Balancing Innovation & Stability

VAISALA'S WIND ASSESSMENT VALIDATION PHILOSOPHY

Introduction

Wind project developers and investors rely on wind energy assessment consultants to predict the energy output of proposed projects. They need to be confident that the numbers reported to them are as accurate as possible. Yet ironically, the two goals of confidence and accuracy can be at direct odds with one another.

Maximum confidence is achieved through a high level of comfort and familiarity with an established and unchanging methodology. Maximum accuracy is achieved by using the best science and latest technology available in the fields of climate science, meteorology, fluid dynamics, and statistical analysis. These apparently conflicting goals can be expressed as a trade-off between "stability" of method, and "innovation" of method. However, as outlined in this briefing, Vaisala has developed and implemented a way to simultaneously achieve stability and innovation through the intelligent use of validation.

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The Case for Stability

Project stakeholders, investors in particular, require end-to-end familiarity with the assessment method, not just the underlying techniques, but also how it performs over a large number of cases and under a wide array of conditions. This allows them to develop an experiential calibration of the method that gives them confidence in a project's future energy production. All of this favors a wind energy assessment method that remains stable and well-tested, with minimal innovation. Yet instinctively we know that we must innovate if we want to improve technology.

Defining the Value of Innovation

The value of innovation within wind energy assessment is best understood in terms of the errors that these methods exhibit when compared against actual energy production. If the average error of a large number of assessments in diverse conditions is not zero, this is a bias in the methodology. Bias can be investigated, its cause identified and corrected to achieve calibration with respect to bias. Even if its root cause cannot be identified, the bias can be accounted for with offsets or correction factors.

The remaining part of the error, is the random error from project to project, and is the uncertainty in the methodology. This error arises from a combination of many small deficiencies in the methodology and unpredictable conditions in real-world wind project operations. The only way to reduce the uncertainty in the methodology is through innovation: using newer, smarter, more efficient, or more science-based methods that reduce these many small deficiencies in the overall process step-by-step.

Innovations can take place at any step throughout the wind energy assessment process: on-site measurements, long-term climate reference data, turbine performance modeling, wake modeling, integration of observations, and so on. In an industry that is constantly evolving, it is tempting to assume all innovations are beneficial, but any innovation may have unanticipated consequences.

This is because the wind resource assessment process is comprised of many components. A new method may improve the bias error of one component, but may uncover new bias in another component which was previously hidden because it was canceled by the opposite bias of a different component. This new net bias now throws the methodology out of calibration.

Synergies between different components may also lead to an amplifying effect, such that a new innovation may actually increase rather than decrease random errors. In short, both the bias and the random errors can be changed in unintended ways, and these changes can lead to sudden shifts in energy estimates for the same wind project, depending on whether it was assessed prior to or following the implemented innovation.

The Role of Validation

A decade ago, the wind industry was in a very different place in terms of what it expected from wind energy assessment consultants and what it was receiving. Energy assessment was focused primarily on a deterministic view (the P50 energy estimate) rather than a probabilistic view (uncertainty, and the higher probability-of-exceedance energy estimates currently used today). A series of important validation studies found that industry-wide, projects were falling short of pre-construction energy assessments by 10% or more. These studies prompted investigation into the deficiencies of methodologies and ways to correct them, leading to the current state of the industry where assessment methodologies are near calibration with respect to bias error.

For example, the histogram below illustrates the results of Vaisala's most recent validation study for its due diligence wind energy assessment methodology. This validation is one of the largest ever conducted within the industry.

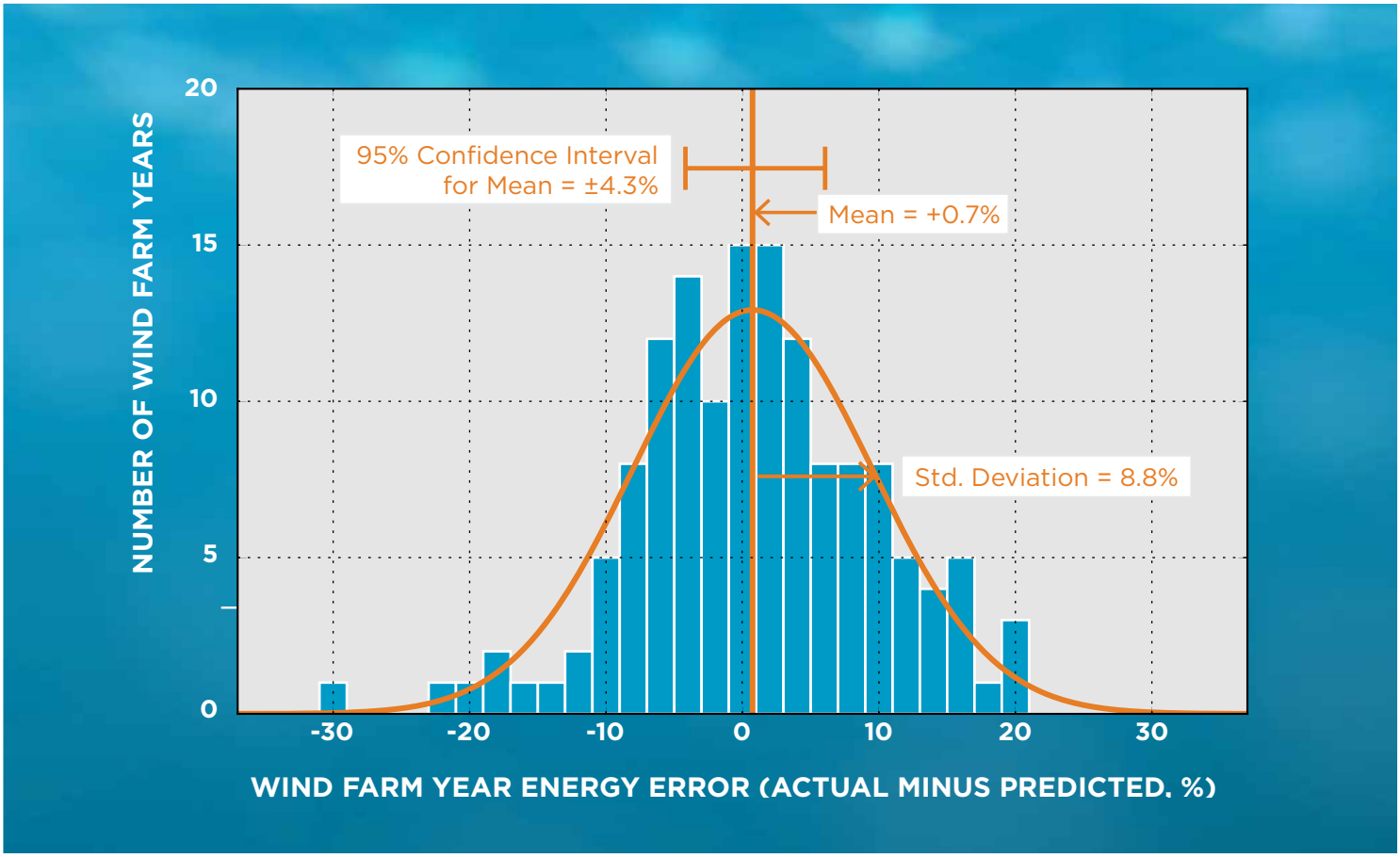
- 30 wind operational farms
- 143 years of energy production
- +0.7 mean bias error
- 8.8% uncertainty

Continuous Validation Allows Continuous Innovation

Today, Vaisala uses a ground-breaking continuous validation process as a bridge between the need for both innovation and stability. This approach provides an ongoing view into how we are performing, so that we can innovate while at the same time monitoring the effects and benefits of each innovation to guard against sudden shifts in accuracy.

In essence, each time a proposed innovation is introduced, a standard test suite is set up, which is designed to completely recreate the energy estimates used in our original validation study. Once the test suite is executed, the results are analyzed to evaluate the corresponding impact on errors and uncertainty. The process effectively tests the innovation against our entire validation database. The operation is not trivial as each iteration requires 600,000 core hours of computer time, and generates over 8TB of output, which are analyzed and compared to our previous validation results. As such, the process fully leverages our state-of-the-art computing infrastructure and in-house automation technology.

If sudden changes in our error or uncertainty values are uncovered during our testing process, either we investigate and address the cause as a result of the new innovation or it is simply not implemented. If the final results show a decreased uncertainty, with no significant change in mean bias error, the



result demonstrates that the innovation is a genuine improvement, and it is incorporated into our methodology. By following this approach and showing transparency, we maintain stakeholders' confidence in our process while incrementally benefiting from new innovation and the improved results they deliver to our clients.

Staying on the Cutting-Edge of Science

Since the December 2015 release of our wind assessment validation paper, we have continued to evolve our methodology. Along with a significant investment to develop and implement our continuous validation process, we have tested and introduced several new innovations to our approach. These innovations are both large and small and impact different components of the process. They include advancements to our algorithms for extreme temperature, shear extrapolation, turbulence intensity, and climate variability.

Core components of Vaisala's wind assessment methodology:

- Approach driven by numerical weather prediction (NWP) models based on the most advanced weather science
- Industry's highest spatial resolutions and longest simulation time periods
- Advanced techniques for integrating measurements in the time domain
- Sophisticated climate ensemble analysis, downscaling all major reanalysis datasets
- Proprietary energy risk framework accounting for full propagation of uncertainty

Vaisala believes that reducing uncertainty and improving confidence in wind energy estimates is a crucial step for the industry. The key is to have a systematic structure in place to validate continuously – not just with occasionally published studies – and to do so in a transparent fashion with close collaboration between our science team, our analysts, and our clients. Vaisala's validation process provides a careful balance between stability and innovation to help build the trust of the financial community, ultimately resulting in better investment decisions and more favorable financing terms for wind projects.

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