
Understanding your Fuel: Wind



Wind resource assessment: Advances in methods and the role of atmospheric modeling

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It was once said, “Without wind, you don’t have a wind energy project.” The most important aspect of any wind energy project is understanding and quantifying the fuel source, the wind. Wind is the driver of numerous financial income streams including the power production agreement, selling wind energy into a merchant market, receiving renewable energy credits, production tax credits and other sources of revenue related to the production of wind energy. And while wind is a free, weather-driven renewable energy resource, it is a variable resource that must be fully understood throughout the development and financing process to ensure the long-term economic viability of the project.

The typical investment for a 100 MW project is over \$200 million, and even a slight variation in wind energy production can have significant financial impacts. In recent years, atmospheric modeling has become an increasingly accurate and accepted tool for evaluating the financial viability of wind energy projects. The adoption of atmospheric models was spurred by the need for increased levels of certainty in making financial decisions, and made possible by the increased computational speed of supercomputers and significant cost reduction in processing.

The fuel questions frequently asked by wind developers, utilities, and financial players include where is the best place to build a project, what is the long-term wind resource variability, is the wind resource available when it is needed, and what are the long-term performance characteristics of the wind resource? In short, stakeholders are trying to quantify with a high level of confidence both the value and risk of the wind resource at the site. Answering these questions is vital to allocate development budgets optimally, diversify and manage project portfolios, evaluate equity investments, develop hedging structures, plan resource availability,

and make energy pricing decisions. In short, all interested parties share a mission-critical need to accurately project how the most important variable – the wind resource – will impact the viability of the project over the long-term.

A COMPREHENSIVE FUEL ANALYSIS PROGRAM

The only way to maximize the value of the wind resource at your project site and mitigate the risk of its variability is to implement a comprehensive fuel analysis program. This program should be designed so that your investment increases in parallel with your level of certainty that the fuel source at the project site will drive economic viability over the long-term. Simply put, if you are investing millions of dollars in project, a relatively small investment in your assessment program will pay big dividends by reducing your risk and maximizing your return.

The fundamental concern with all weather driven renewable energy sources is determining the intermittency and reliability of the resource at a variety of geographic and time scales. Historically, approaches to obtaining this information have been limited, relying upon less than ideal datasets, meteorological towers that aren’t highly correlated, poorly sited and/or maintained observational equipment, and data collected over a time period much too short to determine the actual long-term variability of the wind resource. Wind resource assessments have also focused primarily on reporting the mean conditions of a site, which is not sufficient to address real world integration issues. However, recent advances in the ability to accurately model the wind resource, which will be detailed at the end of this article, provide a new tool to better understand the long-term spatial and temporal variability of

the wind resource at a specific project site, or across an entire region, and over a range of time scales.

The ultimate goal of a fuel analysis program is to progressively increase your level of certainty throughout the development process. A thorough, scientifically based fuel analysis program during the development process should include the following components: the preliminary regional identification of the wind resource, site-specific identification, long-term resource variability analysis, and project-specific performance characteristics.

PRELIMINARY REGIONAL IDENTIFICATION

The first step in any wind resource program is to be able to identify regions that are suitable for wind energy development. The price of energy, access to transmission, and environmental siting issues are all important factors to consider when developing a wind project, but the most important variable is the wind resource. A number of public and private organizations around the world have made wind resource maps publically available. These maps have been used to help craft policies to incentivize wind energy development, and they also help developers target promising areas for further assessment. Many of these maps are available online, with spatial resolutions that are high enough for the early stages of prospecting.

These datasets are also often available as GIS layers, which enable developers to overlay wind resources with transmission grids, population densities, ownership boundaries, soil types, and other fundamental variables that impact the viability of a project in the prospecting stage. Such tools enable developers to quickly identify promising locations for further study, as well as see fatal flaws in a particular location early in the process.

SITE-SPECIFIC IDENTIFICATION

While coarse resolution maps are suitable for identifying general locations of interest, they do not provide the resolution needed to move forward with the next phase of a project – direct wind resource measurement – especially in areas of complex terrain. Even the deployment of meteorological towers entails a significant investment of time and resources, and their siting should be considered carefully to ensure that

the measurement data that are captured are representative of eventual turbine locations. While there is a tendency to site towers at the best locations, it is critically important to also site towers in average and marginal locations within the planned boundaries of a wind farm so that data are representative of the entire footprint of the project. High-resolution maps, which provide insight into the geographical dispersion of the wind over the site and illustrate how the wind interacts with terrain features, should be used to ensure proper, representative meteorological tower placement. As with other aspects of your fuel analysis program, a relatively small investment in high-resolution wind maps can prove invaluable in increasing the value of the project and mitigating risk.

LONG-TERM RESOURCE CLIMATIC VARIABILITY ANALYSIS

All too often even relatively savvy wind developers make the mistake of collecting measurement data over a period of 6-18 months, and then falsely assume that they've captured a representative sample of the wind resource at the project site. In truth, the data they've captured is merely a randomly selected snapshot of the resource without any long-term historical context. Imagine building a hydro project based on streamflow measurements in a flood-prone year without accounting for the inevitable drought years. Similarly, if you're a skier, you're keenly aware that some years have you running for the mountains every weekend, while your skis collect dust in other years. Wind is no different. Assuming that the year in which you took measurements is an average year can have significant financial consequences.

Prior to the adoption of atmospheric modeling, most developers correlated their direct measurement data with off-site historical data. The goal of off-site correlation is to understand how the data collected compares to longer observations. In some cases the off-site observations provide a good reference point, but in others the real correlation can be highly suspect. Large distances between your project site and off-site measurement sites reduce the correlation, and complex terrain features can magnify the discrepancies even more. Additionally, you have no way of controlling the quality of the historical data you're trying to correlate.

An advantage of using mesoscale NWP models is that data can be modeled for time periods without observational data. The ability to simulate the past 10, 25, or 40 years allows greater insight into the historical patterns of your fuel source. Comparing a year of on-site measurement data with a long-term mesoscale numerical weather prediction (NWP) model simulation for your site puts your measurement data in a more reliable long-term historical perspective, and can greatly increase the certainty around the fuel resource. In so doing, you know if your measurements were taken during an average, high, or low wind year, and the expected distribution of these variances over the lifetime of the project. From that you can build realistic financial model for the project, and make better, more informed decisions. As with the other elements of your fuel analysis program, a small investment in a proper climate variability analysis might be the best money you spend on your project.

BRINGING IT ALL TOGETHER

The final step in completing a thorough wind resource assessment involves integrating all the component pieces: high-resolution maps of your project site, the long-term climatic variability analysis data, direct measurement data, off-site data, turbine placement, and turbine-specific power curves. Synthesizing this data gives you a complete picture of the wind resource at your project site and should be used to develop a comprehensive energy analysis.

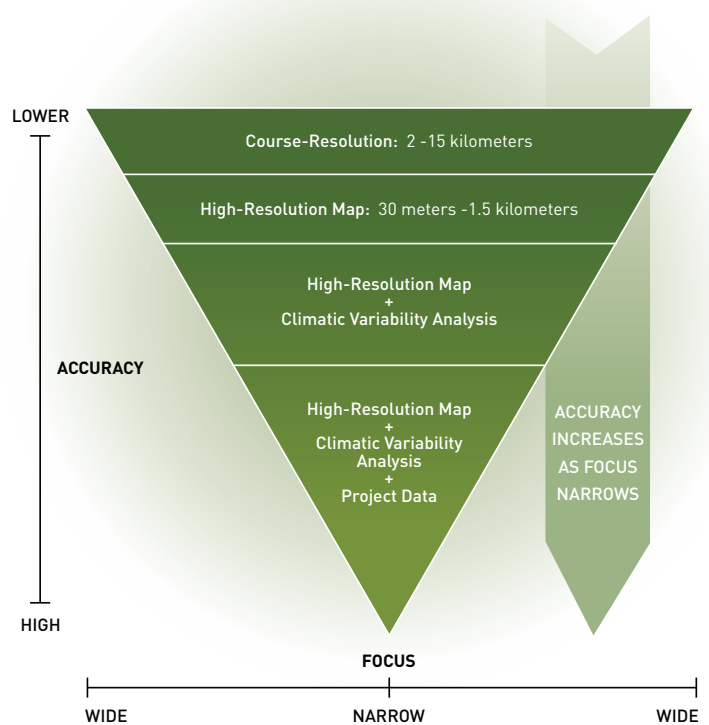
The historic method to determine long-term performance characteristics of a project is to use the technique of Measure, Correlate, and Predict (MCP) which involves measuring data at the project site, correlating it to an off-site data location with a long-term record and using that correlation to predict the long-term average of a project. This approach allows the project data to be correlated with measured data for a longer-term time period. However, as mentioned previously, correlation with off-site data introduces unnecessary and often non-quantifiable risk into the equation.

A modern approach to understanding long-term variability is to replace the remote site data with mesoscale model data simulated for the area actually encompassing the proposed project location. The same level of critical thought must be applied to analysis of model data, but its use offers several advantages, such

as completeness of record and consistency over the entire study period. Most importantly, proper configuration of the mesoscale model provides data that is representative of the exact location of interest.

Atmospheric modeling helps you understand and account for the year-to-year variability in your wind resource, with climate variability analysis for over 40 years. This analysis will provide a high-level of temporal granularity, including hour-by-hour wind and power capacity in a continuous multi-decadal dataset at both individual turbine scale and a project scale.

Atmospheric Modeling Increases Certainty



ATMOSPHERIC MODELS COME OF AGE

In order to fully gain the benefit from incorporating atmospheric modeling into your wind analysis campaign it is important to understand how to most effectively use the models. While there are many factors to consider in the siting of a wind energy project including identifying energy markets, potential off-takers, transmission lines, potential environmental constraints, land-use issues, siting restrictions, and the very crucial component of finding a wind resource that will support an economically viable wind energy project. In the early days of the industry, prospecting was per-

formed mainly by analyzing topological maps, driving thousands of miles looking for wind-blown trees, or on the anecdotal “windiness” of a location. In recent years computer simulations using mesoscale numerical weather (NWP) models are increasingly used and relied upon from the prospecting phase to understanding the long-term climatic variability when performing financial due diligence.

Numerical weather prediction models have been developed by both the private sector and through public collaborative efforts. The most advanced model that has emerged in the last few years is the Weather and Research Forecast (WRF) model, which incorporates advanced physics, numerics, and data assimilation routines. WRF model development has been a collaborative partnership, principally including the U.S. National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the National Center for Environmental Prediction (NCEP), the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA).

The WRF model and other similar models use numerical methods to obtain approximate solutions for the mathematical equations that describe the physics and dynamics of the atmosphere. To solve these equations over a specific model domain, the atmosphere is divided into many small elements, both horizontally and vertically, and the model computes what happens within each model element and how much mass, energy, and momentum is exchanged between the model elements. To resolve the effects of small-scale terrain features on near-surface wind speed and direction, model elements must be kept small. In addition to the inclusion of historical weather data, the mesoscale models also incorporate land surface properties such as topography including terrain slope, land-use, and surface vegetation.

When direct measurements are unavailable or cover only a relatively short period of time in the overall climatology of a location – as is often the case – then numerical weather simulation can provide an independent and potentially more complete estimate of the wind resource across your project. However, mesoscale NWP models can only provide an approximation of the actual wind experienced at any particular location.

Model results will always have limitations and it is only through direct comparison of simulated values to observed values that the accuracy of the model can be assessed, validated, and corrected. Verification against observed values is especially important in areas of complex terrain. The goal of the validation is to understand the relationship between the simulated understanding of the atmosphere and observed data.

INPUTS INTO ATMOSPHERIC MODELING

There are typically three main data inputs into most advanced mesoscale NWP models: historical climatic data; high-resolution terrain, soil and vegetation data; and in the advanced stages of development on-site observational data.

The main input data into most atmospheric models are historic global weather archives, which are maintained by operational weather forecasting centers around the world including the United States National Center for Environmental Prediction (NCEP). These global archives represent the overall state of the atmosphere over the entire planet and are themselves the result of a sophisticated computer analysis of available surface and upper air observations. Each time period of analysis combines tens of thousands of individual measurements around the globe into a consistent physical state.

One such data set is the NCEP/NCAR reanalysis, which includes the NCEP global spectral model, operational since 1995. The assimilated observations incorporate upper air rawinsonde observations of temperature, horizontal wind and specific humidity, cloud tracked winds from geostationary satellites, aircraft observations of wind and temperature, land surface reports of surface pressure, and oceanic reports of surface pressure, temperature, horizontal wind and specific humidity.

While a consistent physical model is applied over the entire reanalysis period, it should be noted that there have been broad programmatic changes in data collection during the past few decades. In particular, three significant phases of the global upper air observational system include: the early period, starting with the first upper air rawinsonde observations and ending with the International Geophysical Year (IGY) of 1957-58; the “modern” global rawinsonde network established

during the IGY and used almost exclusively until 1978; and the advent of a global operational satellite observational system starting in 1979 until the present.

Due to the necessity to represent the entire globe, the NCEP/NCAR reanalysis data set is maintained at a relatively coarse horizontal resolution and, by itself, does not contain the level of detail necessary to resolve the wind flow patterns over smaller geographic regions or over a single project. However, these data do provide a good representation of the history of large-scale spatial patterns in the atmosphere (i.e. the position of high and low pressure systems; the location of the jet stream) as well as the general state of the ocean (e.g. sea surface temperatures) and land surface condition (e.g. soil moistures). Mesoscale NWP models only need a good representation of the large-scale patterns for initialization. It is important to note that the reanalysis data is only used for initialization and boundary conditions and ensures that the mesoscale NWP results are consistent with the actual, observed historic conditions.

The second input for the atmospheric models are high-resolution terrain, soil and vegetation data. Mesoscale NWP models simulate the interaction of large-scale weather systems with the varied terrain, land-use, and vegetation of the region in order to accurately resolve the site-specific wind fields over a particular project or group of projects. An accurate representation of the local terrain is also important for resolving thermally driven circulations (such as land-sea breezes) caused by differential heating and cooling of the land surface.

The final input into numerical atmospheric models, especially in advanced phases of project development, are on-site meteorological tower observations. While it is possible to perform accurate high-resolution simulations of the wind resource over any region of the globe using only the global weather archive and high resolution terrain and land use data, the greatest confidence in the model results are obtained once they have been validated against meteorological data collected on-site or over the region of interest. The on-site observations are used to refine the weather simulations to more faithfully represent the dynamics of the site or region. This assimilation allows for a robust inclusion of on-site data while preserving the ability to

perform climatic variability analysis for periods during which observations do not exist (e.g. over any time in the past 40 years).

SUMMARY

The long-term quality and characteristics of the wind resource at your proposed site – your fuel – is the primary economic driver for the viability of your wind project. Understanding and quantifying the wind's inherent variability is the single most important input into a realistic economic model and your decision making process. A relatively small investment in a comprehensive fuel analysis program, designed to increase your level of investment in parallel with increasing levels of confidence in the wind resource, will help you maximize the performance of the development while also mitigating the risk of underperformance.

As standards of financial due diligence increase, so does your ability to take advantage of cost-effective, state-of-the-art wind resource assessment technologies to increase the level of confidence in the viability of your project. Blending the best of direct on-site measurements with advanced atmospheric modeling techniques gives you a reliable, credible, and comprehensive understanding of the wind resource that will fuel your project over its entire lifetime.