Comparison of Pre-Construction Energy Yield Assessments and Operating Wind Farm's Energy Yields

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Keywords: Energy Yield Assessment, Operating Wind Farms, Pre-Construction Energy Yield, Post-Construction Energy Yield, Comparison of Energy Yield, Operational Production Data,

Abstract

For developers, operators and investors of wind farms it is essential having a most realistic energy assessment including realistic uncertainties before the erection of the farm. A comparison of real operational production data with the pre-construction energy yield assessments has been performed for 235 wind farms globally between 1997 and 2015. Wind farms located in Germany are based on reference energy yields of neighboring wind farms, except of few farms based on wind measurements, international projects are all based on on-site wind measurements.

The main objective of this work is identifying existing deviations between post-construction energy yields and pre-construction energy yields and whether given uncertainties reflect the magnitude of real deviations.

Additionally different analysis' have been performed for identifying whether changes in assessment procedures, tools and methods led to improvements with regards to energy yields or uncertainties.

Possible reasons for deviations are discussed with the aim of lowering these deviations for future assessments.

It is shown that the accuracy of the pre-construction assessments could be improved over the years. A significant share of the assessments is hitting the P50 energy yields and given uncertainties generally reflect the magnitude of deviations between pre- and post-construction assessments. Several dependencies could be identified.

But still there is some gap between expected energy yields and post-construction energy yields, and a large scatter of the uncertainties.

Introduction

Since 1997 DEWI performed about 4'000 energy yield assessments globally. When looking at the latest developments regarding political boundary conditions in form of the country-specific energy acts (e.g. German EEG2017), the financial pressure is steadily increasing, and it is becoming more and more important for developers, operators and investors of wind farms to have most realistic energy yield assessments including realistic uncertainties before the erection of the farm. Having

auction systems and the obligation of back-payments in case of higher real production than forecasted energy yields it is also not sensible to have so-called conservative assessments.

A comparison of real operational production data with the pre-construction energy yield assessments has been performed for 235 wind farms globally between 1997 and 2015. 160 of these farms were located in Germany and are based on reference energy yields of neighboring wind farms, 72 farms are located in France, two in Taiwan and one in Croatia. These international projects are based on on-site wind measurements.

Different analysis' have been performed, such as the development of deviations between the pre-construction energy yield and the real data over the years, the dependency on hub height and difference between measurement height and hub height, evaluation of the influence of regional characteristics as well as the dependency on the terrain type (flat sites with simple meteorological characteristics, orographically complex sites and/or difficult meteorological conditions).

Objectives

Based on the work performed 2008 and 2012 [1, 2], a deeper analysis on basis of more datasets and new wind farms has been performed considering today's turbine types and hub heights.

The focus of the presented work is on the following questions:

- Are the calculation results (P50) within the "expectations", are they over- or underestimating the sites?
- Do the applied uncertainties correspond to reality?
- Are there any dependencies derivable from this data analysis regarding
    - hub height,
    - difference between measurement height and hub height,
    - terrain type and meteorological complexity,
    - regions,
    - manufacturer?
- How can deviations be minimized?

Methods

DEWI pre-construction energy yield assessments from 1997-2015 were used for the comparison with real production data, which were taken from the „Betreiberdatenbank" [3] (only Germany) or provided by the wind farm operator.

This work is based on the following:

- 235 energy yield assessments from Germany, France and Taiwan performed by DEWI using the WAsP model have been analyzed, all evaluations for the period 2011-2015 base on 46 projects.
- Monthly energy yield and availability figures found the basis of the analysis, several analysis have been done on basis of SCADA data
- German and international projects have been analyzed individually;

- Available operational data have been corrected to 100% availability;
- German projects have been long-term corrected based on the BDB-Index, a production based long-term source [3], for which the 100% level was modified using DEWI in-house procedures;
- International projects have been long-term corrected based on data from met stations or reanalysis data as MERRA data sets;
- Obvious monthly outliers have been removed;
- P50 and P90 energy yields have been compared,
- a deviation of +/- 5% for the P50 has been classified as correspondence of “real” to “predicted” energy yield,
- For the P90 90% of the regarded projects need to be above or equal to the predicted energy yield.
- Average deviations depending on hub height have been determined for following hub height ranges: [50;80[, [80;100],]100;120], >120
- Wind Farms have been clustered with regards to index region (Germany) or Regional characteristics (France)

Results

For all energy yield assessments evaluated for the years 2011-2015, 39% are within the expectations. Another 37% is between 5% and 10% of deviation, 22% significantly overestimates the energy yields determined on basis of real production data.

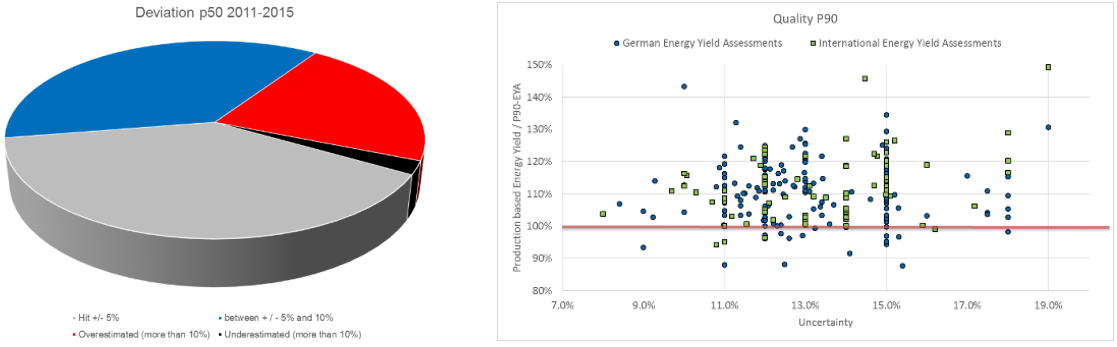

Figure 1: Left: Distribution of the deviation between determined post-construction energy yields on basis of the production data and the pre-construction energy yield assessments. The right scatter plot shows the deviation of the P90 energy yields dependent on the uncertainty of the pre-construction assessment.

The distribution of the P90 energy yields shows that uncertainties are chosen reasonably. For 89% of the evaluated projects the P90 energy yield of the pre-construction energy yield assessment was reached by the calculated post-construction energy yield on basis of the production data. Additionally, it can be seen that generally the deviations increase with increasing uncertainties. One can identify also some projects with very significant deviations in the P90 values with more than 30% or even 40%. When going into the individual projects, these are projects for which the post-construction

energy yield was underestimated for the P50 energy yield, and so lead to even higher deviations in the P90 comparison. A further conclusion is that assessments based on wind data and assessments based on production of neighboring wind turbines are connected with comparable uncertainties and lead to comparable deviations.

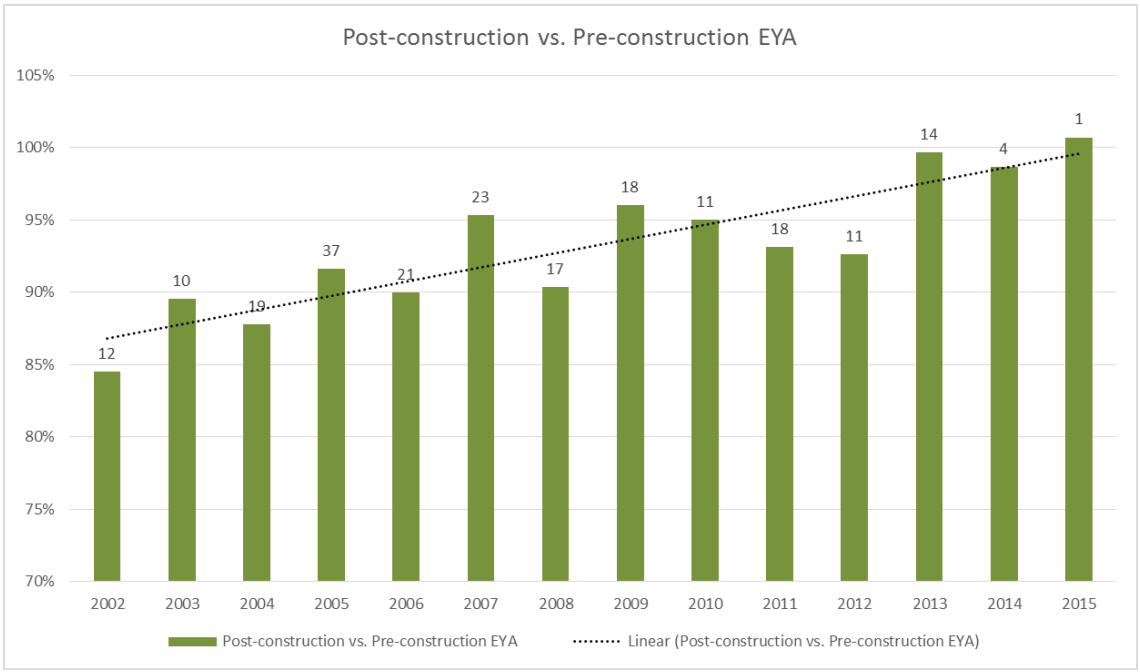

Figure 2: Development of deviation between pre-construction and post-construction energy yield assessments over time.

The development over the years shows a continuous improvement of the prediction quality, for the last years an average relation close to 100% could be achieved for the German and International projects.

For the international projects, when following the development of the deviation depending on the hub height, a clear decrease with increasing hub height can be identified (Figure 3). The number of over-estimations decrease and under-estimations increase.

As hub heights are also an expression of the years in which turbines have been erected, it cannot be clearly stated whether this is resulting from lower influences from the earth's surface or whether it is due to improved measurement campaigns and modeling.

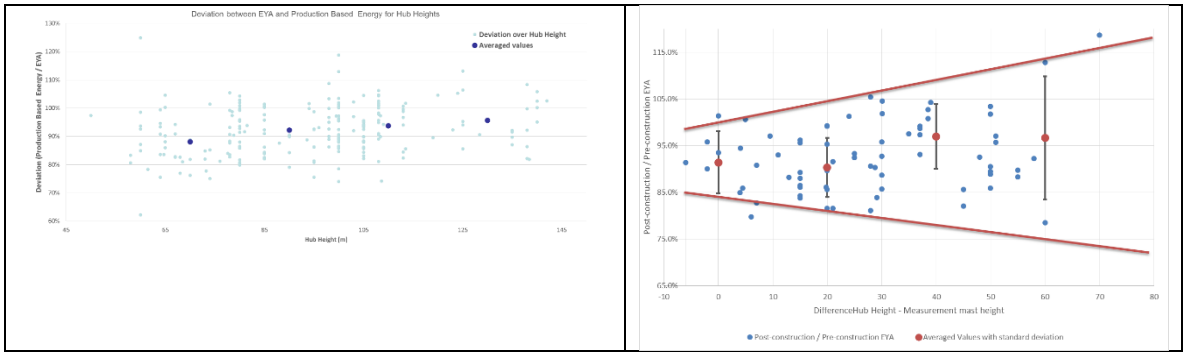

Figure 3: Left: Average and individual deviation values dependent on hub height. Differences decrease with increasing hub heights. Right: Dependency on difference between measurement and hub height.

When looking at the dependency on the difference between measurement height and hub height, one notice that the deviations are – as expected – small when the measurement height is above hub height, so that the hub height wind speed can be interpolated between two measurement heights, or equal to hub height, so the vertical extrapolation uncertainty is approaching zero. Average values are shifting for large differences between measurement and hub height to values closer to 100%, which would correspond in some way to the left figure resulting in lower deviations for large hub heights. Nevertheless, this seems to be more of arbitrary nature. The main conclusion is that the spread is increasing with increasing difference, as can be seen by the standard deviation and is indicated by the visual help lines. This corresponds to the general practice of giving higher uncertainties for larger vertical extrapolation.

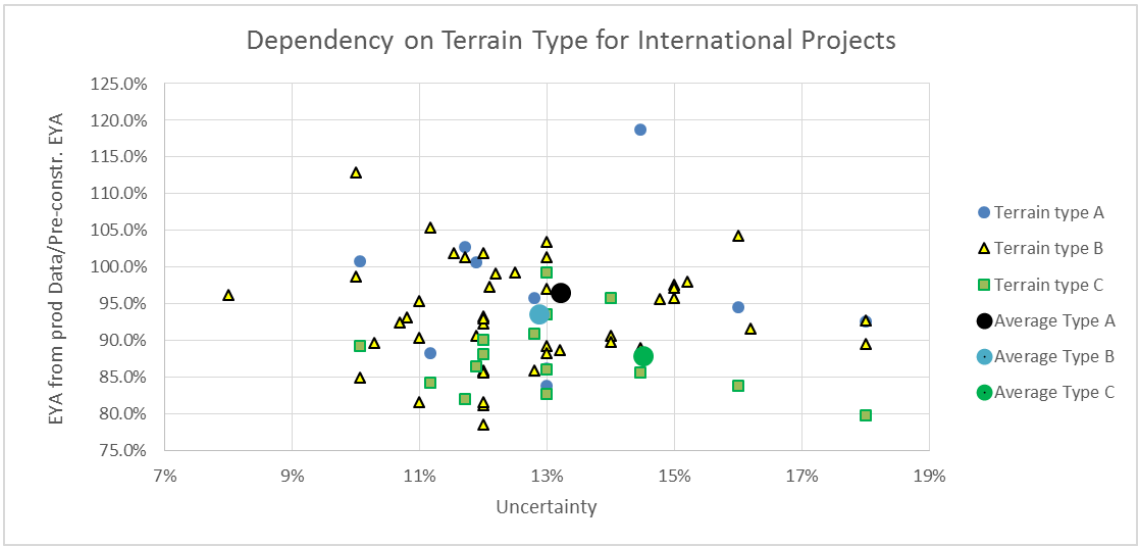

Figure 4: As can be seen, there is a clear dependency existing on the complexity of the site for the deviation of the energy yields and the uncertainties given for it.

Projects are located in differently structured terrain, from flat terrain with uniform roughness, more structured terrain, orographically hilly or even mountainous locations, or locations which are influenced by the open sea or which face special meteorological conditions that are hard to capture with the flow models. The dependency on this parameter is presented in Figure 4. For

sites identified as complex both deviation and given uncertainty of the assessment increase. The averaged values for the terrain types A and B are quite similar, but terrain type B is characterized by a significantly larger scatter, both in given uncertainties and deviation.

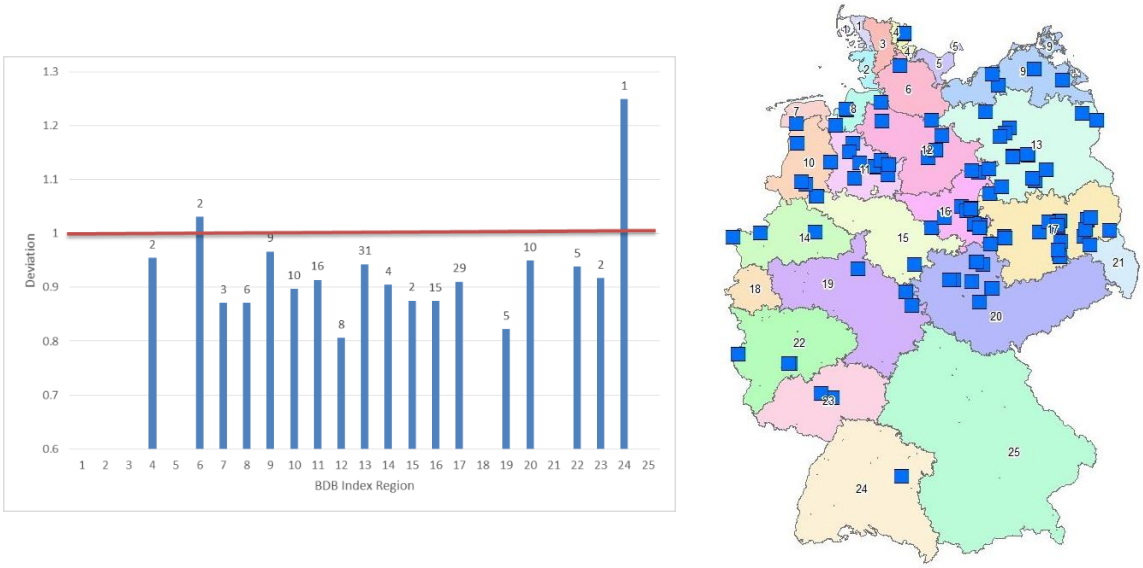

Figure 5: On the left side you see the deviations for each of the German BDB index regions, on the right you see the different regions and projects. The numbers above the histogram bars are indicating the number of projects considered in this region.

Figure 5 and Figure 6 present the deviations between post- and pre-construction energy yields for the different regions in which the farms are located, once for Germany the different BDB index regions for the different French regions, which have been created on basis of the investigated wind farms. The numbers above the histogram bars are indicating the number of projects considered in this region. Although for Germany some variation exists which could indicate a dependency on the region for which the energy yield assessment has been performed, the statistical basis is still insufficient for drawing final conclusions, especially does the variation not fit the expectations. For France, some differences can be identified, and so dependencies on the regions likely are existing, although not all index regions have a representative number of projects.

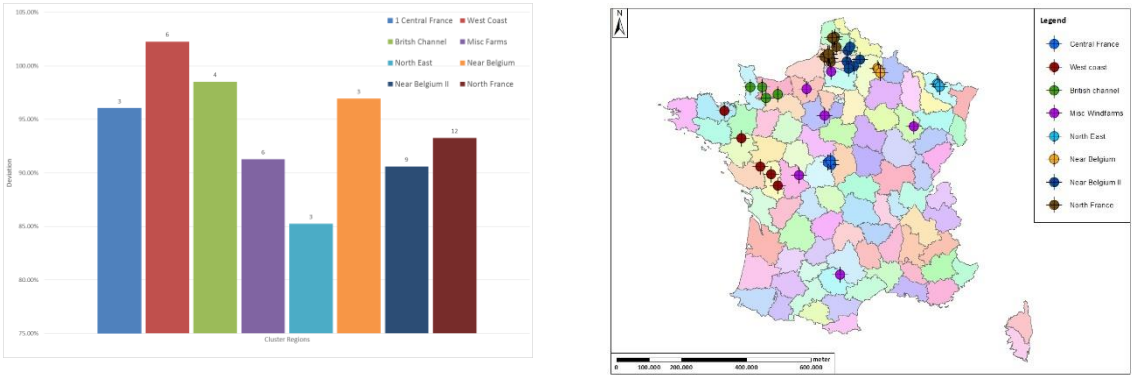

Figure 6: Same as Figure 5, but for different French regions. The numbers above the histogram bars are indicating the number of projects considered in this region as above. "Misc. Farms" within the French regions mean all WT that couldn't be connected with one of the regions.

As can be seen in *Figure 7* there seems to be also some dependency on the manufacturer, which indicates that one part of the deviation is not to be found in the pre-construction assessment, but on the operational data side, and possibly is influenced by the way the operational data are logged, evaluated and treated. Nevertheless, numbers are not fully representative and outliers can cause high deviations.

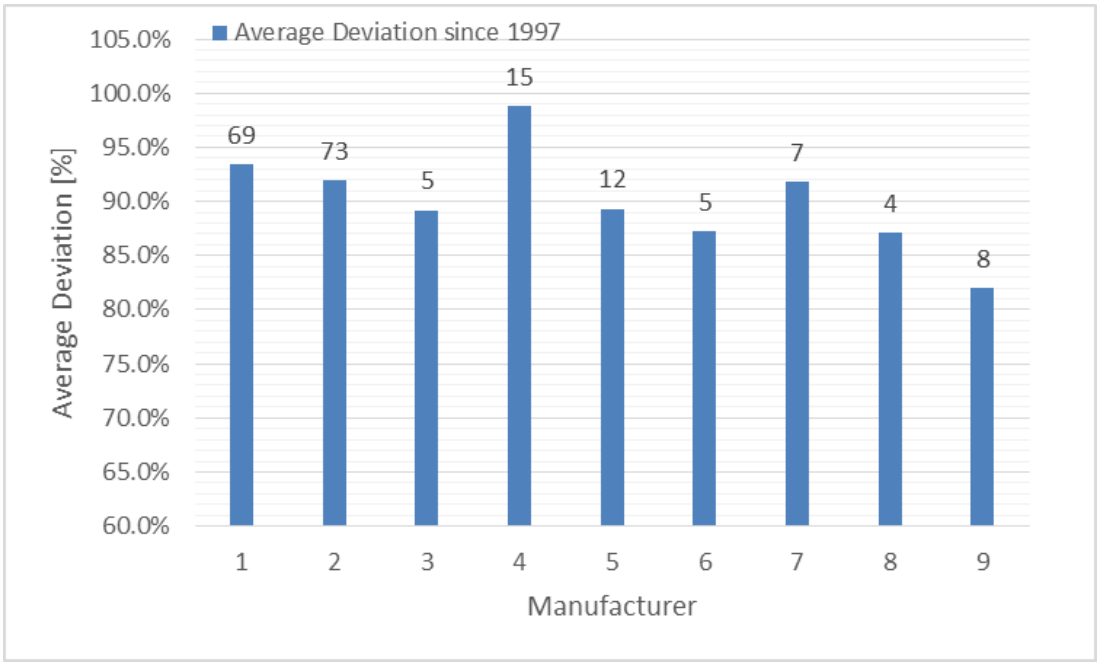

Figure 7: The deviations differ for the various manufacturers.

Conclusions

Energy Yield Assessments got more reliable over the years; while in the beginning average deviations were between 85 and 95%, they are now close to 100% on average. With about 40% a significant share of the assessments is hitting the P50 energy yields for the last 5 years, and a total of more than 75% is within +/- 10% deviation.

Uncertainties are generally fitting, so do 89% of the projects reach at least the proposed P90 energy yield and in this way fit to the definition of a P90 value. This result is valid for both the assessments based on on-site wind measurements as the ones based on verification turbines.

Investigating the dependency of the deviation on hub height, we found a steadily decreasing gap between pre-construction energy assessment and the energy yield calculated on basis of the production data with increasing hub heights (up to 142m), for the difference between measurement and hub height average values are not significantly differing, but a larger scatter can be found with increasing distance.

Further dependencies are existing on the complexity of the flow conditions, which is considered by the given uncertainties. Again, especially for the non-complex but structured terrain we face a significant spread of the individual uncertainty values and deviations. We also face some regional differences, indicating that the models cannot grasp the meteorology at all sites and data cannot be transferred with the same accuracy for different regions. So when setting up the measurement campaigns and inputs for energy assessments and later evaluation for structured terrain and some meteorologically special regions, it might need more care and a detailed look in the site characteristics beforehand.

Although not being fully representative, our investigation regarding the deviation for different manufacturer indicate that also the assessments based on the operational data have their share on the deviation between the pre- and post-construction assessments.

Outlook

Although a continuous improvement of prediction quality could be shown, the investigation is – due to missing data – limited mainly to 2 countries and does not consider high complex sites and the use of other flow models as e.g. CFD calculations. When these data become available, such projects need to be included in future assessments. Generally, the number of investigated projects needs to be increased with most current projects to gain more representative results for today's projects. Additionally, more dependencies need to be identified to gain highest value for an improvement of the methods. For this, and for a better understanding of the scatter in the different investigations, a further analysis of all project details is necessary.

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