REMOTE SENSING **REVOLUTION**

Why remote sensing will become the new standard for wind development financing and operations

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VAISALA

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Foreword

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Profitably developing and operating a wind farm depends on two major factors. One is the ability to find a location with the right wind resource. The other is the ability to manage an asset throughout its operational life to make the most of that wind resource.

Over the last 30 years, this has always involved collecting wind speed data using fixed met towers, constructed during site prospecting, and left up, should the site prove suitable, for the life of the wind farm. If issues are suspected with turbine performance, the reference weather measurement is, yet again, another met tower installed especially for a turbine performance test. Those hub-height met towers can be difficult to move.

But a revolution is coming.
In the following pages, we look at the growing experience among developers, investors, technical advisors, operators, manufacturers and consultants of using remote sensing. We outline the changing approaches of an increasing number of developers and operators when it comes to both assessing resource at prospective sites and collecting resource data spanning the entirety of a wind farm, on an ongoing basis.

We also outline what manufacturers, developers and independent engineers have done to test and validate the accuracy and reliability of remote sensing data, making the case for its acceptance by the investment community.

> ***Greater speed, flexibility, lower costs and reliable data will truly represent a revolution in the way we measure, understand and manage wind resources around the world.***

In doing so, we find that, while met towers have come to be accepted as a universal standard, the global wind power industry is struggling with their lack of versatility. Met towers are a sunk cost that has to be recouped, regardless of whether a site is suitable or not.

By contrast, remote sensing devices offer a more flexible and mobile means of resource measurement. They are easy to set up, regardless of terrain, and capable of being used — and reused — across multiple sites, or moved around at a single site to monitor wind performance.

In recent years, remote sensing has been making gains on met towers, as the industry has answered important questions around the breadth and depth of the technology's experience, the accuracy and reliability of the data collected, and the value of the return on investment. Having recently passed the milestone of 20 million hours — nearly 2,300 years — of data collected around the globe by our own Triton remote sensing units, Vaisala fully understands the need to ask these questions, and have them answered.

In this report, we have gathered together in one place the perspectives of experts with decades of experience using remote sensing equipment, and the data it generates, to support the profitable development, construction and operation of wind farms. With a view to the future growth of our industry, remote sensing — with its offer of greater speed, flexibility, lower costs and reliable data — will truly represent a revolution in the way we measure, understand and manage wind resources around the world.

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Executive summary

Remote Sensing Revolution looks at how remote sensing (RS) has become an essential part of the tool kit of wind farm developers and operators in recent years. Since the first adoption of ground-based SoDAR (Sonic Detection and Ranging) and LiDAR (Light Detection and Ranging) devices by wind industry pioneers more than 15 years ago, the technology and its applications throughout the project lifecycle continue to be refined by Original Equipment Manufacturers (OEMs) and their customers.

Such has been the evolution of RS technology and its operational capabilities that it is now beginning to supplant met towers — the increasingly outmoded industry standard — as the preferred technology for wind measurement and monitoring campaign throughout project development and operations.

However, a number of obstacles continue to stand in the way of a world without met towers, including a lack of formalized requirements for using RS as a standalone measurement tool and ongoing reluctance from financiers to consistently accept the data as 'bankable.'

Liam Smith of investment firm Actis highlights the confidence RS can bring for investors:

> *There is history of people getting investments wrong, but RS allows more confidence, which has ultimately resulted in participation and investment approval.*

"Remote Sensing Milestones" sets out a timeline of the technology's key developments, starting with the discovery in the 1960s that Doppler shifts could provide information to scientists on wind in the atmosphere. Since then RS has followed **a path towards commercialization** and rapidly growing use by wind farm developers.

"Validating the Technology" outlines the response of asset owners, OEMs and accreditation bodies to the concerns of the financial community about the **bankability of RS data**. Industry studies conducted by consultants, OEMs and academic institutions have contributed to standard protocols for comparing the data and data quality of remote sensing units with met towers, and a growing evidence base for the reliability and accuracy of SoDAR and LiDAR units.

These efforts have now been supported by the 2017 launch of the International Electrotechnical Commission (IEC) standard IEC 61400-12-1 covering the use of RS technology in wind turbine power performance testing. This formalized guidance for the first time provides a clear outline of steps the industry must take to validate remote sensing technology. But with standards for other applications not yet available — such as wind resource assessment — there is concern in the industry that the new standards are being used in applications for which they aren't suited.

DNV GL's Reesa Dexter outlines the need to follow industry standards:

> *For RS data to be used confidently for financing and development decisions, the methodology must follow relevant standards, industry best practices, manufacturer guidelines, and meet some or all of the goals of a wind resource assessment.*

"A New Breed of Measurement Campaign" looks at how current approaches to conducting a thorough, ongoing wind measurement campaign can be advanced with the use of RS technology. It considers **how RS devices can be used in project development and operations**, from site prospecting and assessment, through to wind monitoring and project optimization.

Analysis of the comparative advantages of remote sensing technology and conventional met masts shows that RS devices provide a cost-effective means of reducing the uncertainty of wind measurements. Specifically, they offer benefits pertaining to **data**, including most notably the ability to measure across the full rotor sweep at heights of up to 200m, **ease of use**, including lack of permitting and construction requirements, and **cost.**

A further considerable advantage of using remote sensing devices, discussed in "Reducing the Risks", is the decrease or complete elimination of many of the risks associated with met towers. These include **safety risks** to personnel working at height or light aircraft using the same air space, the threat of extreme weather to tower integrity, and installation risks. These risks are evidenced by insurance claims data that show **financial losses of up to $140,000** associated with a single met tower collapse.

Contributions to "The Industry View" come from a number of industry leaders who have been at the forefront of developing the protocols and standards for RS. These individuals and organizations provide perspectives from the entire wind energy value chain worldwide — finance and engineering, project development, project construction and operations.

While many highlight the remaining obstacles to industry-wide standardization of remote sensing as a standalone measurement tool, most contributors are **positive and forward-looking** about the uptake of RS throughout the project lifecycle.

Jonathan Sutanto of UPC Renewables echoes a number of his counterparts from the wind energy developer and operator community in stating that wider financial acceptance would increase adoption. He says:

> *If interest in RS continues to grow and banks start to accept the data in greater numbers, then we would really like to move forward with using the data quantitatively too — in power performance testing and forecasting for operational wind farms.*

Remote sensing: milestones to date

1960s – LiDAR first developed to map the surface of the moon; quickly adopted in aviation and meteorology

Late 1960s – Scientists at the US National Oceanic and Atmospheric Administration (NOAA) demonstrate the practical feasibility of using acoustic sounders to measure winds in the atmosphere via the 'Doppler shift' effect

1970s – First commercial Doppler SoDAR units brought to market

1980s – SoDAR first used to characterize wake effects behind wind turbines

1992 – AeroVironment (now Radiometrics) commercializes its mini SoDAR product, a portable, battery-powered SoDAR system

Early 2000s – Risø DTU begins instrumental research testing performance of first-generation LiDAR and SoDAR systems in comparison with met towers

2001 – SoDAR first used to measure wind speed profiles at an offshore wind farm, in Denmark

2003 – First turbine-mounted LiDAR system installed on a turbine in Germany

2008

Triton Wind Profiler SoDAR system brought to market

2009

Energy research Centre of the Netherlands releases a five-month study validating Triton and concluding it can be considered a valid standalone system for wind resource assessments

2,000,000

Triton hits 2 million hours of collected wind data

2010

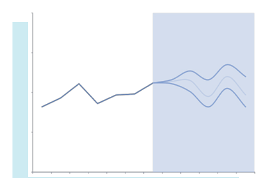
Wind Iris, a turbine-mounted LiDAR system, brought to market for power performance optimization applications

2011

NREL collaborates with Risø DTU in research effort that widely validates and approves remote sensing for resource assessment[1]

Triton first deployed in South America

2013



RS units deployed extensively as part of a $2.5 million US Department of Energy project to improve wind energy forecasting in complex terrain

2014

Vaisala evaluates over 50,000 hours of wind data, spanning 4 continents, to conclude that the Triton is as accurate for wind resource assessment as a met tower

September 2015

Vaisala doubles production of the Triton as demand grows worldwide

The IEC publishes long-awaited new edition of its standard for wind turbine power performance testing, providing guidance on the use of RS[2]

March 2017

20,000,000

Triton reaches 20 million hours (over 2200 years) of collected wind data worldwide

August 2017

[1] Ground-Based Vertically-Profiling Remote Sensing for Wind Resource Assessment, IEA Wind, January 2013
[2] IEC 61400-12-1: 2017: Power Performance measurements of electricity producing wind turbines, March 2017

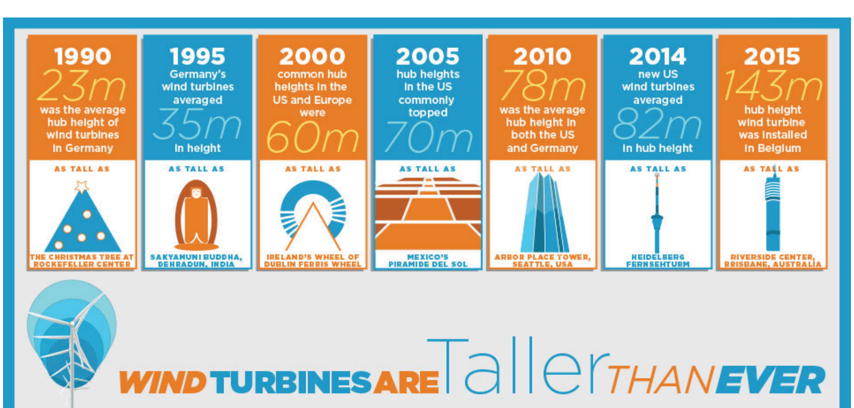
Validating the technology

Even as remote sensing (RS) technology has developed and improved, there has been reluctance on the part of the wider financing community to accept the data as 'bankable'. Met towers, despite their limitations, are the accepted benchmark for wind measurement, and, like any new technology, RS devices must be shown to meet or exceed the standards set by conventional approaches.

Since the turn of the century, the average hub height of onshore wind turbines has rapidly increased, as manufacturers look to produce turbines with greater generating capacities. In 2000, hub heights were typically 60m; by 2014, the average US wind turbine hub height was 82m, and today hub heights commonly exceed 120m. Rotor diameters have increased proportionally, with blade-tip heights reaching 200m.

As this trend has developed, measuring wind speeds at these increased heights and across the full rotor sweep has become more difficult. Erecting a met mast of 80m or taller is a time and resource-intensive process, but using shorter met masts requires a greater reliance on extrapolation techniques and increases the margin for error in estimating conditions above the mast height.

As a result of these challenges, RS has assumed increased prominence in the wind sector, as its versatility, cost-effectiveness, and ability to measure at heights up to 200m have seen it begin to displace met masts as the preferred technology for many phases of wind measurement campaigns.



As part of the industry's ongoing commitment to collaboratively raise technical standards, RS technology continues to undergo a series of validation processes aiming to demonstrate the accuracy of its measurements. These have been carried out by project developers, third-party laboratories and consultants, manufacturers of RS devices, such as Vaisala, and wider industry bodies, including the International Electrotechnical Commission (IEC).

Setting the standard

As SoDAR and LiDAR technologies have become more reliable and accurate over the past 15 years, the following studies, standards and recommended practice guidelines have been developed to reflect this evolution, and are currently the primary points of reference for the industry:

- *Wind Energy SoDAR Evaluation (WISE) project.* The WISE project was conducted from 2002 – 2005 by researchers across Europe. The study introduces the wind energy applications of SoDAR and identifies the main sources of measurement error in this context.

- *DNV-RP-J101: Use of Remote Sensing for Wind Energy Assessments*. Published in April 2011, this document outlines DNV GL's guidelines for using RS to gather data for wind resource and energy assessments.

- *IEA Expert Group Study on Recommended Practices.* First published in January 2013 by IEA Wind, the Ground-Based Vertically-Profiling Remote Sensing for Wind Resource Assessment study documents the steps required to collect high-quality, well-documented RS data for use in wind resource assessments on land.

- *Technical Guidelines for Wind Turbines — Part 6: Determination of Wind Potential and Energy Yield.* Developed by German research body FGW, these guidelines were revised in 2015 and cover requirements for the use of RS devices in wind measurements alone and in conjunction with met towers.

- *IEC 61400-12-1: 2017*. In April 2017, the IEC standard, *Power performance measurements of electricity producing wind turbines,* was updated to include guidelines for the use of RS devices in this context (see 'Power Performance').

In conjunction with the above, RS manufacturers, developers, independent consultants and academic institutions have employed a number of methodologies in recent years to assess and verify the accuracy of RS data for use in wind energy applications.

Comparison studies

Comparison studies — also termed 'validation' or 'verification' studies, depending on the institution undertaking the analysis — typically involve the assessment of a single RS device via comparison with a collocated met tower.

The two main metrics assessed by a comparison study are **correlation** and **mean bias** error.

- *Correlation.* Assessing correlation involves benchmarking the RS device and the data it gathers against measurements from the collocated met mast.

  Wind speed or direction measurements are compared using the correlation coefficient, *r*, and the coefficient of determination, R^2. The correlation coefficient is a number between +1 and −1 describing the strength of the linear relationship of one variable (for example, the met-tower measured wind-speed data) to another (the RS measured wind-speed data). A coefficient of +1 indicates a perfect positive correlation, and a coefficient of 0 demonstrates no correlation whatsoever.

  The coefficient of determination, R^2, is the square of the correlation coefficient and shows how much of the variation in one variable can be predicted using the other variable.

- *Mean bias error (MBE).* An MBE calculation provides information about the average difference in the mean between measurements from the RS device and the 'true wind speed' measured by the met tower. MBE is recorded as a percentage, with 0% indicating perfect agreement, although one should not expect this to be achieved, as the met tower measurements have uncertainty as well.

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A close correlation to a collocated met tower and small mean bias indicates that a RS device is suitable for use at a given site. As such, these assessments are commonly undertaken as standard practice by the site owner and/or their independent engineer ahead of a measurement campaign.

During this process, sources of potential error should be considered, including the location of the RS device in comparison to the met tower, the configuration of the tower itself, and the measurement uncertainty of installed anemometers.

Reliability and performance

Depending on their duration, rigor and specific focus, many independent comparison studies also involve assessment of the wider performance of an RS device in the field. These may include analysis of the **up time** and **data recovery** of the device.

- *Up time.* Reliability or 'up time' is reported as the percentage of time a device is operational during a testperiod. This is not a height-specific metric and applies to the device as a whole, representing the amount of time it is collecting data at any height as a percentage of the total time during which the device is deployed at a site. Typical met tower up time targets for the industry range from 75 to 95%. If a system is operational less than 85% of the time during a wind measurement campaign, its results are usually not considered reliable.

- *Data recovery.* Data recovery is a height-specific performance metric, often reported in comparison studies. It is usually defined as the amount of time the device records a 'good' measurement at a particular height as a percentage of its up time. A measurement is characterized as 'good' if the data meet certain filtering or quality criteria that can vary based both upon the judgement of the analyst and on specific performance characteristics of the RS system being evaluated. Data recovery varies due to factors including signal strength and atmospheric conditions.

Complex flow

Increasingly, another core area of focus for studies assessing the accuracy and performance of RS devices is evaluating how the unit responds to wind flow in complex terrain, in order to determine where corrections to wind estimates can be made.

Most commercially available RS wind profilers employ some variation of a divergent beam strategy, whereby pulses of sound or light are sent upward in different directions, and the Doppler shifts of back-scattered energy are recorded. By measuring the Doppler shifts in at least three unique directions, the horizontal wind speed can be recovered at the heights from which the returned light or sound energy was scattered.

Ideally, the three beams would measure the exact same point in space at each height level, but, because they diverge from each other, they measure points that are separated in space. This is not a problem where the ground is relatively flat (even if it has a slope), because the flow field is uniform.

However, in complex terrain, the flow above the device can also be complex, and the different beams each 'see' different wind vectors. This effect can yield a bias in the measured wind speeds. In particular, if wind flow is convex, such as over a hill or ridge, the RS instrument will underestimate the wind speed. Conversely, RS measurements of concave wind flow, such as over a valley or bowl, tend to overestimate the wind speed.

If the full three-dimensional flow field is known, it is a straightforward calculation to determine the bias of the profiler-measured wind speed. The challenge is that the full three-dimensional flow field is typically not known. However, it can be estimated with Computational Fluid Dynamics (CFD) model simulations. CFD model simulations can also be used to estimate the flow curvature bias as a function of height, wind direction, and perhaps other variables. The estimated bias can be inverted to yield a 'correction factor', which can be applied to the raw RS profiled winds to yield a more accurate wind estimate.

IEC-prescribed testing procedures

Prior to 2017, respected independent laboratories and institutions engaged in the effort to verify RS devices and quantify their uncertainty, using a combination of the methodologies outlined above. However, there was no formalized industry guidance or standard terminology covering these tests.

The new IEC 61400-12-1: 2017 standard, covering the use of RS technology in power performance testing, describes in detail the mandatory set of procedures required prior to use of a remote sensor in a formal power performance test — outlining these in Annex L.

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These requirements focus specifically on power performance testing. Some of the steps outlined by the IEC in this standard are also used in wind resource assessment (WRA), and the terminology included in the document will likely become the language of uncertainty used by the industry. It is also likely that a separate standard will be developed for WRA based on input from the WRA and finance community.

IEC 61400-12-1: 2017 prescribes two distinct types of comparison study, referred to as **classification** and **verification.**

- *Step 1:* Classification. The purpose of the RS classification stage is to systematically measure the sensitivity of the device to atmospheric conditions.

  This campaign must be performed only once for each model version of a sensor. Changes to firmware and hardware will require a new classification. Classification tests may be performed for the sensor independently, or on a case-specific basis using the data collected during the power performance test and verification test.

  Independent classification requires multiple 3-month measurement campaigns to capture the seasonal cycle. One sensor must visit at least two sites, and at least two sensors must be used; that is, a minimum of three tests. In the case-specific framework, the verification test and the power performance test itself cover two of the three required tests.

- *Step 2:* Verification. The project owner must 'verify' their device against a tall tower within one year of the power performance test. This campaign must be performed for every individual remote sensor used in a power performance test. The reference tower must have three heights (including +/−25% of turbine hub height), and the verification test must run for a minimum of 7.5 days after filtering. As with the classification test, the verification test may be performed for every individual remote sensor used in a power performance test.

  Gathering additional data beyond 7.5 days is recommended as it is necessary to measure conditions to which the device has atmospheric sensitivity, as identified in the classification stage. The data is binned by wind speed and the best-fit line to the bin averages and can be used to calibrate the RS to the tower reference, reducing scatter in the next step: uncertainty calculation.

- *Step 3:* Uncertainty Calculation. Finally, the total uncertainty of the power performance measurements is calculated. This takes into account site variation, reference instrument uncertainties and remote sensor uncertainties.

  The standard describes how to compute uncertainties — such as those associated with the anemometer, tower shadow, remote sensor siting and distance between the device and the tower. These sources of uncertainty are combined by taking the square root of the sum of the squares of each source (summation in quadrature).

Carefully completing and documenting each of these steps (classification, verification and uncertainty calculation) is beneficial in reducing the overall uncertainty of the ensuing power performance tests.

Testing Triton

As discussed above, procedures to validate RS technology and the data these devices gather are becoming increasingly rigorous as standard practices are developed.

Most widely available RS devices have been tested using a combination of the above approaches. Vaisala, like other manufacturers, has taken steps to demonstrate the reliability and accuracy of its technology.

In addition to commissioning a number of comparison studies, conducted by independent institutions including Ecofys and ECN, Vaisala is unique in having carried out a more extensive global comparison study[3] for its Triton SoDAR device. The study aims to characterize the accuracy of the Triton in a wide range of operational circumstances.

Vaisala conducted the study using a large dataset of 30 Triton SoDARs and collocated met towers, used in both R&D and commercial applications around the globe, primarily in flat terrain. Aggregating the mean wind speed differences for all measurement pairs revealed that:

- The levels of uncertainty in mean wind speed measured by both tower-mounted anemometers and the Triton are indistinguishable from one another.
- Both sets of results are equivalent to the IEC specification for Class 1 anemometry.
- Combining a shorter met tower with a Triton can virtually eliminate shear uncertainty.

The study also proposed a method of filling in unrecovered data with wind speeds extrapolated using shear values derived from the Triton's own data. This method further improves Triton's wind estimates and provides an additional means through which Triton data can be used to reduce uncertainty in wind resource assessments, specifically:

- Uncertainty in mean wind speed estimates incurred by a bias in the speed at unrecovered times can be reduced by a factor of two, to a root mean-square value of 0.47%, with no degradation in the accuracy of the Triton mean wind speed at recovered times.
- Hub-height mean wind estimates based on Triton measurements, when filled in using Triton-estimated shear, exhibit an uncertainty less than half that of estimates extrapolated from met towers below hub height.

Together, these findings support the use of Triton as a standalone wind measurement device for use in WRA campaigns.

Correcting bias in complex terrain

In addition to the global comparison study, Vaisala has recently conducted a study to test a Computational Fluid Dynamics (CFD)–based flow curvature bias correction for Triton measurements within complex terrain. The study was conducted at 20 sites, each with a collocated Triton and met tower. These sites were geographically distributed around the world, and exhibited a range of degrees of terrain complexity. Without the CFD-based correction, the mean wind speed difference (Triton minus met tower) at all sites was –1.7%, with a standard deviation (among the sites) of wind speed difference of 2.5%. Most of the sites were on hills or ridge tops, so the negative bias was consistent with predominantly convex flow shape.

Applying the CFD-based corrections reduced the mean wind speed difference to −0.1%, and the standard deviation to 2.1%. In other words, the correction not only eliminated the overall bias, but also reduced the spread of error among the sites. These results indicate great promise for the use of RS systems in complex terrain, where use of met towers is especially difficult.

Power performance

The diagnosis of power performance issues is a key challenge for the wind industry due to the expense and high financial stakes involved. However, the process is essential for owner-operators looking to remedy the cause of underperformance and derive maximum value from their existing assets.

The new edition of the standard for power performance testing, IEC 61400-12-1, released in April 2017, saw a number of significant updates to the previous version; in particular, the addition of guidelines related to the use of RS devices in these tests. This shift will potentially offer tremendous time and cost savings.

The IEC's requirements for testing of a RS device prior to its use in power performance tests are outlined above (see 'IEC-prescribed testing procedures') — but, for the benefit of readers, some of the wider implications of the new standard are summarized below.

[3] Triton Remote Sensing Systems: Comparing Accuracy with Collocated Met Towers. Vaisala, 2015.

The International Electrotechnical Commission

The International Electrotechnical Commission (IEC) is the international authority on standardization practices in the electrical and electronic fields. The certification body governing all renewable energy applications, the IECRE, sits within the IEC.

The IECRE promotes safety and provides guidelines and standard best practices for equipment operation and other common procedures across the global wind industry.

IEC 61400-12-1 focuses exclusively on standards related to wind turbine power performance testing in cases involving negotiations with turbine manufacturers. Its goal is to provide uniform methodology to ensure consistency, accuracy and reproducibility in measurements and analysis.

Changes to power performance testing practices

Prior to release of the new IEC standard, there was only one means of proving whether a turbine suffered from a performance fault. Since warranty compensation is at stake, it was necessary to hire a third party to conduct the analysis and install a hub-height met tower to collect the measurements needed for the full IEC power performance test. Under the new standard, in cases of warranty compensation, a full IEC test is still required, following turbine supply agreements and involving a third party.

However, owners now have several options for collecting measurement data at the relevant heights. Along with met towers at or above hub height, they can choose to use a RS device in conjunction with a hub-height or short met tower. In this case, the remote sensor can be used to provide shear validation and other supplemental information, or to provide all of the meaningful data for the power performance test.

IEC limitations on RS in power performance testing

While the inclusion of RS devices in the IEC standard is an encouraging development, it is important to highlight what the guidelines do not cover, and the specific limitations placed on the technology:

- RS units cannot be used as standalone devices for this application; in all cases a met tower is needed to provide a traceable path back to a controlled environment, i.e. a wind tunnel, where met tower instruments have been calibrated. A short tower that reaches the lower blade tip must be present during each power performance test as a “sanity check”.
- The new standard only applies to ground-based SoDAR and LiDAR devices, and only in flat terrain; it does not allow RS for power performance testing in complex terrain.

Conclusion

The growth and proliferation of RS technology over the past couple of decades has been remarkably quick; however, this pace has not been matched by acceptance of RS data among the financing community. In order to assuage concerns over the accuracy of RS and tackle an inefficient over-reliance on met masts to modernize wind measurement campaigns as a whole, a range of studies have been carried out by accreditation bodies, manufacturers and other industry stakeholders.

These studies have demonstrated the accuracy and reliability of RS data, and its suitability for resource assessment throughout the project lifecycle. Equally, while the classification and verification testing, outlined above, requires time and care, the inclusion of RS devices in the new IEC power performance testing standard recognizes their potential to more quickly and cost-effectively complete these tests.

Yet, the development of a specific industry standard for power performance testing has also raised questions about the current lack of a corresponding standard for use of RS devices in other applications such as wind resource assessment. Specifically, there is now some debate as to whether the in-house and independent comparison tests undertaken to date still apply, or whether the more formalized IEC requirements for power performance testing should be applied across the board.

Indeed, direct use of IEC standards for power performance testing may result in a level of data uncertainty that is overly conservative and thus too high for the purposes of wind resource assessment. A number of the independent and manufacturer comparison studies undertaken before the release of the new IEC requirements — such as Vaisala's global comparison study — provide uncertainty values that are better suited for wind resource assessment applications.

Further clarity will be required to ensure ongoing progress in the rollout of RS technology throughout the project lifecycle. In the meantime, manufacturers must commit to continuous validation of their technologies to ensure that project stakeholders benefit from a known, accurate and trusted quantification of uncertainty.

Nonetheless, as the body of evidence attesting to the quality of its data grows, it is expected that RS will come to be seen as increasingly bankable in the future and contribute prominently to securing project financing. This, in turn, will facilitate greater use of the technology, in both development and operations.

While some financial institutions have already begun to accept RS data in specific contexts, or in conjunction with data gathered by met masts, the speed at which this shift occurs more widely remains to be seen.

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A new breed of measurement campaign

Accurate measurement and forecasting data is essential if wind farm developers and owners are to ensure assets deliver the performance and financial returns expected by investors. A robust wind measurement campaign, spanning both project development and project operations, is therefore widely acknowledged as a critical component in the commercial success of a wind farm.

However, faced with challenges including growing turbine hub heights, the expansion of wind energy into remote territories and an increasingly competitive market, limitations in conventional wind measurement approaches are apparent. Industry stakeholders are demanding more versatile measurement methods that are not only accurate, but also cost-efficient and quick to deploy.

Remote sensing (RS) offers users numerous quantifiable advantages when compared with traditional meteorological (met) masts. As a result, ground-based RS technologies, such as SoDAR and LiDAR, are being used not only in combination with met masts, but increasingly as the sole method of data collection.

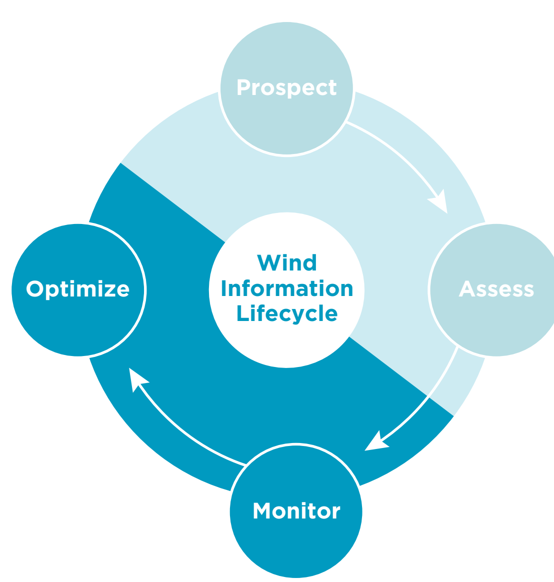
As part of a modern measurement campaign, these technologies offer an array of practical benefits, from speed of deployment — especially with regard to permitting — to setup and technician safety, cost, accuracy, mobility and reusability.

They also enable the collection of a broader range and increased depth of data than a static tower, both at greater heights, and across entire project sites. These benefits enable RS to add value throughout project development and operations, encompassing all four stages of the lifecycle of wind measurement: prospecting, assessment, monitoring and optimization.

Project development

Accurately assessing and quantifying the wind resource at a given site is critical to determining the financial feasibility of a wind project. Initial site prospecting data informs site selection, while a full resource assessment forms the basis for annual energy production (AEP) estimates that demonstrate the viability of a project for investment.

Throughout the development phases, measurement data that is inaccurate, or does not account for site-specific considerations, such as the complexity of terrain or the turbine technology to be deployed, can increase uncertainty for investors, result in project overruns and increase development costs.



RS is increasingly being used in project development, either alone or in conjunction with met towers, as a cost-effective means of reducing measurement uncertainty.

Site prospecting

Prospecting involves a high level analysis of the quality of the wind resource at a site, drawing on wind measurements typically taken over a period of between 3 months and 1 year. A number of factors, including wind speed, direction, temperature, barometric pressure, relative humidity and other atmospheric conditions are considered.

Historically, this process has involved using existing site data from wind resource maps, publicly available data and other nearby weather measurement sites, either alone or in tandem with a measurement campaign using anemometers and wind vanes. Based on this information, additional site visits are required to gather sufficient data, before a rough assessment can be made of the wind resource and expected revenues.

With the advance of RS, site prospecting can be undertaken more swiftly and more accurately, enabling more efficient identification of the most promising sites for development. The mobility and ease of deployment of SoDAR and LiDAR devices mean they can be on site within hours, providing accurate resource estimates. RS devices can be used across many types of terrain and in most climates, allowing developers to easily access multiple sites and conduct a cross-comparison.

Applications of RS in site prospecting:

- Quickly rule out sites where the wind resource is not suitable
- Undertake discreet measurements without alerting competitors
- Access remote sites and move from location to location for comparison, with minimal landowner objection
- Obtain more accurate, site-specific data at hub height

Site assessment

Following preliminary evaluation and identification of promising sites for development, a full site assessment is required to show the resource is consistent over the long-term and assure investors that the project is feasible.

Historically, this has involved construction of one or more met masts of at least 50m in height, equipped with a range of calibrated anemometers, wind sensors, a data logger and other equipment. Where and how to construct and install met masts depends on factors including site terrain, landowner permissions and planning regulations.

However, as wind turbine heights and blade lengths have increased, hub-height met towers have become prohibitively expensive in some cases, and shorter towers are no longer able to provide fully representative measurements of wind conditions. At heights of 80m and above, extrapolations are often required, which reduce the accuracy of the wind estimate at the turbine hub height. By contrast, RS devices can accurately — and more cost-effectively — measure wind speed and direction across a full profile, from lower heights up to 200m, reducing vertical extrapolation (shear) uncertainty and enabling a better understanding of wind veer. Their mobility means that they can also better account for spatial variation across the site and reduce uncertainty in wind flow modeling.

RS therefore offers greater certainty in estimating the AEP of a site and, in turn, demonstrates that site's ability to deliver stable returns to investors.

Applications of RS in site assessment:

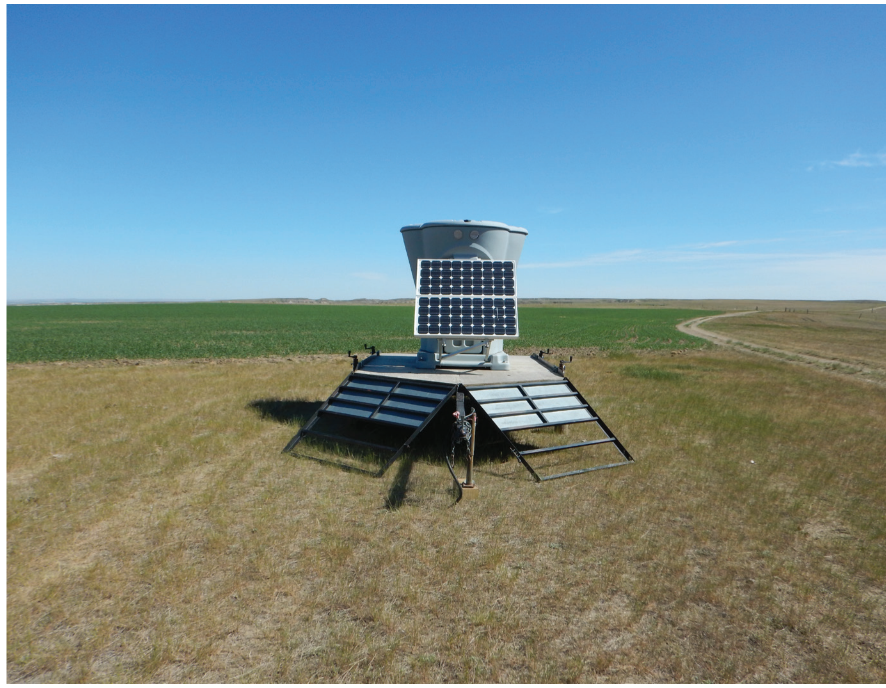
- Accurately capture a site's spatial characteristics and hub-height wind resource
- Reduce vertical extrapolation and spatial variation uncertainty
- Record data at multiple heights and locations across a single site
- Deploy in complex terrain or extreme weather conditions
- Optimize turbine layout and design

Project operations

The applications of RS do not end after a project is developed, but extend throughout its operational lifecycle. Use of RS devices can play an important role in optimizing energy production — and returns — at existing wind farms.

In particular, use of wind measurement data to mitigate the impact of loss factors related to the design of the project and the operation of its turbines — such as wind wakes, leading edge blade erosion and yaw alignment — is growing.

For these purposes, mobile RS devices provide greater flexibility than met towers because they can be moved from one project to another and also deployed at multiple locations within operating wind farms to provide targeted performance data and predict maintenance needs for individual turbines.



Credit: EverPower

Wind monitoring

Traditionally, resource monitoring at operational wind farms has relied either on nacelle-mounted wind measurement equipment or on permanent on-site met towers. The latter are typically used to conduct one-time power verification tests and to provide data to regional authorities for forecasting purposes.

Both of these approaches require measurements to be taken as close as possible to the location of turbines, and as close as possible to the turbine hub height. Meeting this requirement with static met towers poses logistical and data extrapolation challenges.

Installing and constructing additional towers subsequent to those used in site assessment is also expensive, and will often introduce inconsistencies when comparing pre- and post-construction wind measurements. Once turbines have been installed at a site, met tower data often may only be used to evaluate turbine performance in limited areas of the wind farm.

While met towers are limited in the heights at which they can provide direct measurements, RS devices — whether nacelle-mounted or ground-based — offer greater flexibility. They allow developers to measure wind speeds across the entire blade swept area of tall, modern turbines, and their mobility ensures they can easily and much more cost-effectively secure data from all corners of an operational wind farm. The range of data they provide also leads to a greater understanding of how other characteristics, such as atmospheric stability and veer, will affect the performance of turbines on-site.

Applications of RS in wind monitoring:

- Efficiently record wind speed and direction across the turbine blade sweep
- Measure wind speeds at multiple locations across the site
- Collect additional data on effects of atmospheric stability and veer on turbine performance
- Accurately forecast production for scheduling turbine downtime and maintenance
- Meet grid operator reporting requirements

Project optimization

The profitability of wind assets depends on maximizing power production and minimizing repair and maintenance costs. Wind data plays a key role in improving production and reducing the need for maintenance over a wind farm's lifespan.

Hub-height measurements are required for many optimization procedures, but met towers are unable to measure at greater heights without significant jumps in cost. The range of locations in which they can be installed is also limited, and permitting challenges have posed an obstacle to their construction in many regions. Permitting for met towers often takes many months and, depending on the market, requires approval from regional bodies, such as the Federal Aviation Administration (FAA) and the Air Force in the US, and other civil aviation authorities worldwide.

Met masts are also prone to mechanical failure and collapse as a result of weather-induced conditions such as icing, windstorms or tornadoes. As a result, it has often been a slow, expensive and arduous process to use met towers to assess and optimize project performance.

The traditional use of met masts in power performance analyses depended on the assumption that a single-point, hub-height wind speed was representative of wind over the entire turbine rotor. Even if measurements can be taken at hub height with a met mast, this approach may fail to account for phenomena including wind shear, wind veer and low level jets.

The mobility and ease of deployment of SoDAR and LiDAR allows them to assess wind speeds at a range of heights and for individual turbines. In doing so, they are able to contribute to more accurate analysis of power performance, in conjunction with a reference met tower — as outlined by the recent IEC 61400-12-1: 2017 standard (see ‘Validating the Technology’ p. 9).

These power performance applications allow analysts to accurately determine whether a turbine is delivering the expected level of power, and, if not, identify whether warranty servicing or financial compensation may be needed. Given the financial implications of such tests, the technical requirements specified by IEC 61400-12-1 are stringent and it may be around 18 months before RS devices are routinely used for warranty-level power performance testing.

Credit: Innergex

Applications of RS in project optimization:

- Analyze yaw, wake and other loss factors
- Develop mitigation strategies to minimize energy losses
- Identify where investment in upgrades and new equipment may be needed
- Conduct wake studies, noise studies and turbine condition monitoring

Comparative benefits of remote sensing vs. met mast for project development and operations

DATA	
Remote sensing	Met mast
Gathers hub-height information efficiently from multiple sites and locations within those sites, without financial and practical constraints limiting the amount of data that can be gathered	Accepted standard of bankable data for wind measurement campaigns
Provides accurate wind speed and wind direction data at heights of up to 200m	Minimal data interference from environmental factors such as atmospheric absorption
Eliminates dependence on extrapolated wind flow models and the uncertainty they introduce	
Reduces overall time required to assess sites for suitability	

EASE OF USE	
Remote sensing	Met mast
Easy to deploy and transport across and between sites	Familiar technology and established best practices for maintenance
Limited setup/construction requirements, can be up and running within a few hours	
Robust and operational in extreme weather, can be easily stored to avoid more severe conditions	
Deployable in remote or complex terrain	
No planning permission or permitting needed	

COST	
Remote sensing	Met mast
Economical to operate and maintain	Economies of scale may reduce up-front costs for installation, maintenance and component replacements
A capital asset that can be redeployed at no extra cost to support multiple functions at multiple sites	Familiarity of technology may increase efficiency of data processing
	Modular setup allows choice of sensors

Reducing the risks

As is the case with all project-critical infrastructure, the installation and operation of wind measurement and monitoring equipment at wind farm sites carries inherent financial, logistical and safety risks. Managing these risks appropriately is essential in avoiding incidents that both constitute a threat to the safety of the workforce and may lead to cost overruns and delays with a significant impact on project finances.

Insurance claims relating to such incidents are relatively rare, but a number of high-profile losses worldwide involving met towers illustrate the susceptibility of conventional measurement technologies to damage and failure — and the severity of the associated financial impact.

The typical cost range for claims related to met towers is between USD $12,000 and $140,000, depending on a number of factors. These claims range from high frequency, lower severity claims, such as icing and snow damage, to low frequency, higher severity losses including tower collapse caused by high winds and/or human error during construction.

The deployment and operation of ground-based and nacelle-mounted SoDAR and LiDAR units, however, have their own risks and these smaller devices may be more vulnerable to security threats such as theft.

Below is GCube's assessment of the five most significant sources of risk involved in the use of both met towers and RS devices. Each of these factors will need to be considered when deciding on the methods of wind measurement that best meet the needs of a project.

1. Safety — While no centralized and comprehensive database of wind farm accidents currently exists, falls associated with working at height, collisions with objects that fall from height, heart attacks associated with climbing project infrastructure, and electric shock and electrocution, are commonly cited as the core health and safety hazards in wind farm development and operation.[4] Each of these hazards applies for technicians undertaking construction and maintenance of met towers.

From an insurance perspective, third-party liability considerations must also be made, given the potential threat posed by a met tower collapse to people and property in the vicinity.

Met towers can also pose a hazard to aviation, and, in the US, towers over 200 feet must be registered with the Federal Aviation Administration (FAA).

Credit: GCube Insurance Services

[4] Wind Energy Sector: Occupational Health and Safety Risks and Accident Prevention Strategies, IRRST, 2015: https://www.irsst.qc.ca/media/documents/PubIRSST/R-858.pdf

As towers increase in height, FAA rules may lead to further permitting challenges that delay project timelines and increase costs.

Use of RS devices largely avoids the above safety considerations and there is little evidence in the public domain of serious health and safety incidents involving LiDAR and SoDAR. However, safety risks in transit and installation — particularly in areas of complex terrain, or when the equipment is nacelle-mounted — should still be evaluated. Misuse of complex, heavy electronic equipment such as a RS unit can be dangerous to both the operator and the device, and training in its correct use and transportation is essential.

2. Extreme weather — Strong winds constitute one of the main threats to the successful operation of tall met masts, and have been determined as the root cause of several notable incidents of tower collapse, alongside damage to individual components.

More broadly, adverse weather conditions, including storms, ice, fog and extreme low temperatures can restrict access to met towers and impede instrument maintenance and data collection. Icing can also cause damage to and corrosion of sensor wires, leading to financial losses and insurance claims.

Extreme weather is also known to affect the operability of RS devices, and instances of loss or damage to units exposed to strong winds or lightning have been recorded. As a rule, however, these risks are more straight forward to mitigate for easily accessible RS units and do not translate into substantial losses.

3. Security — Vandalism to met towers, typically motivated by strong local opposition to wind farm development, has resulted in claims worth tens of thousands of dollars. Investment in appropriate security measures must therefore be made in order to prevent damage to and theft of components.

While RS devices occupy a lower profile, they may constitute an easy target for theft, given their mobile nature. Secure storage is recommended during periods of inactivity, and, during operation, supervision (either through remote monitoring or periodic visits) is essential.

4. Construction — Met towers require secure foundations on which to build; however, there have been a number of instances where collapse of a mast during high winds has been attributed to human error during construction.

Given the scale and complexity of these structures, there is a need for high-quality local labor, which may be more difficult to source in emerging markets with less experience and familiarity with met mast construction. Standard construction risks must also be accounted for during the erection of a mast, such as crane operation and working at height.

For RS devices, installation is quicker and more straightforward. However, as mentioned above, deployment in more complex terrain elevates risks of equipment damage during the process.

5. Supply Chain — The installation and commissioning of met towers is a complex process, involving significant lead-times. Mismanagement or loss of components can extend this process and add significantly to downtime during the time-sensitive measurement phase. Other risks arise in the transit of large or sensitive components, and siting towers in complex or remote terrain can result in further logistical challenges.

As the standard measurement technology for the majority of developments worldwide, however, met masts currently benefit from a more robust global supply chain than RS devices, which may enable swifter repairs and replacement, once installation is complete equipment damage during the process.

While RS devices benefit from short installation times, should a failure occur, technical repairs require the attention of a specialist technician. Currently, the majority of RS manufacturers are based in Europe and the United States, which can result in longer periods of downtime.

Article contributed by GCube Insurance Services Inc. (GCube). GCube is the leading specialist insurer of renewable energy projects worldwide.

The industry view

Progress towards the adoption of remote sensing (RS) worldwide depends on the readiness of individuals and organizations to drive forward and pioneer new industry practices. The key proponents of the versatility and value of RS are therefore the developers, financiers, independent engineers and owner/operators of wind farms who use RS devices and the data they produce every day to identify, develop and manage assets. Their voices are essential in realizing an industry-wide shift towards a higher standard of wind measurement.

Experience of RS in the wind industry varies considerably in terms of depth and breadth. In the following series of interviews, some executives have experience using RS across a range of applications in development and operations, while others have expertise in specific use cases.

Equally, Vaisala has spoken to experts who have been working with RS data for close to a decade, and others who have been using it for shorter periods of time — or for whom the technology is still under evaluation. Each of the executives in this interview series has used RS data to better understand the wind resource on wind farm sites to inform site selection, secure financing or increase revenues.

Measurement and finance

Could you briefly summarize the activities of Actis in the wind energy sector, and what do you do in particular?

Actis is a leading investor in growth markets across Africa, Asia and Latin America, with US$13bn raised since inception. Assets include an extensive portfolio of energy investments, and we are currently involved in 10 energy platforms, six of which are focused on developing and operating windenergy assets, with portfolios totalling from 500MW to 1.5GW.

Although our role in these projects is primarily as an investor, we are active managers, with participation through both the boards and steering committees, which leverages our extensive experience as a private equity investor in the energy sector. I have a leading role in the operations team. My responsibilities center on the

Liam Smith

Investment Principal, Actis

Actis is a leading investor in new and rapidly expanding renewable energy markets around the world. We invited them to tell us about their experience of RS, and its applications for the compa-nies in which they invest.

Vaisala spoke with **Liam Smith**, Investment Principal at Actis, about how energy businesses owned by Actis use RS technology, the role the technology plays in financing decisions, and the benefits that can be realized for the industry by wider awareness and understand-ing.

technological and commercial issues relating to investment in energy — and so I need to keep my technical understanding of the sector constantly up to date.

How important is accurate wind data for Actis in its funding and investment decisions?

Accurate wind data is critical — it enables us to better forecast the revenue stream of a project. In turn, this determines the profit-ability of the whole operation; capex can only be assessed in light of revenue; thus, the under-standing of the wind regime is just as important (if not more) than the underlying costs.

Though it's such an important element of the financial model, getting accurate wind data is extremely difficult and failure to do so can cause estimates to go very wrong. In investment projects, therefore, it's essential to employ precise measurement techniques.

What is your experience of RS?

Within each platform, developers and operators are responsible for running their own projects, but, in terms of our initial investment, RS is fundamental. Measurements from RS devices are used to complement our own wind resource assessments.

The growth markets in which we operate include a number of challenging sites. Depending on the complexity of the project, you wouldn't want a wind turbine development to be more than one or two kilometres away from the nearest wind monitoring site. With fixed met masts, which are likely to be further away than this, that's difficult, and so we use RS to complement them. RS is also used to calibrate shear profile, as some met masts do not reach hub height. Wind shear can be a significant threat to successful yield estimates, and RS gives more data points, enabling a better understanding of the shear profile.

How long have you been working with RS data?

With Actis, for around six years. The first time was as part of an investment in Jeffrey's Bay Wind Farm, in South Africa. Our project partner there used RS as standard in the development phase.

I also worked with RS during previous roles in New Zealand (over 10 years ago), although with a very different function. Then, RS was more commonly used for short time periods, helping developers to understand wind turbulence and shear profiles at specific sites in areas of complex terrain. Now, it has become a tool for site prospecting and monitoring — an altogether more useful function.

What are the key advantages of RS technology in the territories in which Actis operates?

The main advantage for us is versatility. Not only can RS devices be deployed in more remote, difficult to access locations — a common challenge across our core markets — they can collect data at greater heights and allow a better understanding of shear profile.

Does Actis use RS data as the basis for funding projects?

We only use RS data in combination with measurements from fixed masts. Used alone, there wouldn't be sufficient certainty about the calibration of the RS unit, which is fine tuned using met masts.

However, RS data certainly contributes to decision-making. It increases certainty, which in turn increases leverage, which in turn increases equity returns. There is a history of people getting investments wrong, but RS allows

Morinhos Wind Farm, Brazil. Credit: Actis more confidence, which has ultimately resulted in participation and investment approval for some projects.

Nonetheless, an investment decision cannot be attributed to a single factor — it comes down to corroborating a wide range of risks and rewards.

How confident are you about financing projects using only RS data?

As I mentioned, at the moment we only use it in combination with met masts. In the future, I can't see why we couldn't use RS data on its own — though challenges associated with calibration would first need to be overcome.

We get around this currently by using multiple levels of redundancy and calibration with met masts. There is of course some redundancy in this approach, but if only two pieces of equipment, such as a SoDAR and a LiDAR unit, were used, the chances of error would increase.

An additional limitation is the need to convince the project finance lender about the reliability of a project. This can be achieved by periodic testing and certification, but winning the confidence of the bank is even more complicated.

Do you expect the proportion of projects financed using only RS data to increase in the future?

With certifications and third-party peer review assessments of the technology, it may be possible to finance projects using only RS data in the medium to long-term. As a rule, RS data makes better financial sense than erecting a met mast for smaller wind energy developments, of say 3MW. For larger developments, of 50MW and more, the additional reliability afforded by met-mast data would justify the cost of their construction. Between these two extremes, the business case is more complex to assess and will depend on the specifics of the project.

Do you view projects built using only RS as more or less risky than projects built using met towers?

I think that a complex site assessed with a single mast would be more risky than the same site assessed with two RS units — providing these devices were cross-calibrated across the site, in order to properly understand the wind regime.

However, I wouldn't view either option as a reliable investment, as there is too much uncertainty involved. Banks, moreover, would be less open to the nuances and would trust their technical advisors. As such, a combination of the two is still the least risky approach.

How open is the investment community as a whole to the use of RS data in the financing of wind energy projects?

There's a lot of ambivalence. The Tier 1 developers are much more attuned to the risks and complexities of wind monitoring, while the investment community, especially minority investors, are far less experienced and aren't incentivized to learn about the benefits of RS technology. In Europe, furthermore, there is a history of projects being accurately characterized by met masts, in contrast to territories with more complex wind regimes, such as Chile. If wind farms start to be constructed in these more remote locations, on the other hand, where wind regimes are more complicated and the scale of possible development is smaller, then the use of RS data will probably become more attractive.

What steps still need to be taken by RS providers or independent engineers to increase the confidence of wind energy investors in the technology?

Firstly, there needs to be more transparency when it comes to the comparative accuracy of data from met masts and RS devices. A campaign comparing error rates from both technologies would enhance confidence and understanding of the advantages of RS. The current absence of a robust data set, however, leads stakeholders to assume the worst.

A secondary warranty of the accuracy of this data would also be appreciated — and an accuracy guarantee would be fantastic, but this is likely to be prohibitively costly.

Reesa Dexter

Senior Energy & Performance Specialist, DNV GL

DNV GL's **Reesa Dexter** spoke to Vaisala about the uses of RS in site assessment and asset optimization, highlighting the importance of validating RS technologies on site, and the growing range of acceptable uses for the devices. As a recognized technical authority, **DNV GL** issues guidance on the standard use of RS technology on operational wind farms, and sites identified for development.

Could you briefly summarize the activities of DNV GL in the wind energy sector, and what you do in particular?

DNV GL is recognized as the world's leading technical authority in onshore and offshore wind power generation for over three decades. DNV GL provides a complete cradle to grave consultancy service for all wind industry stakeholders. This includes, and is not limited to: preconstruction energy assessment, measurement services, environmental and permitting services, power performance testing, turbine operation services, asset optimization and SCADA services, wind forecasting services, independent engineering services, and transmission planning.

My title is senior energy and performance specialist at DNV GL. Since 2016, I have primarily been responsible for project management and analysis of wind turbine power performance tests. Before this position, I worked for five years as a preconstruction energy analyst at DNV GL.

How extensive is your personal experience of RS?

I have personal expertise in ground-based SoDARs and LiDARs, with limited experience in offshore and scanning LiDARs. I began installing and validating SoDAR data back in 2006. Since then my expertise in RS technology (SoDAR and LiDAR) has grown, and I have overseen and advised on wind energy RS campaigns globally. I am also a member of DNV GL's global RS working group.

How extensive is the experience of DNV GL in deploying and analyzing data from RS devices?

DNV GL has extensive experience with the use of RS devices in power curve performance tests, wind resource and energy production assessments, and nacelle-mounted measurements. DNV GL has undertaken many gigawatts of onshore and offshore energy production assessments in which SoDAR or LiDAR devices were considered. DNV GL has performed over 20 power curve performance tests using LiDAR devices.

DNV GL publishes offshore and onshore standards and recommended practices which are widely accepted in the renewable energy industry. These include significant standards and recommended practices in the field of RS devices.

As an independent consultant, how confident is DNV GL about supplying RS data as a basis for financing and development decisions?

For RS data to be used confidently for financing and development decisions, the methodology must follow relevant standards, industry best practices, manufacturer guidelines, and meet some or all of

Credit: Finnish Meteorological Institute the goals of a wind resource assessment. The data collected must be of high quality.

What role does RS data play in improving the certainty of preconstruction estimates?

There are two fundamental ways in which RS measurements may be used to reduce the uncertainty of preconstruction energy estimates. First, the technology can be deployed adjacent to a meteorological mast to confirm the wind shear extrapolation assumptions. This approach utilizes the RS device as a supplement to a cup anemometer measurement.

Depending on the RS technology, the second way to reduce uncertainty is to use it as a substitute for a traditional met mast, or help inform the wind flow across a site. This approach may be taken in simple or moderately complex terrain when certain minimum requirements are met in advance of deploying a RS device in a standalone measurement configuration or near other masts.

What are the minimum requirements for this kind of approach?

For a preconstruction energy assessment, there are several minimum requirements for using a RS device in place of a traditional met mast, or to help inform the wind flow across a site. These include the following:

- Successful completion of an on-site verification in which IEC verification KPIs pass.
- There are no significant wind speed biases (≤ 2%) between the cup anemometers and the RS measuremen during verifica-tion.
- Based on the analysis above, the approach reduces the overall project uncertainty.
- For vertical LiDARs and SoDARs, the chosen stand-alone site has similar wind conditions to the verification site.
- The chosen vertical LiDAR, SoDAR or scanning LiDAR sites are representative of the nearby turbines and are within a reasonable distance of at least 2 km.

If the data at the standalone location is deemed to be of high quality, which includes following industry best practices and manufacturer guidelines, such as set back from obstacles, then it can be used to reduce the pre-construction horizontal wind flow uncertainty.

Does DNV GL only use RS data in conjunction with measurements from other sources, or have SoDAR and LiDAR been used as the sole source of data for any projects?

Typically, RS data is used in conjunction with meteorological mast measurements, and this is the most certain approach. For some projects, DNV GL has completed wind energy assessments with only RS data, or with an RS device adjacent to a short reference mast. It should be noted that the latter method has increased risk and DNV GL prefers the use of both traditional and RS measurements for wind measurement campaigns.

How confident would DNV GL — and its client base — be about using only RS data?

The application of a RS-only campaign is specific to the project scope and site conditions. For a DNV GL Stage 3 RS device, data may be used quantitatively within formal wind speed and energy assessments with only limited or no site-specific verification against conventional measurements. It should be noted that only a few commercially available RS devices have reached Stage 3, and only for benign wind flow conditions. Additionally, DNV GL notes that the second edition of the IEC 61400-12-1 prohibits standalone RS devices for power performance testing.

What are the main requirements for a DNV GL Stage 3 device?

A DNV GL Stage 3 device is considered proven for use in the assessment of wind farm sites. The precision and accuracy of a RS device must be demonstrated in all relevant conditions at the project site. The data may be used quantitatively within formal wind speed and energy assessments with only limited or no site-specific verification against conventional measurements. The device must be commercially available and have performed well at a wide range of sites with different meteorological characteristics. The RS has undergone several verification tests to prove that the unit can meet all verification (i.e. KPI) requirements at several test facilities with the same, or similar, level of uncertainty as cup anemometry.

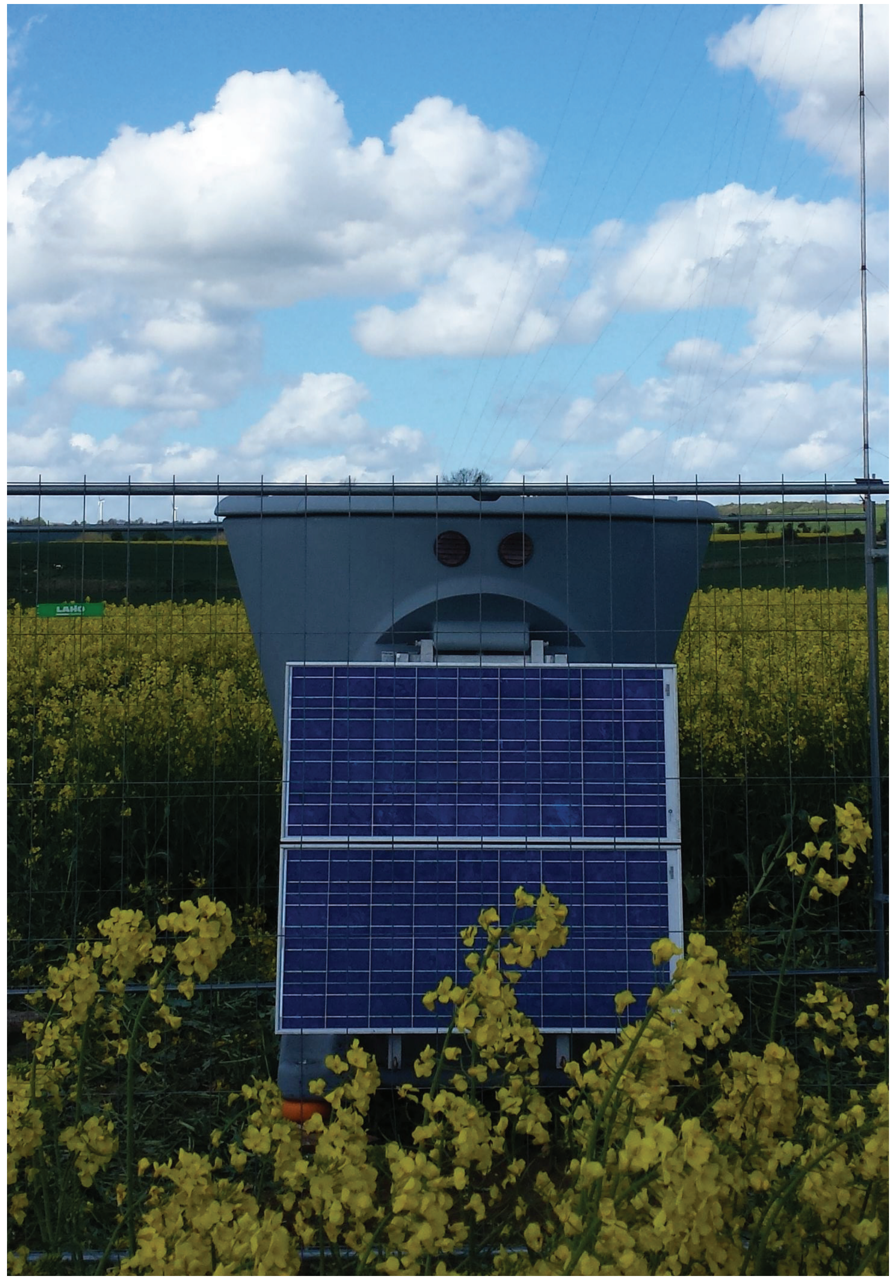
> ***The device must be commercially available and have performed well at a wide range of site with different meteorological characteristics.***

What assurances do you think the industry still needs about the reliability of RS data? What steps do consultants and RS manufacturers need to take?

The main concern for the industry is whether the RS data are at an expected level of accuracy and certainty at the measurement location. To improve confidence in the measurement, the technology must be installed correctly, the measurement campaign must follow industry best practices, including on-site verification of the RS device(s), and the location and the campaign are in line with the capabilities of the technology.

DNV GL has published and will continue to publish standards and recommended practices that help the industry and investors better understand the technology, and hence build confidence in the use of RS data in wind measurement campaigns. Manufacturers can continue to build industry and investor confidence by providing clear guidance on the operation of their device and openly communicating any limitations.

> ***Manufacturers can continue to build industry and investor confidence by providing clear guidance on the operation of their device and openly communicating any limitations.***



Credit: Nordex

How do you see the role of RS changing in wind development and operations over the next five to ten years?

RS technology has a place in the wind industry and will continue to become more common. The utility of the technology is evident as it is now recognized in wind measurement standards (e.g. IEC 61400-12-1 ed. 2, as mentioned previously).

Greater hub heights in recent years have made the economy of installing near or at hub height masts expensive, and therefore, the employment of collocated SoDARs or LiDARs with 60m masts is more economically attractive. Also, given several studies illustrating the benefits of nacelle-mounted LiDARs, this technology will likely become increasingly popular over the next decade.

Development and operations

Julia Clement

Head of Wind Resource Assessment, Nordex Acciona Windpower

Nordex Acciona Windpower, while primarily known as a turbine manufacturer, has a strong track record in wind project development, with a focus on the French market.

Head of wind resource assessment for the project development team **Julia Clement** provided her perspective on the core advantages of using SoDAR and LiDAR, and on how evolving standards will facilitate acceptance of RS data by third party consultants and banks.

Could you briefly summarize the activities of Nordex as a developer in the wind energy sector, and your current role?

Nordex (now Nordex Acciona Windpower) is naturally well-known as a manufacturer in the wind energy sector, having developed and sold multi-megawatt turbines for the past 17 years. However, we are also actively involved in the development of new wind farms.

We first started developing wind farms in France in 2001, and then exported this activity to other markets such as Poland, the United States, or South Africa. Currently our main focus is on the French market. Having started out at Nordex as a wind engineer seven years ago, I am currently Head of Wind Resource Assessment for the project development team.

How extensive is the team's experience using RS devices?

Nordex France Development has been using RS devices since 2009 when we purchased our first LiDAR unit. We now own two LiDARs and three SoDARs, which we use predominantly for pre-construction estimates.

For four years, we have also been using our RS units for acoustic assessments to ensure that our projects are in line with noise regulations in France.

Why do you use RS for your projects? What are the core advantages?

The main function of our RS devices is to help us reduce uncertainties in our pre-construction energy assessments. Initially, many of our met towers were only around 50m–65m in height, and there was a need to reduce the uncertainty of our vertical extrapolations — SoDAR and LiDAR systems, which can measure at hub height, are very useful for this.

On top of this, there are a number of logistical advantages. RS devices are easy to deploy and install, which can be done in a few hours, and installation costs are lower. Mobility is another key advantage, and the units can be moved from site to site, which is very convenient for wind shear validation and increases the amount of data we have available to us.

Besides, in France there's no need to obtain authorization or planning permits, and the device can be deployed with the landowner's agreement. SoDARs and LiDARs are less visible than a met tower, too, which means that there is a lower risk of vandalism if we are facing opposition for a project — and fewer people will recognize what they are. LiDAR has an additional advantage in this respect, since it doesn't emit sound.

Have you experienced any limitations or drawbacks?

Power consumption poses a challenge, especially for our oldest LiDAR, and, while the units themselves are reliable, we have lost data due to issues with the reliability of the power source. Solar panels can be a target for theft.

In terms of the measurements themselves, we occasionally need wind data at heights below 40m — both to measure at the lower blade tip and for our acoustic assessments, for which the ability to obtain data at 10 or 20m is useful. Most RS devices — with the exception of some LiDAR models — can't measure below 40m.

We currently don't use RS devices in complex terrain due to reliability concerns — but we are aware of efforts to address this using Computational Fluid Dynamics (CFD) modeling.

Securing acceptance of the data by third party consultants and banks is also a challenge. We sell our wind farms once they are permitted, and need to obtain an independent assessment of the project and its annual energy output in order to do so. Met masts are still the reference point for wind measurement campaigns and convincing independent consultants to use RS data for assessments remains challenging.

Will the new IEC guidelines for power performance testing help drive acceptance of RS data?

The new IEC [61400-12-1 ed. 2] guidelines focus specifically on power performance testing, but we are already seeing consultants applying these to wind resource assessment (WRA). They should help to increase the overall standard of validation procedures for RS units — for example requiring validation against a tall met mast — and thus, facilitate acceptance by third parties and banks.

> ***The new IEC guidelines focus specifically on power performance testing, but we are already seeing consultants applying these to wind resource assessment.***

However, funding an independent validation report for each device can be expensive — costing €7–10k — which is unfortunate, since one of the main advantages of RS units is their low cost. So refinements to the IEC guidelines — or a WRA-specific version that would enable developers to use the technology in WRA campaigns without this additional cost would be welcome.

Do you expect the number of projects you develop using only RS data to go up in the future?

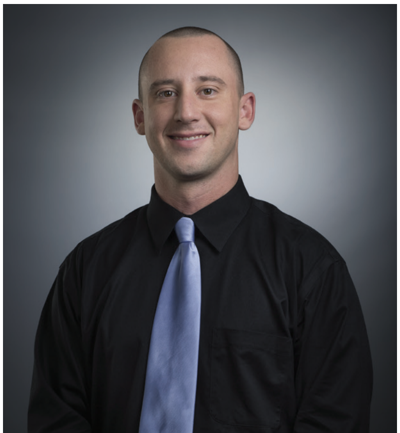
Yes, we are already doing this — we currently have one project under development without met masts, exclusively using measurements from a Stage 3 LiDAR unit. This data will ultimately be used to finance the project.

I think this will become increasingly common across our development sites. Since they are mostly in simple terrain, the quality of RS data is very good, and we can obtain data at hub height without needing to install a large mast. The data is increasingly being accepted by consultants, so it's an encouraging situation and we would expect to use standalone RS devices more and more in our project

Do you view projects developed using only RS as more or less risky than projects using met towers?

While met masts are still seen as a reference point for financing decisions, I would say it is no longer risky to use a Stage 3 LiDAR system as a standalone measurement technology, and would expect uptake to increase over the next five years or so.

Using SoDAR on its own is still risky, but, providing it can achieve the same level of validation, it could provide a more cost-effective alternative to LiDAR, with a lower purchase price and lower power consumption.



Nathan Lehman

Energy Analyst, Apex Clean Energy

Apex Clean Energy is a utility-scale wind energy developer, owner and operator with a portfolio of projects across the United States.

We spoke with **Nathan Lehman**, an Energy Analyst at Apex. He told us about the process Apex goes through to validate RS devices for specific sites, how the technology has reduced costs and timelines for site assessments, and why he would like to see wider adoption of the technology.

Could you briefly summarize the activities of Apex in the wind energy sector, and what you do in particular?

Apex builds, owns and operates utility-scale wind and solar power facilities, and has brought nearly 1,700MW online over the past two years. We oversee projects throughout the entire lifecycle, from greenfield prospecting right though to operations, operating both our own projects and assets developed by other firms. I arrived at Apex in January 2016 as a Met Tower Coordinator, before moving into a broader Energy Analyst role. I previously worked as a lead technician for SoDAR devices, and have also had experience of RS during the course of my meteorology and mechanical engineering degrees.

How extensive is the experience of Apex in deploying and analyzing data from RS devices?

Our experience of RS is quite extensive; we have 16 SoDARs in our fleet, and between them these have amassed over 76 years' worth of wind data.

We use RS for three main purposes. Firstly, for wind shear and veer verification, where we deploy a SoDAR unit for 12 months in conjunction with a met tower, before extrapolating the data to hub height.

Once this is done, we consider the SoDAR unit to be verified as a standalone measurement device for that site, and use it to provide a range of measurements across the site.

Lastly, we also use SoDAR for resource verification where we need a quick and economical way to validate the assumed resource at a site, before we put significant amounts of money into a project. Once enough data has been gathered over the course of three to six months, we can decide whether to end our interest in a site, or install a met tower for the next phase of measurement.

In addition, given its capacity for high-speed data transfer, we have one SoDAR unit dedicated to demonstrating data connectivity in the ERCOT region.

Why do you use RS for your projects?

The cost benefits are a big factor; it's much more economical to get wind speed data from a SoDAR device than, say, a lattice mast, and a thousand times easier. We can relocate a SoDAR for as little as $10,000, while a tall 100-meter met mast would cost up to $135,000 to install. Using SoDAR also involves much quicker lead times; it can take up to a year to get a met mast installed.

In a perfect world I would have a fleet of 50 SoDARs and use fewer met masts, but we will have to wait until third-party confidence and acceptance of the data increases further. Currently some third-party analysts are more accepting than others.

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What validation protocols has Apex implemented for using RS?

As mentioned above, we have carried out collocation work and correlation studies, placing the SoDAR device 50–70m from a met tower and comparing data from the two. We then use backend calculations to determine the source of any data uncertainty.

What are the main drawbacks of using RS technologies? How do these compare with met towers?

Currently the main challenge is the issue of third-party confidence in RS data, which puts limitations on its use as a standalone device in financing. There have also been occasional design and performance issues, and we have found that the units are not rodent-proof — which has caused us problems at greenfield sites where mice and rats have attacked the wiring. Snowfall can also affect performance for both SoDAR and LiDAR.

These issues aren't experienced with met towers — but they have their own reliability and maintenance challenges, such as data loss from icing situations and corrosion to sensor wires. These are typically quick fixes, due to the modular nature of towers.

Do you expect the number of projects you develop or operate using only RS data to go up in the future?

No, the industry is too wedded to physical measurements. I certainly can't see a significant increase in the next ten years, possibly ever. There is an issue with acceptance of the data, with a lot of pushback against the data quality and reliability. This is unlikely to relent to the point where met towers aren't the leading tool for resource measurement. Even as hub heights increase, the industry will likely continue to use smaller met masts in conjunction with RS devices.

There is also an issue with production. We have around 260 met towers in our fleet, and I don't think SoDAR and LiDAR manufacturers would have the capacity to scale up to meet the demand of Apex and the wider industry if the RS market ever reached this scale. That said, I hope I'm wrong and that acceptance for RS devices and data does increase.

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Darin and Ryan

Two senior engineers at a US utility company

Vaisala spoke with two senior engineers at a US utility company with investments in three wind farms, as well as operations in natural gas and hydro-electricity. They talked about their experience using RS technology to manage the operational efficiency of the wind farms in their portfolio.

Could you briefly summarize your company's activities in the wind energy sector?

We are a leading US-based utility company currently operating three wind facilities. Outside of wind, we own and operate gas and hydro facilities, distributing gas to nearly 800,000 customers and electricity to over 1 million customers.

What are your roles and how long have you worked in them?

Darin: I am a mechanical engineer and have worked in our central engineering office for the past eight years. As well as wind, I also support our other generation facilities, including natural gas and hydro.

Ryan: I am currently a senior engineer working exclusively on our wind projects, supporting all three of our wind farms. I previously worked as a wind turbine technician, so have experience of working on wind turbines themselves. I've been at the company for ten years now, and was involved in the construction of all three of our wind facilities.

How extensive is your experience deploying and analyzing data from RS devices?

We own a single Triton SoDAR unit, which we first used during construction, and for subsequent power performance studies at one of our wind facilities. Since then we have deployed the unit at our two other wind farms to support operations and performance optimization.

How is RS data helping you diagnose and optimize site performance?

We are currently attempting to use RS data to verify the effect of blade leading edge protection (LEP) on turbine performance. We deployed our SoDAR device and collected data from before and after the LEP was applied to compare and measure the extent to which the performance changed. Preliminary results have been analyzed, and more data is being collected.

At another of our sites we had damage to the yaw and pinion gears on a turbine, and installed the SoDAR unit to analyze how wind shear and conditions at that location might have contributed to this damage. We have also used it to conduct power performance tests on turbines that have been operating for five years — this gives us a sense of any drop-off in their performance.

One other application is during power outages. When our turbines are offline and met towers de-energized, we can still use SoDAR to measure wind speeds and calculate lost generation, as long as the device is already on-site.

Why do you use RS for your projects?

We originally invested in RS to carry out studies prior to constructing one of our wind farms, but since then we've reused it for a variety of purposes and to gain insights that we otherwise wouldn't have spent money on. As such the main advantage of our SoDAR unit is arguably its versatility — and that we can deploy it as we wish to extract maximum value.

A further advantage is the ability of RS to access remote locations. At one facility, located on a ridge, we deployed the SoDAR device in complex terrain where it would have been very difficult to construct a met tower.

When compared with a met tower, the added benefits of SoDAR include its ability to transmit data wirelessly, which makes data collection very quick and straightforward. The communications equipment used in met towers is often very old, so actually getting the data can sometimes be difficult, especially during outages. One other clear benefit of RS over met towers is that they are not a hazard to aviation — so there is no need for a Federal Aviation Administration (FAA) light, for example.

"A further advantage is the ability of RS to access remote locations. At one facility, located on a ridge, we deployed the SoDAR device in complex terrain where it would have been very difficult to construct a met tower.

What are the main drawbacks of using RS technologies?

There can be issues with environmental interference and noise affecting data collection, depending on where the RS device sits. This interference can come either from the immediate area or if the device is mounted on a metal structure or trailer. As a result, there are some limits on where you can set it — you can't put it next to a highway or somewhere where there's a lot of road noise, for instance. This can be a limitation, but it's not one that we have encountered often.

There are guidelines on where to place the SoDAR, but it would also be good to have the option of further training on how to do so. Training in the use of RS data more generally would also be beneficial. Currently there is no one resource we can draw on, and having this training in place would help make the argument for wider use of the technology as we could more easily teach others to use it.

What are the main drawbacks of using met towers?

The maintenance and replacement of anemometers on met towers means working at great heights. This means there is a need for specialized contractors who can only carry out this work during particular periods of time. There is very limited access to towers during the winter, for instance, due to snow and ice, and there are also issues where cabling can come loose and cable ties fall off. So it is much safer and more cost-effective to carry out repair and maintenance work for a SoDAR.

Do you expect the number of projects using only RS data to go up in the future?

Our opinion is that RS has huge advantages in being easy to deploy, self-contained and reliable. As the data accuracy continues to get better and is increasingly accepted by the industry there will be a big opportunity to increase the use of RS devices. Another key factor leading to increased deployment is likely to be their ability to measure wind speeds at heights for which it will be very expensive to build a met tower.

What do you think financial backers would need to see to have greater faith in RS data?

The latest IEC code for power performance testing still requires the use of a static met tower nearby for comparison with RS data. If a new code was released in the near future that indicated you could rely solely on a RS device, then this would be a big step forwards in encouraging financiers to look on RS data more favorably.

This would also help to pave the way for standalone deployment of RS technology — which would be especially beneficial, as, once projects become operational, met towers are no longer critical and act principally as static weather stations.

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Wind energy assessment around the world

Takahiro Oyagi

Deputy Manager, Engineering Department, Eurus Energy

Eurus Energy is the leading wind energy company in Japan, with investments in wind and solar farms in the US, Europe and Asia.

Eurus Energy's **Takahiro Oyagi** told Vaisala about the need to use RS in Japan, where building codes limit the height of met towers and make it more difficult to collect the right data for a wind farm. Oyagi, who is a deputy manager in the engineering department at Eurus, spoke about how proving the accuracy and capabilities of RS in complex terrain will drive higher adoption rates in Japan.

Could you briefly summarize the activities of Eurus in the wind energy sector, and what you do?

Eurus Energy is Japan's leading wind energy company. We currently operate 29 wind farms with around 680MW of capacity. I have worked for two years in my role as a wind resource analyst.

How extensive is your experience of RS?

Eurus started using data collected by LiDAR in our wind resource analysis two years ago. As such, I have been working with LiDAR technology for two years now, and in the past three months I have also been working with SoDAR.

What is the extent of your deployment of RS technology in Japan?

I have personal experience using these RS devices on working wind farms, and on prospective sites in forest and port locations.

What are the main practical advantages of using RS technologies in Japan?

In Japan, it is difficult to construct meteorological masts with a height of 60m or more because of building codes. However, we need to be able to measure wind at these heights on account of the growth in wind turbine hub heights in recent years. RS devices are useful in this respect.

What other market-specific advantages might RS have for Japanese project developers and operators?

The main advantages for developers and operators in Japan are the mobility of the technology — the same device can be used in various locations — and its ease of installation, which enables it to be deployed more easily than a meteorological mast.

What are the main drawbacks of using RS technologies in Japan?

It is still not possible to receive a loan to build a wind farm based exclusively on RS data. Lenders remain skeptical because there has been insufficient verification of the accuracy of RS for uses in complex terrain. As such, we have never used RS data to arrange project finance.

What protocols has Eurus implemented for using RS in Japan?

Eurus uses RS to collect and validate reference data for meteorological masts. The validation of met masts is the most important function of RS for us. We currently only use RS in non-complex terrain.

Outside of Eurus' activities, how common is the use of RS in Japan?

RS is still used less than in Europe and the US, but its use has been increasing in recent years.

What do you think needs to be done to improve adoption of the technology in new wind energy markets, like Japan?

In Japan, many wind turbines are located in areas of complex terrain. In order to improve the adoption of the technology in the market, we need to prove that RS is able to measure wind conditions accurately even in complex terrain.

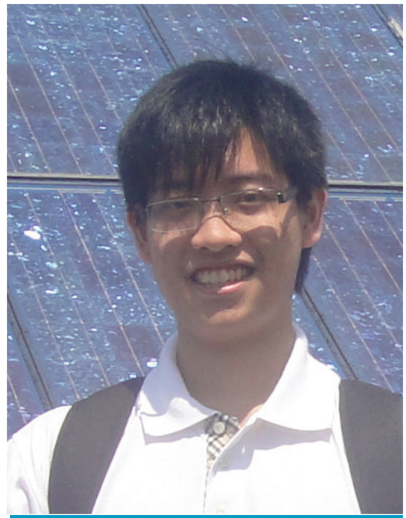
Do you expect the number of projects you develop/operate using only RS data to go up in the future?

We think it would be difficult to increase this number in the short term. Cup-type anemometers have been in use for many years and are now standard, because they have a track record of reliability. For wider adoption of RS, we need proof that the technology is able to measure wind conditions with precision equal to or higher than cup-type anemometers. We expect adoption rates to increase over the next decade.

Do you view projects developed/operated using only RS as more or less risky than projects using met towers?

In simple terrain, projects that have been developed using RS should be no more risky than projects developed using met towers. However, in complex terrain I do think there is more risk.

The problem with complex terrain is that there is currently no established method for evaluating turbulence intensity using RS data, because data accuracy cannot be guaranteed when airflow distortion occurs in the control volume. A method for evaluating turbulence intensity using RS data has not yet been established.



Jonathan Sutanto

Wind and solar engineer, UPC Renewables

UPC Renewables has operations throughout Southeast Asia, Australia, North Africa and North America, and is currently building Indonesia's first utility-scale wind farm.

Vaisala spoke with **Jonathan Sutanto**, a wind and solar engineer at UPC Renewables about using RS in Southeast Asia. The technology allows the company to conduct speedier site prospecting, lower land rent costs, secure faster permitting and obtain more accurate data. Jonathan highlighted the need for greater industry transparency about deployment practices and a more robust support network to speed up adoption of RS technology.

Could you briefly summarize the activities of UPC Renewables in the wind energy sector?

UPC Renewables is a leading renewable energy developer with over twenty years' experience in wind and solar. We have developed 3,500MW of operating wind and solar projects, and have a development pipeline of more than 5,000MW worldwide.

UPC has developed wind projects in the United States, India and the Philippines, and we are currently working on the first utility-scale wind energy project in Indonesia — the Sidrap I Wind Farm, with a capacity of 75MW.

How extensive is UPC's experience in deploying and analyzing data from RS devices?

UPC has been using RS devices for around four years now, starting with the Triton SoDAR in 2013. Since then we've also started using LiDAR, and have deployed these two forms of RS for various purposes throughout project development, including early site prospecting, site validation, met mast substitution and shear analysis. We tend to use RS qualitatively, to get data more cost-efficiently from a particular spot in the project area.

Our RS devices have been deployed in a number of our core markets globally; for example, we currently have one SoDAR and seven LiDARs operating in Indonesia and further SoDAR and LiDAR units deployed in the Philippines.

In what project circumstances do you use RS?

Currently, we use RS for prospecting and the initial development phase and don't use it in any post-development phases. Once we have more confidence in a project, we install masts as required to ensure bankability.

If interest in RS continues to grow and banks start to accept the data in greater numbers, then we would really like to move forward with using the data quantitatively too — in power performance testing and forecasting for operational wind farms.

Are there any market-specific applications for which UPC uses RS in Southeast Asia?

In Indonesia, UPC has only used RS for project development, as there are no operating wind farms in the country just yet. Many prospective sites are located on complex terrain or present challenges in terms of access, as they are spread across Indonesia's many islands, making met mast construction difficult.

> *If interest in RS continues to grow and banks start to accept the data in greater numbers, then we would really like to move forward with using the data quantitatively too — in power performance testing and forecasting for operational wind farms.*

As a result, our RS devices serve as a mobile substitute for a met mast, and are used for site validation. Once enough data has been collected, we can then easily move the SoDAR or LiDAR unit on to the next island.

Aside from mobility, what are the main practical advantages of using RS technologies in Southeast Asian markets like Indonesia?

In our experience, we've found that RS provides better shear analysis. In markets like Indonesia, there is often a lack of experience when it comes to the construction challenges and logistical complexity involved in erecting taller met masts. Given these challenges, RS devices provide us with more reliable shear analysis data.

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They also provide a more cost-effective prospecting tool. Rather than investing in and then constructing a met mast for a project we are unsure of, quickly deploying a RS device tells us whether wind resource at the site is in our favor or not — and this is much more cost-efficient.

What other market-specific advantages might RS have in Southeast Asia?

In some regions, it can be much more difficult to obtain permits to construct met towers, whereas a RS device often only requires a survey permit. Equally, RS keeps land use to a minimum. In Southeast Asia, sometimes the best wind spots are located on local agricultural land or in forested areas. As RS devices occupy much less space than a met tower, it costs less to rent land and negotiate permissions for access from local farmers, who can continue to use most of their land while the RS device is operational.

What do you see as the main drawbacks to using RS technologies in this part of the world?

The mobility and relatively small size of RS devices mean there can be

Credit: Michael Zhang

concerns regarding their security, which can, in turn, bring additional complexity and costs. We need to have much stricter site security, with 24-hour on-site supervision and fences.

The high up-front cost on RS devices can also cause developers or operators to think twice when comparing this price to the cheap cost of local labor and local tower manufacturing.

Use of RS data for securing financing is unlikely given the unproven track record of the technology in the region. Regional efforts to use the data for bankable analysis are limited and, as mentioned, we typically use the data for qualitative purposes instead.

Lastly, there can be issues around reliability and troubleshooting. Since most well-known RS devices are not from the region, we have difficulties when trying to troubleshoot them, including finding matching spare parts, getting real-time support (due to time differences) and site visit inspections from vendors. Finding the source of problems during troubleshooting can also be difficult, due to the technical complexity of the system. This usually results in longer downtime than we would like. In some cases, we we have also had to return RS devices to the manufacturer for repair and this has cost us both time and money.

What do you think needs to be done to improve adoption of the technology in emerging wind markets?

The availability of rigorous guidelines and standards relating to how to deploy RS devices for measurement campaigns should help make the data more bankable. Equally, raising awareness among developers and operators of the improvements made to the technology over the years, and its increasing acceptance by technical and financial institutions, would do much to improve its adoption in the emerging markets — hopefully this report will contribute to that.

Greater transparency when it comes to the number of projects that have been financed using RS data would give the industry increased confidence in its accuracy. With many manufacturers based in the US and Europe, we would also like to see an increase in regional after-sales support.

Having to import the devices and then getting limited remote support is a stumbling block to the rollout of more RS devices in Southeast Asia.

Do you expect the number of projects you develop using only RS data to go up in the future?

Yes — as more and more areas have their wind resource measured, RS devices will play a much greater role in regions with limited accessibility and marginally uncertain wind speeds, given their cost advantages and versatility.

This increase will depend on more projects being financed using only RS data, and the technology becoming more robust, but will probably take place over the next five to ten years.

Do you view projects that are developed or operated using only RS as more or less risky than projects using met towers?

At the moment, I would say it is riskier to use only RS, as the general guidelines still require a mast to validate RS data. Unless there are specific guidelines that are accepted globally for the use of RS devices in wind projects, it will be difficult to change this. However, we do believe that, in the near future, reliability, costs and confidence in RS technology will increase exponentially, such that deploying RS devices will definitely be more advantageous than using met towers.

Romain Barbot

Head of Resource Management and Acoustic Studies, Valorem

Romain Barbot heads the resource management and acoustic studies teams at French project developer and operator **Valorem**. He spoke with Vaisala about Valorem's experience using RS for projects in France, how the company has used portable SoDAR to increase the data it can collect accurately, and how it helps with adherence to planning codes.

For Barbot and Valorem, internal validation processes have provided assurance of the reliability of RS data collected for use in development and operations. With further verification studies they see a possible route to wider acceptance of RS data by the financial community.

Could you briefly summarize Valorem's activities in the wind energy sector, and your current role?

Valorem is a green energy provider, based in France.

Though we started out purely as a developer of wind parks — and have installed 800MW of wind power capacity to date — we have expanded into multiple forms of renewable energy and started to operate a number of our own sites.

90% of our work is focused on the French market, but we also have a growing presence in emerging markets, such as South America, the Caribbean, Eastern Europe and North Africa.

I currently work as a Senior Engineer, with over ten years of experience at the company. I'm responsible for overseeing resource measurement and acoustic monitoring, which is particularly important given strict acoustic legislation in France.

What is Valorem's experience in using data from RS devices?

Valorem has been carrying out on-site measurements at wind farms since 1994, and first began using RS devices for this purpose six or seven years ago.

> *We conducted significant research into RS technologies before adopting them for our measurement campaigns. After extensive tests on both SoDAR and LiDAR devices, we settled on SoDAR for the bulk of our onshore RS needs.*

We conducted significant research into RS technologies before adopting them for our measurement campaigns. After extensive tests on both SoDAR and LiDAR devices, we settled on SoDAR for the bulk of our onshore RS needs.

We now use RS throughout project development and operations — Triton SoDAR for prospecting and development purposes, as well as acoustic studies, and horizontal nacelle-mounted LiDAR to conduct power curve performance testing during operations. As the first French offshore wind projects come online, we would expect to see further deployment of LiDAR devices.

Why did you decide to adopt RS technology in your measurement campaigns?

Although the wind resource throughout France is well mapped, in some regions we need particularly accurate data. RS enables us to achieve greater confidence in the accuracy of this data via verification against other sources.

For this reason, we began to use RS in conjunction with met masts. Doing so doesn't just ensure data reliability; it also decreases costs. If we only need to construct a met mast that is 50 meters tall, because SoDAR can be used to validate wind measurements above that height, then we are saved the expense and the inconvenience entailed in building a much taller mast.

We saw that RS would allow us to keep costs down in several other ways too. Rather than leasing land from farmers to construct and maintain a met mast on their land, a SoDAR device can be deployed quickly and easily. Installation of a met mast requires four or five people over a number of days, while a SoDAR device needs two people at most to set up and can be collecting data within a few hours. The portability of SoDAR was also a significant factor in our decision.

The small size of the units means that they can be moved between multiple sites in the space of a year. Conversely, an area of 6,000m^2 is needed to erect a met mast, presenting additional difficulties if the site under development has an unusual topography or is in a forested area.

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What specific advantages does RS offer in the French market?

RS technology helps us overcome some of the challenges posed by France's strict acoustic laws. When developing a new wind farm, we are required to carry out in-depth research to forecast and assess its noise impacts under different conditions, which typically takes two months to complete.

Erecting a met mast for such a short period of time would be prohibitively expensive, whereas an easily maneuverable SoDAR device is ideal for this purpose. Furthermore, a SoDAR unit can be set up close to neighboring properties for a more accurate noise assessment.

What does Valorem see as the main drawbacks to the use of RS technologies?

The main difficulty we have encountered has been when using RS data to secure project financing. Our own research and development has reassured us of the reliability of data gathered by our SoDAR and LiDAR units, but banks have been slower to accept RS data for financing purposes. As the accuracy of RS is verified by further experience and research, however, we may be coming closer to the day when the technology is seen as a viable alternative to met masts in financing.

What steps did take Valorem to confirm the accuracy of RS data in comparison to other sources? Are there examples of where Valorem has been able to convince financial backers of its accuracy?

As part of the extensive R&D campaign mentioned earlier, data from the Triton SoDAR and a number of LiDAR devices was compared with measurements from a collocated met mast. A very close correlation between the datasets was shown, giving us confidence in the accuracy of the RS technology.

During the prospecting phase of wind farm development, some data uncertainty is acceptable — so this research was enough to make the decision to deploy RS across our prospective development sites.

Financing is a different matter, because it demands higher levels of data certainty. As a rule, therefore, Valorem doesn't use RS for these purposes.

There have been some examples, however, when RS has been used to support financing decisions. On one occasion, we had a lead time of about six months for constructing a free-standing met mast with concrete foundations. Given the tight schedule of the project, we deployed a Triton SoDAR on the site while the met mast was in transit and under construction. Once the mast was up and running, we could demonstrate a very close correlation with the data collected by the Triton. Consequently, we were able to successfully argue that the measurement campaign began when the Triton was initially installed. As such, RS data was used as a basis for project estimates.

Has Valorem used RS technology in markets outside Europe?

To date, we have only deployed RS technology for our projects within France. For a number of logistical and financial reasons, we tend to adopt a different strategy when operating overseas, often working with local companies that have already identified suitable development sites using met masts and other technologies.

Overseas, we also use atmospheric reanalysis datasets for site prospecting, but these aren't of the same quality as RS measurements. There is certainly scope for increased use of RS in our global prospecting.

What do you think needs to be done to improve adoption of RS technology in emerging markets?

This is a big challenge, because people tend to trust the established technology and are wary of change. RS could be an excellent option for wind farm development in remote areas, however, as well as in completely new markets where there is lower resource knowledge and less available funding.

Installing a met mast in remote areas can cost as much as €70,000, while transporting it between prospective sites is also costly and labor intensive. On the other hand, a single SoDAR device could fulfill the same function at a fraction of the cost and, for this reason, Valorem is likely to start using RS technology for prospecting in emerging markets in the near future.

Do you expect the proportion of projects you develop or operate using only RS data to increase in the future?

At Valorem, we use met mast data for financing projects simply because banks have greater confidence in this method. If this were to change, we we would certainly shift towards further use of RS and, in any case, we are already moving in that direction. We have already experienced that measurements from RS are particularly useful when it comes to development, given the cost and difficulty of met mast installation.

For operational purposes, such as power curve testing, however, it is likely that met masts will continue to be deployed, given their role as a static reference point.

Wind energy in a cold climate

Nicolás Briceño

Analyst, Wind & Solar Energy, Innergex

Many project developers and operators are now using RS devices to conduct measurement campaigns in remote regions, where harsh winter conditions and sub-zero temperatures pose unique maintenance and accessibility challenges.

Vaisala spoke to **Nicolás Briceño** of Innergex, a Canadian project developer, owner and operator with sites in the cold climate of Eastern Canada. Briceño spoke about the value of reducing data uncertainty at higher hub heights, the operational challenges of maximizing data recovery from RS and the steps that still need to be taken towards industry-wide standardization of the technology.

Could you briefly summarize the activities of Innergex in the wind energy sector, and what do you do in particular?

Innergex Renewable Energy is a Canadian independent renewable energy power producer that develops, owns and operates run-of-river hydroelectric facilities, wind energy and solar farms. We also oversee acquisitions of projects at all stages of development — from greenfield through to operation. We operate in a number of different markets, and have offices in the USA, France and Canada.

I have been at Innergex for a year and am responsible for the quality control of our meteorological data, constraints studies, performance analysis of operational projects and the development of tools for energy assessment.

What is your experience of using RS? How does Innergex deploy RS devices throughout development and operations?

My personal experience of using RS has been shaped by my work at Innergex. Over the past 12 months we have been using essentially Triton SoDAR units, mainly as part of our energy resource assessments.

In total, Innergex has been using RS for at least six years, and has tried a number of LiDAR and SoDAR units from different manufacturers. Currently we use SoDARs purely for project development. We haven't yet used them for performance optimization, but this may well change in the near future, as the need for performance analysis at our operational sites grows.

What are the advantages of using RS for Innergex? How do these compare to use of a met tower?

We currently use both RS and met tower technologies. RS has a number of advantages, including its mobility and the lack of permitting issues when compared with a met tower. It is able to actually measure at greater hub heights and account for the vertical components of wind speed.

Reducing the vertical and spatial uncertainty factors and being able to measure at higher heights in general is a significant advantage for us, considering the higher hub heights of modern wind turbines.

Nevertheless, in some complex topographic conditions, RS seems to have some higher uncertainties in comparison to met towers; that's one of the reasons why we continue to use both technologies.

Credit: Innergex

RS has a number of advantages, including its mobility and the lack of permitting issues when compared with a met tower. It is able to actually measure at greater hub-heights and account for the vertical components of wind speed.

What are the particular challenges of conducting wind measurement campaigns during the winter in Eastern Canada?

For RS, the main challenges lie in data recovery during the harsh winter months, and the need to deploy backup energy systems to keep units powered up. There is also a need to periodically clear reflector plates of snow and ice, as well as other maintenance. This requires gaining access to the sites themselves, which poses particular challenges during the winter.

Met masts do suffer from icing problems during the winter, but as a rule do not require as much regular maintenance to keep running.

Do you expect the number of projects you develop or operate using only RS data to go up in the future?

We think this is a likely scenario, as we are already making extensive use of RS, despite the fact that industry codes, standards or practices may not have fully caught up with the technology. In general, our use of SoDAR continues to grow.

We are increasingly using our SoDAR units as a standalone measuring device, particularly during the first steps of our sites' development with the addition of met tower(s) when the projects get more concrete.

Do you view projects developed and operated using only RS data as more or less risky than projects using met towers?

I'd say it's equivalent, as there are risks in extrapolating above hub heights, but met towers also bring certain advantages.

I think more companies are going to want to use RS technology. From what we've seen so far on projects where we've deployed both technologies, we have great confidence in our SoDAR units.

I think more companies are going to want to use RS technology. From what we've seen so far on projects where we've deployed both technologies, we have great confidence in our SoDAR units.

What steps need to be taken to improve the confidence of the financial community and the wider industry in RS technology?

The problem for financial backers is that RS is still not an accepted methodology when used alone, meaning that if a development project is successful we're probably going to have to install a met mast.

But we see this as presenting an opportunity, as we would like to see manufacturers move the conversation forward about the use of this technology, making the use of RS devices a standard approach. This has already started to happen for power performance testing and we would also like to see an industry recognition for its use in wind assessment.

What do you think needs to be done to improve adoption of RS technology in cold climate wind markets?

One step manufacturers of RS devices could take would be to develop a more autonomous energy backup system. We currently have to refuel our SoDARs once or twice while they are in the field, as well as sending someone to clean their reflector plates. Optimizing these maintenance procedures would be great for using RS devices in cold climate conditions in Eastern Canada and worldwide.

Manufacturing smaller units allowing site installations with snowmobiles instead of trucks would also allow us to deploy units almost all year long.

Leading the revolution

Conclusion

This report has looked at the use of remote sensing (RS) technology in the wind industry — past, present and future. Alongside our own analysis, we have included the thoughts of a group of industry experts, who have extensive experience using RS technologies. Their view of the technology and the future opportunities it will create is broadly positive. These individuals and organizations see a world in which RS can become the leading method for collecting wind resource data for all kinds of uses by wind farm developers and operators.

The report has also drawn on the expertise of engineers dedicated to developing RS technology and its uses, to not only show how RS can be used by developers and asset owners to optimize the returns on their project, but also to give an insight into what current research and analysis of RS capabilities might mean for its future use in commercial cases.

RS devices offer the wind energy industry many benefits of convenience and ease that met towers do not. Their mobility makes them simple to deploy and redeploy around a project site, enabling prospectors to collect wind resource data from multiple points across the site of a potential wind farm, and thus allow developers to gain a more accurate, representative understanding of resource availability.

Together with their ability to monitor wind characteristics at heights that comfortably reach beyond even the tallest turbine hubs currently being built today, RS devices can provide developers with an accurate whole site view of wind resource for their projects.

They can reduce the need to extrapolate data and toy with error margins, in order to make a project better appeal to backers.

Liam Smith, Investment Principal at Actis, commented on the versatility of RS units:

> ***The main advantage for us is versatility. Not only can RS devices be deployed in more remote, difficult to access locations — a common challenge across our core markets — they can collect data at greater heights and allow a better understanding of shear profile.***

Jonathan Sutanto of UPC Renewables said of prospecting with RS in Indonesia:

> ***Many prospective sites are located on complex terrain or present challenges in terms of access, as they are spread across Indonesia's many islands, making met mast construction difficult. As a result, our RS devices serve as a mobile substitute for a met mast, and are used for site validation.***

Despite bringing dramatic changes to the price and accuracy of collecting wind resource data for wind farms, RS devices face continuing reluctance from financiers to accept the data they collect. In part this is due to a lack of formalized industry standards for using RS tools, which leads to concerns about data accuracy.

However, from the industry side, the body of evidence continues to increase, with comparison studies and research efforts demonstrating the viability of RS as a reliable tool for use throughout the lifecycle of a wind farm. On all sides of the industry, experts at OEMs, classification societies and developers are exploring the full capabilities of remote sensing, whether in practical commercial circumstances, or through carefully designed studies.

Nathan Lehman of Apex Clean Energy on their validation protocols:

> *We have carried out collocation work and correlation studies, placing the SoDAR device 50 – 70m from a met tower and comparing data from the two. We then use backend calculations to determine the source of any data uncertainty.*

Collectively, these studies and analyses by the industry have helped progress the development of standards that support wider adoption of remote sensing, in particular IEC 61400-12-1, for power performance testing. While there is a view that this protocol could go further than just power performance testing, it is also reasonable to suggest that the IEC will only follow where the industry leads.

This means that the initiative will remain with pioneering developers and operators, such as those featured in this report, when it comes to further advancing standards. Developing protocols for using RS in complex terrain, and ongoing research to demonstrate the potential to use RS as a standalone device will be crucial steps in ensuring ongoing prog-

Darin, a senior engineer at a US utility, commented:

> *The latest IEC code for power performance testing still requires the use of a static met tower nearby for comparison with RS data. If a new code was released in the near future that indicated you could rely solely on a RS device, then this would be a big step forwards in encouraging financiers to look on RS data more favorably.*

For Romain Barbot of Valorem, financiers will need to be convinced by reliable data to back projects:

> *Our own research and development has reassured us of the reliability of data gathered by our SoDAR and LiDAR units, but banks have been slower to accept RS data for financing purposes. As the accuracy of RS is verified by further experience and research, however, we may be coming closer to the day when the technology is seen as a viable alternative to met masts in financing.*

In a world without met towers, developers and operators will have a clear-sighted view of the resource characteristics of their entire site, and not have to rely on modeled extrapolations, leading to better optimization of their site. They will face reduced costs in prospecting, as the many demands and risks of permitting, construction and logistics will be mitigated or eliminated. More importantly, their workforce will benefit from a safer approach to wind measurement.

But a 'remote sensing revolution' may bring an even greater benefit to developers, operators, and their backers, than any of the practical and operational benefits of the units alone. Having relied on the met tower as the benchmark for wind measurement for more than two decades, standardization of RS devices may ultimately help the industry adopt a more realistic understanding of what accurate recource measurements entails.

Historically, developers have relied on a cup, calibrated in a wind tunnel, and raised to collect data in a single location, which are then extrapolated, modeled and claimed as representative of wind resource in that location. But mobile RS units, validated and deployed in accordance with well-researched protocols, will provide a quality and quantity of data that will redefine what it means for developers to have a clear understanding of the resource availability on their sites. In turn, they will advance the industry's understanding of the wind, ensure that investors continue to see steady returns, and remove hurdles to the growth of the wind energy market worldwide.

In the meantime, the leaders of this revolution will continue to conduct the studies, record the data and refine the protocols that are making RS an ever more versatile and powerful technology.

About Vaisala

Vaisala is a global leader in environmental and industrial measurement. Building on 80 years of experience, Vaisala provides observations for a better world. We are a reliable partner for customers around the world, offering a comprehensive range of innovative observation and measurement products and services. Headquartered in Finland, Vaisala employs approximately 1,600 professionals worldwide and is listed on the Nasdaq Helsinki stock exchange.

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Our activities in renewable energy:

Weather provides the fuel for renewable energy projects and is one of the largest variables impacting production. Vaisala uses more than 80 years of weather expertise to help the global renewable energy industry develop and operate wind and solar projects better, faster and more efficiently. Our measurement, assessment, forecasting and asset management products and services leverage proven science and advanced technology to mitigate the impact of weather risk on energy generation and support profitable decision-making across the entire project lifecyle, from greenfield prospecting and due diligence through operational forecasting and plant optimization.

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