Evolution of the wind resource over the last 30 to 45 years in 11 European regions (France, Germany and UK)

Variability analyses and considerations about uncertainty for long-term prediction

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Abstract

The evolution of the resource over the long term is one of the key issues of the wind industry. Thus, if it is not possible to predict the wind resource in the coming years or decades, an analysis of its evolution during a significant past period allows to better appreciate its variability and potentially the risk of experiencing periods with low wind resource in the future.

Areas where consistent wind trends could be established for at least 30 years based on ground measurements from meteorological stations were sought over North-western Europe. In the end, long term regional wind trends could be analysed for 11 eleven areas (5 in France, 4 in Germany, 1 in Belgium and 1 in Scotland).

If the wind resource has remained quite stable in a few areas, significant decreasing trends have been observed over the past decades in others. These findings raise the question of the choice of the length of the long-term reference period considered in the past in the framework of energy yield assessments

1- Introduction

The evolution of the long term wind resource is a key issue in the wind industry, especially in the context of energy yield assessments. Thus, analysing the evolution of the long term wind trends in the past should allow to better appreciate its variability and potentially the risk of experiencing periods with low wind resource in the future.

To this end, we have established regional wind trends in several areas in North-western Europe for at least 30 years based on the combination of wind measurements from meteorological ground stations. The stations considered were rigorously selected to ensure the consistency of the resulting trends over time and thus avoid biases due to the evolution of the measuring conditions and/or the environment of the stations.

2 Method

1.1 Data processing and selection

The first step consists in analysing wind data measured by hundreds of meteorological stations over Europe and selecting those offering consistent trends over the longest possible period. Thus, we focused on several regions where data from 3 to 8 stations allowed to establish a reliable long-term wind trend for at least the past 30 years. The combination of datasets issued from independent sources coherent between each other ensures both the consistency and the robustness of the resulting wind trend.

In order to dispose of as much information as possible, wind data measured by meteorological stations were collected from the national meteorological centres in France (Météo France) and Germany (Deutscher Wetterdienst). For other countries (the United Kingdom, the Netherlands and Denmark), wind data are issued from the Integrated Surface Database (ISD) from the National Oceanic and Atmospheric Data. Hence, as more datasets were available for the analysis for France and Germany, more areas could be established in these countries.

The main criteria for the selection of historical data for each station were the following:

- High recovery rate (>96 % and reconstruction of missing data),
- High correlation level with other selected stations in the area (same wind regime),
- High degree of convergence with other stations in the region (criteria on the standard deviation of the standardized wind speeds),
- Wind data of each station should be consistent for at least 20 years including the period 1998-2007 (reference period for the standardization).

1.2 Considered areas

Regions with a homogeneous wind regime were retained only if a consistent wind trend could be established from at least 3 ground sources at once for 30 years.

This process led to identify 11 areas in North-western Europe where a regional wind trend could be established back in time between 30 and 55 years from now. The corresponding areas cover the location of more than 2500 operating wind farms.

Comparison of long-term periods			
	Region	Available history	
1	FR Brittany	1974-2018	44 years
2	FR West	1986-2018	32 years
3	FR Centre	1975-2018	43 years
4	FR North	1963-2018	55 years
5	FR East	1987-2018	31 years
6	NL	1983-2018	35 years
7	DE Middle East	1974-2018	44 years
8	DE North East	1979-2018	39 years
9	DE North West	1988-2018	30 years
10	DE North – DK South	1971-2018	47 years
11	SCO South	1988-2018	30 years

Table 1: Historical wind trends established per region

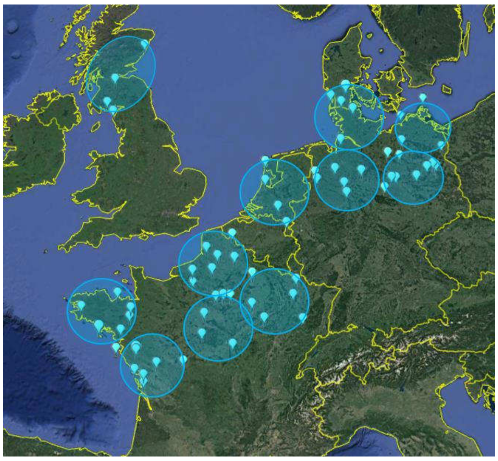

Figure 1: Regional areas where consistent wind trends could be established from ground observations for at least 30 years

Both figures below present the evolution of annual wind speeds of the stations selected in two out of the eleven regions (the Netherlands and Brittany). The regional average wind speeds are displayed in dark blue (rolling 12-month periods), the range of wind speeds proposed by all the stations selected in the region in light blue and the number of considered stations in grey.

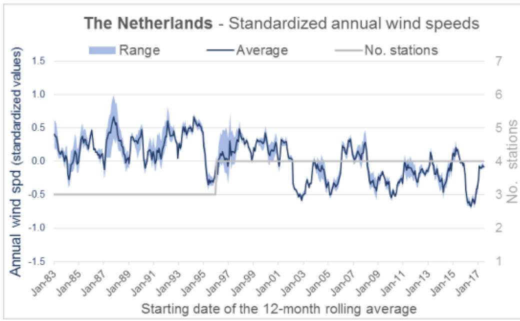

Figure 2: Standardized annual wind speeds of stations selected in the Netherlands

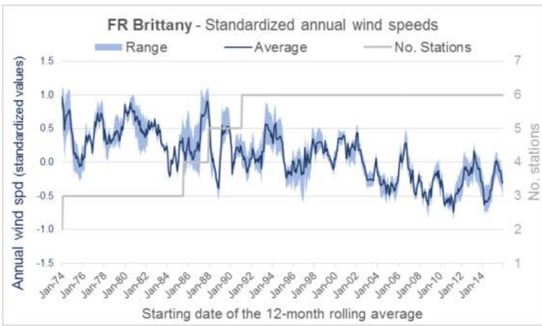

Figure 3: Standardized annual wind speeds of stations selected in Brittany France

3 Results over the past 30 years

In this section, the annual, 5-years and 10-year mean wind speeds for each region are expressed as a percentage of their respective regional average from January 2008 to December 2017 (last decade).

3.1. Breakdown of the regions into three groups (A, B, C)

Regions presenting similar long-term wind trends have been clustered into three groups (A, B and C) in order to synthesize the main outcomes.

Group	Region
A	1 to 5
B	6, 7 and 8
C	9, 10 and 11

Table 2: Breakdown into groups A, B and C

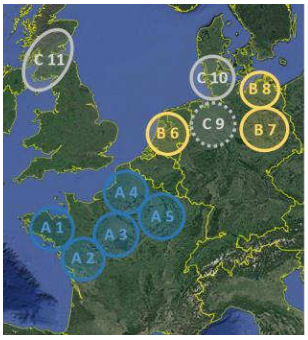

Figure 4: Location of regions and groups

3.2. Evolution of 10-year wind speeds

The graph below presents the evolution of decadal wind speed indexes for all considered regions (10-year rolling averages).

Figure 5 : Evolution of 10-year regional winds speed since 1988

It should be noted that this representation could suggest that wind levels are converging in the most recent decade between all regions, but this is not the case. Trends are converging to 100 % over the last decade, because this latter is considered as the reference period for each region.

Group	Evolution of 10-year wind speeds since 1988
A	Quite stable at first, significant decrease since the early 2000s (-7% to -10%)
B	Continuous decreasing trend (about -5% per decade)
C	No significant trends (variation within ±3 % for region 10 and 11, and ±5 % for region 9)

Table 3: Main outcomes on the evolution of decadal wind speeds

<u>Considerations about region 9 in Germany</u>: Region 9 (dotted grey curves) is part of group C as the decadal wind speed does not vary beyond ± 5% in this region. However, the pattern of the trend is similar to the ones observed in neighbouring regions 6 and 7, but in a smaller amplitude. Although the reason for this difference is unclear at this stage, all stations located in each of the 3 regions comforts the findings.

<u>Considerations about the decreasing trend observed in France</u>: See Appendix

3.3. Evolution of 5-year wind speeds

The graph below presents the evolution of 5-year moving wind speed indexes for all considered regions, gathered in the same groups A, B and C than previously.

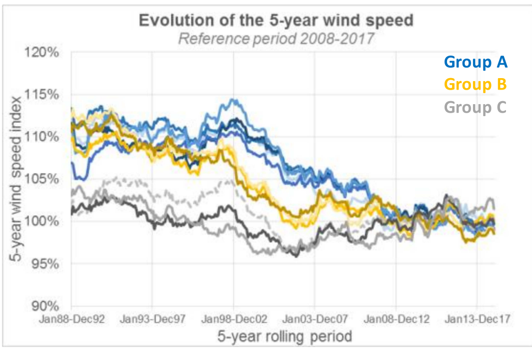

Figure 6: Evolution of 5-year regional winds speed since 1988

This analysis comforts the previous observations, and shows that the decreasing wind trends observed for Group A and B appears to have halted in the early 2000s for Group B and in 2008 for group A. Indeed, since then, the 5-year wind speeds oscillate in a ± 2 % range with no trend becoming obvious.

3.4. Evolution of annual wind speeds

The graph below presents the evolution of the statistical distribution of annual wind indexes over the 3 consecutive decades (1988-1997, 1998-2007 and 2008-2017), using 2008-2017 as the reference value (i.e. 100% for each region). These results were determined from the 12-month moving wind indexes for each region, and are presented for each group A, B and C. Minimum, maximum, medians and quartiles are displayed on the plot boxes.

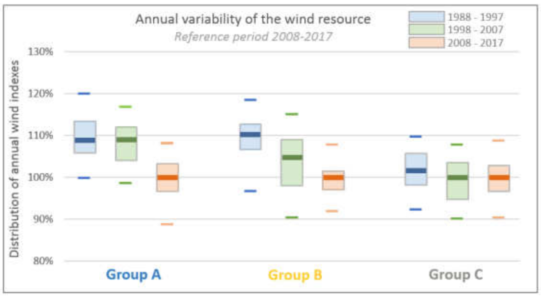

Figure 7: Distribution of annual wind indexes per decade

Beyond the conclusions already presented previously regarding the decreasing trends for regions of groups A and B, the following elements can be highlighted:

- **Group A:** The volatility of annual indexes is rather stable within each decade. The median annual index of the last decade corresponds to the minimum annual indexes experienced the decades before. The high wind speed levels encountered before 2008 have never been experienced in the most recent decade.

- **Group B:** Higher volatility in the first two decades than in the last one. The highest wind speed levels encountered before 2008 have never been experienced in the most recent decade.

- **Group C:** Similar distributions of annual indexes for the 3 decades analysed.

4- Results over the past 45 years

In this section, only regions where a consistent wind trend could be established back to 1974 were considered (1- FR Brittany, 3- FR Centre, 4- FR North, 7- DE Middle West and 10- North DE/South DK).

The corresponding regions are presented on the following figure.

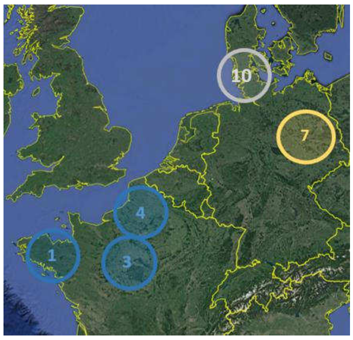

Figure 8: Regions where a consistent wind trend could be established for 45 years

The graph below presents the evolution of decadal wind speed indexes for these regions (10-year rolling averages).

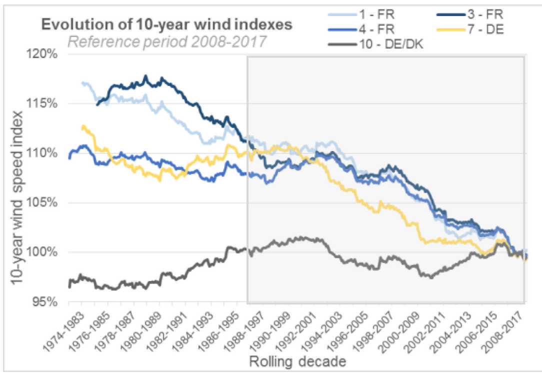

Figure 9: Evolution of 10-year regional winds speed since 1974

In order to make a parallel with figure 4, the past 30 years are highlighted in grey.

For region 1 and 3 in France (respectively Brittany and Centre), a continuous downward trend has been observed for the past 45 years.

The wind trend in region North in France as well as Middle East in Germany was relatively stable during 30 years and have been decreasing since the beginning of the 21th century.

In region North Germany/Southern Denmark, the wind resource seems to have slightly increased and has been stable since the end of the 80s (variation of the decadal wind speed globally within a ± 2% range).

5- Main outcomes regarding long-term prediction for energy yield assessments

5.1. Long term trends

As seen in the sections before, different conclusions regarding the evolution of the long-term wind resource can be made depending on the regions studied in North-western Europe. If the wind resource has been quite stable in some of them (the most Northern ones), most other regions have experienced a significant decrease of the wind resource, especially since the beginning of the 21th century.

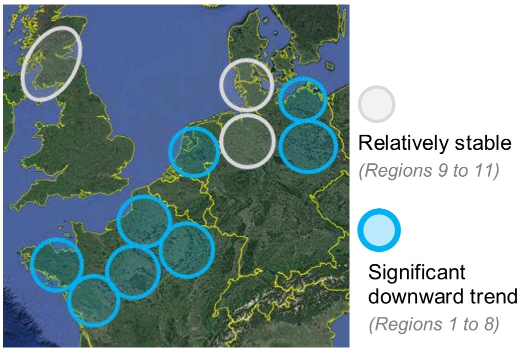

Figure 10: Evolution of wind resource over the past decades

For the regions where a significant downward trend is observed (blue circles), the most recent decade (2008-2017) has been the least windy of the past 45 years, and a decrease of the decadal wind speed of about 10 % has been experienced.

5.1. Risks associated to long term prediction

In the context of energy yield assessment, where long-term prediction is a key issue, the choice of the long-term period should take into account the evolution of the wind resource over past periods.

In order to quantify risks of using past periods to estimate the wind resource to come (usual approach in energy yield assessments), deviations on mean wind speeds between past periods and the directly following 10 years (figure 11) and 15 years (figure 12) were assessed based on the 30 years of data for all considered regions. Main results of this estimation are presented below:

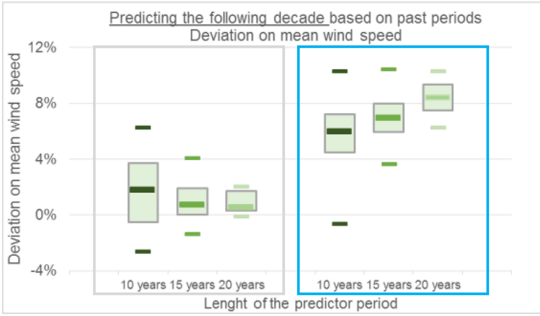

Figure 11: Using a past period to assess the wind resource of the following decade: quantification of deviations experienced since 1988 (Regions 9 to 11 left hand, Regions 1 to 8 right hand)

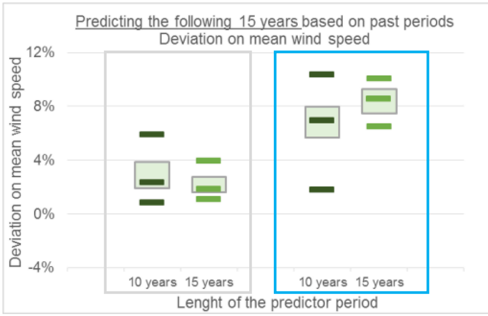

Figure 12: Using a past period to assess the wind resource of the following 15 years: quantification of deviations experienced since 1988 (Regions 9 to 11 left hand, Regions 1 to 8 right hand)

The following comments can be made:

- In regions where the wind resource has been relatively stable (distribution shown on the left side on figures 11 and 12), extending the reference period in the past would have led to improve the long-term prediction (less deviation in the predicted wind speed, whether the period to predict was 10 or 15 years).

- In regions where a downward trend has been highlighted (distribution shown on the right side on figures 11 and 12), extending the reference period in the past have led to significant biases on the predicted wind speed (overestimation of the following 10 or 15 years). The less risky approach would have been to consider 10 years as reference period.

6 Conclusions

A rigorous analysis and selection of consistent wind dataset recorded by ground meteorological stations have allowed to establish long-term wind trends back to 30 years and more in several regions over North-western Europe.

Most of the studied areas have experienced a significant decrease of the wind resource lately (about -10 % on the 10-year wind speed since the end of the 80s), and the highest yearly mean wind speeds experienced in the past decades have not been encountered since 2008.

Hence, for regions where a significant downward trend has been highlighted, extending the length of the reference period might not be the best choice for long-term prediction as it would lead to a risk of overestimation of the future wind resource. In these regions, considering 10 years seems to be the best compromise: shorter periods could be risky regarding the volatility of the wind resource (influence of an extreme year), longer periods would lead to take into account wind speeds levels that has not been experienced once over the last decade.

APPENDIX: Considerations about the decreasing trend observed in France

As shown in Figure 4, all considered French regions (clustered in Group A), present a significant decreasing trend since the beginning of 2000. This observation could rise the question of a bias in wind measurements (disruption of consistency due to changes in sensors or data acquisition system on a national scale) or an evolution of the surface roughness, causing the decreasing wind speeds.

However, these assumptions seem unlikely due to the following elements:

- In some other regions in France (for instance in the Middle East or in Southern France where the wind regimes are driven by other causes than the Atlantic), no such decreasing trends were highlighted.

- When we look at a finer geographical scale, the more North East is the region since the middle of the 90s, the less significant is the decreasing trend, and even if it is in a lower amplitude, this trend can be seen in bordering countries (see Figures below).

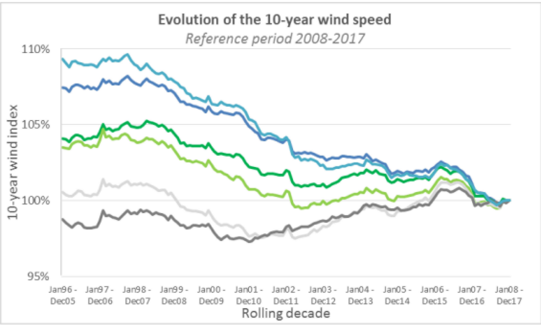

Figure 13: Evolution of 10-year winds speed since 1996 on a more finer geographical scale

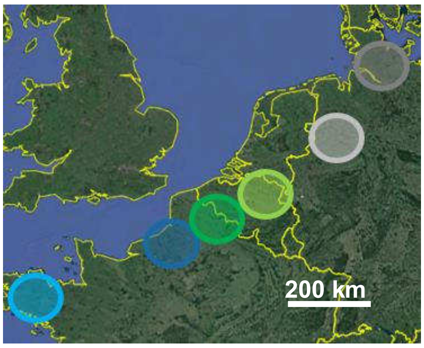

Figure 14: Sub clustering on a shorter long-term period

- Even if some sensor changes have happened for all stations during the past decades, these changes occurred at different times depending on stations, and no disruption of consistency could be highlighted. In addition, this reason would have caused a gap and not a steady decreasing trend over the past 15 years.

- The evolution of the vegetation cover does not seem to be an explanation for the decrease of surface winds recorded by ground stations. Indeed, the vegetation cover is very different from on region to another. For example, regions Brittany and Centre in France consists of very different vegetation covers: high roughness with bocage and downwind-edges existing for decades in Brittany and very open farmlands in Centre with almost no vegetation cover and very few constructions. And in both regions, similar wind trends can be observed.

In addition, within several regions, Brittany or West for example, some stations are inland and surrounded by vegetation, whereas others are coastal or even located on islands with almost nothing on the prevailing wind direction but the Ocean. And all stations converge towards similar wind trends.

For all the reasons mentioned above, it is rather unlikely that a bias in measurements or any effect of change in surface roughness could explain the decreasing trend observed in Northern half of France. We assume that the trends observed are effectively due to a decrease of the wind resource specific to these regions.