Making Wind Energy Assessments Bankable in India

It is no secret that many wind energy projects around the world are underperforming their pre-construction energy yield estimates. One of the factors behind this underperformance is that many projects were built with production estimates that did not adequately account for weather variability in both space and time.

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The weather related risk of renewable energy projects.

Electricity generation from wind energy projects offers the distinct benefit of fixed, often free, fuel costs. However, while free from the volatility of fossil fuel prices, wind energy production is dependent on something entirely different and perhaps much more complex than fuel prices: the weather. Understanding the revenue stream from a renewable energy production requires a thorough understanding of the weather, including how the weather changes from one section of the project to the next and how the weather changes from season to season and year to year. It is no secret that many wind energy projects around the world are underperforming their pre-construction energy yield estimates. One of the factors behind this underperformance is that many projects were built with production estimates that did not adequately account for weather variability in both space and time. We all instinctively know that a single year or less of observations, be it through a sophisticated measurement device or simply living in a region, is not sufficient to truly understand the weather at that location. Yet many wind projects around the world, and particularly in India, are built based on very limited weather data. In many instances a year or less of data are available, and often these observations are located at a distance of several kilometers from the proposed project.

The focus of this article is to show that traditional methods for estimating the average annual energy production from a wind energy project can fall short of capturing the full risk of weather variability, and hence can lead to investment decisions based on a false sense of financial security.

The limitations of traditional approaches are especially problematic in regions of the world, such as India, were long-term records of weather, especially wind, are often un-available or of poor quality. To address this challenge, we outline a superior methodology that uses numerical weather simulation and long-term global weather archives to provide a more complete context for the short-term observational data collected at a proposed wind energy facility. While these models can provide a more complete understanding of both the spatial and temporal variability of the wind resource, this article will focus on temporal variability. We will present an example of the month-to-month and year-to-year variability for a potential wind energy project in Tamil Nadu, India.

Limitations of traditional techniques

The traditional method of determining the average annual energy production (AEP) from a commercial wind energy project is to correlate measurements from a project-located anemometer, often having a relatively short record length, with data from another much longer-term wind observation site located some distance from the proposed project site. This approach, commonly referred to as Measure Correlate and Predict (MCP), then uses statistical techniques to adjust the capacity factor obtained from the shorter-term record with the data from the longer-term record, with the goal of accounting for longer-term variability that the short-term, project-located measurements do not provide.

The MCP technique works well when two important criteria are met:

1. The wind resource experienced at the long-term site is similar to the wind resource experienced at the project location.
2. The record length at the long-term site is sufficiently long to adequately characterize the variability in the wind resource from month to month and year to year.

Unfortunately these two criteria are often not sufficiently satisfied, especially in India, which generally does not have high-quality, long-term observational data. As a result,

MCP in India often gives an incomplete picture of the actual wind resource at the site and creates unnecessary and potentially substantial financial risk for projects.

What's wrong with off-site observations?

A limitation of the MCP method is that frequently the long-term observational data that is available is from a location that does not share similar wind characteristics with the proposed site. Further degrading the value of this data is the fact that throughout much of the world the network of long-term high-quality observations was not designed for wind energy; in fact, the long-term data that is typically available comes from the least windy location in a region, namely at the nearest airport. The lack of a good long-term reference is a common complaint amongst those using the MCP technique, and the problem is especially noticeable in areas of complex terrain and in less developed regions of the world.

In fact, it is not uncommon for analysts to entirely dismiss data from the long-term reference station and base the average annual estimates on nothing more than short-term record from the project, applying some rules of thumb regarding confidence limits on this estimate. In other cases, even when the long-term data set is well correlated with the project-located measurements on a monthly time scale, the long-term measurements may only extend over a decade or so and therefore do not capture the longer-term variability of the weather that occurs over the project. Both practices are problematic, and should be approached and evaluated with caution.

Does record length matter?

To gain a better understanding of the importance of record length, a brief discussion of how weather patterns can affect project output over long periods of time is warranted. Weather is the hour-to-hour and day-to-day variations in various atmospheric phenomena and is the fuel that drives a wind energy project. The study of weather and its patterns over long periods of time is known as climatology and is the science used to provide a general sense of the mean atmospheric conditions, and more importantly the expected variability in these conditions.

For example, when one examines the behavior of a meteorological parameter over time – we'll use temperature since it is the easiest to relate to – various cycles or oscillations become apparent. The daily cycle is clearly evident in temperature, with warmer temperatures observed during the day followed by cooling at night. Another clearly apparent temperature cycle – at least outside of the tropics – is the annual temperature oscillation: warmer temperatures observed in the summer with cooler temperatures in the winter.

Climatologists have become increasingly aware of much long-term oscillations of weather that occur over the course of years or decades and are linked to patterns of global sea surface temperature and other factors. Wind, just like temperature, also experiences cycles at various long-term time scales. Capturing and measuring these cycles at time scales relevant for renewable energy projects is essential for obtaining an accurate capacity factor. Generally, two or even five years of data will not be sufficient to reveal the true long-term average wind energy production at a site. If a longer-term cycle describes the climate at a site, it is entirely possible to collect data during the above average period of the cycle and thereby overestimate the true average annual energy production. A similar problem exists if data is collected during below average periods.

An alternative method

Recent developments in computer speed and high-capacity computer storage devices, as well as advances in weather simulation models and global weather data archives, have facilitated the development of an alternative method for estimating the variability of the resource that fuels a renewable energy project. We have developed a wind energy assessment methodology that uses numerical weather prediction (NWP) models, proprietary statistical algorithms, supplemental models to integrate global archives of weather observations, high-resolution land surface and terrain data, and on-site measurements to simulate the past meteorology (i.e. weather) that occurred at the particular project. While the approach of using NWP to perform a wind resource assessment can proceed without the use of any on-site observational data, the technique performs best when on-site data are combined with the NWP results. In this manner, the NWP data is not used to replace the on-site data, but instead provides context in which the on-site data can be considered.

The NWP- based technique is different from the traditional MCP approach in a number of ways when it comes to understanding temporal variability of the wind resource. However, two very important distinctions directly address the common limitations of the MCP approach:

First, the NWP model uses weather science to provide weather context. The NWP model explicitly represents the complex large- and local-scale atmospheric patterns that affect the weather at a project site and can more fully represent the actual weather patterns that the project experiences than simultaneous observations from nearby locations. This advantage results in NWP results often having higher correlations to on-site data than even high quality off-site reference stations.

Second, the NWP model can be run over periods of time extending as far as 50 years in the past to the current day. The ability to simulate several decades of historic weather allows the NWP approach to provide context over multiple climate variability cycles and provide a robust estimate of the long-term average production and variability of production from a project. This advantage over the MCP technique is due to the use of global weather data sets, which begin in 1948 and extends to the present. On-site data from the project, when available, are integrated into the process in a manner that enhances the quality of the reconstructed meteorological record while not limiting the ability to simulate periods before the on-site measurements began.

Example application

An estimate of the month-to-month idealized (Gross) capacity factor obtained from a 3TIER wind resource assessment using NWP modeling for a proposed wind energy project in Tamil Nadu, India is shown in Figure 1.

As is apparent from this 40-year reconstruction of wind energy production, there is considerable year-to-year variability in the capacity factor, ranging from an annual low of 30% to a high of 45%, with a long term mean over all 40 years of 36.7%. Also apparent in this figure are extended periods of time (two to four years) that are above or below the long-term average capacity factor. Consider if the project were built based on the observational data collected solely during 1999. The project would be expected to perform at over 40% CF. The overestimation would be even worse if 1975 were the year during which observations were taken. However, lack of context can often lead to underestimation. For example, consider if 1997 were the year of observations (30% CF) on which the long-term estimate was based.

In our experience, projects that measure low for a single year are often not built, and those that measure high are built. But in either case, making a financial decision based on a limited amount of on-site data without a longer-term context introduces unnecessary and potential significant risk into the process.

Context is also important for projects that are already built and are underperforming pre-build estimates. At this project, if the decision to build were based on one-year of data, and if that year happened to be 2008, we would expect the project to, on average, over-perform the pre-build estimate. However, if the data were taken in 2009, then we would expect no recovery due weather variability. For either due diligence of proposed projects or investigation of under-performing assets, the long-term weather context provided by NWP models is a powerful analysis tool to develop realistic expectations.

To more directly connect the long-term variability of the wind resource and wind energy production at the proposed project to a limited observational record, it is illustrative to compare the variability over each individual month for the past 40 years to the monthly energy production that would be expected given just a single year of observations.

Figure 2a shows exactly this comparison for the on-site anemometer. Figure 2b shows the monthly variability in wind speed translated to gross wind energy production. In Figure 2a the NWP context is shown as a box-plot and the observed wind speeds are shown as an oval outside each box plot. The upper and lower bounds of each box are the P25 and P75, the interior line of each box is the median (P50) and the whiskers of each box extend to the highest and lowest values in the record.

To illustrate our point, consider May and June. The observed average wind speed for a single year at the met tower in May was above the long-term median and close to the P25 value for the month. In June, the observed value was below the long-term median and below the P75 value for the month. Figure 2a shows that the observed data is actually low during the majority of the monsoonal season. In fact, at this site, the 12 months of observed data report an observed wind speed of 6.2 m/s while the 40 year long-term average is 6.7 m/s. Consider May in Figure 2b, the variability in wind resource translates to an expected range (over 40 years) of average energy production from 10% to 70%.

Now imagine owning this project, with an "expected" energy production in May based on the single year of observations of slightly above the median (i.e. 50% CF), and then the project commences operation on May 1 and the first full month of production comes

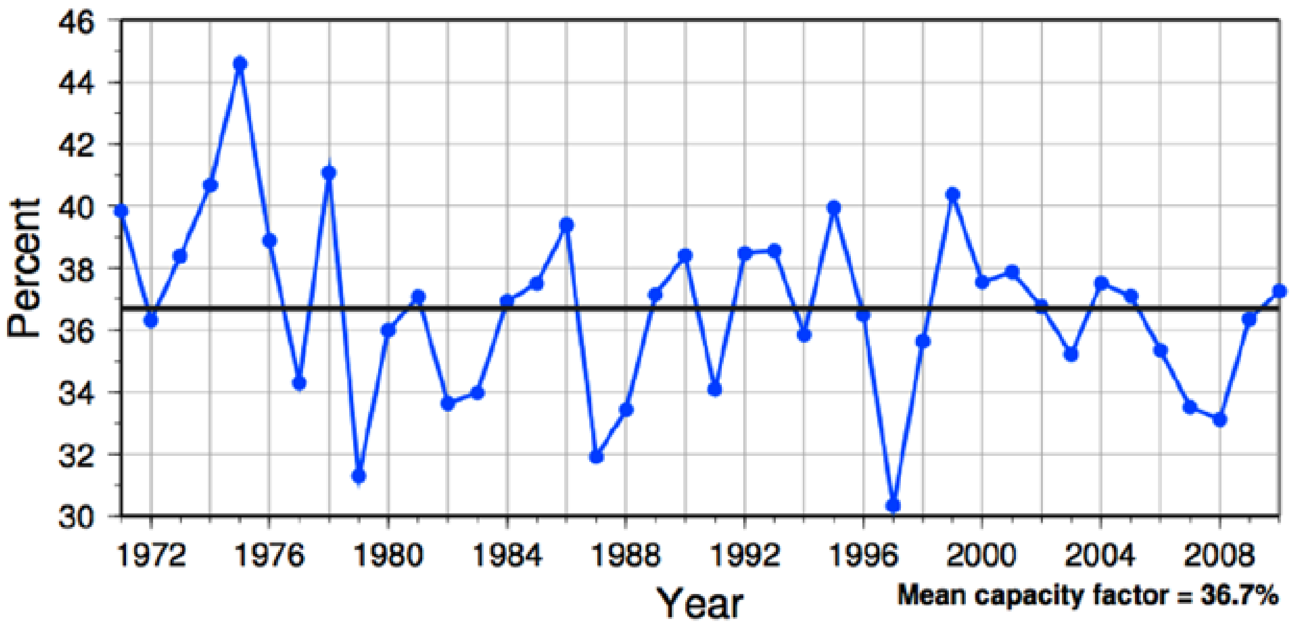

Figure 1. A 40-year estimate of gross energy output from a proposed wind farm in India showing year to year variability of the resource.

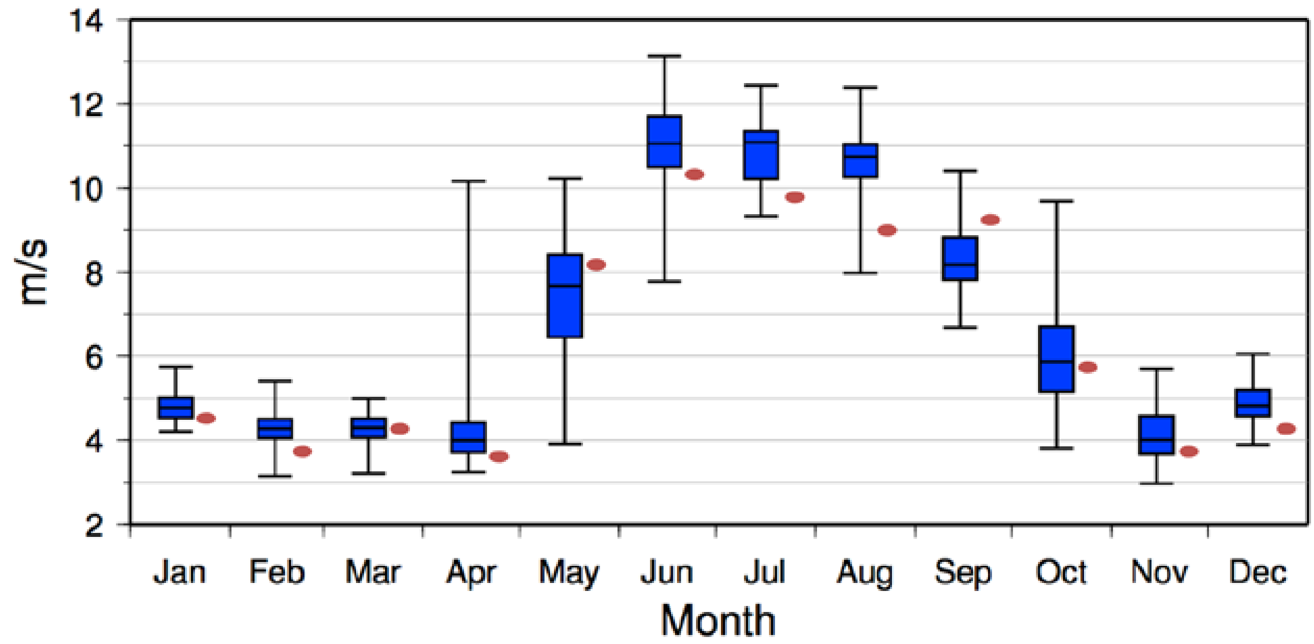

Figure 2a. Comparison of 40 year weather context (blue box-plots) to the 12 months of observed data wind speed data at the met tower.

in at 15%. Without longer-term context, panic may be the result. Having long-term context prepares the owner of a wind energy facility to fully understand the financial risk of owning an asset whose fuel source depends on the weather. May production as low as 15% has occurred in the past 40 years, due entirely to natural climate variability, and could likely occur again. Furthermore, since the NWP model data can be created up until the current day, it is possible to consider not just a typical May (as shown in Figure 2a and 2b) but also to understand any recent period was over- or under-performing due to weather variability or due to other factors.

Conclusion

The amount of power a wind project produces fluctuates at various timescales, and traditional methods often either underestimate or completely miss longer-term variability. Newer and more accurate methods, which are largely based on numerical weather prediction (NWP) models, are widely used by 3TIER for wind resource assessment in India and throughout the world. NWP has distinct advantages over traditional methods, especially in India, where long-term weather observations, especially of wind, are often unavailable or of poor quality. We showed results of a 40 year record recreation of wind speed and gross wind energy production at a site in Tamil Nadu, India. Significant year to year variability of the gross CF is shown, ranging from 30% to 45% with a long-term mean of 37%. Variation of the monthly average capacity factor over multiple years is even greater.

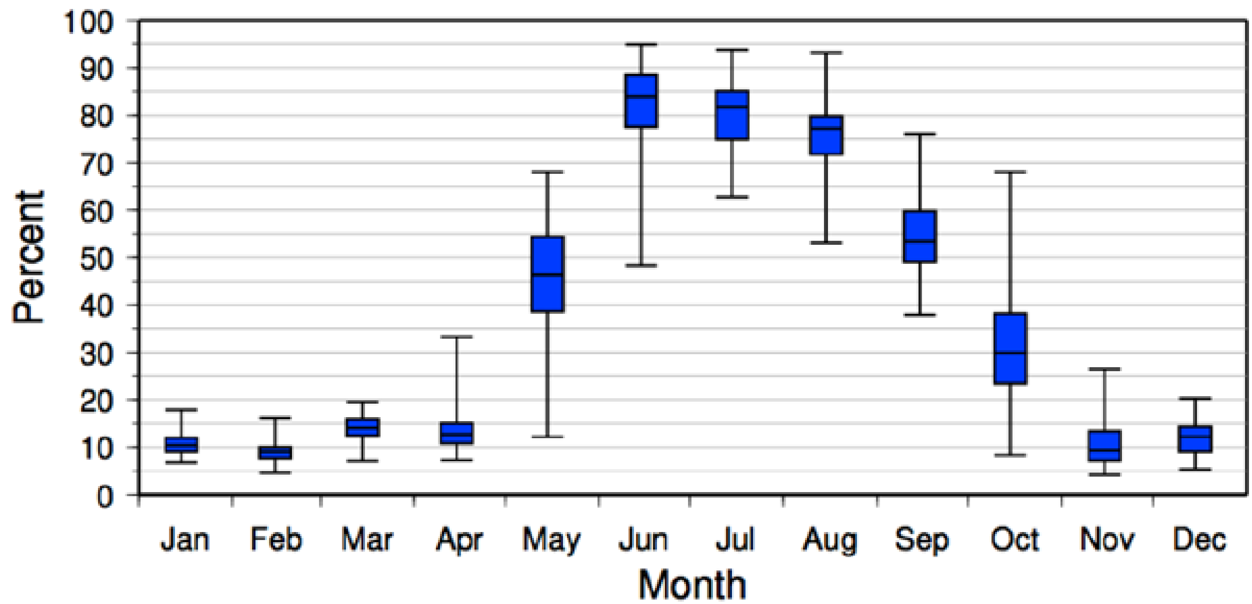

Figure 2b. Variability of monthly gross CF obtained from 40-year weather context. Variability in wind speed at the met tower (Figure 2a) translates into even large variability in power.

The long-term context of the NWP model approach reduces the uncertainty of the long-term capacity factor estimate and provides a more complete understanding of the financial risk of owning a wind energy project.