Vestas®

Energy production Assessment

Capturing the value of accurate power curve predictions

For project planning, energy production estimates are an essential part of a business case. Wind park-specific energy production evaluations are based on climatic conditions and the warranted turbine power curves that are provided by the turbine manufacturer. These warranted power curves, which are a result of the OEM's production estimates, are based on the design choices of technology and performance modelling, which are also validated by measurement campaigns.

Expected performance* (η) is the ratio between Measured Energy Output (MEO) from PCV tests, and estimated energy output from OEM's warranted power curve (WEO)

$\eta = MEO/WEO\ (\%)$

To maximise certainty in estimated wind park energy production, external consultants are often engaged to analyse warranted power curves provided by the manufacturer and conclude on a project's *expected performance*. External consultants' evaluations are typically built from measurement campaigns on actual wind turbine performance, commonly known as Power Curve Verification (PCV) tests , which are then utilized for the estimation method of the specific site.

Current lack of transparency and standardisation in calculating expected performance

Recent research on energy production assessments has uncovered highly under-appreciated risks for end users e.g. developers, financing institutions and investors[1 2]:

Loss factor (LF) is the estimated turbine underperformance resulting from historical industry-wide or OEM-specific performance data. LF varies depending on the consultancy.

1. High variance observed in default expected performance discounts (loss factor)

Without sufficient measurement data, external consultants apply a default discount associated to the *expected performance*, known as *loss factor*, to all turbine manufacturer's estimated power output. While this number may appear precise, it is actually the result of a standardised average of data within a wide range (figure 1). Regardless of a particular turbine's performance, this arbitrary reduction is applied to business case calculations. In fact, DNV estimates that turbines across the industry underperform up to 4% as compared to the power curve provided by the manufacturer[3]. Furthermore, UL, recently optimised their own power curve *loss factor* by reducing it 0.3 percent points[1]. The industry need to standardise and increase transparency of the methodology and data used for calculating the *loss factor* is raised by both DNV and UL, who have assessed more than one third of the global wind parks' *expected performance* in 2019. The fact that DNV has acknowledged variations in their calculations and UL has adjusted their own power curve *loss factor* only reinforces the importance of this industry need.

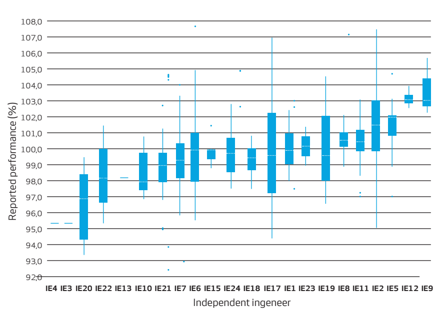

Figure 1 Results of *expected performance* of Vestas turbines calculated by 22 different external consultancies. Each box plot represents the median value of the *expected performance*, as well as the range of the results for each consultancy. Vestas has observed a variation of 3.3 percent points in the standard deviation of the *expected performance*[4], resulting from the different conditions at the site for the measurement and calculation methods. This confirms the lack of consistency in the methodology applied as well as the negative impact of including the climatic conditions in the PCV tests[*].

2. The competitiveness of new technology is impacted by default expected performance discounts (loss factor)

As the pace of innovation accelerates, turbines are increasingly sold in earlier phases of development. Due to insufficient or non existent operational data from the actual wind turbine, a default *loss factor* is applied whenever a new turbine model is released, whereby impacting the true competitiveness of the product. Independent consultants have concluded that a particular turbine's *expected performance* is most correlated with both design choices and manufacturer—not the default *loss factor*[1]. This correlation is so strong that UL has recommended the concept of performance families to give more accurate calculations when insufficient measurement data is available[1]. In addition, further development and standardisation of power curve prediction models that incorporate both historical data and modelling assumptions would mean more accurate calculation of the *loss factor* for each turbine.

Wind. It means the world to us.™

Vestas

Vestas' recommendations to mitigate inaccurate energy production assessments:

- Standardise the methodology for conducting performance assessments from PCV tests
- Transparency in the measurement process and range of variables used for performance assessments
- Further development and application of the performance families concept to calculate the *loss factor*

Energy production estimates significantly impact your business case assumptions

Applying a *loss factor* of 0.1% instead of 2.5% has an impact of >1 additional percentage point on the Internal Rate of Return (IRR)**. While seemingly small, even a reduction of 0.1% in the *expected performance* or *loss factor* means a 0.05% increase in the IRR – a significant economic impact both on the project financing structure and the estimated revenues. Over the project's lifetime, this equates to approximately EUR 1M in increased revenue**, as well as increased financial competitiveness of the investment. Additionally, investment risks increase if there is a high deviation in the consultant's track record of *expected performance* calculations.

These calculations also impact the cost of energy. Project developers can plan their revenue strategies more aggressively by strategically selecting turbine models with proven and high *expected performance*. In an auction environment, this choice allows more competitive bidding to secure larger volume without sacrificing profit.

Vestas' fleet delivers on expected performance

Vestas is committed to optimising our customer's business cases with our solutions, including verifying power curve accuracy from turbine modelling to actual, field proven power plant testing. Experience and knowledge from more than 132 GW of wind turbines installed globally is used to continuously validate and improve the quantitative methods applied to estimate the energy output of our wind turbines.

Vestas' power curves are rigorously tested internally and externally with turbine type tests*** and through scenario-based analysis comparing different climatic conditions. UL and DNV have evaluated a database of more than 400 projects using 28 different Vestas turbine variants across diverse operational and environmental conditions. Both consultancies have validated the accuracy of Vestas' warranted power output: 99.9% with a standard deviation of 2.4%, which is more precise and significantly higher than the industry average (97.5% with standard deviation of 3.6%)[5]. This validated average *expected performance* is applicable to Vestas' fleet regardless of turbine platform or climatic condition, further demonstrating Vestas' consistent performance and accurate analytic prediction methods.

99.9% accuracy
of Vestas' warranted power output

Global consistency in analytical prediction methods and measurement campaigns allow Vestas to provide power curves that are specifically **warranted to your project**, **unlocking business case certainty**, and thus, more **optimisation opportunities**.

*Turbine *performance* is not synonymus with turbine *output*: a turbine's *output* is affected by particular climatic conditions, while its *performance* may remain constant, as the turbine might continue to produce the maximum amount of energy possible for these conditions.

**Case: PPA 45€/MWh flat, 3.600 Gross hours, 252 MW, 25y operational life; leverage below 80%; all in CAPEX >900k€/MW

***Type test: performance evaluation conducted by Vestas on each turbine variant during the proptotype phase, which is then used for turbine type certification by an external party.

Sources:
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2. Lee, J. C. Y., Stuart, P., Clifton, A., Fields, M. J., Perr-Sauer, J., Williams, L., Cameron, L., Geer, T., and Housley, P., 'The Power Curve Working Group's Assessment of Wind Turbine Power Performance Prediction Methods', Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2019-69, in review, 2019.
3. Geer, T., 'An Advanced Understanding of the Impact of Deviations in Turbine Performance', EWEA 2015, http://www.ewea.org/events/workshops/wp-content/uploads/2015/06/Geer-TaylorImpact-of-turbine-performance.pdf
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