Inter-annual wind speed variability over Polish territory

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Abstract

The quantification of a wind farm energy yield over the lifetime of the project remains an exercise based on precision of local measurements. Special attention must be given to converting this usually short term measurements, into lifetime average estimates.

Among the variables measured, wind speed variability is of particular relevance.

The proposed work aims to characterize the natural long term variability of the wind speed over Polish territory and assess the limitations of typical inter-annual wind variability figures for this specific territory.

To achieve this, the NCEP/NCAR reanalysis database was validated by comparison with the local measurements carried out in 11 sites spread all over the country. The use of reanalysis data for the period of the measurements made in the different sites showed that data from the NCEP/NCAR represent in an acceptable way the mean inter-annual variability for the measurement sites tested.

In the quantification of the inter-annual wind speed variability over Poland, the last 20 years of 14 NCEP / NCAR reanalysis data series covering the territory were analysed.

The findings point out that the industry standard figures for annual wind variability can be conservative for the tested territory. The results suggest a value of 4.2% for the standard deviation of the annual mean wind speed for a given site of the Polish territory.

In addition, after comparing the wind variability for random and consecutive years, the results show that the impact of using consecutive or random years in the energy production is practically negligible.

Keywords: reanalysis data, wind variability, long-term wind, Poland

1. Introduction

Understanding the variability of the wind climate over the years is crucial when estimating the wind farm energy yield of a wind farm.

Usually, pre-construction estimates rely on short-term measurements (less than 3 years) of the local wind characteristics. Their representativeness towards a so called Long-Term (typically of 20 years) is very risky.

Often, these observations are projected towards a longer term by means of correlation with nearby reference meteorological data. However, data references with a so called Long-Term of 20 years are rarely available for use.

This is why the inter-annual variability of wind, and specifically of wind intensities, is a well known source of uncertainty and risk on wind farm production estimates.

Several studies have been published on the subject of wind speed variability over different timescales [1, 2, 3, 4, 5]. Regardless of this, it is the authors' opinion that there are considerable limitations in the way that this matter has been treated by the wind sector.

Namely, up until now, the majority of wind farm energy production estimates rely on generic and standard figures for inter-annual wind speed variability. Regardless of the regions under study, it is commonly accepted that this variability can be well represented by a figure of 6% for the annual wind speed standard deviation [1, 2].

This figure, whilst developed from Central and Northern Europe data [3] has been broadly accepted for very distinct locations.

Moreover, the industry also accepts that the evolution of wind variability with the length of observations (in number of years) can be described by the following expression:

$$\sigma_N = \frac{\sigma_1}{\sqrt{N}} \qquad (1)$$

σ_N, as a function of N years of data and annual standard deviation σ_1.

The above expression is in fact applicable only to N random and independent samples. It is arguable that a set of consecutive years of wind data (the typical configuration of a wind measurement campaign) are random and independent. Weather cycles are known to be as large as 5 years (take as an example the North Atlantic Oscillation, NOA, with a typical 3 year cycle and direct impact in all European climates) and smaller seasonal and synoptic patterns go across consecutive years.

To assume that any year of measurements is a random and independent sample of a Long Term wind climate is also a rough approximation that should be evaluated and tested.

This work aims to assess the limitations figures for inter-annual wind variability figures and expression, for the specific case of Poland, as well as to propose more realistic ones.

The undertaken methodology makes use of the wind data taken from local measurements and the reanalysis data of NCEP/NCAR (National Centres for Environmental Prediction / National Centre for Atmospheric Research) [6, 7] for those regions.

Globally, 11 local meteorological stations, spread all over the country, and 14 reanalysis datasets were used for this study.

2. Data and methodology

2.1. Methodology

On a first stage, the capability of the reanalysis data series to characterize the natural variability of wind speed was validated.

A simultaneous reanalysis data series was associated to each measurement site studied. These reanalysis datasets were obtained by bilinear interpolation to the station location using the four grid points surrounding each site. For the interpolation methodology was necessary to use a grid point out of polish territory. In the total 15 grid points were used instead of the 14 covering the territory.

The validation was then performed, using both sets of data, onsite and reanalysis, by evaluating the correlation level of the linear regression between the two sets and by comparing the deviations of the annual mean wind speed of consecutive annual periods with the annual mean speed of the total period.

Proven the capability of the reanalysis data to represent the natural variability of the wind speed, the inter-annual variability study could afterwards be conducted with the reanalysis data only.

The last 20 years of the reanalysis datasets, which cover all Polish territory, were used to study the variability of the annual mean wind speed (AMWS) from one-year of data and up to 15 years average periods. In total 14 grid points were used.

2.2. Local measurements

Wind data collected from local measurements carried out in 11 sites were selected for this study. Figure 1 shows its location and Table 1 provides information on the selected datasets.

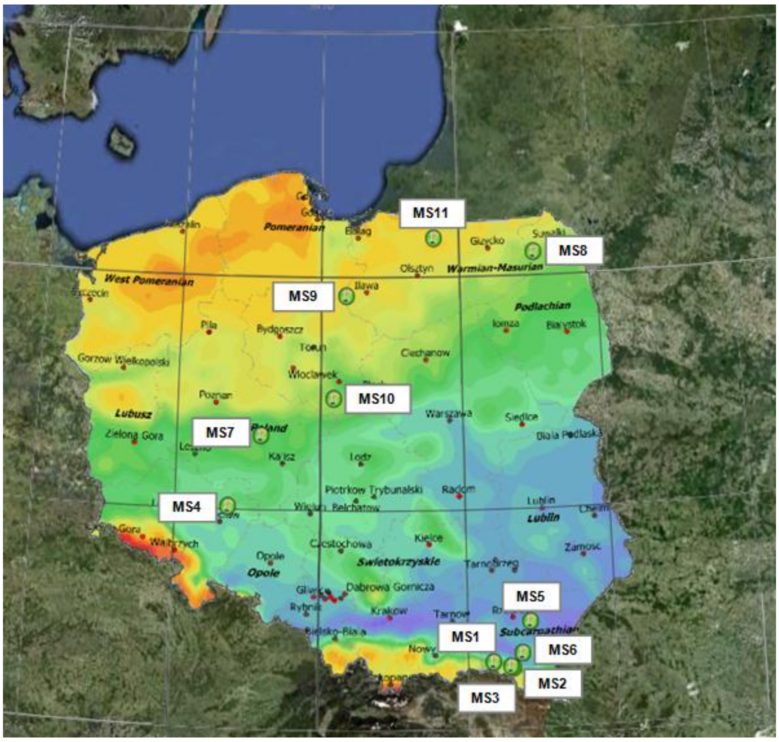

Figure 1 – Local measurements location

Table 1 – Onsite measurements records information

Met. Station	Datasets extension	Nº of valid records	Wind speed recovery rate (%)	Temporal Resolution
MS1	2006 to 2010	246498	93.7	
MS2	2006 to 2010	232458	88.4	
MS3	2006 to 2010	240030	91.3	
MS4	2007 to 2010	186935	88.9	
MS5	2007 to 2010	195931	93.1	
MS6	2007 to 2010	189656	90.1	10 min
MS7	2008 to 2010	152195	96.4	
MS8	2008 to 2010	142772	90.5	
MS9	2008 to 2010	148593	94.2	
MS10	2008 to 2010	149625	94.8	
MS11	2008 to 2010	146363	92.7	

All masts considered in this study were initially used for wind resource assessment. All masts are of high quality and follow the best practices considered by the industry regarding the wind data quality [8, 9, 10, 11].

All masts height is 61m with exception of MS7 mast, which is 83m high.

During the campaigns, collected data was regularly submitted to rigorous data integrity checking. Periods of data for which inconsistencies were detected, were excluded from the analysis.

After validation, all annual periods, whose coverage is less than 75%, were also excluded, in order to avoid distortion in the annual mean wind speed.

All used sets have at least three consecutive years of data and its quality is generally very good, with bad or missing records percentage varying from 3.6% at MS7 and 11.6% at MS2 (Table 1).

2.3. Reanalysis datasets

To allow the use of longer term wind data, weather data from the NCEP/NCAR Reanalysis I project (R1) were also used.

The Reanalysis project, by NCEP/NCAR, generates weather wind casts from global scale numerical weather models based on a large set of a worldwide measurement network (classic meteorological stations, buoys, radio probes, and satellites). These simulations were run from past periods until the present, while keeping the weather model configuration fixed in order to present fictitious trends in the weather forecasts, coming from changes in model parameterization and configuration.

Available R1 data ranges from 1948 to nowadays, with a time resolution of 6 hours and with a spatial resolution of 2.5ºx2.5º (about 300x300 km).

The data is provided by NOAA-CIRES Climate Diagnostics Centre, Boulder, Colorado, USA. Exhaustive descriptions of the NCEP/NCAR global reanalysis data are given by Kistler *et al* [6] and Kanamitsu *et al* [7].

The R1 data sets cover a wide range of weather variables. Those used in this study are the wind speed for a sigma-level (constant or ISO pressure level) of 1000 mBar. Due to the relatively coarse resolution of the employed model (approximately 300 km horizontal resolution), the terrain height varies greatly within the grid node used, creating inconsistencies that are relevant to the correlation techniques employed in the data analysis. In order to simplify the statistical analysis when using Reanalysis data, data from pressure levels were used, as they are adjusted to a homogeneous surface.

Table 2 provides the geographic information, as well as information on the 14 reanalysis datasets used in this study.

Table 2 – NCEP/NCAR geographic and datasets information

NCEP/NCAR grid point		Datasets extension	Pressure level	Temporal resolution
47.5N	20.0E	1991 to 2010	1000 mBar	6 hours
	22.5E			
50.0N	15.0E			
	17.5E			
	20.0E			
	22.5E			
52.5N	15.0E			
	17.5E			
	20.0E			
	22.5E			
	25.0E			
55.0N	17.5E			
	20.0E			
	22.5E			
	25.0E			

3. NCEP/NCAR (II) validation

Two fundamental requirements that reanalysis datasets have to accomplish, in order to be used as long-term reference data for wind resource assessment, are a good correlation level with local wind measurements and a similar pattern for the evolution of the mean wind speed deviations during time. Both requirements were analyzed.

From the local measurements set of wind data, months for which the availability of data is below 75% were discarded. From the whole set of NCEP/NCAR data, the periods for which local measurements are available were selected. The remaining set of concurrent data was used for the analysis.

3.1. Correlation analysis

To quantify the strength of the correlation between onsite and reanalysis data, a linear regression was fitted to the monthly mean wind speed values. The reanalysis datasets were previously bilinearly interpolated to meteorological masts location. The results are presented in Table 3.

Table 3 – Linear correlations coefficients (R) between onsite and reanalysis data.

Met. Station	R-value onsite *versus* reanalysis data
MS1	0.841
MS2	0.886
MS3	0.837
MS4	0.947
MS5	0.912
MS6	0.897
MS7	0.937
MS8	0.918
MS9	0.949
MS10	0.945
MS11	0.916
Máx.	**0.949**
Min.	**0.837**
Mean	**0.908**

The results indicate that reanalysis data closely match the observed monthly wind speed variation. All R-values are above 83%, being the mean value of the coefficients 0.908.

3.2. Maximum AMWS deviation

The deviations of consecutive annual, biannual and triennial mean wind speed to the annual mean wind speed (AMWS) of the complete period of data were investigated, for each location, and considering both, local measurements and NCEP/NCAR reanalysis data. The average of the maximum deviation from all locations, for different averaging periods, is presented in Figure 2.

For both sources of data, the mean values for the maximum deviations to AMWS are comparable and showed the same downward trend with the increase of the period's extent.

Attention should be given to the fact that the representativeness of the calculated average values decreases with the increase of the calculation period, as a consequence of the reduction on number of values obtained.

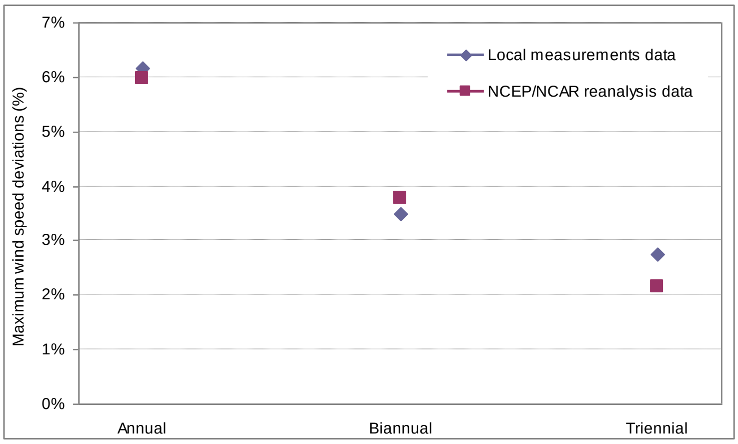

Figure 2 – Average of maximum deviations of the AMWS for different averaging periods

3.3. Conclusion

Taking into account the comparisons between R1 and local data, it was found that the Reanalysis data were sufficiently representative of local wind variations over the years. Thus, the R1 data can be used, from this point onwards, to characterize the wind variability over Poland.

The period between 1991 and 2010 from NCEP/NCAR R1 data was selected to assess the inter-annual wind speed variability over Poland.

4. Wind Variability over Poland

4.1. One-year variability around AMWS

The standard deviations of AMWS to the long-term, here understood as the global 20 years average, were calculated and presented in Figure 3.

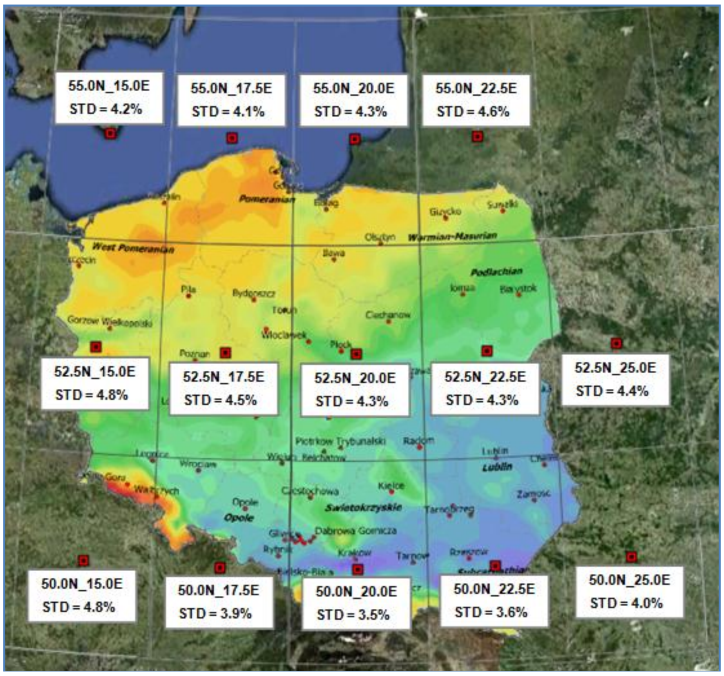

Figure 3 – NCEP/NCAR points location over Polish territory and standard deviation of annual mean wind speeds from 20 yrs reanalysis data sets

The NCEP/NCAR data seems to point that the common figure of 6%, for the standard deviation of one year mean wind speed against the long term, is too high to represent the annual wind variability for Polish territory. The standard deviations range from 3.5% to 4.8% and a value of 4.2% was found for the mean of standard deviations of annual mean wind speeds based on 20 year of data.

Figure 4 shows the 20 years evolution of the ratio to long-term mean of the AMWS taken from R1 data, for all grid points whose location is inside Polish territory. The ratio of AMWS to the long-term mean wind speed, in the tested period, does not exceed 10%.

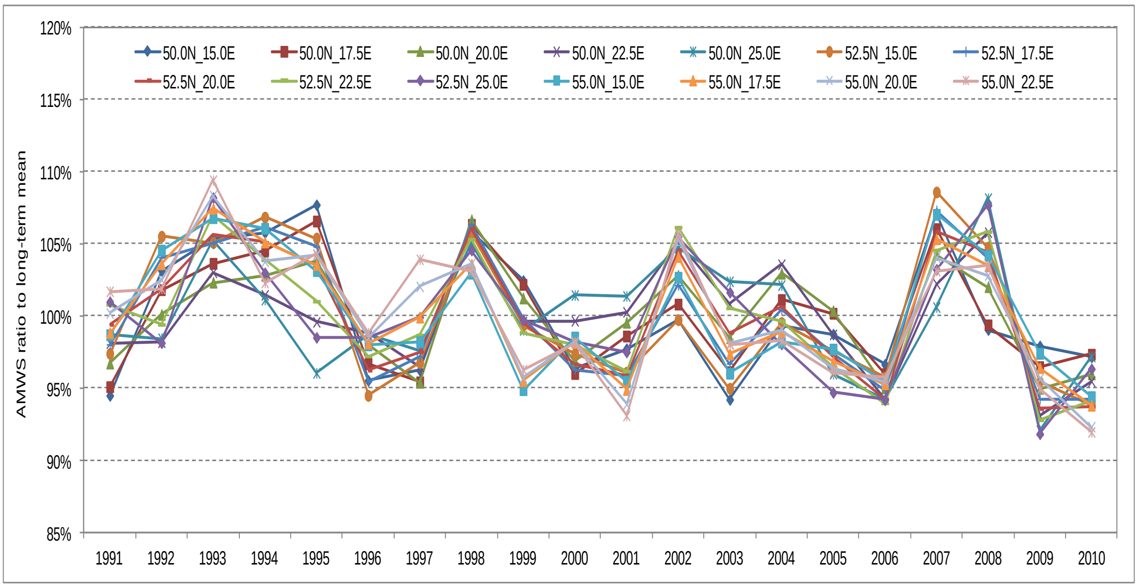

Figure 4 – Ratio to long-term mean of the AMWS taken from NCEP/NCAR database

4.2. Wind Variability as a function of averaging period

The wind variability over periods larger than one year was also studied.

As an example, Figure 5 represents, for NCEP/NCAR grid point 50.0N; 22.5E, the yearly and the four-year rolling mean wind speeds.

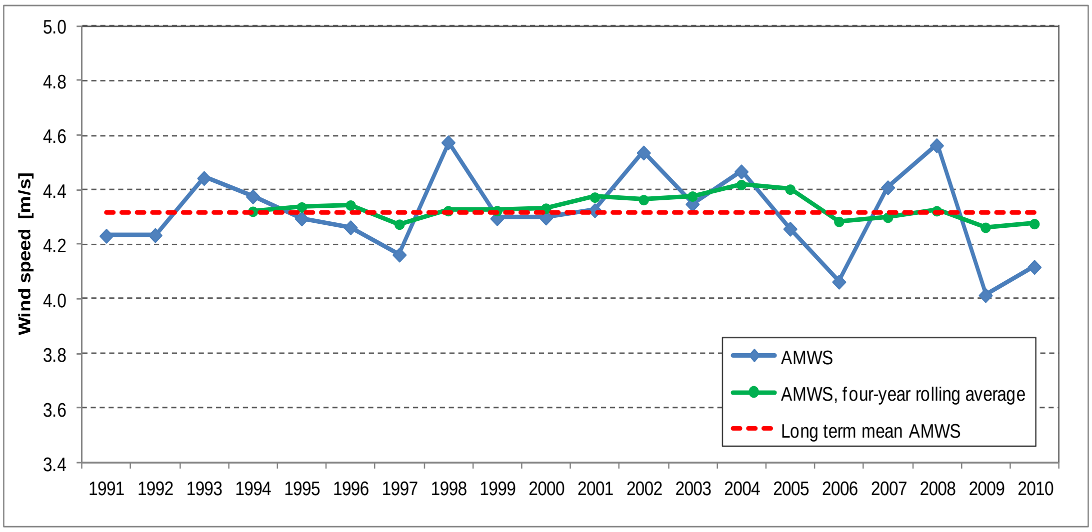

Figure 5 – AMWS and AMWS with four-year rolling average from NCEP 50.0N; 22.5E grid point data

The methodology was to consider 20 years extension of reanalysis data and calculate annual means of the wind speed. A restriction of having samples with at least 6 points was used for the standard deviation calculation, resulting that the maximum length of the analyzed periods is 15 years.

As expected, the plot shows that, as the continuous period of analysis enlarges, the range of deviations of AMWS relative to the long-term decreases, and the scatter around the long-term average is smaller.

The evolution of the standard deviations to long-term obtained for each rolling calculating period is represented in Figure 6. For an easier and direct comparison for each NCEP/NCAR point, the standard deviations for any year were divided by the average standard deviation for one year periods.

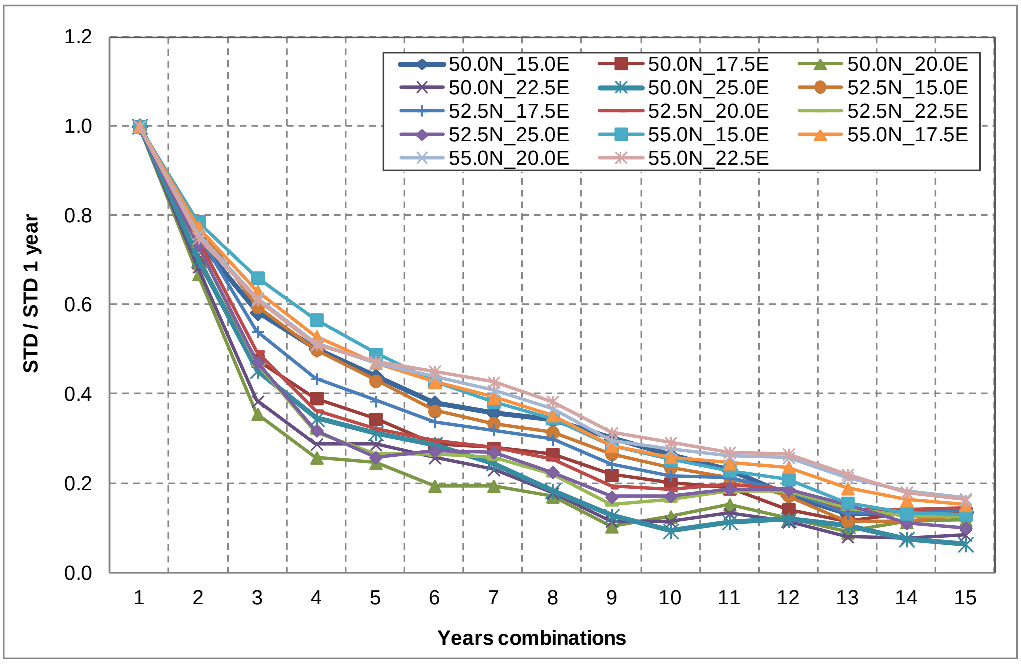

Figure 6 – Standard deviation for each rolling calculating period

The results show a continuous decrease in the values of the standard deviation for longer periods, with a bigger decrease for the initial additions of data periods. The same trend is present for all the 14 NCEP/NCAR points which cover the Polish territory.

4.3. Wind variability for random and consecutive years

The impact of considering consecutive or random years on wind variability was also checked.

Figure 7 shows the result of the standard deviation to long-term taking into account consecutive and random years and the 14 NCEP/NCAR points.

According to this, the standard deviation mean of consecutive and random years show a very similar behavior which means that negligible differences are expected in the energy production when considering consecutive or random years.

This conclusion goes against what could initially be expected. If the effect of inter-annual weather cycles (like NOA) is predominant in defining the annual average wind intensity, then it could be expected that consecutive years would show larger deviations from a long term mean. This does not seem to be the case with the studied data.

It might be the case that annual wind intensities are, by a large amount, defined by smaller and less frequent occurrences, like weather storms and cold fronts. These events occur in a more randomly manner and the probability of occurrence on consecutive years would be lower.

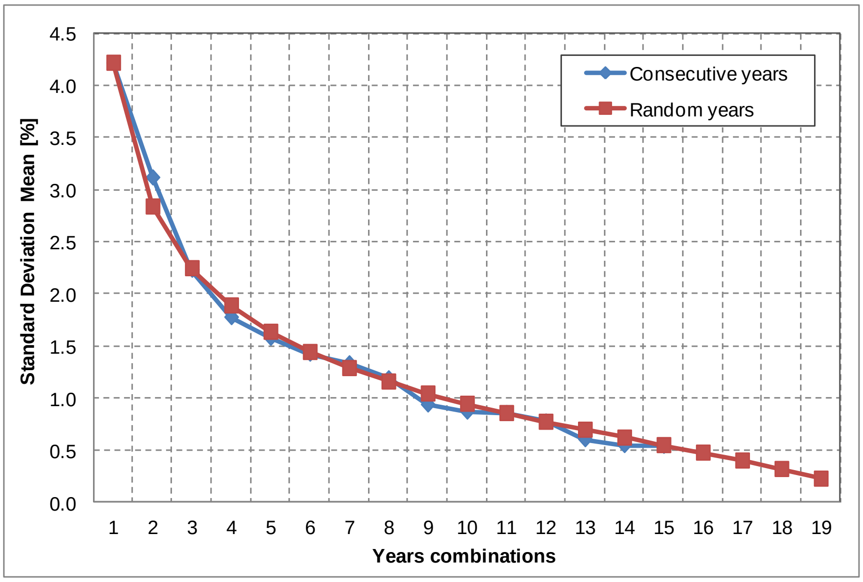

Figure 7 – Comparison of the standard deviation mean between consecutive and random years

It should be mentioned that the sample data considering consecutive years is much lower than the one for random years, for which the possibility of combinations is much higher. Thus, this analysis should be regarded accordingly.

The standard deviation mean between consecutive and random years was compared with the typical evolution of wind speed standard deviations considered by the wind industry as defined by equation 1 using a STD of 6% and a STD of 4.2% from Figure 3. The results are presented in Figure 8.

As expected, the "6% evolution" has a conservative offset compared to the "expected trend" and the "NCEP/NCAR". The only reason being the higher 1-year standard deviation from which the trend is calculated.

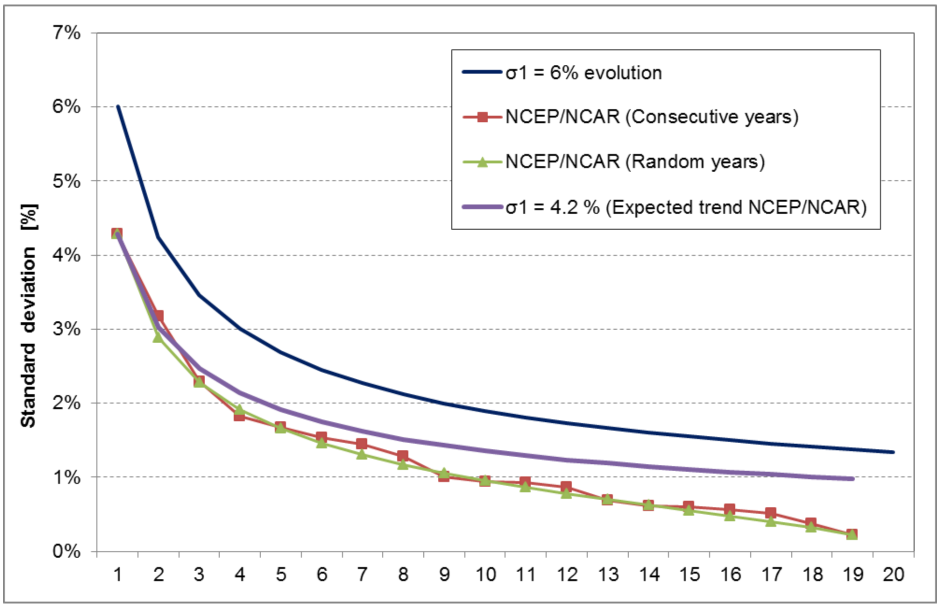

Figure 8 – Standard deviations evolution

Above three consecutive years, the standard deviations from reanalysis data are not very well reproduced by the expected trend. Smallest errors were obtained with reanalysis data but, nevertheless, in a range below 2%.

The difference between considering random or consecutive years is not, in this samples, very significant, justifying the industry practice of using a single constant expression to represent evolutions of wind variability, regardless of the sample of years.

5. Concluding Remarks

As expected, the 20 years reanalysis datasets show a continuous decrease in the standard deviation mean as larger periods are used in the calculation of the mean wind speed. That means that, for wind measurement campaigns in Poland, an addition of another year of measurements offers a reduction of wind variability. This reduction rate is significantly higher for the first added periods (first 3 years). After this, additional periods of data have lower impact in the wind variability.

The data studied also pointed out that the inter-annual variability of mean annual wind speed for Poland could be much lower than wind industry standard figures. A value of 4.2% was found for the mean standard deviation of long-term mean speed, which goes against the typical industry value of 6%.

Changing the assumptions on inter-annual wind variability will change calculated uncertainty on wind farm energy estimates, with direct impact on investment and debt finance decisions. If this conclusion can hold for all Polish territory, this will mean that the length of wind data used for wind resource assessment wind farm energy estimates has a lower impact on uncertainty than what is normally considered.

The use of a single expression to represent random or consecutive groups of years was acceptable, according to the data considered.

The major limitation of this study was the reduced amount of local observations used to validate the NCEP/NCAR R1 wind data to represent wind variability and its concentration in some regions of the Polish territory. Further updates of this study should complement NCEP/NCAR R1 validation with data from other parts of Poland.

This study can be repeated for other regions with wind farm developments, quite specially those more distant from Central Europe/UK (where industry standard practices where primarily derived). NCEP/NCAR reanalysis can be a very useful tool for this kind of studies (being freely available and global) but its use for inter-annual wind variability should be tested in each case.

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