Evaluation of the long term development of wind speed in Germany based on the NAO Index

Background and motivation

There is a wide spread theory according to which an exceptionally strong wind resource governed in Central Europe during the early 1990s and that this period should therefore be ignored when determining the long term average wind resource. This was explained by Garrad Hassan in 2006 based on the traces of the NAO Index (North Atlantic Oscillation Index), the Jenkinson-Lamb Index and the Großwetterlagenindex [1]. It was shown that these indices are relevant for wind energy through the coefficient of determination between them of 0.49. Based on this, it was suggested that the period during the early 2000s, which was generally considered as a low wind period and which had caused high attention in the wind energy business at the time, may simply represent the return to a "normal" long term level.

Garrad Hassan extended the analysis of [1] subsequently. On the one hand, the wind and energy indices of the wind energy business could be compared with the above mentioned indices over increasing periods as time progressed, on the other hand, earlier years of the past were included in the analysis of the NAO Index. Thus, the conclusions of [1] could be repeated in e.g. 2011 [2] and supported much more convincingly.

During the past 17 years, the energy production of wind farms in Germany and neighbouring countries was mainly below the level which is considered as long term average by many consultants, including *aj*. Therefore, the long term course of the wind resource and the long term average wind level are increasingly relevant issues. Since several years have passed since the work presented in [2] and therefore operational results respectively energy production indices can be compared with the above mentioned weather indices over longer periods, the corresponding investigations should be updated. This is undertaken in the present document.

For simplicity, this refers to Germany only. It should therefore be mentioned that *aj* agrees with the statements of [1] and [2] according to which the use of wind related time series of the Netherlands, UK and France lead to basically similar results as production indices from Germany and thus confirm the observations and conclusions. Furthermore, only the NAO Index is considered among the weather indices since it covers the longest period and it is generally considered as the most important one, including [2].

The NAO Index characterises the large scale differences of air pressure over the Northern Atlantic [3]. It is based on air pressure measurements on Island, the Azores, in Lisbon and Gibraltar. The values of the NAO Index increase with increasing strength of the action centres, i.e. the cyclones over Island and the anticyclones over the Azores. This situation is considered as one of the driving phenomena for strong winds in Central Europe, in particular during the winter months.

The following questions shall be treated in the following:

- Can the period of the early 1990s still be considered as exceptional according to the NAO Index?
- Can the NAO Index be confirmed as a proxy for the wind resource in Germany?

Characterisation of the early 1990s

The annual mean values of the NAO Index were examined in [1] and [2]. In addition, the winter periods were investigated separately in [2]. Therefore, the annual means are first considered in the following section, followed by the winter months.

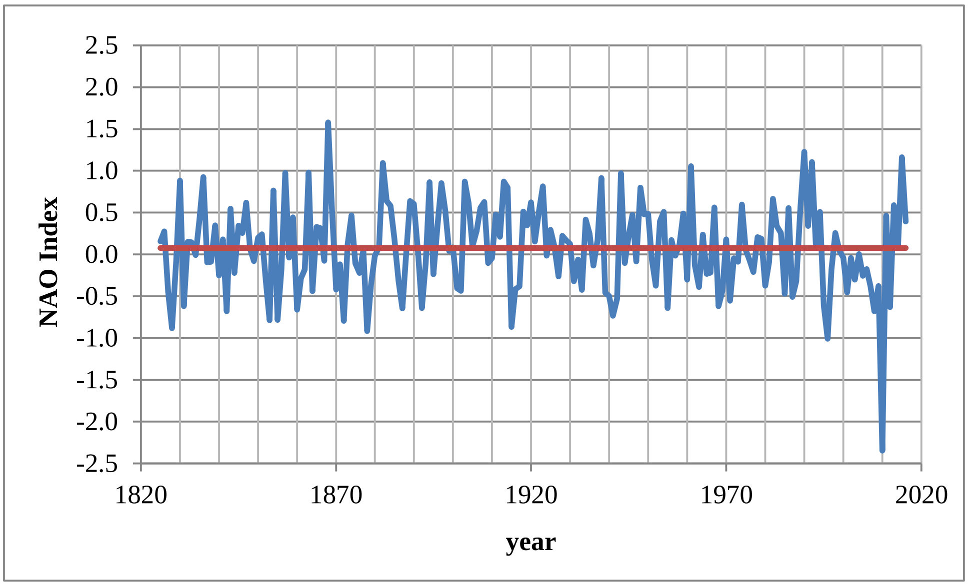

Figure 1: Annual means of the NAO Index, red line: overall average

According to figure 1, the highest annual NAO Index value was determined for the year 1868. The next highest ones were reached, in the order of their magnitude, in the years 1990, 2015, 1992 and 1882. But the most outstanding value is the extreme negative one in 2010. The second lowest one was calculated for 1996, followed by the years 1878, 1828 and 1995.

Since the present investigation considers longer periods of relatively high or low NAO Index values, figure 2 also shows the NAO Index time series, but for moving averages over 5 years, corresponding to [1] and [2].

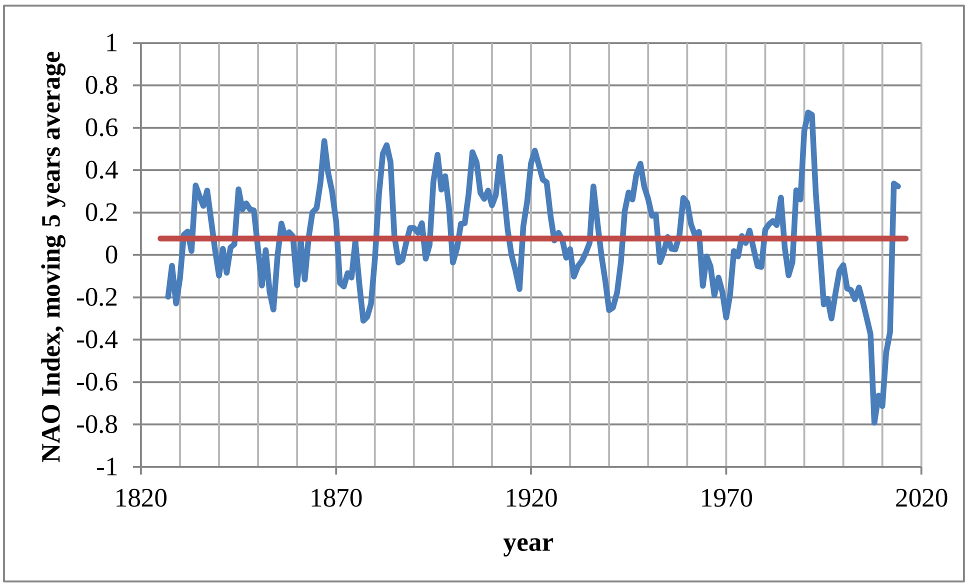

Figure 2: Moving averages over five years of the annual NAO Index, red line: overall average

Different to the time series of individual years in figure 1, the moving 5-year averages (figure 2) show an outstanding maximum around the year 1990. Indeed, the individual annual averages of this period are not extraordinarily high, in particular compared to the year 1868. It is only due to the averaging over five years that this period appears as outstanding, since a succession of several relatively high index values is contained. This is not the case in the years around 1868, where a period of low index values follows the local maximum. But in principle, the patterns around the years 1990 and 1868 are similar (figure 2). Around 1990, the variation is simply stronger and the periods of high and low average indices are longer.

The actual outstanding part of the time series is the period around 2010, where an exceptionally low NAO Index value is reached in a period with predominantly low values. So if the period around 1990 should be ignored due to an anomaly when determining the long term wind resource, this applies even more to the period around 2010.

For further investigation, a recent period was searched for in the NAO Index time series in which the average value over the entire data set covering about 200 years was mostly met. If the NAO Index is used as a proxy for the wind resource, this should provide an indication of a suitable long term reference period. The years 1989 to 2005 were identified as such a period. This result is in full contradiction to the trend of the current discussion and practice, since it includes exactly those years which are often considered as exceptional and therefore not representative. If in exchange the average of the past 100 years is considered as the long term measure, this leads to the period 1991 to 2000, which will similarly not be accepted commonly as long term reference period.

Whilst the annual mean NAO Index had been analysed in [1], as above, [2] considered in addition the winter periods on their own. This is a valid approach since, according to an investigation of *aj*, the winter months (Dec to Feb) are decisive for the characterisation of a full 12 months period as a low or high wind period. Furthermore, a connection between NAO Index and wind resource is generally assumed for the winter in particular [1, 5]. Therefore, the following figure shows the long term time series of the moving average NAO Index for the winter months.

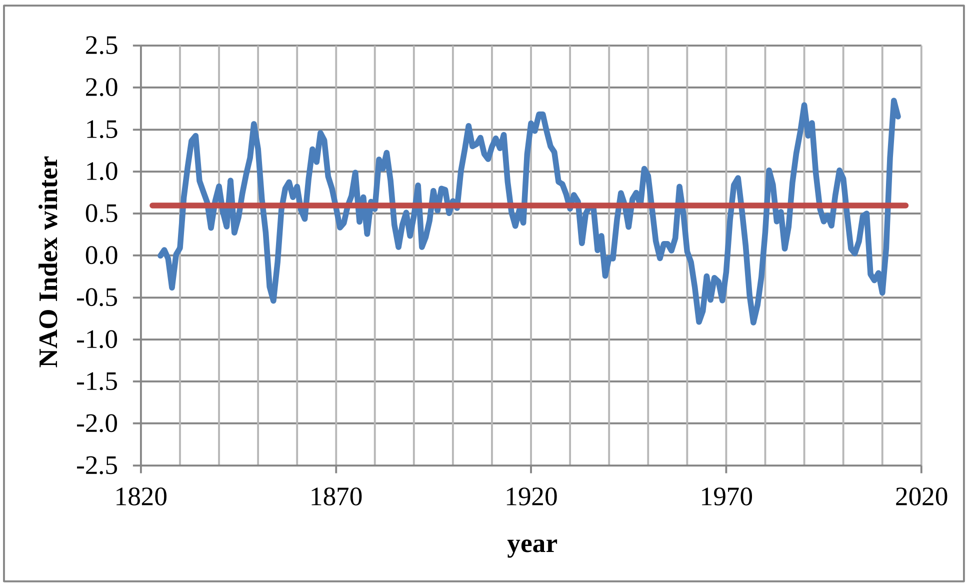

Figure 3: Moving average over five years of the NAO Index for the winter period (December to February)

According to figure 3, the period around 1990 cannot be considered as an anomaly any more if the years before 1925 are taken into account. Only the time series after 1930 had been shown in [2], which made the period around 1990 appear as an extreme one (even more for figure 2). But it is also interesting that the highest 5-year average of the NAO Index for the winter period is determined around the year 2013. Consequently, the winter period (which is decisive for the long term variation of the wind resource) may not be considered as extraordinary any more around 1990.

Correlation of the NAO Indices with wind and production indices

It is common in wind energy to create production indices as a measure of the relative energy production of wind turbines. In Germany, the BDB Index [4] is the most common measure of this kind. It is derived from the production of wind turbines. Published wind and production indices are also known from The Netherlands and Denmark. Furthermore, several companies establish internal indices.

A coefficient of determination of 0.49 had been calculated for the period 1990 to 2005 in [1] between the annual means of the NAO Index and the average across various wind and production indices from Germany, the Netherlands, UK and Denmark (figure 4, left hand green symbol). This value provided an indication that the NAO Index indeed represents a measure of the wind resource in this region, even though with just mediocre correlation. In [2], data from France were added. The coefficient of determination was then about 0.45 for the period 1990 to 2009 (figure 4, middle, green symbol) and, when comparing it with the BDB index only, still 0.47 (not shown).

Now, *aj* updated the calculations of correlation between NAO Index and BDB indices. Due to recently reduced data availability and reliability of some BDB indices, only the BDB regions 6 to 24 were considered, whilst the averages across all regions had been calculated in [2].

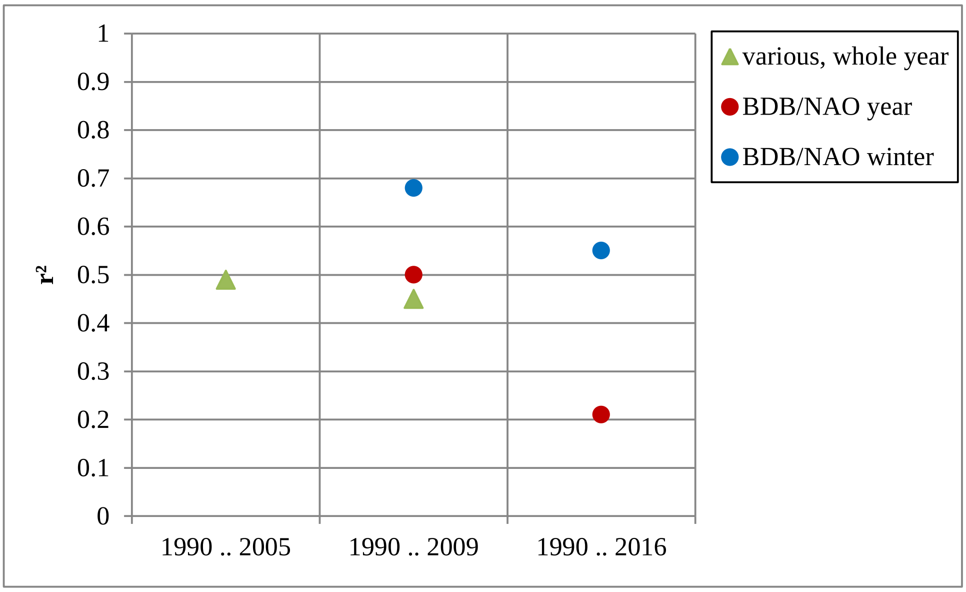

Figure 4: Correlations between the average wind and production indices of several countries ([1], [2] - green) and only the BDB indices (current investigation - red, blue) with the NAO Index for whole years and winter months; different periods starting in 1990 (winter months in 1991)

In figure 4 above, the correlation obtained for the period 1990 to 2016 (based on the data available so far) is compared with that for the period 1990 to 2009 analysed in [2] using consistent data sets. The consistency with the results of [2] is shown for the period 1990 to 2009. The extension of the investigated period leads to a strong reduction of the correlation between the indices for the entire years and a significant reduction for the winter period.

Indeed, the patterns of the average BDB Index and the annual NAO Index are partly similar in the following graph.

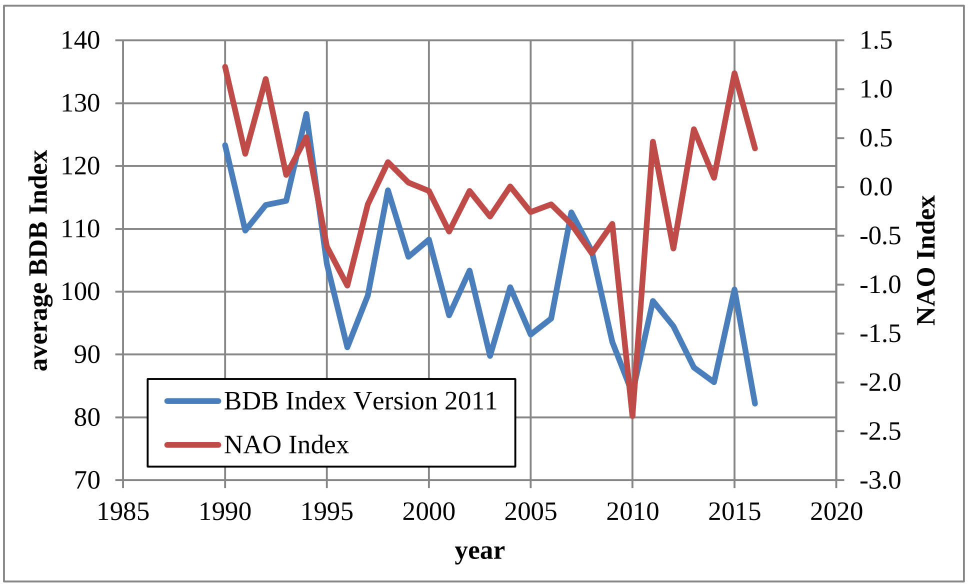

Figure 5: Time series of the annual mean BDB Index (average of the index regions 6 to 24) and the NAO Index from 1990 onwards

However, the time series diverge strongly after 2010. Thus, the coefficient of determination is only 0.21 (see also figure 4, BDB/NAO year, 1990 to 2016). Even this coefficient of determination is strongly influenced by the year 2010 which, due to a low NAO Index, causes an apparent correlation when calculating the linear regression. Without this year, the coefficient of determination only amounts to 0.13. Anyhow, figure 5 does not support a simple connection between the annual NAO Index and the wind resource in Germany.

This changes if only the winter months are considered.

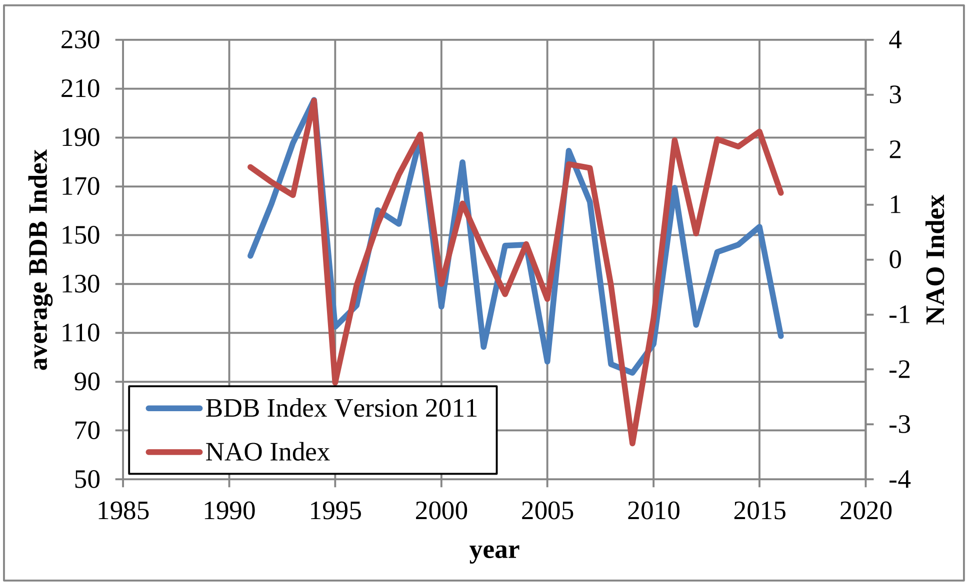

Figure 6: Time series of the BDB Index (average of the index regions 6 to 24) and the NAO Index for the winter months from 1991 onwards

A clear correlation of the year-to-year variability can be recognised, but the relation between the BDB Index and the NAO Index from 2012 onwards differs from that before 2012. Whilst the coefficient of determination between these indices amounts to 0.68 for the winter months over the period investigated in [2], it reduces to 0.55 for the period 1991 to 2016. A coefficient of determination of 0.55 means that there is a clear connection between the data sets. This corresponds to the impression given by figure 6. Consequently, investigations considering only the winter months are more relevant for the present study than those considering annual NAO Index values.

According to the above figures, the relation between the NAO Index and production indices is different when considering a period of about 20 years compared to a 27 years period. Obviously, such periods are not long enough for reliable statements in this context. This means in turn that statements regarding the long term course of the wind resource based on periods of 20 years or less must be very unsecure. Even more, significantly longer periods are needed for investigations on potential trends.

The above graphs provide an opportunity for further considerations: Either the large scale differences of air pressure have a different relationship with the wind resource in Germany before 2012 than during the following years, or other processes and parameters which also influence the wind resource had a different impact during these periods. Since the wind speeds contained in reanalysis data sets are decisively based on differences in atmospheric air pressure [6], the divergence between the NAO Index values and the wind and production data shown above is linked with the divergence between wind speeds in reanalysis data sets and those wind and production data, which has been subject to many discussions recently. Similar to the different relation between NAO Index and BDB Index during recent years compared to the years before shown in figures 5 and 6, a higher wind resource is also derived from reanalysis data compared to real production data for the recent years in several regions of Germany. An example is shown in the following figure.

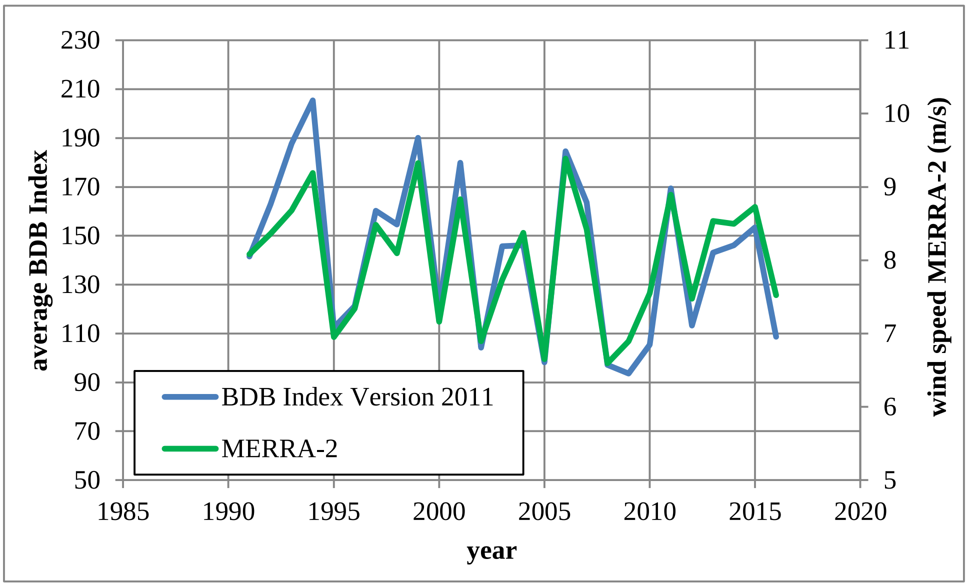

Figure 7: Time series of the BDB Index (average of the index regions 6 to 24) and the wind speed of the MERRA-2 reanalysis data set for an area in Northern Germany for the winter months

The divergence appearing in figure 7 for the years 1992 to 1994 does not relate to a similar divergence in the NAO Index values and, similarly, the differences appearing in the year 2009 are not similar between figures 6 and 7. However, the above consideration of the recent years provides a key for an understanding of the differences between the wind speeds contained in reanalysis data and observed wind speeds and energy production, which are currently in discussion. Only if these differences are understood, the future trends of the wind resource contained in climate predictions can be evaluated.

Summary and conclusions

The assumption that an anomaly of unusual strong winds occurred during the early 1990s compared to longer periods could be supported plausibly some years ago by reference to weather pattern related indices, among which was the NAO Index. However, if the recent years are included in the analysis of the NAO Index, the period around 1990 is not the only unusual one. This applies to the annual means, but even more if only the winter months are considered.

Thus, the so far common arguments for ignoring the early 1990s when determining the long term average wind resource are not valid any more. It does not necessarily mean that the wind resource of this period was not unusual. It only states that based on the reference data considered here this period cannot be considered as outstanding compared to much longer periods. So with unprejudiced evaluation, this period should be included when determining the long term average wind resource just like the past 5 to 10 years.

In contrast to earlier investigations, the use of the annual weather pattern indices as proxies for the wind resource does no longer appear justifiable due to lower correlation. However, this is still valid if only the winter months are considered. These still show a significant connection between the NAO Index and production indices, though with strongly reduced correlation. It must therefore be retained that any conclusions drawn from such comparisons are still subject to high uncertainties, because the duration of the available time series that can be compared are still relatively short from a climatological point of view. This also means that statements on the long term wind resource based on periods of less than 20 years are relatively uncertain.

The fact that the NAO Index only explains part of the variation of the wind resource leads to possible explanations for the differences sometimes observed between the long term traces of wind speeds in reanalysis data and observations.

References

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