VALIDATION OF GH ENERGY AND UNCERTAINTY PREDICTIONS BY COMPARISON TO ACTUAL PRODUCTION

Andrew Tindal, Keir Harman, Garrad Hassan and Partners Ltd.

1 INTRODUCTION

Garrad Hassan (GH) has been predicting the energy production of wind farms for fourteen years. Predictions have now been produced for over 50,000 MW of plant internationally, and many of these projects have gone forward to construction and have now operated for considerable periods.

In order to assess the accuracy of these predictions GH maintains an internal data base which allows the actual production of wind farms to be compared with pre-construction projections. Using the information within this data base GH has conducted a high level investigation of how these constructed wind farms have performed in relation to the original GH pre-construction predictions. This investigation has been designed to complement a range of more detailed validations that GH conducts on individual aspects of its methodologies and models.

GH has previously published energy validation results [1]. This paper presents the latest validation results and it is GH's intention to continue to maintain the energy validation data base and to publish updated validation results.

To overcome issues associated with different periods of data being available from the various wind farms, each year of actual production data has been considered separately, and compared against the GH net energy central estimate (P50) and 1 year 90 % probability of exceedence level (P90).

It is the aim of this work to be able to evaluate as large a volume of validation data as possible. For many wind farms only "high level" data are available such as monthly sub-station meter readings with no detailed information on wind farm availability or performance. Wind farms with only high level data have been included within the analysis. However, where wind farms are known to have been affected by gross issues, for example very poor turbine or grid availability, or these issues are apparent from comparison with data from nearby wind farms, these wind farms have been excluded from the assessment. Such exclusion of wind farms from the data base is inevitably somewhat subjective, however, the results are also presented in this paper for the subset of data for which the availability is known.

For historical reasons the vast majority of data available are from Europe and North America and these regions are therefore the focus of this assessment.

2 RESULTS FOR EUROPE AND NORTH AMERICA

Results for the whole of Europe and North America have been considered. The data base includes results from 156 wind farms with operational periods which vary from 1 year to 14 years. There are currently a total of 510 wind farm years in the validation data base. The distribution of these data in terms of time and location is presented in Figure 1 below. It can be observed that the longest data sets are available from northern Europe, the greatest number of wind farm years is available from Southern Europe and that there is an order of magnitude more data from Europe than from the USA. The specific breakdown within the data base is 59 % of wind farm years is from Southern Europe, 31% from northern Europe and 10 % from the US.

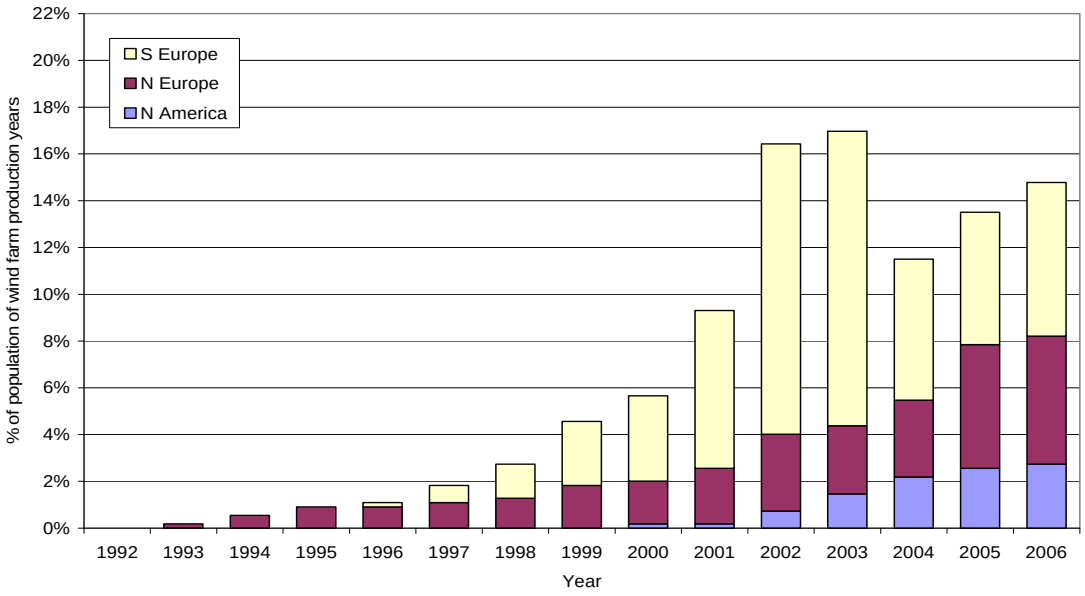

Figure 1 Distribution by region and year of validation information in the wind farm data base

The distribution of annual energy production, relative to the GH central estimate, for the 510 wind farm years in the data base is presented in Figure 2. An equivalent distribution for the 322 wind farm years for which availability data are available and for which the energy production has been adjusted to reflect the pre-construction assumed availability level is presented in Figure 3.

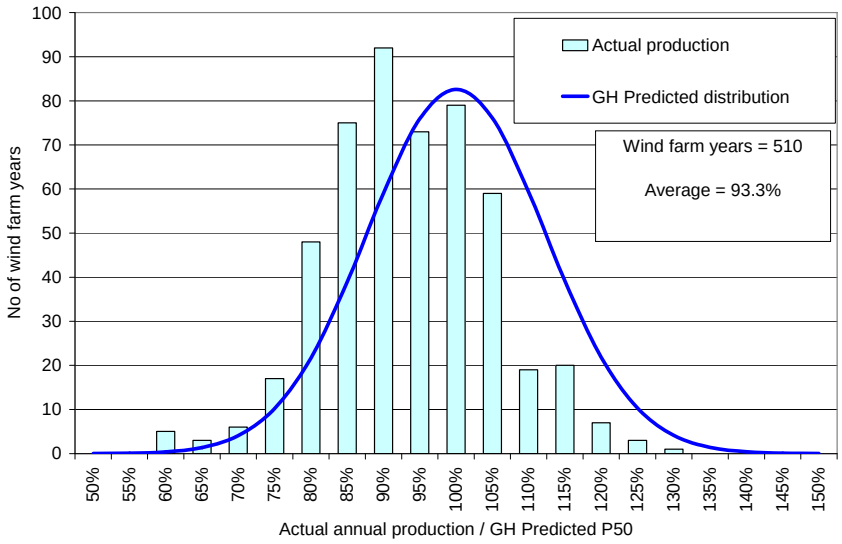

Figure 2 Distribution of annual production relative to GH projected central estimates

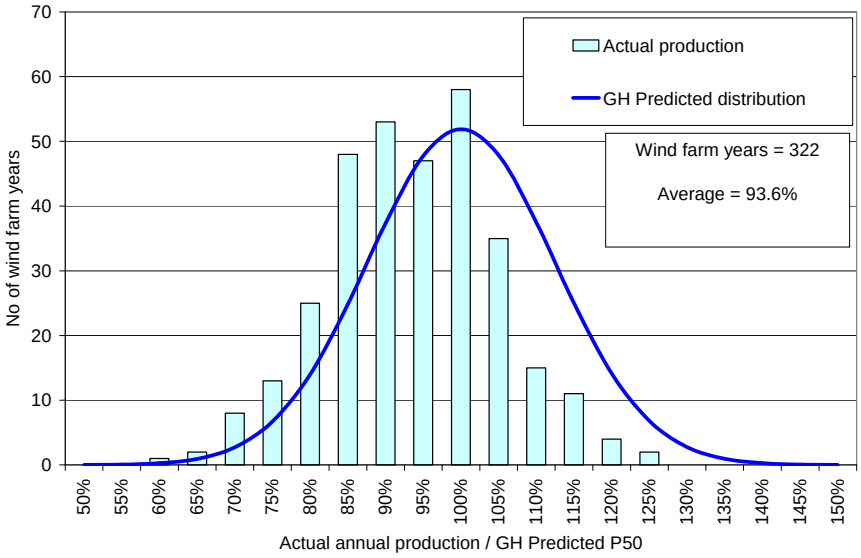

Figure 3 Distribution of annual production relative to GH projected central estimates including availability adjustment for a subset of 322 wind farm years

The average ratio of actual to predicted wind farm energy production is presented within the figures and is summarised in Table 1 below which also includes the subset of the data base for which an availability adjustment can be made. The number of wind farm years which fell below P90 prediction levels was also assessed and these results are also included in Table 1 below.

	Whole data base 510 years	**Availability adjusted subset 322 years**
Average ratio actual / predicted	93.3%	93.6%
Wind Farm Years below P90 energy level	21.2%	18.0%
Wind Farm Years below P95 energy level	11.6%	9.6%

Table 1 Actual performance compared with pre-construction projections - Europe and North America

It is apparent from the above results that for the validation data base as a whole, the currently available data indicates that the wind farms are, on average, underperforming compared with pre-construction estimates and that more wind farms years have production levels below P90 and P95 values than was projected. When availability adjustments are applied for the subset of 322 wind farms for which availability data are available then the average underperformance is seen to reduce and less wind farm years lie below the P90 and P 95 values than for the whole data base without availability adjustment.

Further discussion of the results obtained for the whole data base are presented in Section 4.

3 UK VALIDATION RESULTS

A study was undertaken to validate predictions undertaken in the UK. The assessment of the UK data is of considerable interest as:

- GH's first energy predictions were for wind farms in the UK and therefore the longest potential data sets are available;
- GH has developed a windiness index for the UK and, as a single annual windiness index is reasonably representative of the whole of the UK, it can be used to apply an indicative windiness adjustment;

- Significant detailed production and performance data for UK wind farms are available;
- Some of the older UK wind farms have experienced good availability throughout their lifetimes.

For the UK data set it is therefore possible to attempt to reconcile the causes behind any discrepancies between actual production and expected production observed in a more sophisticated way than is currently possible for other regions owing to the availability of the necessary information for this process.

A UK production index, which has been derived from wind data from UK Met Office stations which have been carefully screened for consistency, is presented in Figure 4. More details on the derivation of the index are given in [2] and can also be found on GH's web site. Note the windiness index derived from UK meteorological stations has been converted into a production index using a realistic sensitivity of variation in energy production to variation in wind speed. The data point for 2007 is a year to date figure suitably normalised by the expected windiness of each calendar month.

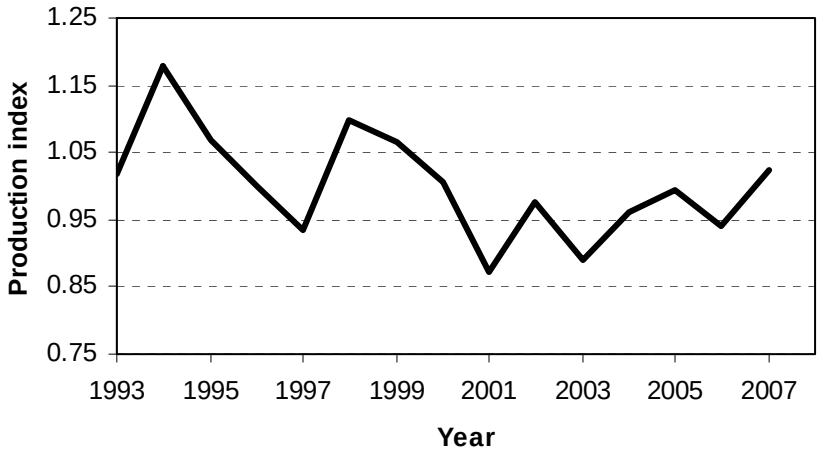

Figure 4 Annual production index for the UK based on data from carefully screened UK Met Office meteorological stations

Approximately three quarters of wind farm years within the GH UK data base were recorded in or since the year 2000. It can be seen from the above trend that on average wind speeds since 2000 have been lower than the period which preceded 2000 and so it is to be expected that an upward adjustment in production data to "correct" for windiness is necessary. The wind speed trend in the UK and the selection of long term reference periods is discussed in more detail in [2]. However, it is interesting to note that the year to date figures indicate that 2007 is on course to be a relatively high wind speed year. It is noted that as this paper presents a "high level" validation of the energy production of UK wind farms it was considered a reasonable approximation to assume a single annual windiness value for the whole of the UK. However, there will be some regional variations in the "national" trend presented here.

Data on annual substation metered energy from 27 wind farms have been compiled. The wind farms have been operational for between 1 and 14 years and are located across the UK. There is a total of 113 UK wind farm years in the data base of which for 34 wind farm years there is availability data.

A few wind farms have been excluded from the validation as they have experienced gross issues, such as extremely low availability. Also from some of the earliest assessments either very short met towers or very short periods of data were available for the original analysis. These were not considered to provide a useful comparison for "modern" assessments and were excluded from the assessment.

The distributions of annual energy production, relative to the GH central estimate for the 113 wind farm years in the data base have been derived and are presented in Figure 5 below. Summary results for the whole UK data base and also for a subset of the data base where availability and windiness adjustment can be applied are presented in Table 2 below.

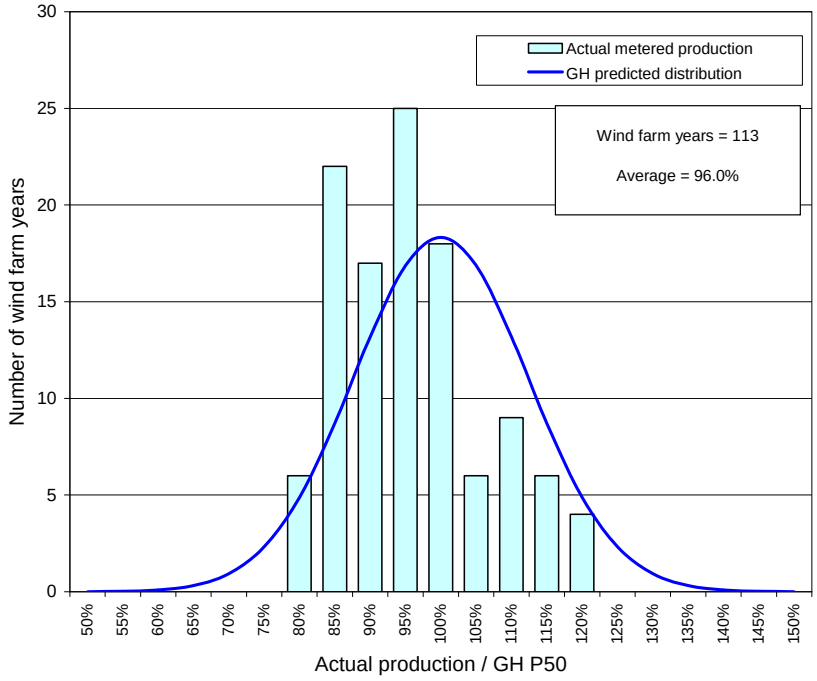

Figure 5 Distribution of annual production relative to GH projected central estimates for screened UK data set

	Whole UK data base 113 years	Availability + windiness adjusted subset 1993 to 2006 reference 34 years
Average ratio actual / predicted	96.0%	101.7%
Wind Farm Years below P90 energy level	13.3%	-

Table 2 Actual performance compared with pre-construction projections for whole UK data base and for subset with availability and windiness adjustment 1993 to 1996 reference

It is apparent that for the UK data set the average production has been 96% of the expected production for the 113 wind farm year data base with 13.3% of wind farm years below the P90 value compared with the ideal 10% value. When the data set is adjusted for availability and windiness, assuming a period from 1993 to 2006 as reference, the actual production is 101.7% of the expected production. When availability and windiness adjustments are applied the number of wind farm years below the P90 value defined within the original energy assessment report reduces substantially. However, as the P90 value includes the influence of inter-annual variability on wind speed, comparison with the 1 year P90 projection is no longer directly relevant and therefore no availability and windiness adjusted result is presented in Table 2.

The results within the above table include the application of a windiness adjustment based on the full period over which production data are available from 1993 to 2006. However, there is evidence that the period in the early 1990s experienced wind speeds which were higher than those which have been experienced before or after the period [2]. It is now relatively common practice to exclude the early 1990's from long term reference data sets and if, alternatively, a reference period from 1997 to 2006 is selected a smaller windiness adjustment is observed. Results are presented in Table 3 which assume a windiness adjustment reference period from 1997 to 2006.

	Whole UK data base 113 years	**Availability + windiness adjusted subset 1997 to 2006 reference 34 years**
Average ratio actual / predicted	96.0%	99.0%
Wind Farm Years below P90 energy level	13.3%	-

Table 3 Actual performance compared with pre-construction projections for whole UK data base and for subset with availability and windiness adjustment 1996 to 2006 reference

For the UK data set it can be concluded that if the data are screened to include only data representative of "modern" assessments, and corrected for both availability and windiness, then the actual wind farm production data are in close agreement with the original pre-construction projections. It is noted that the number of wind farm years for which data are available and for which availability adjustments can be applied is relatively small so some caution must be exercised in the interpretation of these results.

4 DISCUSSION OF US AND GLOBAL RESULTS

Having obtained the validation result for all wind farms in Europe and the US which are included within the data base the next task is to try and understand the causes behind the observed result.

To attempt to reconcile the observed result detailed work is required to drill down into performance on a regional basis and to attempt to correct for the influence of issues such as windiness and availability. The UK reconciliation above is an example of this process.

GH has not yet undertaken this process for the Southern European data set which, in fact, represents the largest proportion of data in the data set. GH has submitted a paper for the 2008 European Wind Energy Conference in which it is anticipated that a commentary on the Southern European results will be provided and GH will then be in a position to provide a more detailed commentary on the results for the whole data base.

GH has assessed the performance of US wind farms [3] and the reader may obtain the paper which describes this work through the GH website. As the quantity of US data is relatively small the work undertaken on the US data base does not allow the overall result observed for the 510 wind farm years to be explained. However, the main findings from the US work are summarised below and it is likely that some of the issues identified in the US will also have influenced the results observed in Southern Europe.

The results in the US indicated that on average actual wind farm production has been 92.1 % of pre-construction estimates. It is considered that wind farm availability in the US has generally been less good than in Europe over recent years and this has played a significant part in the observed result. Additionally some early US wind data sets were affected by poor sensor mounting arrangements which are considered to have had a significant influence on the observed result. Furthermore there is some evidence that recent years - and 2005 in particular, which have contributed a significant proportion of all US wind farm years within the data base, have been relatively low wind speed years in several parts of the US.

The data base available for the US work is smaller than the UK data base with a lower level of detail. The US results must therefore be treated with some caution until more data become available. GH expect to present an update of the US result in 2008.

5 OVERALL CONCLUSIONS WITH A FOCUS ON UK RESULTS

GH maintains an internal energy production validation data base which contains actual wind farm production data and GH pre-construction energy projections. The data base contains only "high level" information which, as a minimum, includes monthly wind farm production, and in some cases more detailed information such as availability.

It is only by looking at large volumes of data that a scientific view on the typical accuracy of predictions can be taken. This paper has presented the current results from the energy validation data base containing 510 wind farm years with 113 wind farm years in the UK. Some wind farms where there have been gross issues such as grid curtailment or very poor availability have been excluded.

Global results

The "raw" results show that predictions, on average, have been over estimates. For the full data base of 510 wind farm years the average actual production has been 93.3 % of pre-construction projections.

As discussed in the main text a detailed regional analysis is required to attempt to reconcile and understand the causes of the observed result. GH has yet to attempt a detailed reconciliation of the energy validation results for Southern European wind farms. Such work is ongoing and it is anticipated that an attempt to reconcile the causes of the observed results for Southern Europe will be presented at the EWEC conference 2008. When this work is completed GH will be in a better position to explain the causes behind the observed overall global result.

An initial reconciliation has been attempted for the US wind farms within the data base and from this it was concluded that wind farm availability, poor mounting arrangements of sensors and windiness are all likely to be causes of the observed discrepancy. These issues to varying degrees will also have affected the Southern European result.

UK Results

For the UK there are 113 wind farm years included within the data base and these indicate that average actual production has been 96.0 % of pre-construction projections with 13.3 % of wind farm years below the P90 value compared with the expected 10 %.

For the UK data set, if adjustments for availability and the windiness of the period are included, then the average result is close to 100 %, although it is noted that the data set for which the availability adjustment can be carried out is significantly smaller than the whole UK data base.

For the UK, therefore it may be concluded that where wind farms perform with high levels of availability, where "modern" wind measurement campaigns are conducted, and when recent windiness is considered, future wind farm energy production may be expected to be in line with pre-construction estimates.

Next steps

The results of the global validation exercise certainly demonstrate that the industry should not be complacent about wind farm energy projection and the need for high quality measurements.

GH will continue to maintain and publish updates of the energy validation data base. Clearly the more data which are available, the better the understanding we will have about our ability to predict accurately the future output of wind farms.

There are many areas in which further work is merited; however key areas on which the industry (and GH) continue to work include:

1) Continue promoting high standards for monitoring campaigns;
2) Understanding loss factors through rigorous analysis of the data;
3) Validating advanced measurement techniques;
4) Understanding power performance in complex terrain;
5) Increasingly sophisticated wind flow and wake modeling techniques.

REFERENCES

1 Raftery P, Tindal A, Garrad A, “Validation of GH energy and uncertainty predictions by comparison to actual production”, Proceedings of the European Wind Energy Conference, London 2004.

2 Atkinson, N, Harman, K, Lynn M, Schwarz, A and Tindal, A, “Long term wind speed trends in northwestern Europe”, BWEA 28, Glasgow 2006.

3 Tindal A, et al, “Validation of GH energy and uncertainty predictions by comparison to actual production”, AWEA Special Topic Workshop, Portland USA, September 2007