LONG-TERM WIND SPEED TRENDS IN NORTHWESTERN EUROPE

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ABSTRACT

Windiness indices for countries in northwestern Europe were shown in [1] to display similar annual wind speed trends over the past 15 years. The wind speed trend over this period was subsequently shown to compare favourably with three wind speed proxies which are available from the beginning of the 20th century. Based on this conclusion, the proxies displayed that the period centred around the 1990s was subject to atypically high wind speeds. This work is an extension to the work published in 2005 [1] which includes the latest data since this publication. In addition, the indices and proxies have been reviewed to indentify the level of inter-annual variability of wind speed and whether there is any discernable pattern of annual mean wind speeds from one year to the next.

1. WINDINESS INDICES

For the purpose of this investigation, windiness indices from Germany [2], Denmark [3], the Netherlands [4] the UK [5] and northern France [6] have been considered alongside pressure-based data sets derived from measurements and isobar maps. Given the correlation observed in annual windiness between the five countries for which windiness indices are available, it is assumed that the results are broadly representative of much of northwestern Europe. However, it is considered that the results will become less applicable with increasing distance from the countries mentioned above.

Figure 1 shows the main windiness indices from Germany, Denmark, the Netherlands, the UK and northern France. The former three are all based on energy production data while the indices for the UK and northern France are based on wind speed data. In order to allow comparison of wind and energy based indices, the indices have been normalised by dividing the annual index anomalies by the standard deviation for the period 1990 to 2008.

It is clear from Figure 1 that there is a reasonable correlation between the windiness indices, with an average coefficient of determination, R^2 value, of 0.65. All the indices support the observation that average wind speeds in northwestern Europe were higher in the early 1990s than they have been for the past 5 to 10 years. There may be concerns about the consistency of the indices over the years. However, as all the indices, derived from somewhat different data sets, show the same broad trend, this increases the confidence in this observation.

From the data plotted in Figure 1, it would be easy to conclude that annual mean wind speeds are dropping due to some regional effect and to make the further hypothesis that a potential cause may be global warming. A consequence for future wind energy projections would be that we should ramp down future expectations of wind speed, the only question being how rapid the ramp down should be.

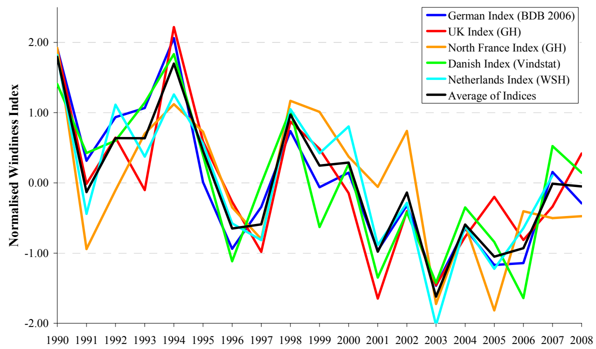

Figure 1 – Windiness Indices in Northern Europe

However, an investigation of wind speed trends going back further than 1990 indicates that such an assumption is probably incorrect. In order to investigate the past trend in wind speed we need data going back several decades, covering the period before the start of the windiness indices. An obvious source of data is wind measurements. However, changes to measurement equipment, location or procedure at a measurement mast can result in inconsistencies in the data recorded, and taking these inconsistencies into consideration, it is common to have consistent data extending back no more than 15 to 20 years and often less.

2. PROXIES FOR WIND SPEED

In the absence of wind speed and wind turbine production data prior to the start of the windiness indices, several potential sources of data have been considered, which could be used to investigate trends in wind speed in northwestern Europe going back several decades. It is known that the quality of wind measurements has varied substantially over this period. However, due to the simple, slow changing nature of pressure and the simple instruments used to measure it (the mercury barometer, for example, has been in use since the 17th Century, long before the anemometer), pressure measurements are not subject to the same number of variables as wind speed measurements, and as such are likely to be more consistent. These data sets are available from the beginning of the 20th century but as it is considered that the certainty of the data increases with time, care should be taken when considering the weight to be put on the earlier years of the data. Although it is not known whether any inconsistencies are present within the data sets, it is considered that as they are based on synoptic charts and sea level pressure measurements, these proxies are likely to be some of the most reliable available. In particular, the Grosswetterlagen and Jenkinson Lamb data sets are based on weather types, and as such are not likely to be sensitive to inconsistencies in recorded pressure data. An investigation of data recorded over the past few decades is deemed sufficient to gain an understanding of possible future wind speed trends and therefore, for the purpose of this investigation, data have been considered from 1965 onwards. The North Atlantic Oscillation (NAO), Grosswetterlagen (GWL) and Jenkinson Lamb indices discussed below are considered to be representative of northwestern Europe, northern Europe and the British Isles respectively.

2.1. NORTH ATLANTIC OSCILLATION

A widely used index in meteorology is the North Atlantic Oscillation (NAO) index. This is commonly defined as the difference in normalised pressure between a station in the Azores and one in Iceland. Although the NAO occurs throughout the year, it has a particularly dominant effect on the climate in winter months. In general, a positive NAO index is associated with windier, warmer and wetter winters in northern Europe and a negative NAO index is associated with less windy, colder and drier winters.

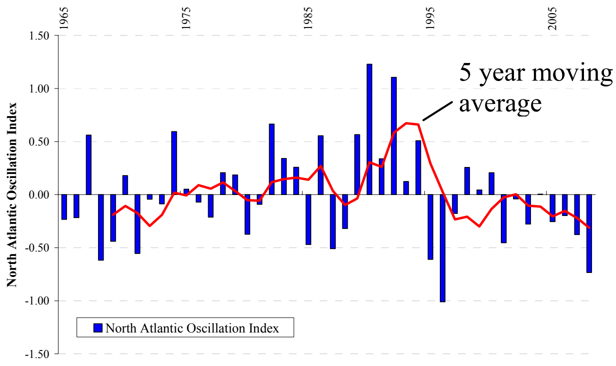

Figure 2 – North Atlantic Oscillation Index

A monthly NAO index derived using pressure data from Gibraltar and SW Iceland is available to download from the University of East Anglia Climatic Research Unit [7] for the period from 1821 to the present. To calculate this index, the monthly pressure measurements at each station are normalised by dividing the anomalies by the monthly standard deviation over a defined reference period. The difference between the two normalised pressures is then calculated. Figure 2 shows the NAO index for the period 1965 to 2008, along with the 5 year running average.

2.2. KATALOG DER GROSSWETTERLAGEN EUROPAS

Katalog der Grosswetterlagen Europas (GWL) [8], translated as "catalogue of large-scale weather patterns in Europe", is a taxonomy of large-scale weather patterns over Europe based on a subjective analysis of meteorological charts. For each day from 1881 to the present, the large-scale weather conditions are classified into one of 29 types or as 'unclassifiable'. The work of Pryor et al [9] has shown that only a few types, which occur frequently, contribute to above average wind speeds over the Baltic region. Namely, westerly anticyclonic, westerly cyclonic and northwesterly cyclonic (Types 1, 2 and 8). According to Pryor et al [9], the GWL classification has been extensively used in previous research and has been demonstrated to be free of artificial bias or trends. A GWL index has been created by taking the total annual occurrence of classification types 1, 2 and 8 and normalising each value to the 1965 to 2006 mean annual occurrence. The GWL index is plotted in Figure 3 for the period 1965 to 2006 along with the 5 year running average.

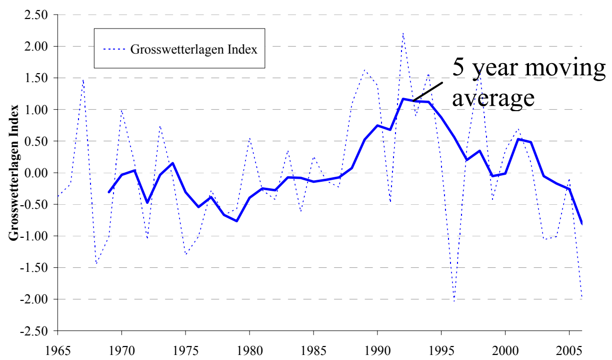

Figure 3 –Grosswetterlagen Index

2.3. JENKINSON LAMB WEATHER TYPES

The Lamb weather classification is a widely used daily large-scale weather classification for the British Isles. The data set was created by subjective analysis of the weather system over the British Isles each day and classification into one of 28 types or as 'unclassifiable'. An objective scheme to classify the daily weather system according to the Lamb weather types was later developed by Jenkinson and Collison using daily grid point mean sea level pressure data. The data used here are those derived using this objective scheme and are available to download for the period 1880 to 2006 from the University of East Anglia Climatic Research Unit [10].

In order to ascertain which, if any, of the Lamb weather types are associated with high wind speeds, mean daily wind speed data from four UK Met Office stations for the period 1994 to present were compared with the Jenkinson Lamb weather types data and a mean wind speed associated with each weather type was derived. It was found that Lamb weather types 13 to 17 and 23 to 27 are associated with above average mean daily wind speeds. An index has been created by taking the annual occurrence of these weather types and normalising each value to the 1965 to 2006 mean. The Jenkinson Lamb index is plotted in Figure 4 for the period 1900 to 2006.

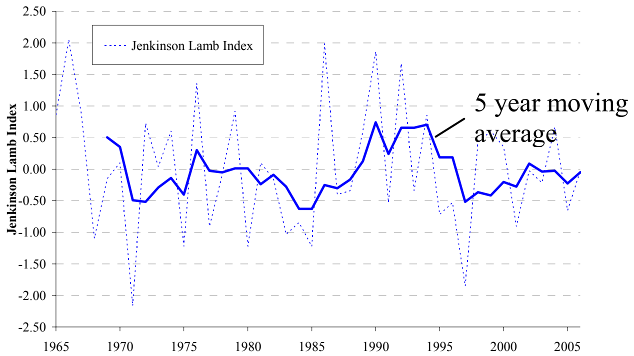

Figure 4 –Jenkinson Lamb Index

3. DISCUSSION OF PROXIES

In Figure 5, the three proxies for wind speed described above are plotted alongside the average of the five windiness indices (UK, North France, Denmark, Germany and the Netherlands) for the period 1990 to 2008. To allow comparison, the indices have been normalised by dividing the index anomalies for each annual value by the long-term standard deviation. Correlations of the proxies and the average of the windiness indices indicate an average coefficient of determination, R^2 value, of 0.46. It is clear that, although the correlation quality is not high, on the whole the proxies follow the same trend as the windiness indices and it is considered that the correlations are strong enough to justify the qualitative but not quantitative use of these proxies. It is assumed that the relationship observed between the proxies and the windiness indices over the period 1990 to 2006 would hold were the windiness indices available going back further. It is apparent that the three proxies for wind speed show a similar downward trend to that exhibited by the windiness indices over the period 1990 to 2006 shown in Figure 5.

In Figure 6 the NAO, the GWL, and the Jenkinson Lamb indices are plotted for the period 1965 to 2006 along with the 5 year running average. For comparison purposes, the indices have been normalised by dividing the index anomalies for each value by the standard deviation for the period 1965 to 2006.

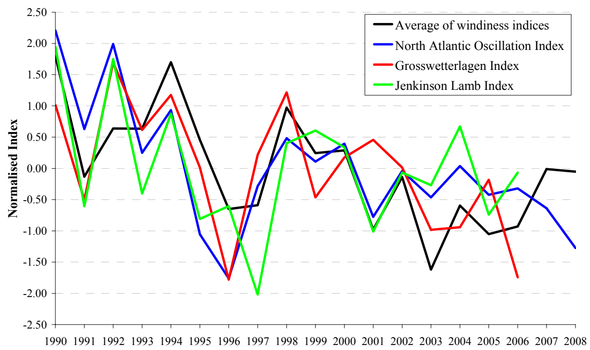

Figure 5 –Wind speed proxies and average of windiness indices

The data plotted in Figure 6 provide valuable information on the trend in wind speed prior to the start of the windiness indices discussed in Section 1. It is clear that the recent downward trend does not exist prior to about 1990. Inspection of the NAO, GWL, and Jenkinson Lamb indices for the period since 1900 indicates that there have been several fluctuations in the indices. This suggests that the recent downward trend in mean annual wind speed seen in the indices may represent a return to the longer-term mean, and therefore it would be illogical to conclude that this downward trend in wind speed will continue for the next 15 to 20 years. This is supported by the increase in annual wind speeds in recent years as displayed in Figure 1.

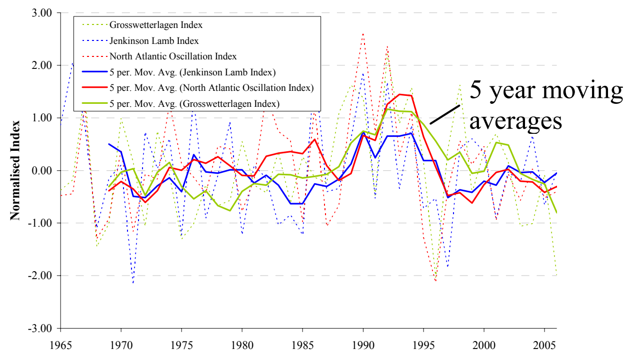

Figure 6 – North Atlantic Oscillation, Grosswetterlagen and Indices

It is also implied from the proxies for wind speed discussed here that the period centred on the early 1990s experienced unusually high wind speeds. The data in Figure 6 show that this period, while having higher wind speeds than the period since the mid 1990s also appears to have had higher wind speeds than the previous 20 to 30 years. In fact, inspection of these data sets prior to 1965 indicates that this period was one of the windiest periods, if not the windiest period since the beginning of the century. An investigation carried out by Pryor et al [11] using reanalysis data sets concluded that the 1990s exhibited atypically high wind energy density.

If it were possible to obtain a source of reference wind speed data that were consistent for the past 30 to 40 years, it is considered that the inclusion of this period of higher windiness would have little effect on the average wind speed for the reference data. However, due to consistency considerations relating to both windiness indices and wind speed measurements, such a long consistent period is not typically available. Long-term references used in energy production assessments typically extend back no more than around 15 to 20 years, and as such, are likely to include an unrepresentative proportion of data from this windy period. Where this is the case it is considered that care is needed in the selection of the most appropriate long-term period to use.

4. INTER-ANNUAL VARIABILITY

In Europe, a figure 6 % is commonly assumed for the inter-annual variability of wind speed [12]. The standard deviations of the windiness indices considered in this work have been calculated and are presented in Table 1 below. The standard deviations determined from production data have been divided using an assumed energy to wind speed sensitivity ratio of 2.

Index	Years of data	Annual wind speed standard deviation [%]
German Index	18	5.8*
UK Index	18	4.9
North France Index	18	3.9
Danish Index	30	4.6*
Netherlands Index	20	5.0*

*Adjusted from production standard deviation using a wind speed to energy sensitivity ratio of 2

Table 1 – Annual wind speed standard deviation estimates

The indices are all shown to have an annual wind speed standard deviation less than 6 %. It is recognised that the indices represent a large region and therefore a lower variability would be expected than that observed on an individual wind farm site. With this in mind, a figure of 6 % appears to be a sensible assumption for inter-annual variability in wind speed at a wind farm site in northwestern Europe.

5. PATTERNS IN ANNUAL WIND SPEED

A common question associated with long-term wind speed predictions is the relationship between the annual wind speed from one year to the next. In an attempt to answer this question, underlying patterns in the windiness indices and proxies were investigated using the Box-Jenkins autocorrelation function [13]. Autocorrelation functions, such as the Box-Jenkins method, are commonly used tools for checking randomness in a data set. The randomness is assessed by computing autocorrelations for data values at varying time lags. If random, such autocorrelations should be near zero for any and all time-lag separations. If there is an underlying pattern (non-random), then one or more of the autocorrelations will be near ±1. The results of the investigation are presented in Table 2 below.

Index	Level of pattern from one year to the next [rh]
German Index	0.4
UK Index	0.2
North France Index	0.1
Danish Index	0.1
Netherlands Index	0.1
NAO	0.1
GWL	0.0
Jenkinson-Lamb	0.0

Table 2 – Level of pattern in the windiness indices and proxies from one year to the next.

The results indicate that the indices and proxies show no discernable pattern in wind speed from one year to the next. The one exception is the German Index where it could be argued that the results indicate some pattern in wind speed from one year to the next. However, it should be noted that the data sets for all the windiness indices are relatively short and therefore subject to greater uncertainty compared to the longer data sets of the proxies.

6. CONCLUSIONS

From investigation of several northwestern European windiness indices and three proxies for wind speed, the following conclusions are drawn regarding long-term trends in wind speed.

- Several northwestern European windiness indices have been obtained and a comparison between them carried out. A similar trend in wind speed over the period 1990 to 2008 can be observed in all of these indices.
- Due to changes in measurement equipment, location and procedure at measurement masts, consistent wind speed data going back more than 15 to 20 years are not typically available. The windiness indices compared above are only available since between 1979 and 1989, although the usefulness of the early years is questionable due to the small number of contributing data sources. Therefore, in the absence of reliable and consistent data for the several decades before the start of the wind indices, several alternative data sets have been investigated that cover this period; the North Atlantic Oscillation, Grosswetterlagen and Jenkinson Lamb indices are presented in Sections 2.1 to 2.3.
- It has been demonstrated to an acceptable degree that these three data sets show reasonable agreement with the windiness indices, with an average coefficient of determination, R^2 value, of 0.46. It is therefore considered reasonable to use these data sets as proxies for wind speed prior to the start of the windiness indices. It is clear that, although the correlation quality is not high, on the whole the proxies follow the same trend as the windiness indices and it is considered that the correlations are strong enough to justify the qualitative but not quantitative use of these proxies.
- The downward trend observed in the windiness indices for the period 1990 to 2005 is also reflected in the North Atlantic Oscillation, Grosswetterlagen and Jenkinson Lamb data. However, these proxies for wind speed indicate that there was an upward 'blip' in wind speeds centred on the early 1990s, which suggests that this recent downward trend in mean annual wind speed may represent a return to the longer-term mean. It is therefore concluded that a continued ramp down of future wind speeds should not be assumed. This is also supported by the increase in annual wind speeds in recent years as displayed in Figure 1.
- Given the trends identified within this paper, care needs to be exercised in the selection of the most appropriate long-term reference period to use for a

prediction of the long-term mean wind speed at a proposed wind farm site.

- The standard deviation of the windiness indices varied between 3.9 % and 5.8 %. When it is recognised that indices represent a large region of a country a lower variability would be expected that that observed on an individual wind farm site. These results are considered to be broadly consistent with a 6 % figure for individual wind farm sites which is a commonly used assumption.
- The indices appear to show no discernable pattern from one year to the next and therefore it is reasonable to assume annual mean wind speeds are randomly distributed.

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