HIT THE TARGET – EVALUATING THE MATCHING QUOTE OF LONGTERM YIELD PREDICTIONS

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Summary

Correctness of longterm yield predictions can be checked by comparison of the calculated energy yields with the respective operating data of wind farms erected later. The present paper describes continuous indicators, partly including uncertainties, characterising the goodness of accordance between predicted energy yields and the respective ones earned later, or derived from them. These indicators are applied to a sample of altogether 176 yield predictions compiled by Ingenieurbüro Kuntzsch GmbH. So, key parameters influencing the goodness of hits are found and described.

1. Experimental set-up: simple or complicated

During their development phase, wind power projects need data about the expectable energy yields. After the implementation of a project and its operation over an adequate period of time, predicted and actual earned yields can be compared to check how accurate the predictions were.

The elementary setting of this comparison can be characterised as follows: results of the predicted yield's calculation are an expectancy value E_{PRED} and a measure of its expected inaccuracy, preferably a relative standard uncertainty U_{PRED}. Later, the wind farm is realised and operated without deviations regarding positions, types, hub heights, operation modes etc. of the WECs from the features assumed for the prediction. Information regarding yield losses due to downtime or changes of operation modes is recorded permanently during operation. The wind farm's configuration is not changed during a representative period of time. After expiration of this period, estimated yield losses due to downtime are added to the energy yield accumulated E_{OP}; normalised to a yearly mean value, this sum can be compared to the respective yield E_{PRED}.

All these ideal conditions are obviously not fulfilled frequently, because:

- The operational and site-specific conditions often differ from the ones supposed in the models used for predictions [5]. Such changes have, if known, to be re-introduced to the model.
- Records regarding downtime-related yield losses are often not available or even not maintained.
- It is likely that the yield expectation is checked against operational data *before* a time period which can be assumed to be representative by itself has expired. Operational data of shorter time periods have to be set into relation to the long term wind climate. So, at the latest here they get associated with an additional uncertainty U_{OP}. It is assumed in the following to be a relative standard uncertainty as well as U_{PRED}.
- Normally, yield predictions are based on a long term relation. It has to be regarded that the base level of long term normalisations in Germany had to be adapted remarkably several times in the past [4].

2. Target and hits

How can the situation called 'hit' be characterised? A first expectation following from common sense shall be formulated: the ratio $V_E=E_{OP}/E_{PRED}$ should be close to the ideal value 1. Without aiming to establish any recommendations for standard values here, a range of $0{,}9 \le V_E \le 1{,}1$ shall be assumed to be criterion for a *hit,* and a range of $0{,}95 \le V_E \le 1{,}05$ [6] for a *direct hit* in the following. If these are the targets for each single prediction, what does uncertainty mean for the chance to hit?

When, for example, taking a value of U_{PRED}=12,3% for a fictitious project, the probability for a *hit* is 58%, and the probability for a *direct hit* is 32%. So, the chance for a hit depends on the uncertainty declared for the prediction.

Therefore, in some situations there is need for criteria describing the goodness of predictions which do not fade out the effect of uncertainties.

3. Enhanced indicators for goodness of accordance

An enhanced indicator for the goodness of accordance between the yield's prediction and its manifestation in operational data should feature

- the inclusion of both the mean values of yield E_{PRED}, E_{OP} and of their uncertainties U_{PRED}, U_{OP},
- ease of use by non-dimensionality and interpretability as frequency or probability.

The well-known approach using one-sided confidence intervals which has led to 'p-values' like p75 and which has become broadly accepted for risk considerations in connection with yield predictions can be extended to the relation of two probability distributions; one describing the predicted yield and the other one the yield from operational data (or, in most cases, the result of their longterm normalisation). Figure 1 shows the exceedance probability of the prediction being set into relation to the probability of non-exceedance from the respective operational data.

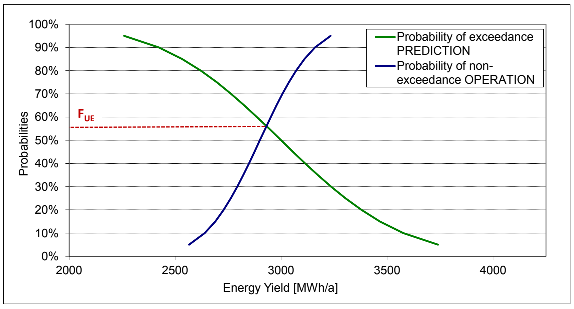

Fig. 1: Exceedance probability of prediction (E_{PRED}=3000 MWh/a; U_{PRED}=13%) in relation to non-exceedance probability of longterm-normalised operational data (E_{OP}=2900 MWh/a; U_{OP}=7 %)

The intersection point of both graphs represents the probability for the assumption that the yield resulting from the prediction exceeds the yield resulting from the operational data. In the following, this probability $F_{UE} = F(E_{PRED} > E_{OP})$ is another goodness indicator simply named *exceedance probability*. The indicator mirrors an approach of risk minimisation; a situation where the operational yield falls below the predicted one is characterised by an indicator exceeding the value of 50% and shall be avoided.

Seen from the perspectives of a consultant providing yield predictions or of a project developer, this approach may be not completely satisfying, because the yield prediction should both not exceed and not fall below the operational yield too much. An indicator should be able to picture this expectation as well.

The probability distributions of both predicted and operational yield can be used to derive two-sided confidence intervals being characterised by the same level of significance α. As illustrated in Figure 2, there is one level of significance α_G for a pair of distributions of probability density leading to confidence intervals touching even close. α_G actually represents a probability of error for the assumption that there is *no* relation or similarity between the two distributions. So, it seems to be a continuous measure for the goodness of this relation.

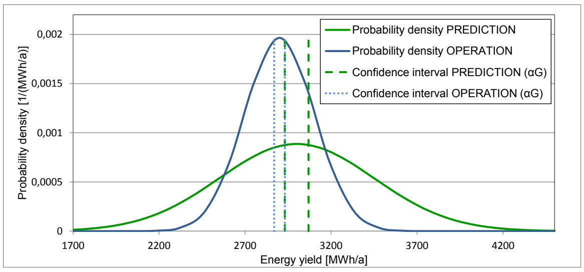

Fig. 2: Probability densities of prediction (E_{PRED}=3000 MWh/a; U_{PRED}=13%) and of longterm-normalised operational data (E_{OP}=2900 MWh/a; U_{OP}=7 %) and their two-sided confidence intervals for a confidence level α_G=0,88

In analogy to a definition in [2] ("closeness of the agreement between the result of a measurement and a true value of the measurand"), our third goodness indicator α_G will be designated as *accuracy* in the following. Table 1 summarizes features of the three indicators introduced. Uncertainty values of U_{PRED}=13% and U_{OP}=6,5% were assumed for the transformation of the value ranges of V_E into respective ranges of F_{UE} and α_G.

Name	Yield ratio	Exceedance probability	Accuracy
Symbol	V_E	F_{UE}	α_G
Value range	≥0	0…1	0…1
Value to seek	1	0,5	1
Range for hit	0,9…1,1	0,31…0,7	0,6…1
Range for direct hit	0,95…1,05	0,4…0,6	0,8…1

Tab. 1: Features of the goodness indicators

The behaviour of the latter two goodness indicators was checked by 3-dimensional graphical visualisations; assuming E_{PRED} and U_{PRED} to be predetermined, F_{UE} and α_G could be plotted as curved surfaces over a base area with an abscissae representing V_E=E_{OP}/E_{PRED} and an ordinate representing U_{OP}. Exceedance probability shows a surface without local extremes and having a reversal point at E_{OP}/E_{PRED}=1. Rising uncertainty U_{OP} corresponds to falling gradient of the surface.

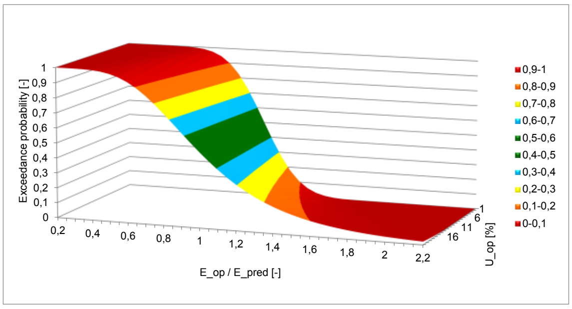

Fig. 3: Visualisation of exceedance probability F_{UE} vs. V_E and U_{OP} with U_{PRED}=13%

The indicator *accuracy* features a clear local maximum at E_{OP}/E_{PRED}=1 and the same correspondence of falling gradient of the surface with rising uncertainty U_{OP}.

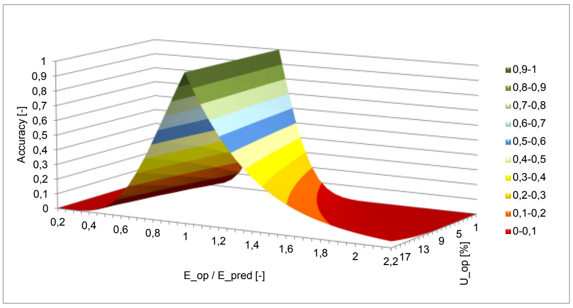

Fig. 4: Visualisation of accuracy α_G vs. V_E and U_{OP} with U_{PRED}=13%

4. Evaluation of a sample of yield predictions provided by Ingenieurbüro Kuntzsch GmbH

During more than 20 years of consultance activity, Ingenieurbüro Kuntzsch GmbH has compiled reports regarding predictions of energy yields of WECs for more than 1100 sites. Since about 10 years, realised projects are systematically collected in our organisation, together with characteristics regarding predicted and operational yields, their locations, the prediction's data base and the WECs. Operational data featuring a sufficient time resolution were available for evaluation in the present study for 176 of these sites.

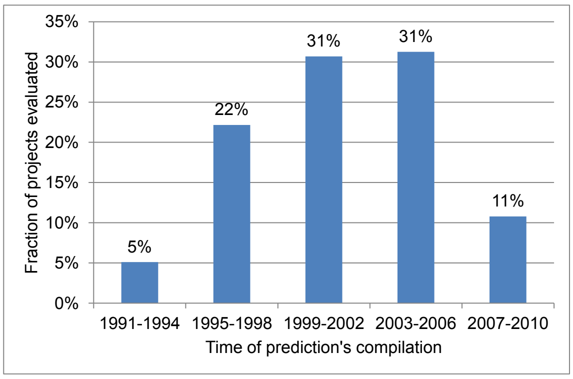

Fig. 5: Distribution of the times of compilation of the 176 yield predictions

The distribution of the times of compilation shown above mirrors the rapidly rising number of evaluations during the first years. The falling fraction of projects at the rear end of the row can be explained by the remarkable time elapsing after handover of a prediction until the project's implementation, the discovery and finally the evaluation of operational data.

Solely 5 of the projects fulfil the ideal requirements regarding operational data and conditions which have been described in section 1, i.e. detailed operational data were available for a time period of 10 or more years with unmodified wind farm and WEC's configuration and without deviations from the configuration assumed for the yield prediction.

The majority of the projects' locations are in Germany; only 4 projects are situated abroad, but even than close to the border to Germany. With one exception, the modelling of wind flow was performed using WAsP (different versions) for all projects.

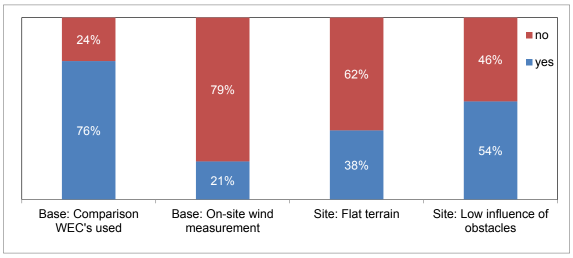

Fig. 6: Selected features of the prediction's data base and of the sites

For all projects, goodness indicators according to table 1 were calculated from the average yields and uncertainties. As a start, the long-term reference level presently being broadly accepted to be representative was assigned to all projects. As this reference level has changed in the past several times, long term normalisations of 3 additional reference levels having been applied in the years 1989…2003, 2003…2006 and 2006…2011 were assigned to the projects if applicable.

These data base could now be used to check the influence of different parameters to the frequency distribution of goodness indicators.

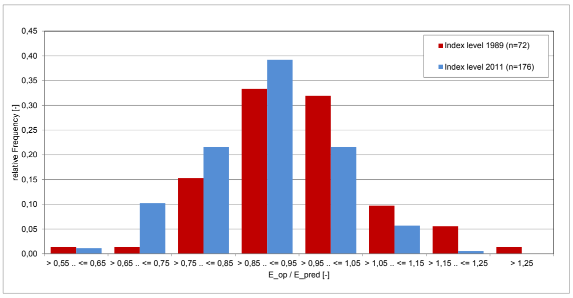

Fig. 7: Comparison of V_E's frequency distributions based on longterm climate levels 1989…2003 and 2011

Applying significance tests or regression analyses, the influence of a couple of parameters assumed to have essential impact on the goodness of hits was tested. For nearly all questions, sufficient large, independent samples ($n \geq 30$) were available to perform statistical hypothesis tests. Questions concerning expected values were tested by two-sample Gauss-test; questions concerning variances were tested by two-sample F-test. The common significance level (α) of 0,05 was applied for all tests. A selection of performed statistical tests and their results and interpretation can be found in table 2.

hypothesis	confirmed?	interpretation
expected value F_{UE} with long term level 1989 lower than with long term level 2003	yes	The basis of longterm normalisation systematically influenced the results of the evaluation. This factor had to be compensated by assigning matching longterm levels of prediction and evaluation.
expected value F_{UE} as before (levels 2003 and 2006)	yes (not significant)	
expected value F_{UE} as before (levels 2006 and 2011)	yes	
increasing accuracy of the yield predictions over the years	yes	Motivating!
expected value V_E higher if power curve/availability are trustable	yes	projects with untrusted power curves or availability were excluded from subsequent tests or equilibrated concerning this influence
variance V_E is higher without comparison WECs AND without on-site measurement	yes	on-site measurements or comparison WECs are mandatory today
variance V_E is lower with comparison WECs AND with on-site measurement	yes	combined use of both data bases was ideal
variance V_E is lower if only on-site measurement is available	yes	adding of comparison WECs was helpful if on-site measurement available
accuracy dependents on the site elevation	no	
variance VE is lower in flat terrain than conversely	yes	modelling of complex terrain was more sophisticated

(continuing…)

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hypothesis	confirmed?	interpretation
variance V_E is higher if roughness class is high	yes	modelling of high site-roughness was more sophisticated
variance V_E is higher if influence of obstacles is high	yes (not significant)	modelling of obstacles worked satisfactory
variance V_E is higher in large and narrow designed wind farms	no	modelling of wake effects was not the main issue
standard deviation V_E is not higher than the dimensions of U_{PRED} declared	yes	standard uncertainties weren't too low by tendency; but contradicted by the monotonic decrease of longterm levels

Tab. 2: Overview of performed statistical tests

After having evaluated the longterm-related hypotheses it was obvious, that the longterm normalisation has a significant influence on the test criterion. To eliminate this influence, the subsequent tests were done at the basis of the longterm normalisations valid at the time of preparation of the respective yield predictions.

Matching quotes with respect to the indicator's value ranges from table 1 were calculated.

Indicator	V_E	F_{UE}	α_G
Range for hit	0,9…1,1	0,31…0,7	0,6…1
Fraction of hits	0,6	0,65	0,65
Range for direct hit	0,95..1,05	0,4…0,6	0,8…1
Fraction of direct hits	0,36	0,40	0,40

Tab. 3: Matching quotes based on different goodness indicators

Compared to the expectable matching quotes shown in table 1 and considering a median uncertainty value of U_{PRED} of about 12,3% in the sample the calculated matching quotes are slightly higher than the expectable ones for this uncertainty level stated in section 2; but it shall not be forgotten that the influence of long term normalisation to the matching quote had been compensated before.

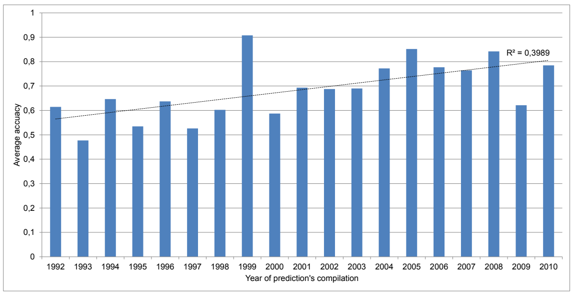

Fig. 8: Average accuracy vs. year of prediction's compilation

Accuracy of the predictions has obviously changed year by year; a slight improvement over the time can be concluded from the data.

5. Conclusions

The data base described has confirmed its remarkable value for the internal quality management of our institute during the study. The maintenance of the data base is continued permanently.

Key parameters for the quality of yield predictions have been investigated; partly, their significant influence could be proved for the sample evaluated by statistical methods. Besides the basic level of long term normalisations, the character of the data base used for predictions seems to be crucial for the expectable level of uncertainty – and thus the frequency of hits. When aiming low risks, on-site-measurements, optional combined with comparison WECs, were the best choice for the sample.

In connection with significance tests, the goodness indicators described were flexible instruments for the decision of quality-related questions. When having a big-enough sample, the *Yield ratio* V_E seems to be appropriate for most cases; *Exceedance probability* F_{UE} and *Accuracy* α_G are especially helpful for small samples or single projects and for the description of changes of the goodness of hits over operational time. Further work will be done to apply these indicators on additional samples or in different contexts, e.g. for monitoring of wind farms especially in the first months or years of operation or for comparison of different yield predictions for a project portfolio.

6. References

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