GOING FAR BACK IN TIME TO ANALYSE THE WIND RESOURCE
CAN PRESSURE DATA REPLACE WIND DATA?

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ABSTRACT

The aim of this study, carried out with the financial support of ADEME (French Environment and Energy Management Agency) was to analyse the evolution of the wind resource over a very long-term period (> 30 years) using pressure data instead of wind data. Unlike measured wind data, pressure data present the advantage of being independent from the evolution of its surrounding environment. Thus, as the difference of horizontal pressure between two locations is one of the main origins of wind, the objective of the analysis was to determine through pressure data the evolution of the wind resource in the Northern half of France as far back in time as possible. To this end, a process was set up based on direct correlations between pressure measurements of more than 100 ground stations in Europe and production data of operating wind farms in 3 different regions in Northern France on 1 to 2-year periods. Comparisons between the reconstructed production and the effective production over at least 5 years have shown satisfactory results and allowed to validate the process (monthly correlation coefficients superior to 95 % and annual error < 5 %). Although the method was validated on relatively short periods (5 to 6 years), the reconstruction of very long-term trends based on pressure data could be questioned. Indeed, the trends obtained in the studied French regions since the year 2000 match the ones proposed by MERRA-2 wind data but differ from a multisource index based on rigorously selected independent ground wind measurements.

1. INTRODUCTION

1.1. Context and objectives

This study focuses on the possibility of analysing the wind resource on very long-term periods (> 30 years). Since the wind resource has significantly decreased between the decades 2000-2009 and 2008-2017 in the Northern half of France, this study allows us to take a step back from this observation in order to better appreciate how this decrease falls within time. To do so, the analysis of pressure data has been favoured to wind speeds as their measurements are less sensible to the evolution of its environment. Hence, the risk of a disruption of the consistency in time is reduced with pressure data.

1.2. Process

The chosen approach consists in reconstructing production data on very long-term periods based on correlations established between wind farm production data and pressure gradients in Europe on short periods (1 to 2 years).

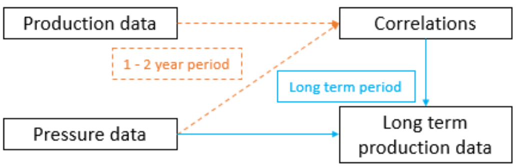

Figure 1: Illustration of general concept

This study was carried out in several steps:

- Collection and processing of pressure data from meteorological stations in Europe
- Collection and processing of production data from operating wind farms in France
- Research of a generic approach to correlate production data and pressure gradients
- Validation of the results:
  - on short periods (5 to 6 years),
  - on a long-term period 2000-2017.

2. COLLECTED DATA

Two types of data were required and collected on a daily time-scale in this study: pressure data and production data from operating wind farms.

2.1. Pressure data

Sea level pressure data were collected from the Integrated Surface Database (ISD) from the portal http://www.ncdc.noaa.gov/isd. This database managed by the NCDC (National Climatic Data Center) contains data from more than 35 000 meteorological stations. As this daily database contains few data in 1972 (data from only 500 worldwide meteorological stations in 1972 compared to 8 000 in 1973), sea level pressure data were collected over the period 1973-2017.

Stations meeting the following criteria were chosen:

- Stations located in or nearby Europe
- Stations evenly distributed in Europe and mesh more concentrated around France
- Stations must have at least 2 nearby stations (as close as possible) to validate its pressure data
- Stations must have a minimum recovery rate of 95 % on period 1973-2017.

Finally, sea level pressure data from 118 meteorological stations on the period 1973-2017 in Europe were collected (Figure 2).

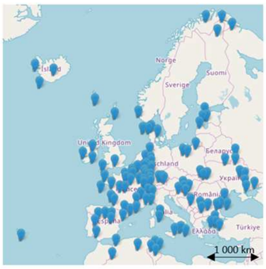

Figure 2: Map of 118 meteorological stations measuring pressure data used

These data were processed by comparisons with nearby stations and missing data were reconstructed to dispose of daily pressure data with 100% recovery rate on 1973-2017.

2.2. Production data

The other dataset required in this study is wind farm production data in France. The chosen wind farms met the following criteria:

- in operation for more than 5 years,
- high availability rates,
- not subject to any kind of curtailment strategy (acoustic, bats or other).

With these criteria, production data from 4 operating wind farms in France were considered in this study.

Figure 3. Map of the 4 operating wind farms considered.

Production data were collected on a daily time-scale on short periods (1 to 2 years) and on a monthly time-scale on longer periods (5 to 6 years). Daily data are used to establish the correlations between production data and pressure gradients (over 1 to 2-year periods) whereas the monthly production data were used to compare the reconstructed production data to the measured one (over 5 to 6-year periods).

These data were processed in order to dispose of equivalent production data with 100% availability rates.

3. METHOD

3.1. Principle

The general principle consisted in finding a generic approach to correlate production data of the wind farms and pressure gradients on 1 to 2-year periods while considering each wind direction. The following steps are furthermore described afterwards:

- Step 1: Recalculation of pressure data on a circle of fixed radius around each wind farm
- Step 2: Separation by sectors to consider each wind direction
- Step 3: Calculation of pressure gradients and association to a sector
- Step 4: Correlations by sectors between production data and calculated pressure gradients
- Step 5: Reconstruction of production data on period 1973-2017

3.2. Step 1: Calculating pressure data

This step is essential as it allows the use of pressure data independent from the location of the meteorological stations. The pressure data have been recalculated using a distance inverse weighting function and the pressure data measured by the 118 meteorological stations.

This distance inverse weighting function was tested and validated against effective measurements. Results have shown that for pressure data recalculated close to France (where the density of measured pressure data is higher), the mean error with the actual measured data is comprised between - 0.7 % and + 0.5 % and the correlation coefficients exceed 98.3 %. On the following map, ME corresponds to the mean error, RMSE the root mean square error and CC the correlation coefficient.

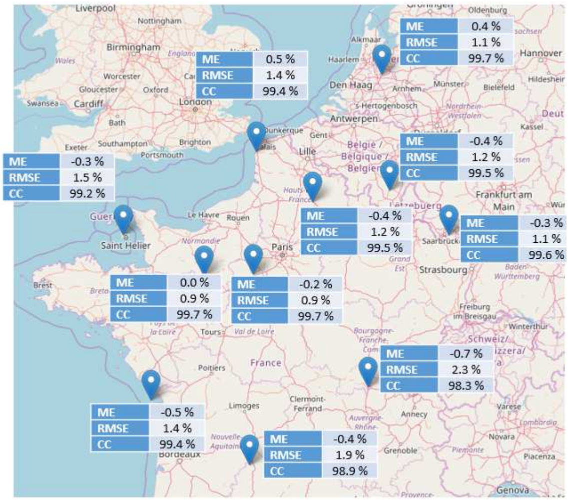

Figure 4. Results of comparisons between measured and recalculated pressure data

This function is used to recalculate pressure data around each wind farm on the perimeter of a circle with a fixed radius.

Figure 5. Step 1 (generic approach)

For each wind farm, several radii were tested and only the one that allowed the lowest errors on reconstructed production after validation were used.

3.3. *Step 2: separation by sectors*

The circle created around each wind farm is then divided into sectors in order to consider every wind direction.

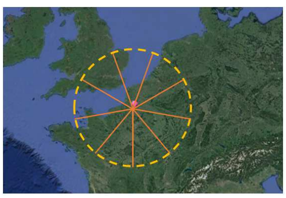

Figure 6. Step 2 (generic approach)

As for the radii, the number of sectors has been tested and for the 4 wind farms, a number of 8 or 9 sectors was retained as they showed the best results during the validation process (i.e. lowest errors).

3.4. *Step 3: Associating pressure gradients with sectors*

The pressure gradients are defined as the difference between the pressure data of 2 points located on opposite sides of the circle. As, for each day between 1973 and 2017, several pressure gradients exist on the circle, only the highest one is kept. Indeed, the highest pressure gradient on the circle should be the one that influences most the wind speeds.

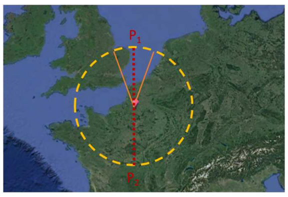

Figure 7. Step 3 (generic approach)

The pressure gradient (ΔP) is calculated with the formula below:

$$\Delta P = P_1 - P_2$$

Hence, each day between January 1st, 1973 and December 31st, 2017, corresponds to one pressure gradient associated with a unique sector.

3.5. *Step 4: Correlations between production data and pressure gradients*

Correlations between production data of the 4 wind farms and the calculated pressure gradients were established on each sector and on periods of 1 to 2 years. The graph below shows an example of correlations obtained for one sector and wind farm n°1.

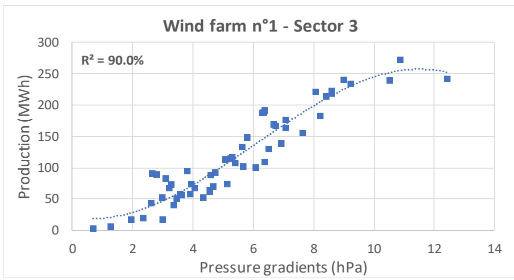

Figure 8. Example of correlation between pressure gradients and wind farm production data

3.6. Step 5: Reconstruction of production data

The equations for each sector derived from these correlations were applied to the calculated pressure gradients on the period 1973-2017 in order to reconstruct wind farm production data.

Hence, with this method, production data of the 4 wind farms have been reconstructed over the period 1973-2017.

4. RESULTS

To validate the method, the reconstructed production data of each wind farm was:

- compared to its measured production data on periods of 5 to 6 years (available history),
- compared to regional energy indexes and MERRA-2 data since 2000.

4.1. Short-term validation

The short-term validation (5 to 6 years) was carried out by comparing the reconstructed production data to the measured data on a monthly and on an annually time scale.

4.1.1. Monthly comparisons

For the considered wind farms, comparing the results to the monthly effective production data showed that the reconstructing method seemed efficient.

The 4 graphs below illustrate the monthly evolutions of the reconstructed and the measured production data of each wind farm.

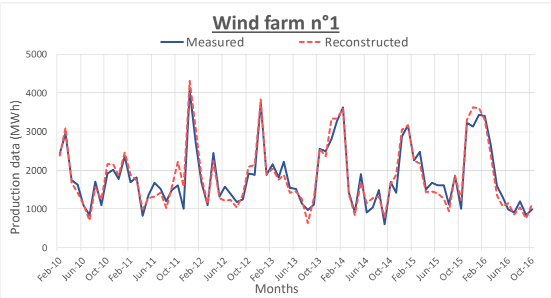

Figure 9. Evolution of monthly production data of wind farm 1 (North of France).

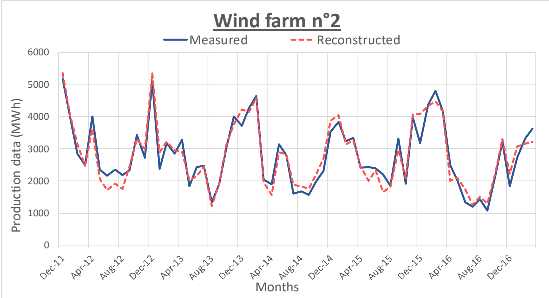

Figure 10. Evolution of monthly production data of wind farm 2 (Champagne area).

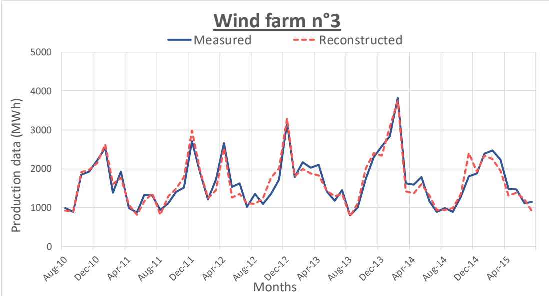

Figure 11. Evolution of monthly production data of wind farm 3 (West of France).

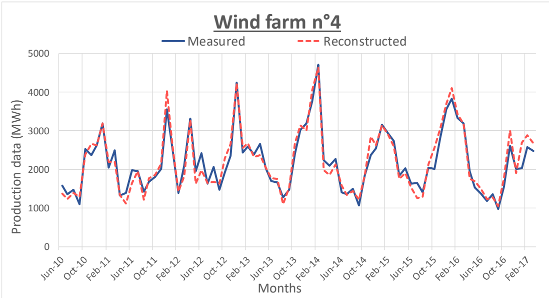

Figure 12. Evolution of monthly production data of wind farm 4 (West of France).

These comparisons (Figures 9 to 12) show that the reconstructed production data from pressure gradients is coherent with the measured production data on 5 to 6-year periods on a monthly time-scale.

The correlation coefficients as well as two types of errors are shown in the table below (mean error and root mean square error).

Wind farm	Region	CC	ME	RMSE
1	North	96.7%	+0.3%	6.2 %
2	Champagne	95.9%	+0.1%	7.0 %
3	West	95.7%	+0.0%	6.2 %
4	West	96.4%	-0.2%	5.8 %

Table 1. Monthly Correlation Coefficients, Mean Error and Root Mean Square Error.

This table illustrates the high monthly coherence between both sets of data (the reconstructed production data and the measured production data) as the correlation coefficients exceed 95 %, the mean error is close to 0 % and the root mean square error is quite low.

4.1.2. Annual comparisons

Reconstructed and measured production data were compared on 12-months rolling periods, as displayed on Figure 13.

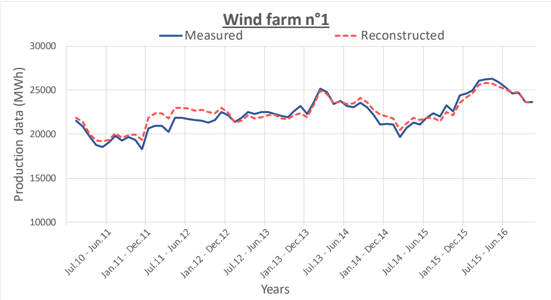

Figure 13. Annual evolutions of production data of wind farm 1 (North of France).

The table below presents the annual correlation coefficients, the annual mean error and the annual root mean square error.

Wind farm	Region	CC	ME	RMSE
1	North	95.0%	+2.8%	8.3%
2	Champagne	96.9%	+0.8%	6.9%
3	West	98.9%	+1.6%	4.4%
4	West	98.0%	-0.3%	4.8%

Table 2. Annual Correlation Coefficients, Mean Error and Root Mean Square Error.

According to the table above, the correlation coefficients exceed 95 % and both the mean error and the root mean square error are quite low for all 4 wind farms. Furthermore, the mean error is mostly positive (for 3 wind farms out of 4) which indicates that there is a slight tendency to overestimate the production data.

For all wind farms, the occurrences of the annual discrepancies observed between the reconstructed production data and the measured data have been divided into ranges.

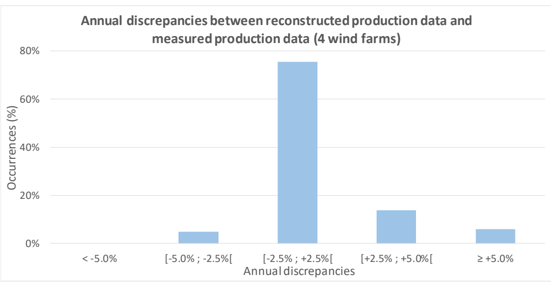

Figure 14. Occurrences of annual errors between reconstructed production data and measured data for the 4 wind farms considered.

Figure 14 shows that for all considered wind farms, the annual discrepancy between the reconstructed and the measured production data is within the range ± 2.5 % for almost 80 % of the time. Also, for more than 90 % of the time, the annual discrepancy is within the range ± 5.0 %.

For the tested wind farms, the reconstruction of the production data can be considered to have a mean accuracy of 5 % on 5 to 6-year periods.

4.1.3. Conclusions on short-term periods

These short-term comparisons (5 to 6 years) are satisfactory as they show that the production data reconstructed based on pressure gradients are very similar to the effective production data (similar evolutions, high level of coherence and low mean errors).

To validate furthermore this approach, the reconstructed production data were tested on a longer period (2000-2017).

4.2. Long-term comparisons (2000-2017)

4.2.1. Considered long-term sources

As no wind farm operating since 2000 with homogeneous long-term operating conditions could be found, the reconstructed production data were compared to two other sets of data over the long-term period 2000-2017:

- Energy indexes (IREC Index)
- Reanalyses data (MERRA-2)

IREC Indexes have been developed by Eoltech since 2011 and cover 7 of the main regions where wind farms are developed in France. They are based on the combination of ground wind measurements from at least 4 consistent and independent sources of information (multisource approach).

MERRA-2 data are reanalyses data generated by NASA and available worldwide since 1980 on an hourly time step with a resolution of 0.5° in latitude and 0.625° in longitude.

As production data and wind data are comparable when converted into standardized values (same evolution), comparisons between IREC indexes, the reconstructed production data from pressure gradients and MERRA-2 wind data were performed in annual standardized values (dimensionless values).

4.2.2. Important considerations

Recent studies have shown that in several areas over Europe and especially in France, long-term trends issued from ground measurements differ from reanalyses data for periods longer than 10 years[1].

For example, the figure 15 illustrates this bias in the North of France between these two sets of data standardized over the period 2000-2017. On this figure, the doted lines correspond to the general trends observed for both datasets.

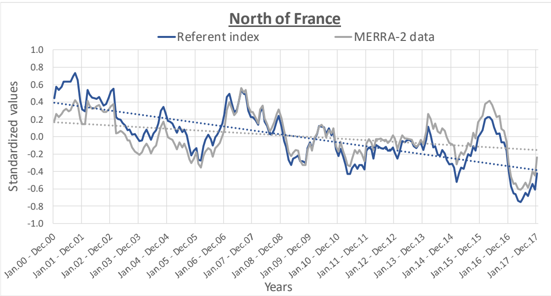

Figure 15. Comparisons of the 2 considered sources in the North of France.

Even though Eoltech considers the energy indexes as the referent source for this study because they result from the combination of several consistent and independent sources of wind speed data, comparing the reconstructed production data from pressure gradients to MERRA-2 data remains an interesting analysis as reanalyses wind data such as MERRA-2 are partly based on pressure data.

4.2.3. Results

The graph below displays both the reconstructed production data of wind farm n°1 in the North of France with the associated energy index and the nearest MERRA-2 data standardized on the period 2000-2017.

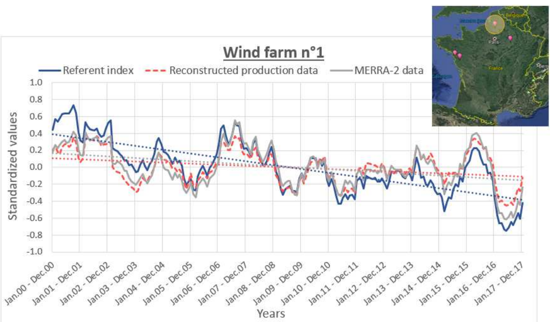

Figure 16. Comparisons of reconstructed production data of wind farm 1 (North of France) with the 2 considered sources.

As mentioned previously, the North of France corresponds to one of the French regions where a bias exists between the trends proposed by the energy indexes and MERRA-2 data. The figure 16 shows that the evolution of the reconstructed production data:

- is quite similar to the one of the energy index in terms of variations,
- indicates a decrease in the wind resource since 2000 even though it is less stressed than the one from the referent energy index,
- is almost the exact same as the one proposed by MERRA-2 (which is coherent with the fact that these two data are partly generated from pressure data).

The graph below illustrates the evolutions for the wind farm n°2 located in region Champagne.

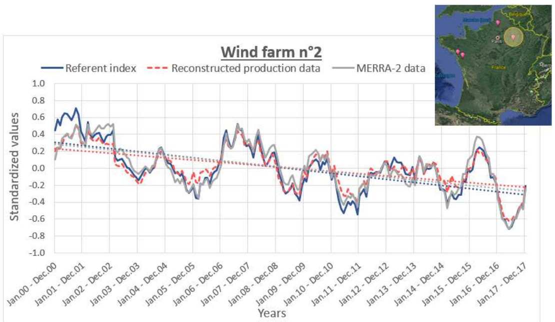

Figure 17. Comparisons of reconstructed production data of wind farm 2 (Champagne area) with the 2 considered sources.

This wind farm has the particularity of being located in a French region where the energy index and MERRA-2 data propose the same wind trends since 2000. Hence, in this case, the evolution of the reconstructed production data is coherent with both the evolution of the energy index and the one proposed by MERRA-2 data.

Finally, the 2 following graphs (Figures 18 and 19) correspond to the results for wind farms n°3 and n°4 both located in the West of France.

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[1]*http://www.eoltech.fr/doc/Full%20paper%20-%20Workshop%20Wind%20Europe%20March17-%20Eoltech.pdf*

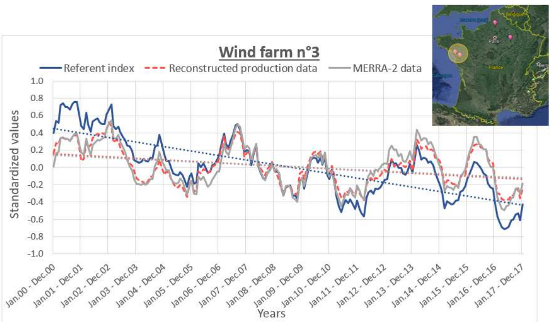

Figure 18. Comparisons of reconstructed production data of wind farm 3 (West of France) with the 2 considered sources.

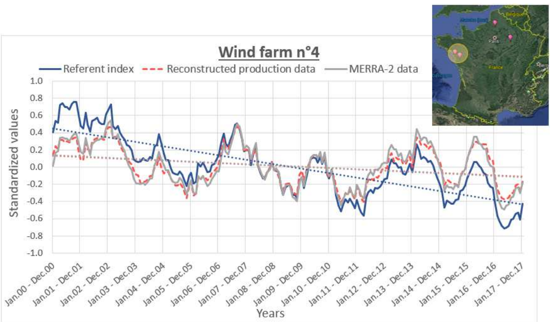

Figure 19. Comparisons of reconstructed production data of wind farm 4 (West of France) with the 2 considered sources.

For these two wind farms, the conclusions are the same than the ones for wind farm n°1 (i.e. there is a deviation between the referent energy index and MERRA-2 data, the observed trend is similar to the energy index but same decrease observed as the one with MERRA-2 data).

4.2.4. Conclusions on long-term periods

These comparisons over the period 2000-2017 have shown that:

- the fluctuations proposed by the reconstructed production data are very similar to the ones proposed by the energy indexes.
- a decrease of the wind resource is observed in the 3 French regions even though, for all wind farms except wind farm n°2 in Champagne region, the decrease is less stressed than the one observed with the referent index since 2000.
- the evolution of the reconstructed production data matches the one of MERRA-2 data which is coherent with the fact that both data are issued partly from pressure data.

These long-term conclusions tend to consider that the reconstructed production data recreated before 2000 (since 1973) should be questioned as long-term trends might not match the ones issued from ground measurements.

5. CONCLUSIONS

In order to determine the very long-term evolution of the wind resource in the Northern half of France, a method consisting in reconstructing wind farm production data based on pressure gradients was designed to reconstruct wind farm production data since 1973.

The short-term analysis of the reconstructed production data on 5 to 6-year periods were considered as satisfactory as:

- the monthly and annual evolutions are similar to the measured ones,
- the monthly correlation coefficients are superior to 95 %,
- the mean annual error is inferior to 5 %.

However, deviations are observed when they are compared on more significant periods (2000-2017) to referent energy indexes in some French regions (no bias observed in the region Champagne – wind farm 2).

This study seems to indicate that some deviations in long-term wind trends appear depending on whether they are issued from ground wind measurements or pressure data (methodology proposed by Eoltech or reanalyses data such as MERRA-2). Hence, **this study shows that pressure data could be used to analyse the wind resource on relatively short periods (< 10 years) but the long-term trends could be questioned in several locations such as North-western France.**