Return on Investment of a Lidar Remote Sensing Device

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Introduction

The Annual Energy Production (AEP) is the quantity of energy delivered per year by a wind farm. During the project study, a Wind Resource Assessment Program (WRAP) is designed to estimate the mean expected AEP (P50) and the uncertainty on the AEP (σ_{AEP}). These two decisive numbers drive the financing of the project. Small derivations in the calculated level of uncertainty can have a significant effect on project financing.
The WRAP enumerates a quantity of independent uncertainties, some of which can strongly influence the global AEP uncertainty. Among the uncertainty related to the wind resource estimation (σ_{WS}) are the wind profile vertical extrapolation from mast height to hub height and horizontal extrapolation from measurement location(s) to turbine locations.
At the same time, the emergence of commercially available Lidars, very portable and accurate remote sensing devices based on Laser technology (see Fig. 1), offers new possibilities for wind experts when setting up a wind measurement strategy.
We study the use of a Lidar system in addition to traditional met mast measurements to achieve a reduction of AEP uncertainty. This leads to optimized financing of a wind farm project by reducing the equity investment and increasing the Return on Equity (RoE) of the investor. The Return on Investment (RoI) of a Lidar system is eventually extremely positive through the financial gain of uncertainty reduction minus the Total Cost of Ownership (TCO) of the Lidar.

Estimation of Future Energy Production and Uncertainty on the Future

The AEP is a combination of the wind resource available on site and the power curves of the specific wind turbines selected for that site. The AEP prediction is usually considered as a Gaussian statistic with a mean value P50 and an uncertainty on this value σ_{AEP} which directly drives the exceedance probabilities Pxx. For example, a P90 of 110GWh/year means there is 90% chance that the wind farm will produce at least 110GWh yearly. The lower the uncertainty the higher the P90, as depicted in Fig. 2.

Sources of Uncertainty and Reductions Associated through the Use of a Lidar

Uncertainties are related to both turbines efficiency (power

Fig. 1 : WINDCUBE® Lidar from LEOSPHERE/NRG Systems

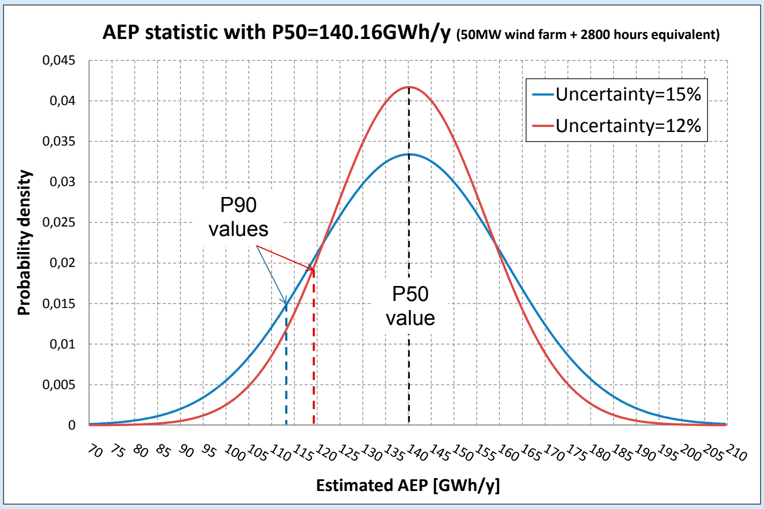

Fig. 2 : Annual Energy Production estimates: Gaussian statistic with a 50MW wind farm, NCF of 2800 hours, and AEP uncertainty 15% (blue curve) and 12% (red curve). Reducing the AEP uncertainty of a few points leads to a consequent increase of energy expected at P90

curve, wake effects, losses…) and wind resource estimation (sensor accuracy, vertical extrapolations to hub height, horizontal extrapolations to turbine locations, long-term extrapolation and representativeness of measurement period).
The intensity of these uncertainties varies from project to project and is highly dependent on project size and site complexity. The uncertainty related to the wind resource estimation is however the highest one in most cases.
It has been previously highlighted by several wind energy experts that direct measurement at hub height and multiplication of measurement locations are two ways to significantly reduce the global AEP uncertainty. Based on the experience of wind consultants and wind farm developers regularly using 80m met masts and Lidars, we provide in Tab. 1 sample values for the main sources of uncertainty obtained with a traditional 60m met mast and the reductions associated with the use of additional measurement systems.
The additional locations (one in the case of an additional 60m or 80m met mast; three in case of additional moving Lidar or 60m met mast) offer a reduction of the horizontal extrapolation uncertainty. An 80m met mast and a Lidar allow for the cancellation of the vertical extrapolation uncertainty for 80m turbine hub heights. When using a moving system for shorter periods of time, the uncertainty related to the representativeness of the measurement period is increased due to the seasonal variation of the wind speed only partially captured by the moving system.

Selected Wind Measurement Strategy to Reduce AEP Uncertainty

Eventually, the use of a Lidar in combination with at a minimum one met mast offers the greatest reduction of several uncertainties according to the following promising practice: fixed mast(s) for the whole WRAP period plus moving Lidar at various additional locations for shorter periods of time (see Fig. 3).
Note that the actual number of met masts and Lidar measurement locations required at a project site is contingent upon a variety of factors, including terrain, project size, and assessment campaign goals.

Lidar Total Cost of Ownership (TCO) for Onshore WRAP

We have seen that a way to reduce the uncertainty on the wind resource estimation is via the use of additional measurement systems (60m mast, 80m mast or Lidar) further from fixed met mast(s). It is also important to study the operational costs generated by additional measurements. In Fig. 4, the Total Costs of Ownership (TCO) are compared when performing such methodology with the following hypothesis:

- One system (60m or 80m met mast or Lidar) is added to one fixed met mast.

Sources of uncertainty	60m mast	80m mast	2 x 60m masts	60m + 80m masts	2 x 80m mast	60m mast + moving Lidar	60m mast + moving 60m mast
Sensor accuracy	2%	2%	2%	2%	2%	**2%**	2%
Hub height extrapolation	2%	0%	2%	1%	0%	**0%**	2%
Turbine locations extrapolation	5%	5%	4%	4%	4%	**2%**	2%
Long-term representativeness of measurement period	2%	2%	2%	2%	2%	**2.5%**	2.5%
Long-term scaling (correlation with meteo/airport data)	4%	4%	4%	4%	4%	**4%**	4%
Total WS uncertainty	7.3%	7%	6.6%	6.4%	6.3%	**5.5%**	5.9%
Uncertainty ratio between AEP and WS	1.9	1.9	1.9	1.9	1.9	**1.9**	1.9
Wind farm efficiency (PC, wake effect, losses…)	6%	6%	6%	6%	6%	**6%**	6%
Total AEP uncertainty	15.1%	14.6%	13.9%	13.6%	13.4%	**12.1%**	12.7%

Tab. 1: Sample values for the main sources of uncertainty and reduction associated for seven possible wind measurement strategies: 60m mast, 80m mast, 2x60m masts, 60m + 80m masts, 2x80m mast, 60m mast + moving Lidar, 60m mast + moving 60m mast. The values are mean values coming from a variety of wind experts and are assumed to be representative of a 50MW wind farm project on a wide and complex terrain.

- The moving system is relocated every 3 months within the project site.
- One WRAP per year: the measurement systems are moved every year.
- Costs related to the 60m mast: equipment 15k€/year, 1 installation or dismantlement 7k€, maintenance 5k€/year.
- Costs related to the 80m mast: equipment 30k€/year, 1 installation or dismantlement 20k€, maintenance 6k€/year.
- Costs related to the Lidar: equipment 130k€ (3 years amortization), 1 installation or dismantlement 0.5k€, maintenance 7k€/year, power supply 15k€/year.

Impact of a Lidar on the Wind Farm Financing

Wind farm investment is usually financed by bank loans and equity with a ratio determined by the Debt Service Coverage Ratio (DSCR). Banks can require a DSCR of 1.2 based on the P90 as a minimum "guaranteed" revenue to secure the loan payment capacity.

The Internal Rate of Return (IRR) is a determinant indicator that can be extracted to understand the financial benefit of increasing the leverage. It indicates the profitability of an investment, and can also distinguish a project as the preferred choice by an investor where several independent investment opportunities are considered. On the same wind farm project, reducing the uncertainty leads to an IRR increase. Tab. 2 takes one basic project and applies the uncertainties obtained by the different measurement strategies previously described. The results emphasize the effect of the uncertainty reduction on the global economy of the wind farm. Hypotheses taken are:

- 50 MW wind farm
- P50 = 2800 hours
- Capex = 1.5M€/MW
- Revenue = €80/MWh
- O&M = €20/MWh
- Inflation = 2%
- Project period = 20 years
- Interest rate = 6%
- Debt period = 15 years

Fig. 5 shows the economic benefit of collecting wind measurements at additional locations within the project site. The Lidar generates the greatest increase of IRR, P90 revenue and equity investment savings for a medium additional cost.

Expectations on the Complementary Remote Sensor

In order to achieve significant financial gains through uncertainty reduction, however, the complementary remote sensor accuracy has to match cup anemometer standards and be as accurate as cup anemometers in all types of terrain.

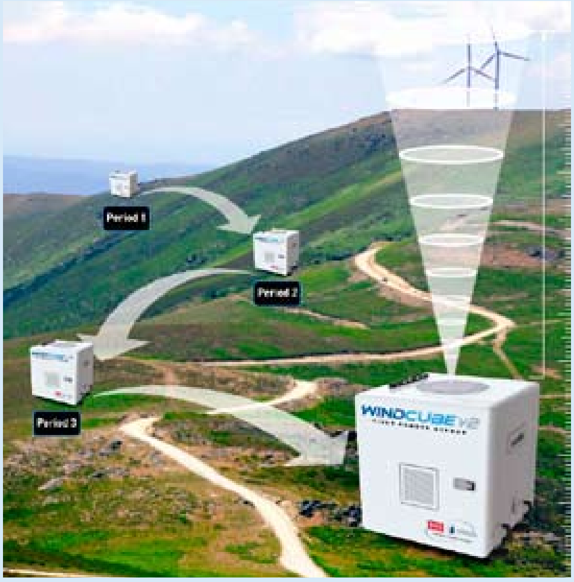

Fig. 3 : Optimised wind measurement strategy using a Lidar moved onto several locations to reduce uncertainties related to both horizontal and vertical wind speed extrapolations.

1 year WRAP	60m mast	80m mast	2 x 60m masts	60m + 80m masts	2 x 80m mast	**60m mast + moving Lidar**	60m mast + moving 60m mast
Further investment (k€)	*0*	*43*	*35*	*79*	*122*	***75***	*80*
AEP uncertainty	*15.1%*	*14.6%*	*13.9%*	*13.6%*	*13.4%*	***12.1%***	*12.7%*
P50 (GWh/y)	*140.16*	*140.16*	*140.16*	*140.16*	*140.16*	***140.16***	*140.16*
P90 (GWh/y)	*113.62*	*114.5*	*115.75*	*116.25*	*116.62*	***118.85***	*117.85*
P90 (M€)	*9.09*	*9.16*	*9.26*	*9.3*	*9.33*	***9.51***	*9.43*
Leverage	*76.5%*	*77.5%*	*78.5%*	*79%*	*79.5%*	***81.5%***	*80.5%*
IRR	*15.18%*	*15.41%*	*15.65%*	*15.78%*	*15.91%*	***16.48%***	*16.19%*
Equity investment (M€)	*18.03*	*17.27*	*16.52*	*16.12*	*15.74*	***14.22***	*14.98*

Tab. 2: Impact of uncertainty reduction on the project financing provided by the seven measurement strategies

Moreover, it must have high operational capabilities, i.e. being easily transportable and deployable even in hard-to-reach terrain, and having its own power supply. Since an interruption during the measurement period is also prejudicial, the system has to take continuous wind data under all weather conditions.

After years of research on developing a remote sensing device that ideally complements traditional mast measurements, the wind industry has found an unparalleled answer to this very demanding operational and metrological equation through the adoption of laser anemometry technologies.

Global Economic Benefit

It is important to note that the uncertainties reduction, the economic benefits and the further initial investment for a wind resource assessment campaign will depend on the number and the length of additional measurements as well as on the site size and complexity.

Though, it has been shown that on a 50MW wind farm project, with an initial further investment of 75k€ (for an adapted Lidar remote sensor) and through the application of a good wind measurement strategy, the developer increases his yearly P90 revenue by 420k€. This leads to a higher bank loan and consequently to a 3.8M€ saving in equity investment and to a significant increase of the Rate of Return.

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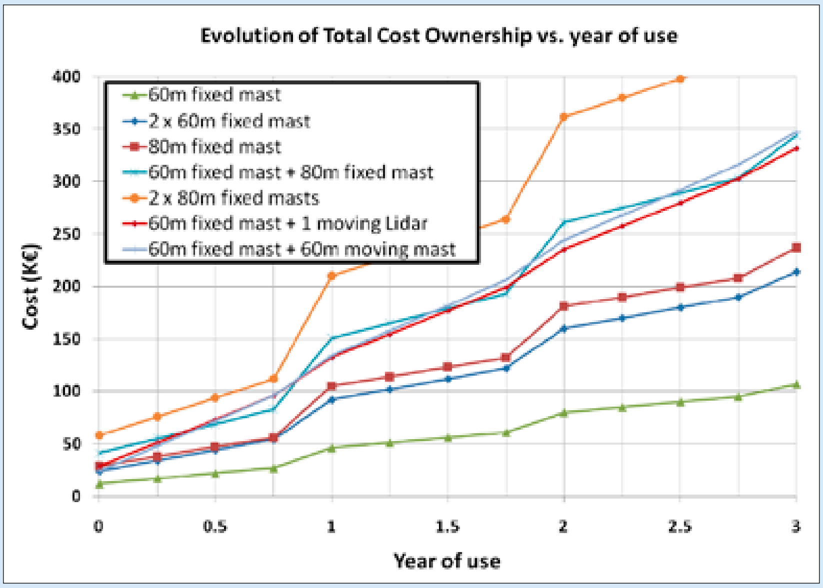

Fig. 4 : Total cost of ownership of the seven wind measurement strategies.

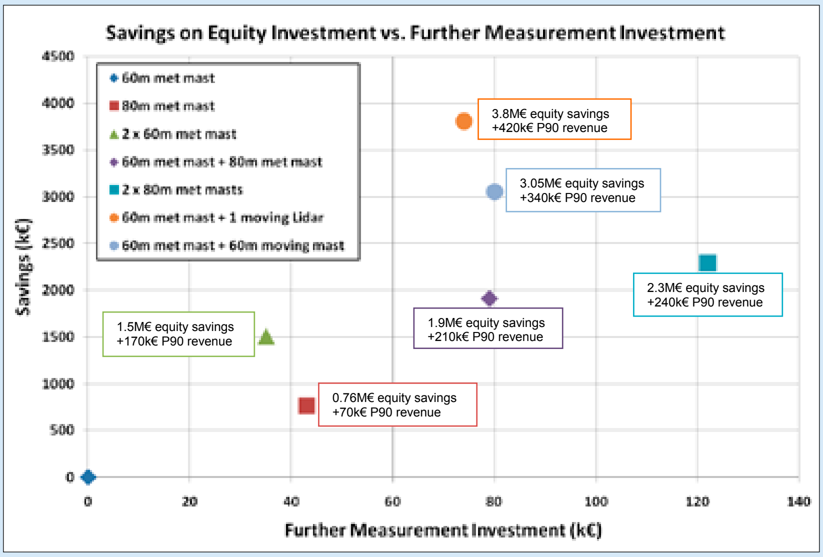

Fig. 5 : Savings on equity investment and additional P90 revenue generated by the further measurement investments involved by the different wind measurement strategies. Reference measurement strategy is one 60m met mast, and is thus the (0, 0) point. The Lidar allows the wind farm developer the greatest increase of P90 revenue and saving on its equity of 3.8M€.

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