

**Review and analysis of wind farm operational data**  
**Validation of the predicted energy yield of wind farms based on**  
**real energy production data**

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## **Introduction**

DEWI GmbH has performed more than 150 different energy yield assessments in Germany within the last 5 years. It is the aim of the investigations performed to review these assessments on base of a comparison with the real energy production of the wind farm sites calculated. In order to perform the analysis on a realistic and representative data base a large amount of more than 100 different wind farm sites have been analysed.

The following different parameters were part of the investigation

- Over- or underestimating the site energy production
- Uncertainty analysis (are the results within the given uncertainties and p-values)
- Determination of the exact causes of deviation
- Problem identification

Within this project DEWI performed:

- Review and evaluation of monthly production data of more than 100 different wind farm sites
- Long-term correction of the production data
- Comparison with calculation results (only DEWI assessments)
- Evaluation of uncertainties, technical availability and losses

Within the investigation performed DEWI evaluated site production data which have been extracted from the operator database available [1] or which have been provided by the clients and operators of the wind farms.

All in all 97 sites of the 102 different wind farm sites evaluated are located in Germany. Therefore the results are related to the particular situation corresponding to energy yield assessments for German projects (the application of the wind index [2]). For the other sites long-term assessment of the production data on base of meteorological long-term station data have been performed.

Any comparison must be performed on results which are in fact comparable to each other. For this purpose all energy yield assessments, production data evaluation and reviews which have been performed before 2002 or where no uncertainty assessment has been performed (up to the end of 2003) have not been regarded for detailed analysis. Wind farm sites which are showing a high deviation between calculation and operation result, have been examined in detail. The presentation on DEWEK 2008 was focused on the statistical results for the completeness of the regarded wind farm sites. Results for single sites will not be discussed, as the data and the information have to be treated confidential. Furthermore the analysis performed is focused on German sites. Therefore the following restrictions apply for this investigation:

- Not spatially representative
- Not independent in the long-term correction (for the German sites)
- Not all sites could be checked completely in detail
- Not enough sites and therefore no real statistics possible

Still under the explicit consideration of these restrictions, the data basis is considered to be suitable for the above mentioned analysis steps.

## 1. Procedures

The monthly production data and the information about the technical availability have been used for the determination of the long-term energy yield, finally to be compared with the calculation results of the DEWI assessments. A long-term correlation must be considered as an exigency of this data analysis, to ensure a comparability of both data, as long as the long-term correction of the production data is performed correctly and according to the state of the art. In this context DEWI performed an investigation on base of the simple application of the wind index [2] and furthermore after corrections of the index 100% level as applied by DEWI also during the energy yield assessments performed [3][4]. Both results are shown in figure 2.

The following figure shows the location of the wind farm sites and the corresponding wind index regions which have been evaluated within this investigation:

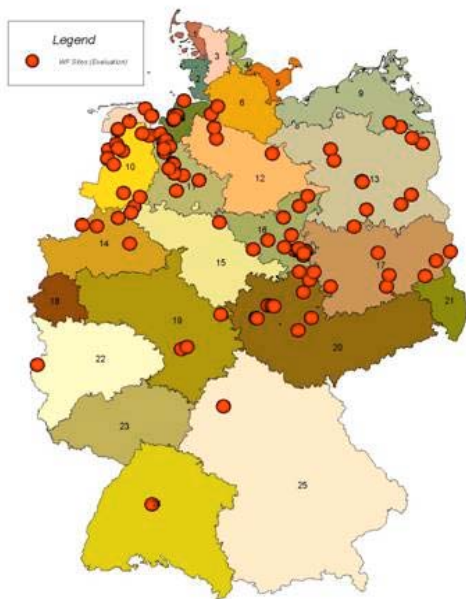


Fig.1: Wind Farm sites and the wind index regions

As seen in figure 1, the spatial distribution of the evaluated wind farm sites does not allow a deeper geographical analysis. Detailed investigations between the site complexity and the general suitability of some of the applied wind index regions were not derivable from the analysis performed.

## First results

The following tables give a general overview of the results of the comparison analysis:

Deviation REAL/CALC (mean values of all sites)				
Services	Long-Term DEWI / Calculated	Long-Term IWET-BDB / Calculated	Uncertainty	Amount
Feasibility Studex / Preliminary				
Investigations	96%	100%	17%	3
Detailed Review	94%	99%	14%	8
Operational Data Analysis	98%	102%	9%	17
Energy Yield Assessment	94%	98%	14%	74

Overestimated / Underestimated				
Services	Overestimated (more than 10%)	Underestimated (more than 10%)	Hit (+/- 5%)	Amount
Feasibility Studies / Preliminary				
Investigations	1	0	1	3
Detailed Review	2	0	3	8
Operational Data Analysis	0	0	14	17
Energy Yield Assessment	15	2	32	74

Outliner P-Values				
Services	P75	P90	Uncertainty	Amount *)
Feasibility Studies / Preliminary				
Investigations	0	0	0	1
Detailed Review	2	0	1	8
Operational Data Analysis	0	0	0	15
Energy Yield Assessment	13	0	7	68

\* only sites where a detailed uncertainty assessment has been performed

Fig.2: Main results of the comparison analysis

As seen in tables the assessments are:

- mostly within the given uncertainties (displayed as mean values),
- on average too optimistic p50 calculation results compared to DEWI long-term results and within the line compared to IWET/BDB long-term results.

## Uncertainties

As a matter of fact, any energy yield assessment has to be considered as a prediction and therefore contains uncertainties, as the model applied, the data and assumptions are related with specific uncertainties: It is therefore indisputable that the correct and project-specific determination of the uncertainties is a minimum requirement for any energy yield assessment study [5].

The mostly applied uncertainty results are the related p-values, which determine a probability level that the energy yield calculated will be reached or exceeded. These values generally allow a risk assessment concerning the energy yield prediction. No general recommendations are given in DEWI assessments, which p-level should be applied. This finally depends on the actor involved and his market strategy, but in practice often the P75 or the P90 are named as base values for project financing. Often still the "safety margin" will be applied and enhanced on the values provided of the overall uncertainty in the energy yield.

Experience has also shown that there are considerable deviations between the uncertainties assumed by different consultants (in some cases they are often only sporadically assumed), which makes it difficult to perform a unique uncertainty evaluation for external analysts.

The following charts illustrate the results of the evaluation performed in respect to the related p75 and p90 values given in the DEWI assessments.

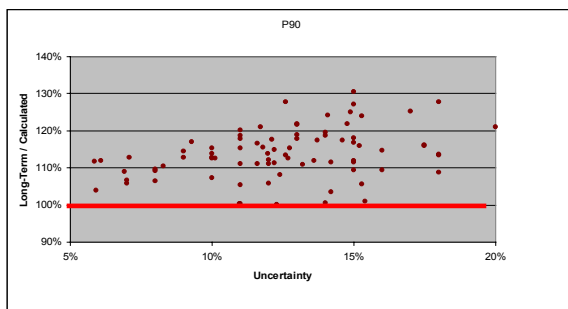
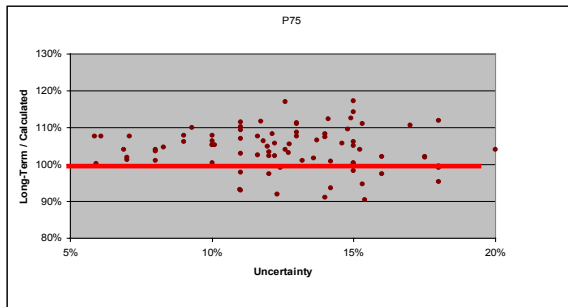


Fig.3 and 4: Results vs. p-values

As seen in the figures 3 and 4 the related calculation results are only less and in case of the p90 not below the given probability value. This is in fact remarkable, as the p-values in this case determine a value still containing a risk of 25% or 10% that the results are below these numbers. Even considering that these results also are still related to uncertainties (long-term correlation, future operational behaviour of the wind turbines etc.) and that further future evaluation on base of a larger amount of data may show higher deviations, the results are indicating generally too high uncertainties for the p90. This is not corresponding to the real meaning of these values anymore to be applied for a realistic risk assessment.

Furthermore the analysis reveals some - also generally known - deficits, concerning the distribution of values lower than the p50 (the former calculation results). In fact, there are significantly less sites which have been underestimated (see figure 2) than the other way around. Any further analysis of wind farm portfolios should finally consider that there are model- and input

data specific significant more causes existing for lower than for higher energy production than predicted.

Finally from DEWI's viewpoint it is the aim of any energy yield assessment to determine as much realistic p50 calculation results as possible and therefore the results should be evaluated concerning this viewpoint in more detail, in order to derive exact causes for energy yield over- and underestimation.

### Specific Parameters

The generally existing suggestion that large **hub heights** are significantly underestimated could not be derived from the analysis, but it should be considered that especially the large hub height (for example 120-130m) is not covered within the available data basis. Anyway, a trend in the results that confirms the underestimation of the hub heights between 90 – 110 m could not be taken from the analysis.

What has been clearly proven, is that there is a strong trend to calculate too optimistic results for **large wind farm sites** (in this case more than 15 wind turbines). These sites have been overestimated in the mean by 4% more in the long-term energy yield than the sites with less than 15 wind turbines. Such a result must be investigated in more detail. Further investigations revealed that a lot of the wind farm sites regarded have been extended during their operation time. Former small sites are now in fact part of larger wind farm sites, which have not been considered in the first energy yield assessments. Anyway, there is a remaining rest of 10 sites showing higher deviations, especially for sites located in non complex or only slightly complex terrain between the different wind turbine positions. This is mostly explainable due to real higher farm losses than have been calculated with the standard procedures. The results in [6] presented on DEWEK 2006 could therefore be confirmed additionally.

The key points are included in the fact that energy yield prediction generally relates to assumptions and ideal energy yields that are in contradiction to the real operation of the wind farms. One major point is the **technical availability** of the wind turbines, which is generally assumed to be 100% for the determination of the gross energy output. Also within this investigation the availability has been corrected to 100% level and furthermore low availability values have been disregarded. In fact these values are of course lower. Within usual project finance often the guaranteed availability according to the information of the manufacturer will be applied. The results in technical availability (as mean value) is

varying site specific between 95% -99%, including still some sites with unexplainable less production compared to the given availability values.

#### **Further losses**

Any comparison of the nominal and actual production is incomplete as one of the values is linked to further parameters, not considered or only assumed in the related energy yield assessment, as it is the case for the technical losses.

In fact these losses are in most cases only assumed or experience values will be applied without taking care of the real site-specific losses related to the energy production. For energy yield assessments in Germany the determination of losses normally is not performed within the energy yield assessment, in some cases they are not even named or included in a kind of safety margin, which must be considered as simple and not site-specific assumption.

Within this context DEWI evaluated 36 wind farm sites in detail on base of more complete information concerning these losses. A more detailed investigation of the different sources will be performed:

Losses due to the operation mode of the wind turbines:

- These losses are generally predictable and therefore integrative parts of any energy yield assessment. They include any kind of temporal stops scheduled in the building permission as well as power-reduced operation modes.
- Even if in most cases a 100% accurate determination of these parameters is not possible, these aspects have to be considered in the related energy yield assessments (as far as they are known)

#### **Technical availability of the wind turbines**

- The technical availability remains a value which is not predictable. Even if the evaluation performed shows in some cases a strong correspondence between wind turbine type and finally reached availability a concrete determination of this parameter is not possible.
- As derived in the evaluation of the production data the technical availability in most cases is higher than the known guaranteed values covered by the O&M strategy. In this context a more detailed analysis of the wind farm operation, the failure of components and further

corresponding factors would help to consider the technical operation more correctly.

- As the technical availability is finally defined by the unforeseen stops of the wind turbines (repairs, failure of components etc. defined in the status codes) a reliable determination before the start of operation has to be considered as not possible.

#### **Electrical Losses / Grid Losses**

- The generally made assumptions concerning these losses are mostly too low. DEWI evaluated real losses for all 36 regarded wind farm sites of about 3%. Especially for the large wind farm sites the losses are significantly higher.
- The more exact determination of these losses is possible before starting the operation. It is strongly recommended to determine these losses in detail before building the wind farm site.
- Grid losses (also defined as grid downtime) are also assumed. These losses are neither part of the technical availability nor included within the electrical losses which determine the losses between wind turbine and finally the connection point (the counter). The determined grid availability losses are varying between 0.7% to 2.5%.
- For some regions the grid management is a factor which is not considered correctly within the assessments so far. Especially for the seasonal strong wind months grid downtimes have been discovered leading to several percent additional losses in the energy production.

#### **Conclusion and outlook**

The results concerning the comparisons between energy yields calculated by DEWI and the long-term corrected production data are considered to be quite good for the wind farm sites regarded. Considering the project related uncertainties and furthermore the p-values it is shown that DEWI energy yield assessments are in fact of the necessary quality for project financing purposes. Anyway, DEWI will start to investigate the different sites in more detail to determine possible outliers and the exact causes for the deviation in order to consider these parameters adequate within the energy yield assessments themselves and if not possible within the uncertainties.

It is one of the main conclusions of this investigation that possible deviations should not be considered only in form of higher or additional uncertainties. Such a procedure finally turns a reliable assessment of the probability values simply to a worst case scenario, which is not in the interest of project financing and developing. The uncertainties should be given realistically in respect to the site conditions and not on base of the highest deviation values.

Another result of the analysis is that energy yield assessments should be related to the real technical operation of wind farms and to the site-specific losses. In this context, the operation control and the wind consultants are working with different "languages" and not comparable values. The challenge is therefore to determine a realistic NET energy production. The application of standard values and assumptions alone is considered as not suitable and should be avoided.

Furthermore DEWI still sees research deficits concerning the large wind farm sites. Evens considering that some of the sites regarded have been temporarily extended, the observed deviations are high.

Future research should focus on these aspects and a more reliable and practicable determination of the farm efficiency for large wind farm sites onshore or to determine the related uncertainties in a realistic way.

The open question remains, what of these loss parameters could be included in the frame of an energy yield assessment and what finally depends on other information normally not available for the wind consultant or not related to the technical assessment of wind turbines.

Together with a large German wind farm operator DEWI started a research project to determine the aspects of the real wind farm operation in detail in order to derive new results also applicable for the related works in the energy yield assessment and Due Diligence.

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