UNDERSTANDING AVAILABILITY TRENDS OF OPERATING WIND FARMS

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1 INTRODUCTION

The availability of a wind farm is directly related to revenue, therefore understanding availability that can be expected over the lifetime of the wind farm is essential in managing the performance of a project and quantifying its value. Over the past 10 years, Garrad Hassan has assessed hundreds of operating wind farms worldwide and it has been noted that the wind farm availability in North America has been significantly lower than the availability maintained globally.

To enable an understanding of the expected availability of a new wind farm project, this paper proposes that, if the probability of occurrence of a particular level of availability on historical wind farms was known, this could be used to aid understanding of the risks on a new wind farm project. Such information is additional to the "standard" availability forecast methodology currently used and would provide potential validation of current availability assumptions.

Using work completed for wind farm owners and lenders, Garrad Hassan has gathered a large amount of operating data. It is this independently validated data that has been used to derive and summarize historical availability trends in an attempt to answer some key questions:

- What level of availability can be expected throughout the operating life of a wind farm globally?
- What level of availability can be expected throughout the operating life of a wind farm in North America?
- How do turbine size and number of turbines on the wind farm impact availability?
- Does availability reduce at high wind speeds?

2 AVAILABILITY DEFINITION

There are two main definitions of availability: Turbine Availability and Wind Farm System Availability. Clarifying the definition of availability is important; often only one type of availability, Turbine Availability, is quoted when discussing the performance of a project. As discussed below, this may be very misleading when trying to understand the true impact of availability on a wind farm project.

Turbine Availability is a measure of the turbine system only and is the focus of contractual warranty arrangements. This availability excludes wind farm system downtime such as grid down-time and force majeure. This definition often includes an allowance for routine scheduled maintenance such as annual service. This allowance varies from project to project but allowances of 60 hours a year, or approximately 0.7% of time, are common. Clearly, turbines cannot generate revenue when shut down for maintenance. The definition of Turbine Availability is negotiated on a project by project basis before project construction and so there is no "standard" definition of Turbine Availability. This presents two significant problems. First, attempting to use this as a comparative measure across a range of projects may be misleading. Secondly, Turbine Availability does not reflect total down-time and therefore the true energy losses of the turbine or the wind farm system.

An IEC working group was established in 2007 to produce a standard that outlines a common definition of availability down-time categories. Until the resulting standard is issued there remains no internationally agreed definition of availability.

System Availability more closely represents the true amount of time that the wind farm as a whole is available to generate. The majority of down-time counts against availability, regardless of the cause, and only shutdown due to normal operating conditions is excluded, for instance high wind shut-down or cable unwind events.

The definition of System Availability may be summarized as follows:

$$\textit{System Availability} = \frac{\textit{Time that the turbines were available and ready to operate}}{\textit{Total time in the period}}$$

System Availability most closely represents the availability used in the financial models of a project. A System Availability of 97 % represents 97% of time that the wind farm is ready to produce project revenue. Using these definitions it follows that the Turbine Availability will always be higher than the System Availability. The trends presented in this paper are based on System Availability.

3 COMPILATION OF A DATABASE OF AVAILABILITY STATISTICS

Working for banks, developers and owners, Garrad Hassan has assessed over 14 GW of operating wind farms, which, at the time of writing, is approximately 15% of the world's installed capacity. From this, a database of availability statistics has been created with the aim of identifying trends in the historical data that may be used to understand the levels of availability that may be expected from a new project.

In summary, the database consists of and represents:

- Monthly Turbine and System Availability statistics for over 300 wind farms across the world including 60 wind farms in North America;
- All major wind farm markets with varied climatic conditions;
- All major turbine manufacturers with turbine rated capacity ranging from 300kW to 3MW;
- The wind farms sizes from 1 or 2 turbines to well over 100 turbines;
- Varying operational periods for wind farms from between 1 and 15 years.

The information has been subject to a quality checking process. In most cases the data have been subject to validation through detailed analysis of 10 minute average SCADA data and fault logs.

4 AVAILABILITY TREND RESULTS

4.1 Distribution of annual availability

The dataset shown in Figure 1 is the distribution of annual availability. This distribution gives an insight into the frequency of occurrence of different levels of availability that have been seen historically, and demonstrate how realistic the industry standard of 97% availability is.

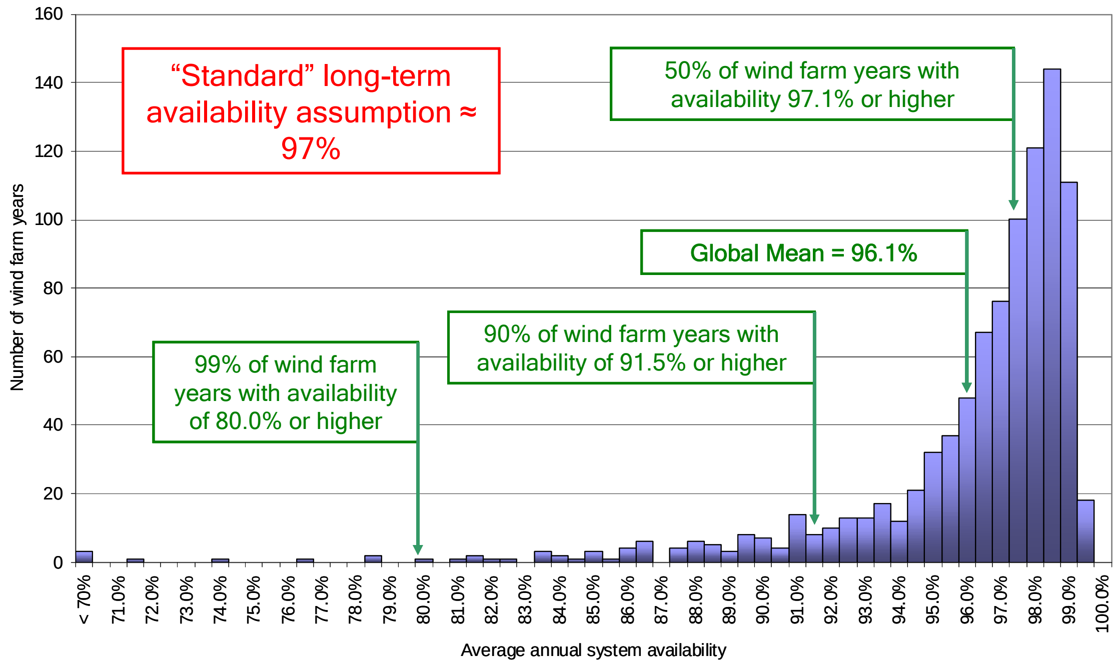

Figure 1 Distribution of average annual availability

The average annual availability for all wind farms in the database is shown on the x-axis and the percentage of wind farm years in the database is shown on the y-axis. A wind farm year represents one independent annual period at one wind farm. For example, a wind farm with six years of availability data contributes six data points in the chart above.

The distribution of annual availability presented in Figure 1 is a skewed, rather than Gaussian, distribution. The mean of the distribution is 96.1%, which is a little lower than the industry standard. However, due to the skewed nature of the distribution the 'most likely' availability is higher than this level. In fact 50% of the wind farm years are 97.1% or higher while 90% of the wind farm years are above 91.5%. Only 1% of the dataset is below 80% availability.

Although not shown in Figure 1 above, the annual availability for the North American wind farms in the database exclusively is 94.1 %. This value is clearly below the industry standard. In order to understand the differences between availability in North American wind farms and wind farms globally, the availability of each project was plotted over time as discussed in the following section.

4.2 Variation in System Availability over time

Figure 2 presents availability versus the years of wind farm operation, with zero being the commissioning date. The individual solid points show the average availability for all wind farms in the database for each month since commissioning. The diminishing dashes show the number of wind farms in the database that make up the individual monthly availability figures. Also shown, as solid lines, are the quarterly and annual moving average availability. Figure 2 shows that the availability of the wind farms 'ramps up' over time as teething issues are resolved. On average, the wind farms show availability of approximately 93% in the first quarter of operation, rising to close to 96% from the end of the second year. Beyond the end of the second year the availability hovers around 97 %, with the availability increasing significantly after year 7. The increased volatility between year 8 and 10 is due to the reducing number of wind farms in the database.

Beyond year 10, the picture becomes very unclear as there are few wind farms in the database that have operated beyond this date. However, Garrad Hassan considers it prudent to assume that O&M budgets should be increased beyond year 10 in order to maintain higher levels of availability.

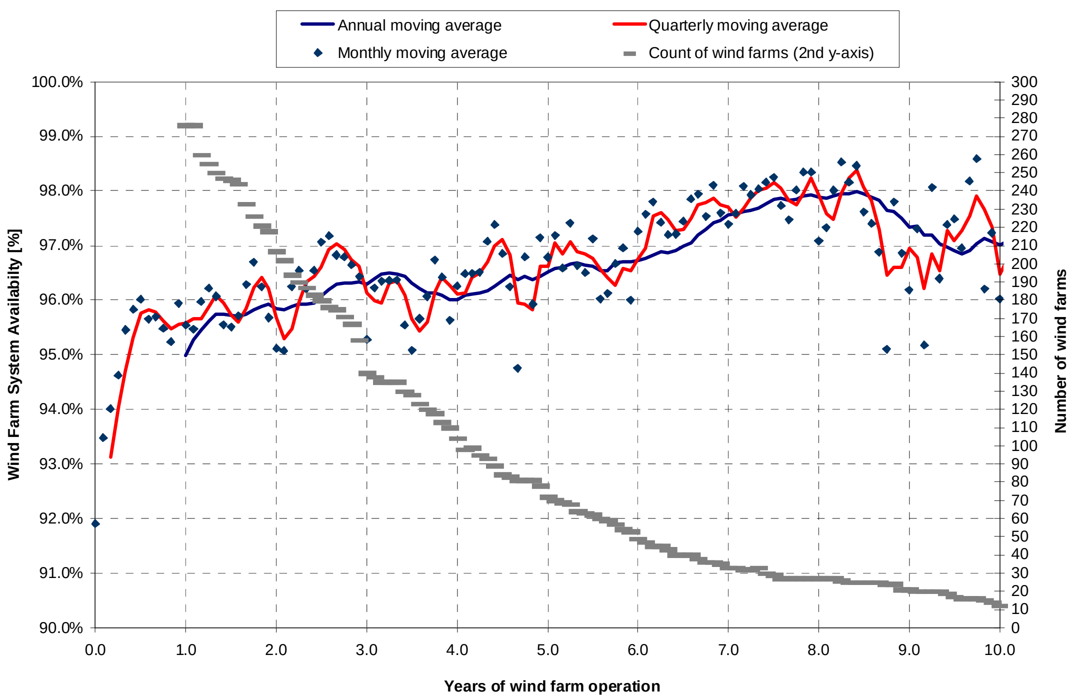

Figure 2 Availability versus time trend; shown monthly, quarterly and annually

As noted in the previous section, the most likely availability is actually higher than the average trend as there is a non-normal distribution underlying each of these data points.

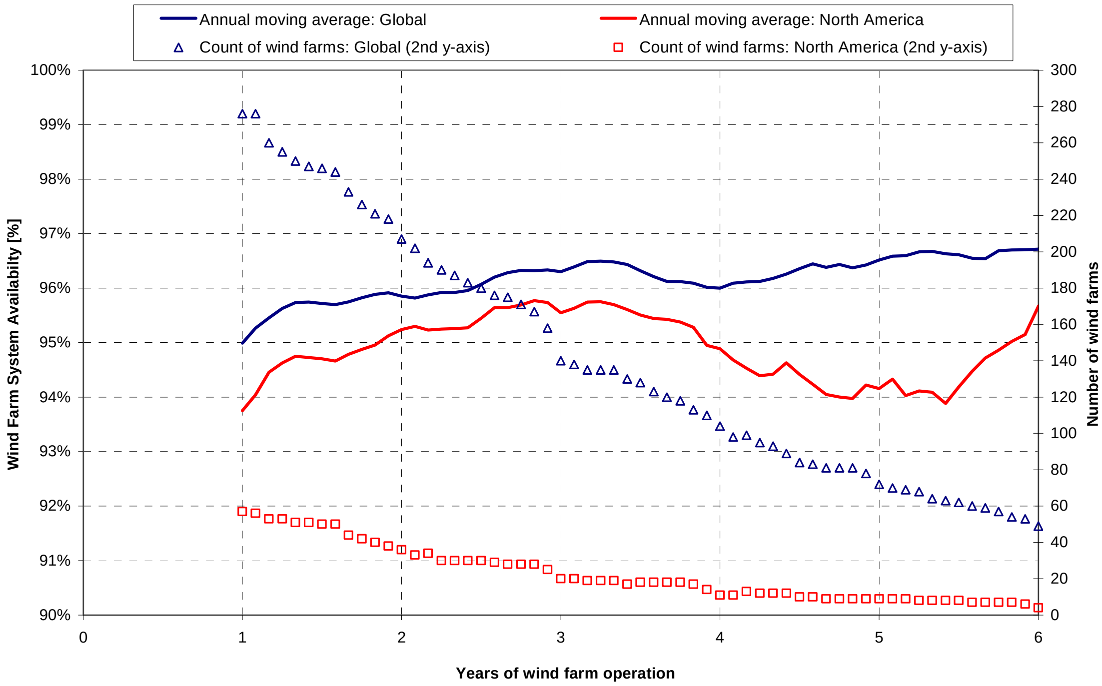

Figure 3 Annual availability versus time globally and for North America

The blue solid line in Figure 3 is the same annual moving average availability presented in Figure 2, while the red solid line represents the annual moving average for North American projects alone. In Figure 3, the count of wind farms in the global trend is shown by the blue triangles, instead of the grey dashes presented in Figure 2. The North American projects display the same "ramp up" behavior observed in the global trend, but the ramp up is steeper, and system availability appears to be reaching an asymptotic value closer to 95.5% instead of 96.5% by year 3. As with Figure 2, the increased variability beyond year 4 is a result of very few projects in the database, as shown by the red squares, and should not be treated as representative of a long-term trend.

For both the global and North American availability trends above, the presented trends are dominated in the latter years by the previous generation of sub MW turbines. As a result, it is important to understand if the performance of sub MW turbines on generally smaller wind farms is representative of the latest generation of larger multi-MW turbine wind farm projects consisting of more turbines.

4.3 Do large turbines and large wind farms result in lower availability?

Figure 4a shows System Availability for the first three years of operation with the database subdivided into sub-MW and MW-plus turbines. It is apparent that there may be more teething issues associated with the larger turbines, which are generally more complex, but once these issues are resolved a similar level of availability can be expected from the MW-plus turbines to the sub-MW turbines.

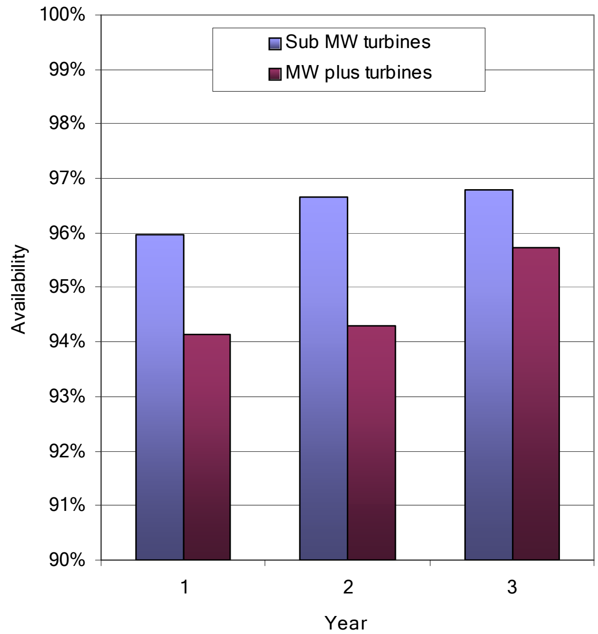

Figure 4a Availability vs. turbine size

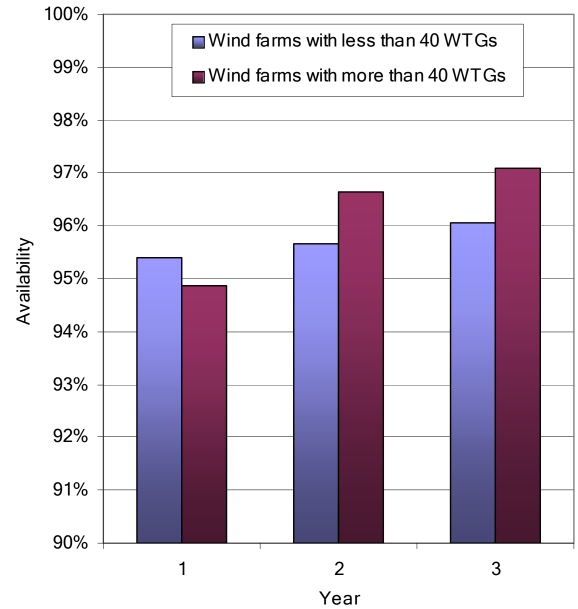

Figure 4b Availability vs. wind farm size

Figure 4b shows the database subdivided by the number of turbines on the wind farm; those consisting of less than 40 turbines and those consisting of more than 40 turbines. At a wind farm of approximately 40 turbines or larger, a full-time on-site crew becomes a necessity. Lower availability levels due to initial teething issues are more evident in the first year at the larger wind farms. However, by the second year of operation a higher availability average is evident.

It can be concluded from these plots that availability is relatively insensitive to turbine size and wind farm size once initial teething issues have been resolved in the first couple of years of operation.

4.4 Does availability reduce with wind speed?

In the industry presently, there is an argument that downtime occurs more frequently during periods of greater energy capture. In other words, 1% of downtime at a wind farm results in greater than 1% loss of energy production. In order to assess the validity of this argument, the system availability for each wind speed bin between cut-in and cut-out wind speeds calculated from the 10 minute average for a subset of 25 wind farms outside of North America and a subset of 18 wind farms in North America. These wind farms represent geographically diverse locations, varied turbine type and wind farm size as well as varied climatic conditions.

For each wind farm, one year of operating data was subdivided into wind speed bins 1m/s in width. The System Availability was calculated in each of the bins over the normal operating range. Figure 5 shows the combined result for all 25 wind farms located outside of North America.

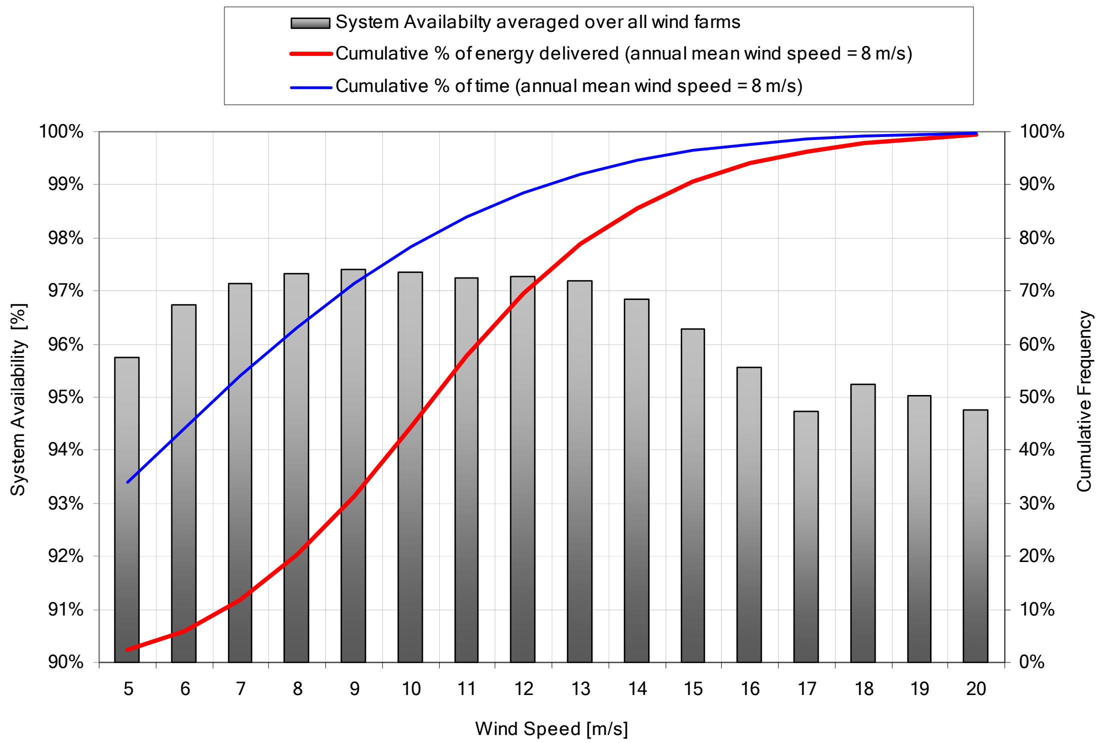

Figure 5 Availability versus wind speed

On the x-axis is wind speed measured by the nacelle mounted anemometers and on the y-axis is System Availability. The bars show the average of all wind farm results for each wind speed bin. The solid blue line shows the cumulative % of time in one year spent at or below a given wind speed for a site with a nominal annual mean wind speed of 8 m/s. The solid red line shows the cumulative amount of nominally energy delivered in one year.

In Figure 5, the availability is relatively constant between 7 and 14 m/s and it is in this wind speed range that the majority of energy is delivered.

At high winds, above 15 m/s, high load faults may be more common causing a notable reduction in availability. Such faults may be associated with vibration protection alarms, pitch mechanism malfunction or generator over-heating. As well as an increased likelihood of these faults occurring at high winds, turbine repair time is often prolonged due to restrictions associated with safe access to the site and turbines.

Conversely, at lower winds, below 7 m/s the availability also is lower. This is due to down-time associated with non-urgent maintenance activities that are scheduled for calm periods. For instance, annual servicing can be scheduled for lower wind summer months and on a more macro level turbines may be shut down during calmer periods forecasted on a daily basis.

In order to assess what this means in terms of energy losses, it is important to consider the frequency of occurrence of wind speeds in each of these bins. The significance of the lower availability at high winds is shown to be less than Figure 5 may initially indicate. In energy production terms, the impact of lower availability at high wind speed is in fact balanced with lower availability at lower wind speeds. For the subset of wind farms considered here, the overall result is that there is no significant overall bias in the wind speed versus availability relationship and for these wind farms a 1% loss of energy resulting from 1% downtime seems sensible. This is a reasonable assumption that can be made on a new project.

However, it is imperative that availability risks must also be considered on an individual project basis. One striking example of where an external issue has caused an exception to the above trend is in a region of Texas where there is a high penetration of wind power. During high wind periods, when wind power outstrips demand on a relatively weak grid, the utility company enforces wind farm projects to shutdown. This external factor leads to a dramatic correlation between reduced availability and high wind speeds. This effect is shown in Figure 6 below.

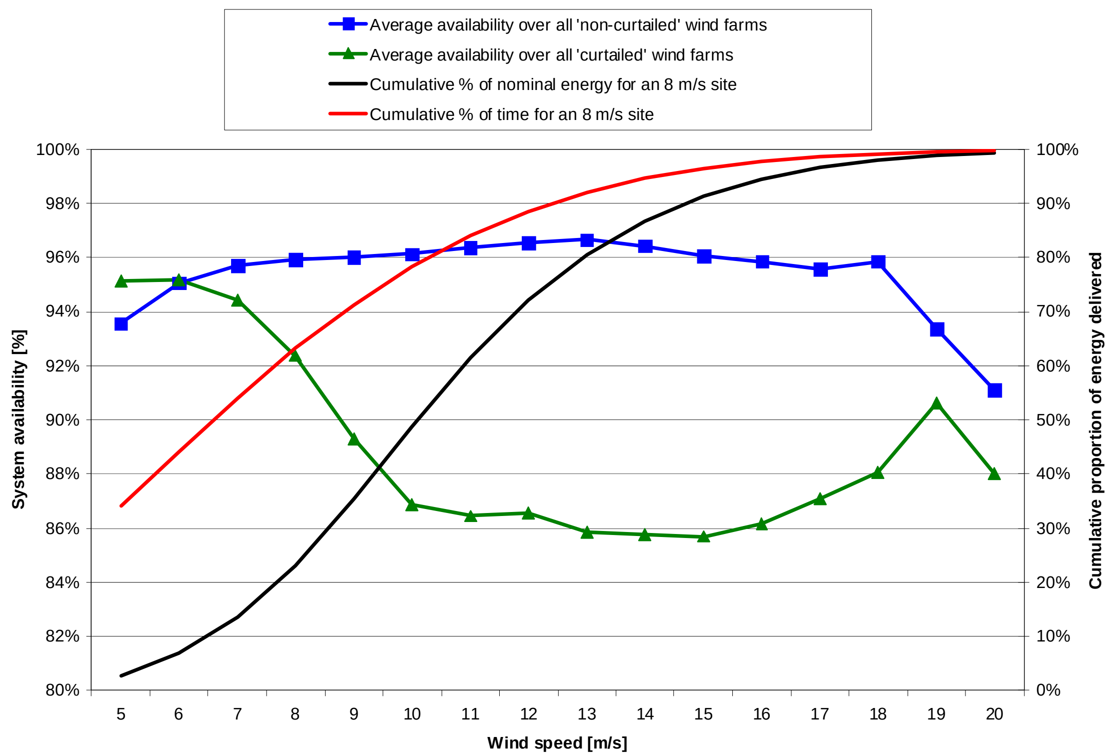

Figure 6 Availability versus wind speed for North American wind farms

Figure 6 splits the grid curtailed wind farms apart from the non-grid curtailed wind farms in the blue and green lines, respectively. The blue line shows the same relationship with wind speed as the global trend. For the wind speed range where most of the energy is delivered, 1 % of downtime is equal to approximately 1 % of energy loss. For the wind farms which experience grid curtailment, such as described for Texas above, 1 % of downtime equals approximately 1.3 % energy loss because the grid is curtailed only during high wind periods.

Other examples of potential issues that may impact the relationship between availability and high wind speed are:

- Severe climate issues, including icing issues;
- Severe systematic turbine faults associated with high load;
- Wind sector management where downtime is enforced in particular sectors to minimize noise or other external impact.

These issues, and others not listed, require review and potential factoring in on a project by project basis.

5 CONCLUSION AND DISCUSSION

When investing in a modern wind farm development, it is generally considered appropriate to expect 97 % availability averaged over the life-time of the project, typically 20 years. The results of this study provide confidence that, as wind farms reach maturity and teething issues are resolved, it is reasonable to assume availability close to 97% on average for wind farms outside of North America. Specifically in North America, however, availability levels have been significantly lower, and currently projects are only achieving a system availability of 95.5 % after reaching maturity.

The availability in North America is demonstrated in the above data base to be lower than that which is seen in Europe and elsewhere. There is currently significant debate in the industry regarding the causes of the above difference. The causes of lower availability are discussed in more detail in the presentation "Why is North America's Availability Lower than Europe's?" [1]. Key causes include the availability and training of experienced turbine maintenance crews, the current availability of spare parts and cranes, technical support (in some cases) being dependant on European input, size of projects, remoteness of projects and harsh meteorological environments. The recent unprecedented rate of wind turbine installation is also having an impact. It is considered that in the near future and certainly in the medium term there is scope for many of the issues listed above to be addressed. It is therefore considered appropriate to assume that, on average, availability levels above the currently observed 95.5% North American availability level discussed above will be achieved. However, some issues, for example harsh meteorological conditions and project size are reasons why maintaining high levels of availability may be more challenging in North America than elsewhere and therefore it is considered appropriate to assume a mature availability level a little lower than 97 % until such time as the data demonstrate a different assumption is merited.

The distribution of annual availability demonstrates that the number of occurrences of annual availability levels of less than 80% on a modern wind farm is relatively low. Such low availability may be caused by external factors, for instance utility enforced downtime, as well as turbine issues such as large component serial defects including gearboxes and blades.

It is useful to consider how these risks can be mitigated. Minimizing the turbine availability risk is possible through procurement of a turbine availability warranty associated with an operation and maintenance agreement. This is typical in the first years of operation of the project. Some manufacturers will provide longer term agreements, up to 12 years. Some owners have negotiated availability warranties that actively encourage the performance of maintenance in low wind periods. A simple approach is to discount all planned outages that occur when wind speed is less than 4 m/s from the warranty availability calculation.

Availability risks associated with environmental conditions should also be considered on a regional or individual wind farm basis. For instance, icing can impact the ability of the turbines to operate efficiently as well as causing accessibility problems. At high wind speed sites, repairs to components such as blades can be delayed causing high turbine downtime. It is therefore very important to establish the impact of environmental conditions as this type of down-time is often a risk taken on by the wind farm owner.

Increasingly, it is industry practice for the turbine manufacturer to negotiate an allowance of between 48 and 120 hours a year for 'routine maintenance' of the turbines. This includes such activities as oil changes, greasing and bolt tightening. In some contracts, work associated with "retrofits" is also excused. Time taken carrying out these activities up to the allowance limit does not count against Turbine Availability. The impact of this allowance on the warranted availability should be fully understood.

The trends presented from the historical wind farm data show that, on the whole, availability is relatively insensitive to turbine size and wind farm size once teething issues have been resolved, usually in the first year or two of operation. In some respects the lower availability from the larger turbines in the first year or two of operation is to be expected, as the turbines are generally more complex in design and therefore teething issues may be considered more likely. The risk of a lower availability from teething issues may to some extent be mitigated through the turbine warranty.

Many owners and operators have shown concern that availability may be lower at high wind speeds and that the true energy loss is not reflected in the availability figures seen in operating reports. In an attempt to address this concern, the relationship between availability and high winds has been investigated. It has been demonstrated that it is reasonable to assume on average, for a wind farm not impacted by unusual external constraints, that 1% of downtime will generally result in 1% of energy loss in the long term. There are exceptions to this rule on a project specific, especially if the project experiences external grid curtailment.

The risk of lost production, and hence lost revenue, as a result of low availability should be clearly understood on a project by project basis. This is typically done through an independent technical due diligence assessment prior to investment or purchase.

There are few wind farms which use what may be considered to be “modern” technology that have operated in excess of 10 years and therefore no strong conclusions are drawn for availability beyond this time. However, it is considered prudent to allocate increased operation and maintenance budgets after operational year 10 and again after operational year 15 to minimize the impact of increased probability of component failure as the end of the turbine design life is approached. From GH experience of the operation of older wind farms GH find the reality of the situation is that as prudent wind farm operators place increased focus on the operation and maintenance of their asset with a commensurate, often significant, increase in operational costs rather than allow availability levels to materially decrease over time. It is noted that there is not uniform agreement on this assumed model for longer term availability within the industry.

The conclusions drawn from reviewing the trends presented in this paper are to be taken in the context of the wind farm data included in the database. Therefore, the following points are to be considered:

- The statistics are collected from a geographically diverse population of wind farms and therefore the equivalent trends may vary from region to region;
- The database contains statistics from all turbine manufacturers and turbine types for which data were obtained. Some turbine types may be considered ‘unproven’ and availability levels may vary between turbine manufacturers;
- The database has a significant proportion of availability statistics for the previous generation of sub-1MW turbines. Indeed the majority of wind farms included that have operated for over 5 years are sub-1MW turbines;
- The smallest turbine size represented in the database is rated at 300 kW and the largest is rated at 3MW. The wind farm sizes vary from only a few turbines to wind farms consisting of over 100 turbines. No weighting is applied for turbine or wind farm size;
- For a subset of wind farms where only Turbine Availability has been provided a further adjustment factor of 99.5% has been applied to convert to an estimate of wind farm System Availability.

Having taken these points into consideration, the trends and observations presented in this paper provide a valuable instrument which, if used appropriately, can help gain an understanding of the risks associated with availability throughout the lifecycle of a modern wind farm project.

REFERENCES

1 Stevens, J and Harman, K, “Why is America’s Availability Lower than Europe’s?”, Proceedings of American Wind Energy Association Asset Management Workshop, AWEA, San Diego, January 2008.