WHAT A GOOD WIND INDEX CAN BE GOOD FOR

Dipl.-Ing. Henning Krebs (*), Stud. Met. Jana Sebecker (*)
(*) Ingenieurbüro Kuntzsch GmbH, Moritzburger Weg 67, D-01109 Dresden,
Tel. ++49-351/885 071, Fax ++49-351/885 07409, eMail: gutachten@ib-kuntzsch.de

Summary

In Germany, wind indices are commonly used for the purpose of evaluating yields of existing wind farms or wind measurements. They are a simple model that relates the wind climate of a short period of WEC operation (or measurement) to the long-term average value. The present report attempts to give some answers to the questions: How should a good wind index behave? What could a good wind index be used for?

1. Preface

Wind is a moody energy source; the energy content during a winter month can be 7 times higher compared to one in summery calm periods. Wind indices are an attempt to describe these variations by non-dimensional fraction numbers corresponding to the pattern

$$\text{index} = \frac{\text{parameter}_{\text{short term}}}{\text{parameter}_{\text{long term}}}$$

Parameters can be WEC yields or power densities derived from wind measurements. Knowledge of the long-term average value is assumed here, its length comprised usually 10 or more years so far. The index values are ascertained monthly or yearly; regional differences occurring even in this time scale are taken into account e.g. by creation of index regions.
In Germany, wind indices are commonly used for the purpose of “normalizing”, or establishing a relation to the long-term of yields for existing wind farms or wind measurements. As a reaction to reports published before several suppliers of wind indices are available meanwhile ([1], [2]). Additionally it is possible that the long-term yield can be determined with several methods using only one index ([2], [4]). Different evaluation methods or in-dices can and should be compared [3] by means of test data and quality criteria that are described in the following.

2. Behaviour of good wind indices

If a wind index is used for the purpose of long-term-normalization of yield or wind measurement periods, the evaluation procedure can be illustrated from the view of the user by the following black box model:

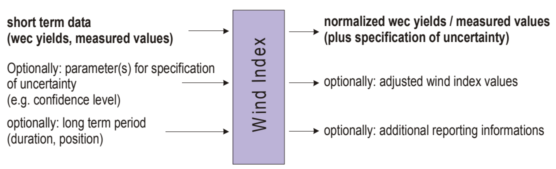

Figure 1. Wind index – view of a typical user

Notice that the wind index values themselves are, from the viewpoint of a simple user, actually just interesting for test purposes, as they are only a means of the service of normalization. This is especially valid, because plausibility checks and adaptions of the raw index values related to WEC type, hub height and wind power density level are compulsory in any case during the normalization procedure.
For that reason, we regard a wind index not only as raw index values, but actually as software provided by the index publisher to the user for data import, plausibility check, the normalization itself, data export and reporting.
For a comparison of different yield evaluation methods or wind indices from several providers at a WEC site, test data (energy yields, wind measurements) are available over a long period of time in the ideal case. But even shorter periods are suitable for a test by means of quality criteria.
The explanation of the criteria is done by means of yields of a WEC located in the region 17 of the Betreiberdatenbasis (BDB) [4]. With these data the average long-term yield was calculated for every monthly energy yield from July 1999 to August 2004 by means of three methods.
One very easy method to calculate the monthly long-term yield is to average all monthly energy yields of a WEC up to the month of consideration.
Another method is the quotient method. At first all monthly energy yields are divided by the monthly wind index. Then all monthly results are averaged.
The third method used is described in [2]. Here a linear functional relation is established between the wind index and the monthly energy yields.

2.1. Robustness against outliers

Outliers occur in energy yields of WECs and in wind index values. In both cases, outliers can influence the result of a yield evaluation considerably and lead to wrong results [2].
A method or a wind index is robust against outliers if an outlier hardly or at best not at all influences the result of a yield evaluation. Robustness depends on the number of values available and can be achieved by means of a reliable diagnosis or by an insensitive method of index usage.

In order to test the robustness of a wind index or a method of yield evaluation with a wind index one needs a test that is prone to outliers. One of the easiest tests is to determine the influence of every single energy yield on the result. This can be done at first by determining the monthly average long-term yield using all monthly energy yields available. Then the monthly average long-term yield is calculated by successively leaving out one monthly energy yield. A value that has a very big influence on the result can be identified as an outlier.
The result of the outlier determination for the regression method is shown in figure 2. It shows that, for example, the result is especially influenced by the values of December 2003 and January 2004. Therefore they can be identified as outliers.

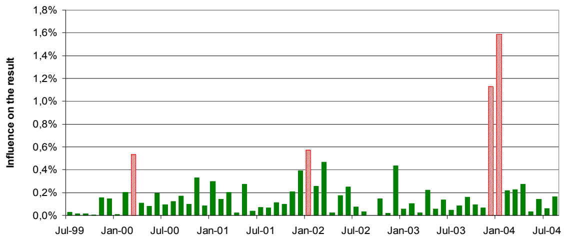

Figure 2. Influence of monthly yield evaluations on the final result the regression method. Outliers are marked red.

Other methods to identify outliers are methods investigating the relation between monthly energy yields and contemporaneous wind index values, or more advanced, comparing monthly energy yields of the WEC with the ones of nearby WECs.

2.2. Speed of convergence
Another criterion is the convergence. A user of a wind index would like to use as less as possible energy yields of a WEC to calculate the average long-term yield and be able to designate the point in time when convergence occurred. A method with one is able to check the convergence of a yield evaluation is to calculate the ratio of successively determined monthly long-term average yields. If the absolute value of the deviation to 1 declines with time and falls below a threshold value then the result of the yield evaluation is converging.

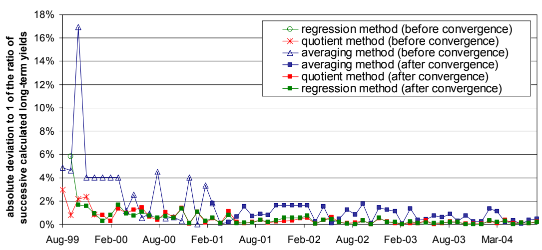

Figure 3. Convergence behaviour of the three investigated methods

Figure 3 illustrates, after all outliers are identified and left out from further calculation, the convergence behaviour of the three methods considered. The threshold value is taken here as 2%. As expected, the averaging method converges at last. The other two methods converge already after 5 to 6 months.

2.3 Absence of trends
After the yield evaluation converges a trend can still affect a yield evaluation. Therefore it is suggested to apply the trend estimation once after the convergence of the yield evaluation. Then a trend can be detected e. g. by a trend line. If the slope of the trend line is below a threshold value then the yield evaluations can be considered as free of trends.
As shown in figure 4 the averaging method is the one that is affected strongest by a trend. After its convergence the average long-term yield declines by 0,02% per month. The other two methods are less influenced by a trend but are still affected after their convergence.

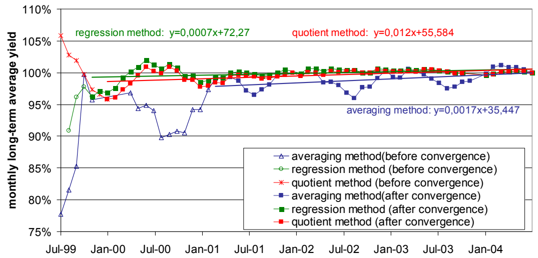

Figure 4. Results of yield evaluation (normalized on the last monthly average long-term yield of the respective method) and estimation of trends

To sum up, one can say that the regression method is the most suitable evaluation method for the considered WEC. For other sites or WECs this might be different. Moreover, it is also possible to compare wind indices from different suppliers by means of these criteria in order to find out the most suitable for a WEC site.
A wind index satisfying these criteria should be suitable for a long-term-normalization as mentioned above. But the daily routine in the field of wind energy shows sometimes additional ways of usage.

3. Alternative ways of usage

3.1 Prediction of annual wind index value of the current year

A question that frequently occurs is: What will be the annual wind index value of the current year? A statistical analysis, which was carried out here on the basis of the wind index of the BDB [4] (average of all 25 regions, normalized on the period 1989 to 2003), is able to answer this question and to predict the expectable annual wind index of the current year. Additionally the remaining uncertainty can be expressed in terms of probabilities of exceedence for various annual wind indices.
At the beginning of every year the monthly wind indices of the past years and their annual averages are known but nothing about the development of the weather and consequently the wind and the wind index values of the coming 12 months. For that reason, at January 1st the best guess is that the coming

year is going to be an average year with a probability of exceedence of 50% (figure 6).
With progressing time more information is gained with the publication of monthly wind index values. Sometimes the average of these monthly values is assumed to equal the expectable annual wind index value, which is at the beginning of September 86% for 2004. But this approach doesn't take into account the influence of the coming months. For example, at the beginning of September, the annual wind index is more influenced by summer and spring than by winter and autumn wind indices. But as shown in figure 5, the autumn and winter wind indices add essentially to the annual wind index value.

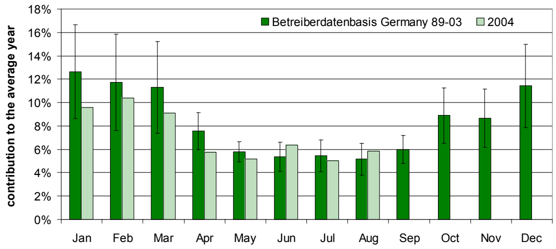

Figure 5. Monthly values (normalized) of the BDB-index of the average year together with their standard deviation compared to the values of 2004

Therefore it is suggested to calculate the expectable annual wind index of a current year from 12 monthly wind index values. Those monthly wind index values of the present year which are not known at this time can be substituted by their monthly long-term averages and their standard deviations as their best estimates. With this approach one obtains at the beginning of September 2004 an annual wind index of 92% for 2004 (figure 6), which is reached at the end of the year if the weather conditions of the remaining 4 months will develop like in an average year (green dashed line in figure 6).

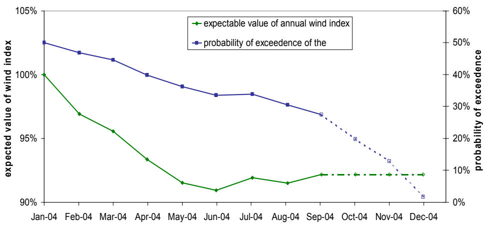

Figure 6. Time plot of monthly expectable values of the annual wind index 2004 and of the probability of exceedence of the average year (for an explanation of the dashed lines see text)

In addition one can determine the probability of exccedence for different wind index values. Figure 6 shows a time plot of the probability of exceedence for the average year. It illustrates that the probability of exceedence declines with progressing time implying that the probability density distribution is getting narrower and that the reliability of the prediction is increasing with time. At the beginning of September 2004 the probability of exceedence for the average year amounted to 27 % and will fall under average conditions to 2% until the beginning of December (blue dashed line in figure 6).

3.2 Risk consideration for different reference periods
For the last few years, the "Long-term" was a topic that maybe wasn't discussed thoroughly. It simply meant a period of time that was long enough to be representative for the assumed duration of WEC's operation.
The operation period of WEC's usually assumed for liquidity considerations has a length of 20 years; the duration of the wind climatological reference period was determined in past by the availability of surface wind measurements consistent over long time periodes or by the operation period of existing WEC's. E.g. the wind climatologies published and adapted to wind energy purposes by the German weather service [6] comprise measurements with durations between 4 and 17 years; the long-term wind measurement stations operated by Ingenieurbüro Kuntzsch GmbH started their operation not before 1992. Eventually, the reference period of the BDB-index starts 1989 and was adapted several times to the observed mean yield level.
The availability of world wide data of the NCEP/NCAR Reanalysis-Project [5] has made it possible, to view behind (or better, before) the previous time horizon in order to gain informations about the level of wind energy content in the 70s or 80s and to generate index values for longer reference periods eventually. But is this necessary?
An investigation was performed about the co-domain of possible reference levels based on the NCEP wind speed values of a coordinate point at 52,5° latitude/ 12,5° longitude (0,995sigma level). An adjustment based on surface wind measurements or yields was not performed because of the long duration of the periods considered (at least 10 years).
Average values of wind power density were calculated for reference periods of different durations (10 years, 14 years, 20 years, 30 years) and positions inside the complete calculation period of the reanalysis project (since 1948). Next, these power densities were related to the one in the last 20 years (1984 – 2003). Naturally, the number of possible reference periods decreases with increasing lengths. Results of these calculations are summarized in Figure 7.

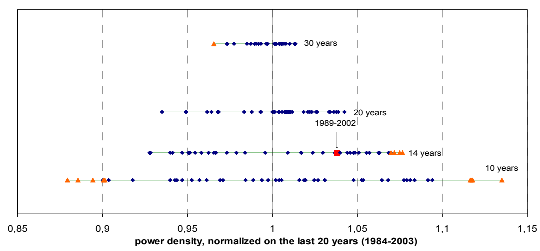

Figure 7. Average power densities for different durations of averaging period, derived from NCEP/NCAR reanalyzed data and normalized to period 1984 – 2003

- As expected, increasing duration of the reference period results in decreasing band width of the normalized power density: 10-yearly periods scatter from 0,879 to 1,135; 30-yearly ones just from 0,966 to 1,013.

- Extreme values pile up conspicuous, when containing exclusively values from long past time periods are considered (see figure 7: the periods marked by orange triangles are containing exclusively data of the years before 1980). This corresponds to the data base of the reanalysis that is necessarily not completely consistent during the long period of consideration.
- The reference level of the BDB index 1989 – 2002 [4], marked as orange quadrangle, seems to be higher than the level of the last 20 years.

Finally, an investigation about changes of reference levels of different duration during the lifetime of a virtual wind power project (20 years) was performed. Start-up date of the project would have been 1984, so the complete operation period would be past.
The change of mean wind power density level within this operation period depends on the period that would have been assumed as reference level in 1984 and amounts to the values in the following table:

Reference period	energy difference to period 1984 –2003 [%]
10 years (1974 – 1983)	2,9
14 years (1970 – 1983)	4,9
20 years (1964 – 1983)	-0,7
30 years (1954 – 1983)	-0,6

Amount and direction of changes additionally depend on the year of start-up. In general, long reference periods correspond with low amounts of climate changes. Risk considerations of this kind make it possible to number the impact of term climate changes to WEC yields and to take them into account in liquidity considerations.

3.3 Construction of possible time rows of annual yield

Liquidity prognosis of wind power projects is normally based on constant yearly yields for the entire period of operation (see figure 9).

Incomes	2001	2002	2003	2004	...	2011	2012
1. Energy proceeds	1.837.271	3.674.542	3.674.542	3.674.542	...	3.674.542	3.674.542
2. Interest income	...	...	...	...	...	...	...

Figure 9. Extract from a typical liquidity prognosis for a wind power project

Uncertainties, yield losses and the liquidity reserve necessary to survive calm periods are usually considered before by different kinds of safety margins.
But the case of constant annual yields is obviously the one that won't ever eventuate. More realistic yield scenarios can be derived from the predicted yield value as follows:

- Constant yield deductions should be applied only for wire and transformer losses, downtime losses due to maintenance, possible deviation of power curves.
- Assumptions about long-term change of climate can be included as long-term trend with constant gradient – depending on duration of reference period used for yield calculation.
- A time row of yearly wind indices can, on the one hand, be „learned" from time rows of the past.
- On the other side: Investigation of the statistical behaviour of yearly wind indices shows that they can be assumed to be normal distributed with an expectation value of 1 (obvious!) and a site depending standard deviation. Knowledge of these parameters gives the possibility to generate time rows of possible wind index regimes.
- Reliability of technical components is usually time dependent. A plot of the failure rate over time is often characterized as the so called „bathtub curve", be-cause of its shape. It consists of 3 periods: during the Early Failure Period, failure rate rapidly decreases from a high beginning level; followed by the Intrinsic Failure Period with normal operation of the unit and a constant failure rate. The failure rate of this period seems to conform with contractual agreements about guaranteed availabilities of WEC's. Finally, material wears out and the failure rate begins to increase again (Wearout Failure Period). This model can be applied to repairable systems, too; experience shows that WECs use to behave like this. As there is a close connection between failure time and yield losses, a function of the "bathtub" type can be superposed to the yield scenario as shown in fig. 10.

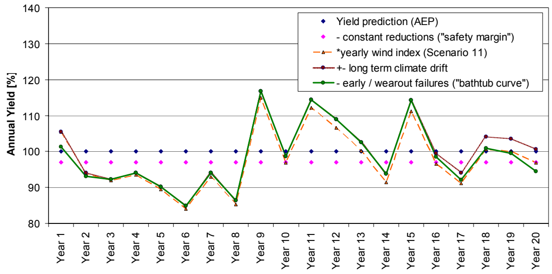

Figure 10. Yield scenario, considering constant yield losses, climate drift, a wind index scenario and early/ wearout failures

Liquidity prognosis doesn't comprise just one test case when applying this methodology. Rather a set of possible scenarios is pre-defined and later used to check the "robustness" of different variants of financing.

4. References

[1] M. Strack, A. Westerhellweg, W. Winkler, DEWI: Zuverlässige Methoden zur Normierung und Bewertung von Energieerträgen von Windparks, DEWEK 2002, Proceedings, Wilhelmshaven 2002.
[2] H. Schwarz: „Wieviel bringt sie wirklich ?", Windenergie 2003, BWE-Marktübersicht Osnabrück 2003.
[3] Stellungnahme des Windgutachterbeirats zur aktuellen Entwicklung der Windindex-Methodik, in: Neue Energie 07/2004.
[4] Betreiberdatenbasis (http://www.btrdb.de)
[5] NCEP/NCAR Reanalysis-Project (http://www.cdc.noaa.gov).
[6] Stephan Traub, Burkhard Kruse: Winddaten für Windenergienutzer, Deutscher Wetterdienst, Offenbach 1996.