as the length of record of that data.*
Quality / appropriateness of methods used in modeling	5	21%	*Local site within the limits of retained modeling approach (ex. complex terrain vs. linear perturbation models... ? CFD ?)*
Experience / expertise of actors conducting assessment	4	17%	*Experience and knowing the limitations of tools is far more important than any given cookie cutter method. Could use the best method in the world and still screw it up.*
Quality of long-term record / weather input	4	17%	*The weather input - this should be conducted by using ensemble forecasting instead of single deterministic input, often not even at the place where a wind farm is being built.*
Correlation of observations with long-term record	3	13%	*Comparison to reference data (wind rose, correlation)*
Consistency	3	13%	*Multiple methods, similar results.* *Consistency.*
Reporting uncertainty / error	2	8%	*the results, and the transparency of the methods used*
Transparency of methods	1	4%	*reporting uncertainty and error in the analysis is crucial*
Survey question is flawed	1	4%	*This is a flawed question since you don't specify the base method against which I'm supposed to judge an increase or decrease in quality.*

Note: Percentages in this table are out of 24 respondents who answered this question.

Use of Third Party Assessments

We asked users of wind resource assessments whether those assessments were produced “in-house” or by a third party. For those who use third party assessments, we asked whether those assessments are purchased. Results are presented in Table 16. Of the 32 WRA users who responded to these questions, less than 10% use only “in-house” assessments. A little more than half of the user sample (17 individuals) said that their organization had purchased at least one assessment from a third party in the past year. When we look only at the wind energy development company respondents, we see a much higher use of third party assessments: only one respondent said that all of the assessments s/he had used in the past year were produced in-house, while the remaining nine developer respondents said they used a combination of in-house and third party assessments, and all of these respondents said they had purchased assessments in the past year.

Table 16: Use of third party assessments

	All users		Developers only	
	#	%	#	%
Source of Assessments				
In-house only	3	9%	1	10%
Third party only	12	38%	0	0%
Some in-house and some third party	16	50%	9	90%
Don’t know/ not sure	1	3%	0	0%
If third party assessments were used, did organization purchase any assessments in the past year?				
Yes	17	61%	9	100%
No	10	36%	0	0%
Don’t know/Not sure	1	4%	0	0%

Note: For “Source of Assessments,” the “all users” percentages are out of the 32 respondents who answered this question, while the “developers only” percentages are out of 10 respondents. For purchase of assessments, percentages are out of the number of respondents who said third party assessments had been used: 28 for “all users” and 9 for “developers only.”

For respondents who had used WRAs produced by a third party, we asked about the importance of different factors in the choice of which third party organization to use to conduct a particular assessment. Table 17 provides an “importance score” for five factors, where this score could range from 1 (not at all important) to 5 (very important). We also show the percentage of respondents who rated each factor as “important” or “very important,” and for each of these metrics we break out the “developers only” sample in comparison to the sample of all users. The most highly ranked factor is the ability of the consultant to provide a “bankable” assessment. (We understand this to mean that the report will be trusted enough by financial institutions that they will use it to make their financing decisions. However, the term was not defined in the survey so respondents may have had different ideas about what “bankability” means.) All of the developer respondents rated this “very important.” Accuracy of previous assessments also rates very highly, as does the reputation of the consultant. The specific methods used by the consultant are rated as somewhat less important, as is the cost of the assessment.

Table 17: Importance of factors in decision about which third party organization to use to conduct a wind resource assessment

Factor	Importance score		% rating factor as "important" or "very important"	
	All users	Developers only	All users	Developers only
Ability of the consultant to provide "bankable" assessments	4.43	5.00	83%	100%
Accuracy of past assessments conducted by the consultant	4.41	4.25	87%	100%
Reputation of the consultant	4.39	4.63	91%	100%
Methods or techniques the consultant uses to conduct resource assessments	4.09	4.00	74%	63%
Cost of the assessment	3.30	3.00	48%	38%

Note: Percentages in the "whole sample" column are out of 23 respondents who answered this question. Percentages in the "developers only" column are out of 8.

Finally, we asked respondents whose organizations purchase assessments to provide a range of costs that their organization has paid for a single site assessment. Minimum costs ranged from $2,000 to $27,000 (mean=$12,111), while the maximum costs ranged from $10,000 to $100,000 (mean= $48,889).

Overprediction in Wind Resource Assessments: Causes, Consequences, and Solutions

Following the survey sections targeted separately to producers and users of wind resource assessment, three additional sections asked *all* respondents about 1) the problem of *overprediction* in wind resource assessments, 2) opinions on communication and quantification of *uncertainty* in these assessments, and 3) overall priorities for improving information available to assist wind energy development decisions.

Our questions about overprediction were prefaced by the following background information:

> Overprediction has been a problem with wind resource assessments in the past. By "overprediction," we mean that actual wind energy production has been lower than what was predicted by wind resource assessments that were conducted pre-construction.

Respondents were then asked, "In your judgment, what factors are most responsible for overprediction in wind resource assessments?" In total, 42 respondents provided text responses to this question. We analyzed these text responses for common themes (and subthemes) and tallied the number of times each theme was mentioned in respondents' comments. (Each comment could and often did mention multiple themes). Table 18 provides the resulting summary of these responses.

Table 18: Causes of overprediction in wind resource assessments

Causes of Overprediction	#	%	Sample responses mentioning cause
Modeling issues	**29**	**69%**	
Wind flow modeling issues	15	36%	*Poor flow modeling coupled with not enough masts.*
Wake	8	19%	*Wake-effect modeling*
Shear	6	14%	*Improper estimation of wind shear; or not having actual localized wind shear data*
Stability	4	10%	*Ignoring stability effects*
Climate/ interannual variability	4	10%	*Interannual variability*
Turbulence	3	7%	*Poor terrain/surface layer turbulence modeling in the codes that are used*
Terrain	2	5%	*Mountain terrain (difficult to assess resource across the peaks/valleys)*
Loss factors	10	24%	*Poor understanding of downside risks. All the risks are downside. Icing never increases production. Blade soiling never increases product, etc.*
Assessment method issues	9	21%	
Long-term correction methods	3	7%	*Quality of long term climate correction of short term observations (correlation, stability of reference, mathematical approach)*
Distributional assumptions	2	5%	*The whole concept of Guassian probability distribution and climatological reference sites is fundamentally flawed*
Uncertainty	2	5%	*Loss and uncertainty assumptions not founded in empirical data*
Climate change	1	2%	*Climatic changes over time*
Other	6	14%	*Modeling techniques that rely more on engineering practices than an understanding of weather or climate.*
Data Issues	**18**	**43%**	
On-site data issues	13	31%	
Insufficient data	5	12%	*Relying on sparse measurements*
Instrumentation	4	10%	*The primary reason has been overspeeding of mechanical anemometers, leading to overestimates in the average wind speed.*
Placement of met masts	2	5%	*Masts being placed on the windiest areas of a site.*
Long-term reference data issues	3	7%	
Not representative	1	2%	*Lack of representativeness of the climate reference*
Resolution	1	2%	*Resolution of the assessment work (wind farm level, or region level; 70-meter height or 100-meter height, etc.)*
Performance issues	**10**	**24%**	
Turbine power curve issues	5	12%	*We also need a better understanding of the under-performance of wind turbines against their warrantied power curves and under different atmospheric conditions.*
Curtailment / outages / availability	3	7%	*Operational curtailment* *Unforeseen turbine outages and downtime (ex. Siemens blade issues this year)*
Transmission constraints	1	2%	*Transmission constraints*
Incentives	**7**	**17%**	
Developers' incentives	3	7%	*Incentives of developers to put forward most optimistic view of project viability.*
Consultants' incentives	2	5%	*There is usually a financial incentive for an "independent" assessment to overpredict the wind resource.*
Not specified	2	5%	*Need for optimism in generating value*
Overprediction not a problem	**2**	**5%**	*In fact, the site I dealt with had the opposite problem.*

Note: The # column tallies the total number of text responses that mentioned each cause. Percentages are out of 42 total responses that were provided for this question.

Perhaps not surprisingly given our sample's area of expertise, many of the causes mentioned by respondents focus on modeling issues of various kinds. These include a variety of issues with wind flow modeling, from wake effect modeling to turbulence and terrain considerations. Several respondents mentioned problems with assumed "loss factors" that are used to translate gross energy production to net energy production estimates. Other methodological issues related to the wind resource assessment include problems with the long-term correction method, distributional assumptions, and the handling of uncertainty. A second broad category of problems identified by respondents relates to the data used to produce wind energy assessments. Respondents are particularly concerned with on-site data, mentioning that there is often not enough of these data and that problems with instrumentation and the placement of met masts can create problems with data quality. A smaller number of respondents mentioned problems with long-term reference data.

About a quarter of the responses mentioned issues related to the operational performance of wind farms – particularly the performance of turbines relative to their advertised power curves, as well as curtailment and outage problems and transmission constraints. An additional category of problems identified by respondents involves the incentives that different actors have to overestimate production. In particular, some respondents noted that both developers and consultants may have an incentive to present high energy production estimates. Finally, two respondents argued that overprediction has not been a big problem in their experience.

Respondents were then asked an open-ended question about the *consequences* of overpredicting the wind resource for a particular site. Thirty nine respondents provided text responses to this question. Once again, the responses were analyzed for common themes, which were categorized and tallied. In Table 19, we present a summary of these themes according to the *timing* in which the consequences are experienced. That is, we grouped respondents' consequences into effects that occur in the pre-construction and operational phases of wind farm development, as well as in the longer term. For many of these consequences, we categorize further by specifying *whom* the consequences affect. We also provide a tally of whether the impacts mentioned by respondents are positive or negative (or neutral / variable), and note a few suggestions respondents provided about possible solutions or ways to mitigate the consequences of overprediction.

In terms of the phases in which consequences are experienced, most of the responses focus on the operational period. In particular, many respondents mentioned financial impacts for the owners / operators of wind farms arising from lower production: reduced return on investment, revenue, and profits. Other financial impacts include possible penalties for underperformance specified in power purchase agreements. A handful of responses discussed impacts in the pre-construction period, while several discussed longer term impacts including effects on credibility / reputation for both individual developers or consultants and the industry as a whole.

The vast majority of responses (34/39) mentioned negative consequences of overprediction. However, a few noted possible neutral or even positive effects. For example, in the pre-construction phase, a few respondents argued that for developers who subsequently sell the project to another owner / operator, there are relatively few consequences for overpredicting the wind resource. Another respondent said that one "silver lining" of overprediction is that operators can get better at minimizing downtime during operational winds.

Table 19: Consequences of overprediction in wind resource assessments

Consequences of Overprediction	#	%
Pre-construction	**5**	**13%**
Developer has few consequences / can sell project for higher price / has perverse incentives	3	8%
Wrong models lead to wrong choice about whether or not to build project	1	3%
Wrong / compromised turbine selection	1	3%
During operations	**20**	**51%**
Financial impacts for owners / investors	16	41%
Lower return on investment / revenue / profits	10	26%
Hard to meet financial targets	4	10%
Mismatch between price of power and actual cost of producing energy	2	5%
Penalties (for PPA underperformance; for energy imbalance)	2	5%
Longer debt service period	1	3%
Have to pay back tax credit	1	3%
Operational impacts for owners / operators	6	15%
Energy / power production doesn't meet targets	4	10%
Operating on incorrect model	1	3%
Turbines unavailable	1	3%
Get better at minimizing downtime	1	3%
Longer term	**11**	**28%**
Credibility/ reputation issues	5	13%
For consultants / other setting expectations	4	10%
For the industry as a whole	2	5%
Impacts on power purchasers	4	10%
Supply uncertainty / mismatch with need	2	5%
Increased energy costs	1	3%
Shortfall in portfolio standards	1	3%
Hard for developers / investors to finance next project due to low cash flow	2	5%
Impacts on policy	1	3%
Fewer state and federal incentives for wind development	1	3%
Solutions / ways to mitigate consequences	**3**	**8%**
Structure of PPA (multiyear catch-up or "take or pay")	2	5%
Make financial models more conservative / focus on uncertainty (e.g., using p90 production)	2	5%
Overall		
Negative impacts	34	87%
Positive impacts	1	3%
Neutral / it depends	5	13%

Note: The # column tallies the total number of text responses that mentioned each cause. Percentages are out of 39 total responses that were provided for this question.

We asked respondents how concerned they currently are about overprediction in wind resource assessments. Forty six respondents answered this question. Response frequencies are presented in Figure 4. About 30% of the sample is "not at all" or "slightly concerned," while 46% are "very" or "most" concerned about this problem.

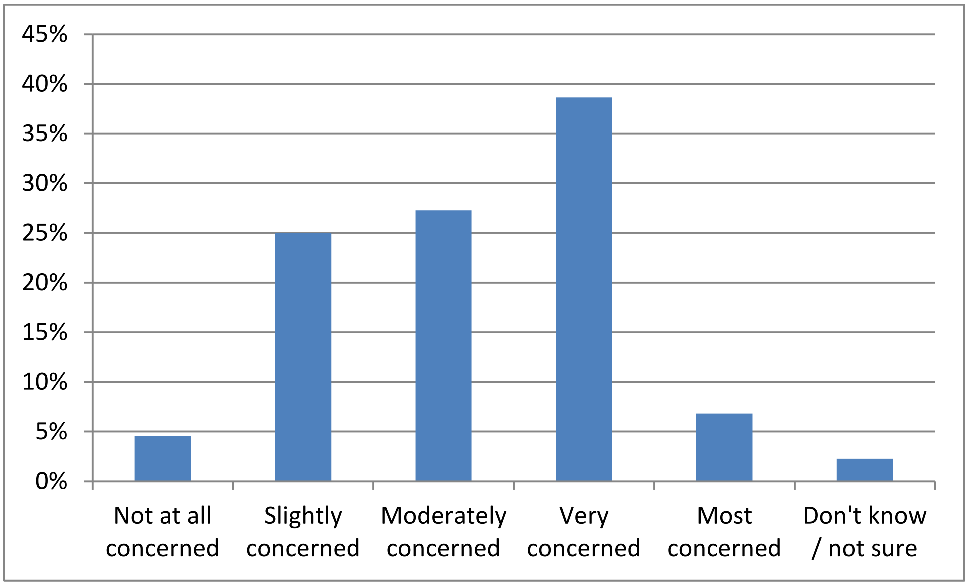


Figure 4: Respondents' level of concern about overprediction in wind resource assessments
Note: Percentages are out of 46 responses.

Next, we discussed possible responses or solutions to the overprediction problem. We were particularly interested in the practice of "haircutting" wind resource estimates. In other discussions and interviews, we had learned about this practice of making adjustments to model output out of a concern about overprediction. We wanted to know how prevalent this practice is among our sample respondents and what these respondents' opinions are regarding this practice. As background, the survey displayed the following text:

> Some organizations use a "haircutting" process to adjust the results of wind resource assessments or wind energy estimates. By "haircutting," we mean reducing the wind energy estimate by some amount to avoid overestimating the wind resource for a particular project.

We then asked respondents whether or not their organization applied "haircuts" to wind energy estimates. Of the 46 respondents who answered this question, only four (8.7%) said that their organization uses "haircuts" in the WRA process. In contrast, a subsequent question asked respondents how widespread they thought the practice of "haircutting" is across the wind industry. Responses range from 20 to 100%, with a mean of 64% and a median of 70%. In other words, while few respondents claim to use haircuts themselves, most respondents think the practice is fairly common among other industry members. (This may be the case if, for example, haircutting is most prevalent in the financing stages of wind farm development; very few of our respondents are involved in this phase.)

The survey then displayed the following text:

> Across the industry as a whole, the extent of overprediction appears to be decreasing. According to one study, the industry-wide shortfall (i.e., the difference between predicted and actual wind energy production) was about 9% between 2001 and 2009, but this shortfall decreased to 3% between 2010 and 2012.

We asked respondents to provide their opinion about how big of a role three factors have played in reducing overprediction in wind resource estimates: the use of haircutting, improvements in wind resource assessment methods, and improvements in data used to inform wind resource estimates. Improvements in wind resource assessment methods were judged by this group to have played the largest role in reducing overprediction, followed by data improvements. Survey respondents seem to think that use of haircutting has played a relatively small role.

Table 20: Importance of factors in reducing overprediction in wind resource estimates

Factor	Number of responses	Importance score	% rating factor as having "major" or "most important" role
Improvements in wind resource assessment methods	38	3.97	76%
Improvements in data used to inform wind resource estimates	41	3.68	59%
Use of haircutting to reduce wind resource assessments	27	2.96	26%

Note: In total, 46 respondents answered each these questions. Number of responses indicates the number of respondents who answered the question and did not select "don't know/not sure."

The survey also asked an open-ended question about any other factors that may have reduced overprediction. Eighteen respondents answered this question. Several responses mention operational experience and data improvements, including remote sensing data. Other responses include "adjustments in loss estimates," "use of uncertainty estimates," "learning from past mistakes," and "fear of the banker!". Finally, we provided a text box for respondents to enter any additional comments about the practice of haircutting. Ten respondents wrote in comments. Three samples are provided below:

> "Don't use haircutting, use uncertainty analysis instead."

> "The larger resource assessment firms have spent the last several years 'calibrating' their losses based on lessons learned. I think this is the reason we've seen overprediction go down and in fact they may be too conservative at this point."

> "NCAR and NREL should put effort into educating the resource assessment industry and O&M industry on climatic impacts and methods that should be used and also banks and other financiers to be more aware of what is a reliable assessment and what is not."

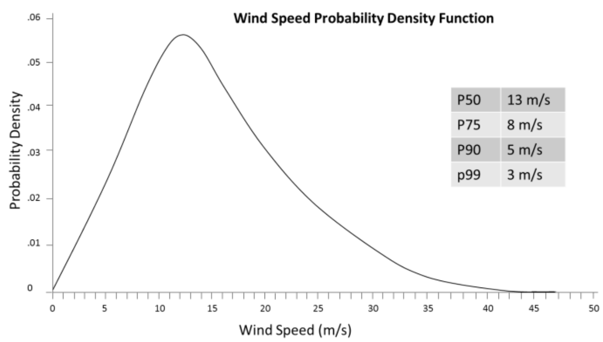
UNCERTAINTY IN THE ESTIMATED WIND RESOURCE

There are several sources of **UNCERTAINTY** in wind resource assessments. By uncertainty, we mean that we can never be sure ahead of time what the exact wind energy production will be at a given site. A variety of factors influence how sure or confident we are in our wind resource estimates. Some of these sources of uncertainty are related to the modeling of the wind resource, while others are related to other factors (e.g., power curves, wake losses, curtailment, etc.).

Looking specifically at the wind resource, **certain methods are able to QUANTIFY the uncertainty in wind parameters such as wind speed**, providing a range or confidence interval around these parameters. In addition to providing the "average" or "best guess" of the wind speed distribution, these new methods would also tell you how confident you should be that the "best guesses" are close to the exact value.

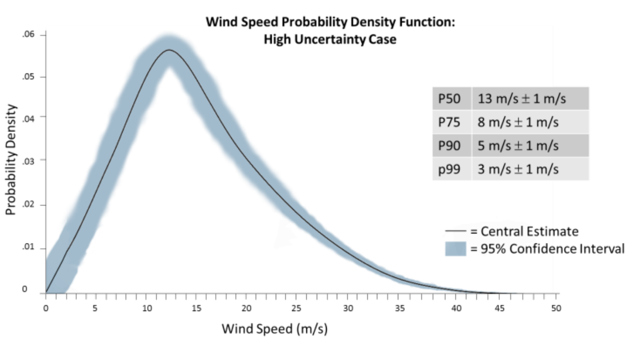
INFORMATION AVAILABLE FROM CURRENT METHODS

This is an example of the kind of information about wind speed that is provided by many conventional wind resource assessments. This figure shows an estimated wind speed distribution for a particular site over one year. The table provides point estimates for key parameters in that distribution: the p50, p75, p90, and p99 wind speeds (i.e., winds should be at least this strong for 50%/75%/90%/99% of the year, respectively).



METHODS THAT QUANTIFY UNCERTAINTY

Alternatively, some methods are able to provide confidence intervals along with those central estimates. This uncertainty could be depicted as error bars reflecting the wind speed distribution and its key parameters. The figures below illustrate a HIGH UNCERTAINTY case and a LOW UNCERTAINTY case.



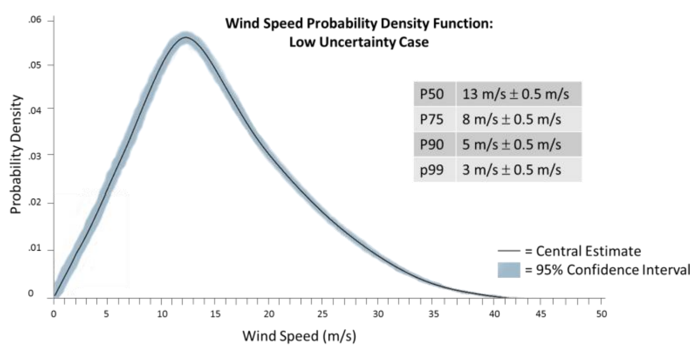


Figure 5: Background Information Displayed in Survey for Uncertainty Questions

Opinions about Uncertainty Communication and Quantification

One potential benefit of the new MERRA-based WRA methods developed at NCAR is their ability to systematically quantify and communicate the uncertainty associated with a given wind resource estimate. We were interested in respondents' opinions about whether the kind of uncertainty estimates these methods could produce would be valued by WRA producers and users, as well as any barriers to the use of this information within the wind industry. Figure 5 shows background information that was presented in the survey as a precursor to the uncertainty questions.

After reading this information, the respondent was asked whether they thought this kind of uncertainty would be valuable and why (or why not). Responses are summarized in Table 21. Of the 35 respondents who answered this question, 30 indicated that they think this information could be useful in the wind energy development process. Several respondents mentioned that this information could help to understand or reduce the investment risk associated with a wind energy project. Other respondents said that similar methods are already being used in some cases. Some respondents also emphasized the connection between uncertainty information and project financing decisions, while others suggested that this kind of information could be helpful in showing clients the value of gathering high quality data.

Four respondents said that uncertainty *might be* useful under the right circumstances, with examples of these responses given in the table. Only one respondent indicated that the information would *not* be useful – this respondent argued that this type of uncertainty information would add more confusion to project financing and potentially increase financing costs.

Finally, the survey asked respondents, "What, if any, barriers to you think might prevent this kind of information from being used more widely within the wind industry?" Thirty two respondents offered opinions in response to this question. Four primary themes emerged from these responses (Table 22). First, many respondents noted a *lack of understanding* of uncertainty information among potential users. In particular, several comments emphasized the difficulty of communicating complex, technical uncertainty estimates. Two respondents suggested that providing users with decision support tools or other training (webinars, courses) could help to overcome this barrier. Second, respondents cited "vested interests," competing incentives, and a reluctance among various players to change their existing practices. For example, one respondent said that making uncertainty information widely available might make it more difficult for developers to sell their projects. Third, some respondents thought this information might be more expensive to generate relative to existing methods. Finally, a few respondents said it could be difficult for WRA producers to learn new methods and to ensure that these methods were consistent and validated against real data.

Table 21: Opinions on whether or not uncertainty information would be useful

Response	#	%	Examples
Yes	**31**	**89%**	
Would help to understand or reduce investment risk	10	29%	*Uncertainty should be considered in investment decisions. Two projects with equal P50, but different uncertainties should not be evaluated equally.*
Would inform project financing	7	20%	*It's fundamental to educate developers and financing parties as to the difference between low and high uncertainty sites. The uncertainty should be a fundamental metric that is included in every pro forma evaluation of a project.*
Already being done	5	14%	*Wind forecasts are moving away from deterministic to probabilistic forecasts. There will probably be a similar trend in wind resource assessment.*
Would demonstrate value of good data	4	11%	*It would cause a desire to collect data for longer period of time and need to validate the data somehow.*
If methods are properly validated	2	6%	*To the extent they are statistically validated*
If presented clearly	1	3%	*If presented in a useable format for owner/operators.*
Maybe	**4**	**11%**	
If uncertainty not uniform	1	3%	*Only if uncertainty were not uniform across the wind speed spectrum*
If users understood	1	3%	*If people understood or paid attention. [Our organization] has been using confidence intervals on mean wind speed since 2008 and what we found was generally the spread was ignored and people focused solely on the "one number".*
Could inform insurance design	1	3%	*The possible scenario would be to quantify year-to-year differences in annual output. This translates to year-to-year differences in revenue. Insurance products could then be procured to mitigate against a low revenue year. Though, to get this type of insurance, you would have to be pretty sure about the year-to-year variability in energy production - I think it's a long shot...*
No	**1**	**3%**	*I think they would confuse the project financing industry even further. Additional uncertainty would increase financing costs, leading to difficult times for developers.*

Note: Percentages are out of 35 respondents who answered this question.

Table 22: Barriers to use of uncertainty information from wind resource assessments

Barrier	#	%
Lack of understanding among users	**20**	**63%**
Readiness to use probabilistic inputs. We live in a probabilistic reality, but tend to fit everything into a confortable deterministic world. Few people really understand what a stochastic approach is, and is not. Few managers and deciders (even scientists!) are really ready to say, and defend a standpoint such as: "on average, over the long term, we will be optimal, but on any given circumstance we will usually be off a little and sometimes by much. Live with that!"		
People don't know how to use uncertainties. I think it would be important to teach them how through online webinars, courses, etc.		
Vested interests / incentives	**7**	**22%**
It would make it more difficult for developers to sell a project.		
Conservatism and reluctance to change practices has prevented much development and kept the word at "WASP" level far too long. Thinking of that this was invented in the early 1990'ies and already then was criticized by meteorologists, it is almost unbelievable that it still exists. There is need to bring people away from believing in it only because it has been used for so long. This is reliance on wrong type of experience!		
most developers are set on their ways (for good or bad) and are not likely to change.		
Costs of producing uncertainty information	**6**	**19%**
more expensive, more complex requiring more knowledgeable industry.		
A little more expensive and time consuming.		
Producers' lack of expertise in new methods	**5**	**16%**
lack of methods and expertise of wind resource assessment providers		
Comparing actual vs. forecast could take a long time unless there is backcasting at existing windfarms to check the accuracy of the methodology.		
non standardized calculation methods		

Priorities for Improvement

Referring back to Figure 1, it is clear that there are multiple wind-related information inputs into the wind energy development process. Improving any of these inputs could potentially help to facilitate better decision making at multiple stages in the process. In light of this reality, we were interested in understanding how respondents would prioritize different efforts to improve WRA information. The last section of the survey thus asked the respondent to imagine that he or she had been made the “wind information tzar” and had been given a large budget to spend on research and development on ways to improve the quality of wind-related information that is available to inform project development. The

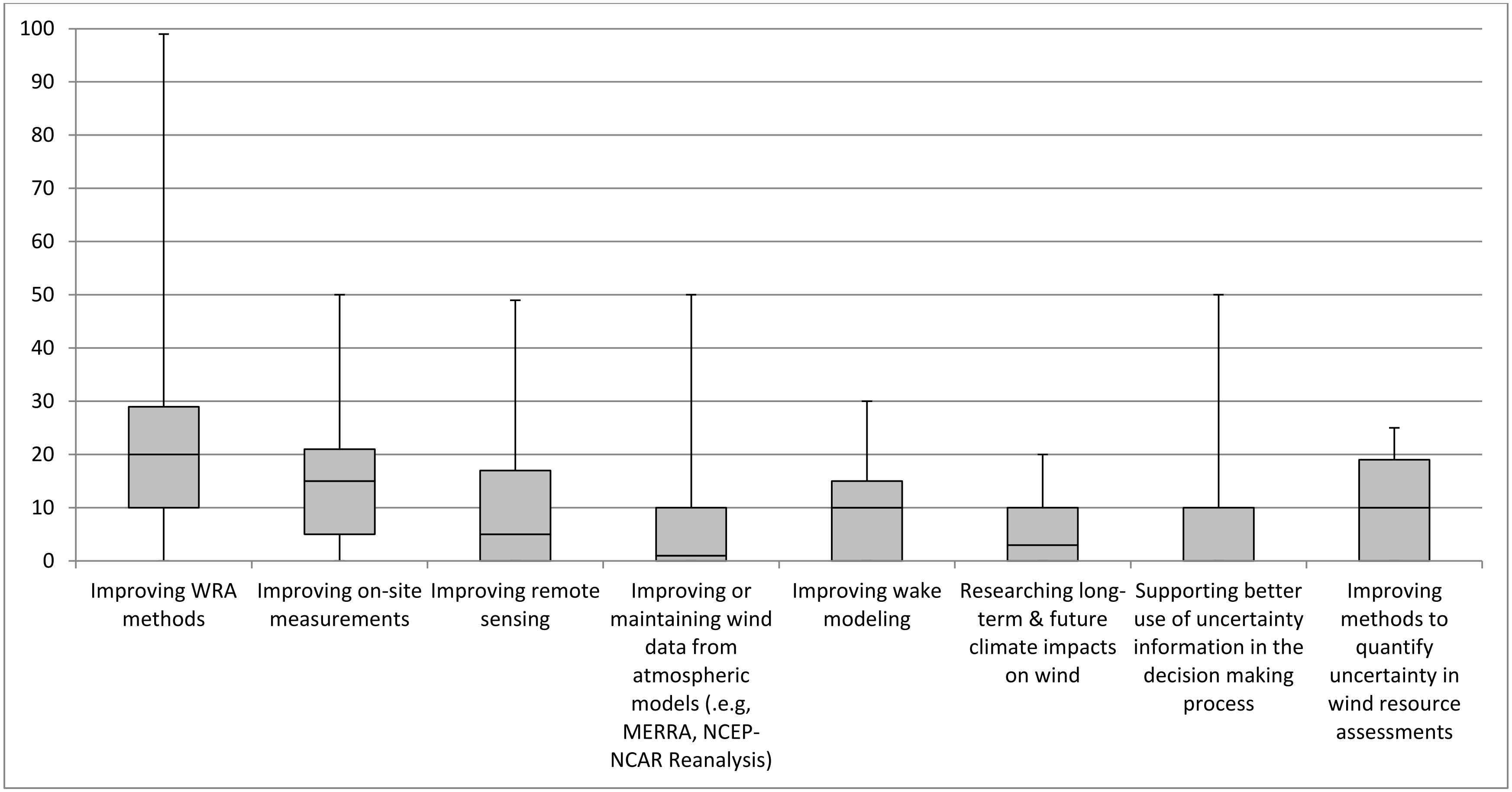


Figure 6: Box plots showing distribution of responses for budget allocation to different research areas in "Wind Information Tzar" exercise

survey then listed several areas of research and asked the respondent to use a “slider” between 0 and 100 to show what percent of the budget s/he would choose to allocate to each area. The online survey software automatically randomized the order of the research area items across respondents, and imposed the constraint that the total allocation across all items had to add up to 100. (In addition to the research areas we provided, there were three “other” categories that the respondent could use to write in their own research areas.)

Results for the eight research areas we presented are show in Figure 6. For each item, the box plots show the median (center line), interquartile range (outer box), and minimum and maximum responses (tails) for the allocations respondents provided for each item. Of the options we provided, the item that received the highest median allocation is improving wind resource assessment methods (20% of budget), followed by improving on-site measurements (15%). Improving wake modeling, supporting better use of uncertainty in decisionmaking, and improving methods to quantify uncertainty each have median allocations of 10% of the budget. The range of responses for many areas is also quite broad, and the distributions for most items are heavily weighted toward zero. It seems that there is some disagreement within our sample as to what the main research priorities should be; however, perhaps not surprisingly given that our sample consists of wind resource assessment experts, there does seem to be some agreement that improvements in modeling is a worthwhile and needed investment.

Other research areas that were written in by respondents include: improving understanding of turbine performance; producing power curve standards; improving physics in the models with use of real time data; improving shear methodologies; carrying out ensemble predictions for sites; quantifying uncertainty of base weather forecasts used in operational forecasting; climate fields improvement for forecasting; and centralizing the wind industry.

V. Conclusions

The group of respondents who participated in our online survey is a diverse set of individuals working across multiple sectors in the wind industry, from wind energy developers to members of utilities and consulting firms, to people involved in research and wind farm manufacturing and operations. While this group of respondents is not statistically representative of the industry (or WRA-experts) as a whole, there are nonetheless several key insights and conclusions that can be drawn from the feedback this group provided.

One conclusion is that the diversity and complexity of WRA production and use may pose some challenges in both identifying priorities for information improvements and, to an even greater extent, quantifying the value of such improvements. Prior to conducting the survey, we might have expected to find a clear division of labor in which one group (e.g., consultants) produced wind resource assessments and handed these off to clients who then put the results to use in wind energy development decisions. With a more uniform group of producers and users, and a clearer division of labor between these groups, we might expect more consensus as to how wind resource information could be improved. As it stands, our results indicate that this process is far from linear: many individuals in our sample both produce and use wind resource assessments, and many users indicated that they use WRAs that are produced “in-house” as well as ones that are obtained from third parties. Given this complexity, it is not surprising that respondents have a variety of perspectives on everything from the methods and data sources that are used in producing a WRA to the factors that affect WRA quality and the factors responsible for historical overprediction in wind resource estimates.

However, this diversity of respondents, most of whom had direct experience either producing or using wind resource assessments, also presents some opportunities. It is clear that WRA plays a role in multiple stages and facets of the wind energy development process. The potential value in improving this information is thus large and far-reaching. Survey results also reveal some areas of general agreement among users, including the need for high-quality on-site measurements as an input into any WRA, a fairly high overall priority for continued improvement of WRA methods, and, specifically, the potential utility of better quantification and communication of uncertainty in wind resource estimates. To the extent that the development of WRA methods can continue to engage groups similar to the survey sample in the process of identifying current challenges and priorities for improvement, there is much potential for expanding the capacity of this diverse group to generate value for the wind industry and for society more broadly.

In light of our initial motivation for conducting this survey, it is also interesting to draw conclusions that specifically address the NASA MERRA dataset and NCAR’s new WRA methods that harness the power of this dataset. Our survey sample includes several respondents who have already been using the NASA MERRA dataset to produce wind resource assessment, and these individuals cite several important benefits of this dataset. We also found that more WRA producers had an interest in using MERRA – additional information and training on how to use this dataset could expand the user base. Among individuals who use wind resource assessments, MERRA’s name recognition seems fairly low. There may be opportunities to increase users’ awareness of how this dataset has or could contribute to higher quality WRA information. In particular, our findings related to communication of uncertainty point to some key ways in which NASA MERRA-based techniques, such as those that have been developed at NCAR, could add value to this industry. While respondents noted several challenges to using uncertainty information, they were also in agreement that overcoming these barriers was a worthy endeavor that would have major benefits. One of these benefits cited by a few respondents involved showing WRA users the value of better data inputs (like MERRA) that could help to reduce the uncertainty in wind resource estimates. Thus, the combination of this NASA dataset and the NCAR WRA techniques has the potential to help deliver higher quality information to inform wind energy development.

APPENDIX A: ONLINE SURVEY TOOL

Wind Energy Resource Assessment: Information Production, Uses, and Value

A. INFORMED CONSENT

The purpose of this survey is to gain a better understanding of information uses and the value of improving wind resource assessments for the wind industry. The survey is being administered by Dr. Katie Dickinson (303.497.2758, katied@ucar.edu) from the National Center for Atmospheric Research in Boulder, CO, with funding from a National Aeronautics and Space Administration (NASA) Research Opportunities in Space and Environmental Sciences Grant (NASA Grant No. NNX10AB30G).

As part of this project, we are surveying stakeholders and experts with different connections to this industry to assess how information is used and what kinds of improvements in information might be more or less valuable. We estimate that this survey will take 10-20 minutes of your time. **We are interested in getting the perspective of a wide range of individuals with different areas of expertise, so even if you are not an expert in wind resource assessment methods, your input will still be quite valuable.** You are free to contact the investigator at the above address and phone number to discuss the survey.

Risks to participants are considered minimal. There will be no costs for participating, nor will you benefit from participating. We will NOT ask you to reveal any proprietary information about your organization. All of your responses will be anonymous and only aggregate results will be reported. Participation is voluntary and you are free to withdraw from the survey at any time, or refuse to answer any question. If you feel you have inadvertently revealed proprietary information, please contact us and we will delete that information from our records.

If you have any questions or would like us to email another person for your organization or update your email address, please call or email Dr. Dickinson.

This study has been reviewed by the National Center for Atmospheric Research (NCAR). If you have questions about your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact the NCAR External Relations Director Peter Backlund by phone at (303) 497-1111 or email at backlund@ucar.edu .

By clicking “yes” below, you give your consent to participate in this project.

Do you agree to participate in this interview?
___ Yes
___ No [End survey]

B. BACKGROUND AND EXPERIENCE

1. What organization do you work for?
   ____

2. Is your organization…
   a. A wind energy development company?
   b. A manufacturing company?
   c. A consulting firm that provides wind resource assessments or wind forecasts to wind developers?
   d. A company that finances wind energy projects?
   e. A company that conducts technical due diligence for wind energy financing (“IE reports”)?
   f. A public sector research organization?
   g. How
   h. Other ____________________________

3. How long have you worked for this organization?
   a. Less than one year
   b. 1-5 years
   c. 6-10 years
   d. More than 10 years

4. How long have you worked in a wind-related field?
    a. Less than one year
    b. 1-5 years
    c. 6-10 years
    d. More than 10 years

5. Select the regions in which your organization conducts work related to wind energy development:
    a. US
    b. North America
    c. Central America
    d. South America
    e. Europe
    f. Africa
    g. Middle East
    h. South Asia
    i. East Asia
    j. Southeast Asia
    k. Australia/South Pacific
    l. Other:

6. What phases of the wind energy development process is **your organization** involved in? [Check all that apply]
    a. Site selection/prospecting
    b. Wind resource assessment
    c. Environmental impact assessments (including wildlife studies)
    d. Community outreach & engagement
    e. Financing
    f. Technical due diligence
    g. Power purchase agreements
    h. Transmission/interconnection agreements
    i. Manufacturing
    j. Construction
    k. Operations & maintenance
    l. Other ____________________________

7. What phases of the wind development process are **you** most familiar with? [Check all that apply]
    a. Site selection/prospecting
    b. Wind resource assessment
    c. Environmental impact assessments (including wildlife studies)
    d. Community outreach & engagement
    e. Financing
    f. Technical due diligence
    g. Power purchase agreements
    h. Transmission/interconnection agreements
    i. Manufacturing
    j. Construction
    k. Operations & maintenance
    l. Other __________________________

C. PRODUCTION FILTERING BLOCK

This survey is focused on WIND RESOURCE ASSESSMENTS and how they are produced and used within the wind industry. By "wind resource assessment," we mean a quantitative estimate of the likely wind characteristics (such as speed, direction, and variability) and energy production at a proposed wind farm site over the farm's lifetime. These assessments are typically conducted after a candidate site has been chosen and on-site measurements have been collected for at least one year.

For the purposes of this survey, we are interested in both:

- the PRODUCTION of wind resource assessments (for example, for in-house development decisions or for sale to clients);

and

- the USE of these assessments (for example, for informing project development, for determining project financing, or for conducting technical due diligence).

The following questions ask about the production and use of wind resource assessments in YOUR ORGANIZATION, as well as your own personal experience with these assessments.

1. Does anyone within your organization conduct wind resource assessments?
    a. No [Skip to **end of block**]
    b. Yes
    c. Don't know/not sure [Skip to **end of block**]

2. Are the wind resource assessments your organization conducts… [Check all that apply]
    a. Used "in-house" to inform project development?
    b. Produced for research purposes?
    c. Provided to other users (e.g., developers) for free?
    d. Provided to other users (e.g., developers) for a fee?
    e. Other: ______________________________

3. Do you personally conduct wind resource assessments?
    a. No, I have never conducted wind resource assessments
    b. No, I do not currently conduct wind resource assessment but I have in the past
    c. Yes, I currently conduct wind resource assessments

4. [Display if Answer to Q3 is a]
   Are there other individuals in your organization who conduct wind resource assessments? If so, please enter their name and email address below, OR send their contact information to Katie Dickinson (katied@ucar.edu), OR forward them a link to this survey. [Text box]

D. WIND RESOURCE ASSESSMENTS: USE FILTERING BLOCK

1. Does anyone within your organization use the results or output from wind resource assessments?
    a. No [Skip to end of block]
    b. Yes
    c. Don't know/not sure [Skip to end of block]

2. How are wind resource assessments used within your organization? [Check all that apply]
    a. Research purposes (e.g., investigating or improving wind resource assessment methodologies)
    b. Informing site selection
    c. Informing turbine layout
    d. Securing power purchase agreements for a project
    e. Conducting technical due diligence
    f. Informing project financing
    g. Supporting operations and maintenance
    h. Other: ______________________________

3. Do you personally use or review wind resource assessments?
    a. No, I have never used wind resource assessments
    b. No, I primarily conduct wind resource assessments that others use rather than using them myself
    c. No, I do not currently use wind resource assessment but I have in the past
    d. Yes, I currently use wind resource assessments

4. [Display if Answer to Q3 is a or b] Are there other individuals in your organization who use or review wind resource assessments? If so, please enter their name and email address below, OR send their contact information to Katie Dickinson (katied@ucar.edu), OR forward them a link to this survey. [Text box]

E. PRODUCING WIND RESOURCE ASSESSMENTS

Since you indicated that you are involved in PRODUCING wind resource assessments, we will now ask some follow up questions about your experience with these assessments and the methods you use.

1. Approximately how many wind resource assessments have you personally been involved in conducting over the past year? [Text box]
2. In the wind resource assessments you have conducted, what methods or techniques have you used? (Check all that apply)
    a. Statistical methods
    b. Measure-correlate-predict (MCP) methods
    c. Wind Atlas Analysis and Application Program (WAsP) - Version 10 or earlier
    d. Wind Atlas Analysis and Application Program (WAsP) - Version 11
    e. Dynamical downscaling, including Numerical Weather Predictions, WRF, MM5, others
    f. Computational Fluid Dynamics (CFD)
    g. Hybrid methods combining two or more techniques
    h. Other: ____________________
3. In the wind resource assessments you have conducted, what data sources have you used?
    a. Wind resource maps published by private- or public-sector organizations (e.g., NREL or AWS Truepower maps)
    b. On-site measurements from meteorological towers
    c. Long-term meteorological data from weather stations near the site
    d. Remote sensing data (e.g., lidar, sodar)
    e. Long-term climate reanalysis datasets (e.g., MERRA, NCDC, …)
    f. Other: ____________________________

4. For each of the following data sources, please indicate whether your organization provides or collects the data, whether the data is provided to you by another source, or whether you do not use this data. [Options listed will be those selected in question 3 above]

Data source	**We provide or collect these data**	**We get these data from another source (e.g, client provides data)**	**We use both internally provided data as well as data from other sources**
Wind resource maps			
On-site met tower data			
Reference station data			
Remote sensing data			
Long-term climate reanalysis data			

F. MERRA BLOCK

NASA's "Modern Era Retrospective Analysis for Research and Applications," also known as NASA MERRA, is one of the global atmospheric reanalysis products that is publically available. Other examples of atmospheric reanalyses include the NCEP-NCAR Reanalysis, and the ERA-Interim Reanalysis.

1. Have you ever used the NASA MERRA reanalysis dataset?
    a. No [Filter to Q2 & 3 below]
    b. Yes [Filter to Q4-7 below]
    c. Don't know/not sure

2. Why haven't you used MERRA?
    a. I've never heard of MERRA
    b. I've heard of MERRA, but am not sure how to use it
    c. The methods I use don't require reanalysis data
    d. I use other reanalysis datasets that I think are better than MERRA (Which ones? _______)
    e. Other: _____________________

3. What, if anything, would make you more likely to use MERRA in the future?
    a. Making MERRA time series data available in ASCII format at user-specified sites
    b. Faster access and download of data files
    c. Other: ____

4. Over the past year, how many of the assessments you've conducted have used MERRA? [Text box]

5. What do you see as the main benefits of using MERRA? [Check all that apply]
    a. Publicly available
    b. Spatial resolution
    c. Temporal resolution (i.e., hourly wind data)
    d. Vertical resolution (i.e., 50 m)
    e. Reliability of updates to data (i.e., data consistently updated within 30 days of real time)
    f. High correlation with site data
    g. Other: _________________________

6. What, if any, problems or issues have you had using MERRA? ____________________________
7. In your experience, how does MERRA compare with other reanalysis datasets?
    a. MERRA is less useful than other reanalysis datasets for resource assessments
    b. Depending on the site, MERRA is sometimes better and sometimes worse than other datasets
    c. MERRA is more useful than other reanalysis datasets for resource assessments
    d. Other: __________________________

5. When you are deciding which method(s) or technique(s) to use for a particular wind resource assessment, how important are each of the following factors?

	1 Not at all important	2 Slightly important	3 Moderately important	4 Important	5 Very important	Don't know/not sure
My own familiarity/past experience with method						
Familiarity/past experience with methods among end users (e.g., clients)						
Data availability & requirements						
Computational requirements of method (e.g., computing time, need for supercomputer)						
Results of validation or intercomparison studies showing accuracy of method compared to others						
Site characteristics (e.g., complexity of terrain)						

6. Are there any other factors that play an important role in your choice of wind resource assessment methods?
____

G. <u>SELLERS BLOCK – Display if option d is selected for Block A, Question 2</u>

1. Can you provide a range of costs that your organization charges for a SINGLE SITE wind resource assessment that is sold to developers or other organizations (e.g., lenders)?
   Minimum ($): _________
   Maximum ($): _________

2. Please indicate whether each of the following characteristics of a wind resource assessment would DECREASE or INCREASE the cost of the assessment for the client.

	1 Greatly decreases cost	2 Slightly increases cost	3 No effect on cost	4 Slightly increases cost	5 Greatly increases cost	6 Don't know/not sure
The site has complex terrain						
The site has a large amount of high-quality on-site met tower measurements						
There are very few comparable reference stations in close proximity to the site						
The assessment uses reanalysis data (e.g., MERRA, NCEP)						
The assessment has high computational requirements						
The client needs the assessment to be completed within two weeks						

3. Are there any other factors that play a big role in determining the cost of a wind resource assessment?
   [Text box]

H. WIND RESOURCE ASSESSMENT PRODUCTION SCENARIOS

Suppose a developer is looking at building a 100 MW wind farm in simple terrain in Kansas. The developer has on-site data from 2 tall (60 m) meteorological towers that have been collecting wind speed and direction at sub-hourly intervals for the past 3 years. Additionally, within 80 miles of the site there are three reference weather stations maintained by the National Weather Service or other government-sponsored entities that both have hourly wind data for at least the past 10 years, with measurements taken 3 m above the surface.

1. What methods would you use?
    a. Statistical methods
    b. Measure-correlate-predict (MCP) methods
    c. Wind Atlas Analysis and Application Program (WAsP) - Version 10 or earlier
    d. Wind Atlas Analysis and Application Program (WAsP) - Version 11
    e. Dynamical downscaling, including Numerical Weather Predictions, WRF, MM5, others
    f. Computational Fluid Dynamics (CFD)
    g. Hybrid methods combining two or more techniques
    h. Other: ____________________

2. [For SELLERS] Approximately how much would you charge to conduct this wind resource assessment?

Now suppose that a developer is looking at building a 100 MW wind farm in complex terrain in Colorado. The site has 1 met tower with 1 year of data, and there is only one reference station within 80 miles of the site.

3. What methods would you use?
    a. Statistical methods
    b. Measure-correlate-predict (MCP) methods
    c. Wind Atlas Analysis and Application Program (WAsP)
    d. Dynamical downscaling, including Numerical Weather Predictions, WRF, MM5, others
    e. Computational Fluid Dynamics (CFD)
    f. Hybrid methods combining two or more techniques
    g. Other: ____________________

4. [For SELLERS] Approximately how much would you charge to conduct this wind resource assessment?

I. ASSESSMENT USE BLOCK

Since you indicated that you are involved in USING or REVIEWING information from wind resource assessments, we will now ask some follow up questions about your experience with using these assessments and your information needs.

1. Approximately how many wind resource assessments were you involved in using or reviewing over the past year?

2. In your opinion, would each of following characteristics DECREASE or INCREASE the quality of a wind resource assessment? [Randomize order of statements]

	1 Greatly decreases quality	2 Slightly decreases quality	3 No effect on quality	4 Slightly increases quality	5 Greatly increases quality	6 Don't know/not sure
The assessment was produced using NASA's MERRA reanalysis dataset						
The assessment was produced using the Wind Atlas Analysis and Application Program (WAsP)						
The assessment used a new method that produced more accurate results in a recent intercomparison study conducted by the European Wind Energy Association (EWEA)						
The assessment was produced using computational fluid dynamics (CFD)						

3. Can you tell me what features or practices most strongly influence your opinion about the quality of a wind resource assessment? [comments box]

4. Were any of the wind resource assessments you used over the past year conducted by a third party (e.g., a consulting firm)?
   a. No, all the assessments I used were produced within my organization ("in-house")
   b. Yes, all of the assessments I used were produced by a third party
   c. I used some in-house assessments and some third party assessments
   d. Don't know/not sure

J. USE AND SELECTION OF CONSULTANTS

1. Did your company purchase any wind resource assessments from third parties (e.g., consulting firms) in the past year?
    a. No [skip to Q4]
    b. Yes
    c. Don't know not sure [skip to Q4]

2. Can you provide a range of costs that your organization has paid for the assessments that are purchased from third parties? if possible, provide costs for a SINGLE SITE assessment.
   Minimum ($): ___________
   Maximum ($): ___________

3. When your organization is choosing a third party consultant to conduct a wind resource assessment for your company, how important are each of the following factors?

	1 Not at all important	2 Slightly important	3 Moderately important	4 Important	5 Very important	Don't know/not sure
Cost of the assessment						
Reputation of the consultant						
Methods or techniques the consultant uses to conduct resource assessments (e.g., WASP, numerical weather prediction)						
Accuracy of past assessments conducted by the consultant						
Ability of the consultant to provide "bankable" assessments						

4. Are there any other factors that influence your choice about which consultant to use for wind resource assessments? [Comments box]

K. HAIRCUTTING BLOCK

Overprediction has been a problem with wind resource assessments in the past. By "overprediction," we mean that actual wind energy production has been lower than what was predicted by wind resource assessments that were conducted pre-construction.

1. In your judgment, what factors are most responsible for overprediction in wind resource assessments?
2. What are the consequences of overpredicting the wind resource for a particular project?
3. Currently, how concerned are you about overprediction in wind resource assessments?
    a. Not at all concerned
    b. Slightly concerned
    c. Moderately concerned
    d. Very concerned
    e. Most concerned
    f. Don't know/not sure

Some organizations use a "haircutting" process to adjust the results of wind resource assessments or wind energy estimates. By "haircutting," we mean reducing the wind energy estimate by some amount to avoid overestimating the wind resource for a particular project.

1. Does your organization apply "haircuts" to wind energy estimates?
    a. No [Display Q5 below]
    b. Yes [Display Q2-4 below]
    c. Not sure

2. Which of the following estimates typically receive "haircuts"?
    a. Wind speed parameters (e.g., p50 wind speeds)
    b. Power production parameters (e.g., p50 GW)
    c. Wind energy production parameters (e.g., p50 GWH)
    d. Net Capacity Factor (NCF)
    e. Other: ______________________
    f. Don't know/not sure

3. How is the size of a haircut for a specific wind energy estimate determined? [Text box]

4. How widespread do you think the practice of "haircutting" is currently across the wind industry? [Slider from 0 (Very Uncommon) to 100 (Very Common)]

Across the industry as a whole, the extent of overprediction appears to be decreasing. According to one study, the industry-wide shortfall (i.e., the difference between predicted and actual wind energy production) was about 9% between 2001 and 2009, but this shortfall decreased to 3% between 2010 and 2012.

5. In your opinion, how big of a role have each of the following played in reducing wind energy overprediction across the industry? (Scale: no role to largest role)

	1 No role	2 Minor role	3 Moderate role	4 Major role	5 Most important role	6 Don't know/not sure
Use of haircutting to reduce wind energy estimates						
Improvements in wind resource assessment methods						
Improvements in data used to inform wind resource estimates						

6. What, if any, other factors have helped to reduce overprediction?

7. Is there anything else you'd like to share about your experience with or opinions about "haircutting?" [Text box]

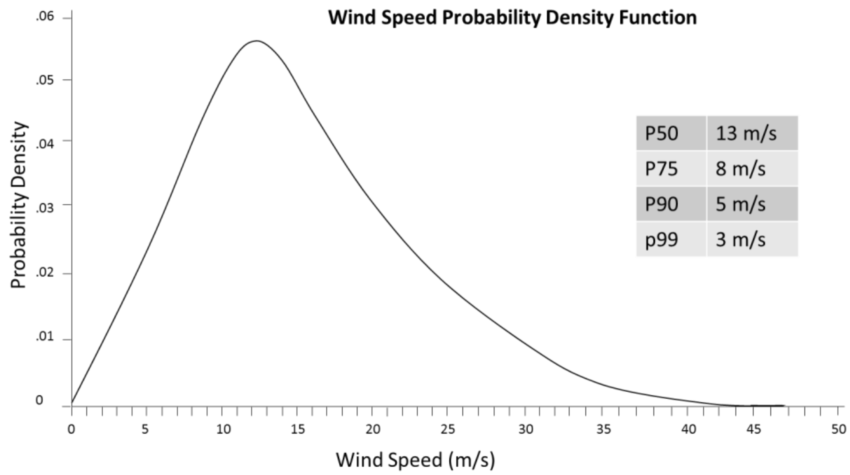
L. UNCERTAINTY BLOCK

There are several sources of UNCERTAINTY in wind resource assessments. By uncertainty, we mean that we can never be sure ahead of time what the exact wind energy production will be at a given site. A variety of factors influence how sure or confident we are in our wind resource estimates. Some of these sources of uncertainty are related to the modeling of the wind resource, while others are related to other factors (e.g., power curves, wake losses, curtailment, etc.).

Looking specifically at the wind resource, certain methods are able to QUANTIFY the uncertainty in wind parameters such as wind speed, providing a range or confidence interval around these parameters. In addition to providing the "average" or "best guess" of the wind speed distribution, these new methods would also tell you how confident you should be that the "best guesses" are close to the exact value.

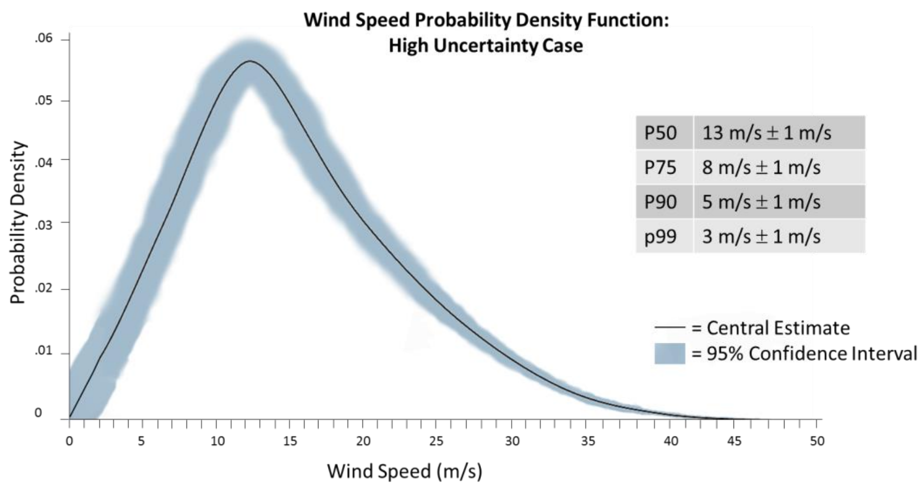
INFORMATION AVAILABLE FROM CURRENT METHODS

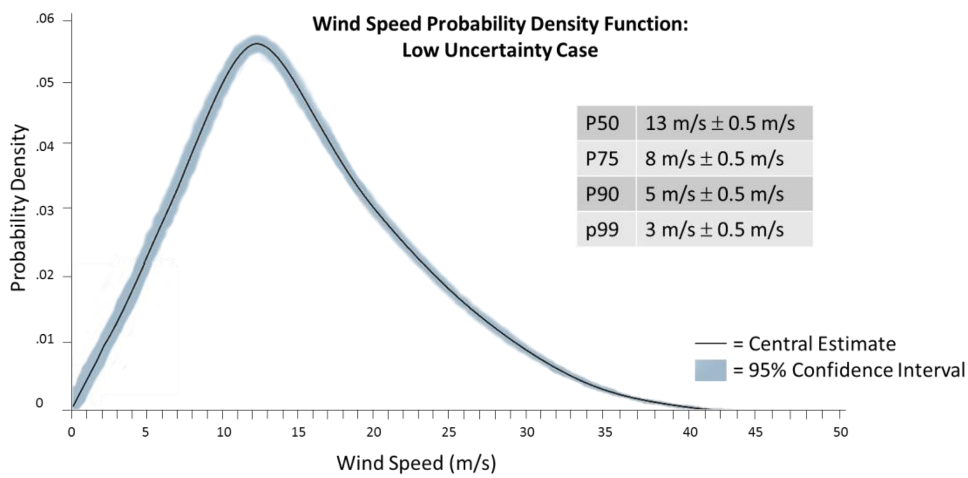
This is an example of the kind of information about wind speed that is provided by many conventional wind resource assessments. This figure shows an estimated wind speed distribution for a particular site over one year. The table provides point estimates for key parameters in that distribution: the p50, p75, p90, and p99 wind speeds (i.e., winds should be at least this strong for 50%/75%/90%/99% of the year, respectively).



METHODS THAT QUANTIFY UNCERTAINTY

Alternatively, some methods are able to provide confidence intervals along with those central estimates. This uncertainty could be depicted as error bars reflecting the wind speed distribution and its key parameters. The figures below illustrate a HIGH UNCERTAINTY case and a LOW UNCERTAINTY case.





1. From your perspective, would methods that quantify uncertainty around the wind resource be valuable? Why or why not? [Text box]
2. If you think this uncertainty information would be valuable, how do you think this information could be used to better inform wind energy development? [Text box]
3. What, if any, barriers do you think might prevent this kind of uncertainty information from being used more widely within the wind industry? [Text box]

M. TZAR BLOCK

1. Suppose that you were made the "wind information" tzar and were given a large budget to spend on research and development on ways to improve the quality of wind-related information that is available to inform project development. Use the sliders below to indicate how would you allocate your budget across the following research areas: [Qualtrics online survey software has a question format that will allow the respondent to slide a bar corresponding to each option below – the scale will go from 0 to 100, and the sum across all categories must add up to 100%. Order of the items will be randomized]
    a. Improving wind resource assessment methods
    b. Improving uncertainty quantification methods
    c. Improving on-site measurements
    d. Improving remote sensing
    e. Improving or maintaining modeled data (like MERRA, others)
    f. Improving wake modeling
    g. Researching long term & future climate impacts on wind regimes
    h. Supporting better use of uncertainty information in the decision making process
    i. Other: write in ________________________
    j. Other: write in ________________________

N. FINAL COMMENTS

5. Is there anything else you'd like to share about the wind resource assessment process or informational needs to support wind energy development? [Text box]

6. Do you have any suggestions related specifically to atmospheric models and how they could be made more useful for wind resource assessment? [Text box]

7. If there is anyone else you know (in your organization or another organization) that you think would be able to respond to these questions about wind resource assessments, either on the "production" or "use" side, you can provide their email address below, send their contact information to Katie Dickinson (katied@ucar.edu), or forward them the link to the survey. [Text box]

8. The final report for this project will be completed in September 2013. If you would like to receive an electronic copy of this report, please provide your email address below OR send your contact information to Katie Dickinson (katied@ucar.edu). [Text box]

THANK YOU FOR YOUR TIME AND INPUT!