

# Wind Power

## John Constable and Hideaki Aoyama on wind power load factor in the United Kingdom

### Introduction

The United Kingdom has ambitious plans to construct large fleets of wind generators both on- and off-shore. This programme is driven by the Renewables Obligation (RO), a support mechanism that adds around £1 billion a year to consumer bills at present and is forecast, in its current incarnation, to have cost the consumer around £32 billion in total by 2027. Revisions intended as part of the Renewable Energy Strategy to meet the EU's 2020 target of 15 percent of Final Energy Consumption must be expected to require an even greater levy on electricity users.

The effectiveness of the Renewables Obligation is difficult to gauge from build rates and total installed capacity, since it is not immediately evident that the RO encourages the selection of higher rather than lower load factor sites. Load factor is also a matter of considerable interest to investors, due to its effect on Internal Rate of Return (IRR). This article aims to move towards a better understanding of these matters via a statistical examination of the distribution of load factors in 2006 and 2007.

The monthly load factor for all renewable generators registered under the Obligation can be calculated from raw data issued by the regulator, the Office of Gas and Electricity Markets (Ofgem). These load factors are published in a convenient and where necessary corrected form by the Renewable Energy Foundation. Using this database we have extracted annual load factors for those operational wind farms for which a complete year's generation data are available in 2006 and 2007. This amounts to 139 sites and approximately 1,600 MW of installed capacity.

### Overall Load Factor Distribution

A histogram of the data shows that the distribution does not fit the normal or log-normal curves; however, if the data is charted as a scatter plot (Figure 1) a striking feature becomes apparent.

There are two groups, the lower consisting of nine wind farms and the upper of the remaining 130, separated by a gap (indicated by a grey band) corresponding to a mean load factor of between 12.65 percent and 15.5 percent. Given this finding, it is preferable to consider these two groups separately, and in what follows we will concentrate on the upper grouping.

If we rechart the histogram for the

upper 130 wind farms we find that the distributions now fit the normal and log-normal curves with acceptable accuracy and with smaller standard deviations (Figure 2).

Since the lower group size is small it is likely that statistical errors will be large; however, if statistical means of analysis are to be selected then the log-normal method should be preferred, since it covers the range 0 to + infinity, rather than the - to + infinity covered by the normal distribution. We note that the data in this set cover smaller, older, wind farms and we conclude that this is of little further interest here. In effect, our finding above enables us to separate the misleading data from the main data set.

Figure 1: Scatterplot of UK Wind farm Load Factor in 2006 and 2007

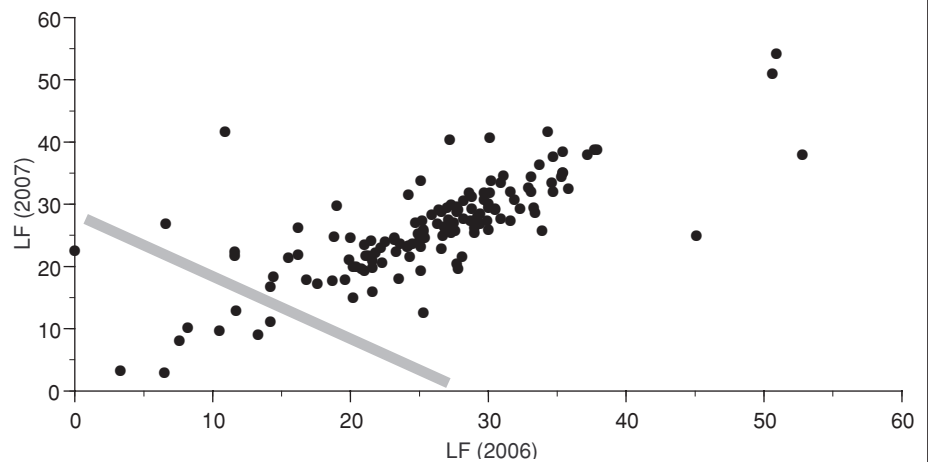
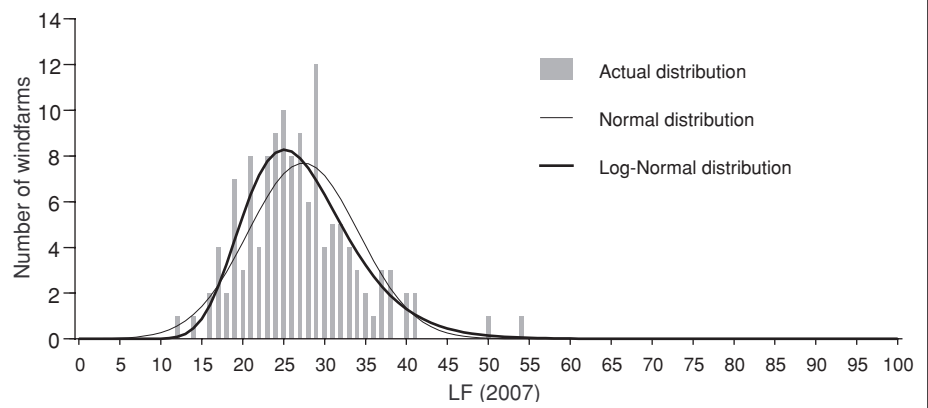


Figure 2: UK Wind Farm Load Factor Distribution 2007: Upper Group



### Standard Deviation of Load Factor

On removing these data from the main data set we see that the standard deviations of load factor in both 2006 and 2007 are substantial, namely 7.2 and 6.7 around a mean of approximately 27 percent. Put another way, the overall mean is a poor guide to the performance of any particular wind farm.

A closer analysis reveals that variability is particularly marked for smaller wind farms, and though reduced for larger wind farms is still substantial. Figure 3 charts mean load factor against installed capacity (upper lines), and standard deviation against installed capacity (lower lines).

The mean is more or less stable for wind farms over 15 MW, though the standard deviation remains at around 4. For sub-15 MW wind farms the mean is volatile, and the standard deviation is high.

This is to be expected for several reasons. For example, the mechanical failure of one or two turbines in small wind farms will cause a larger proportional impact on annual load factor than it would in larger wind farms. However, we have no way at present of determining the significance of this and other similar effects.

While acknowledging the role of such other causal influences, we hypothesise that since larger wind farms are more costly to develop,

and require more capital to construct than smaller ones, companies involved in their planning are more likely to focus on available wind resource to ensure adequate return on capital. By contrast, smaller wind farm developers will be more speculative. It may also be the case that developers of larger wind farms are more likely to intend long-term ownership of the site, rather than an early exit through sale of the consent.

### Refining the Understanding of the Load Factor Distribution

While the observed data are an approximate fit to the normal distribution it is clear that they are not a close fit. This can be confirmed by a more sophisticated examination. For example, let us take the upper load-factor group of 130 wind farms in the 2007 data. If the data obeyed the normal distribution, the skewness would be consistent with a distribution with a centre equal to 0 and a standard deviation of 0.21. However, the observed positive skewness is 0.89, which is some 4.15 times the standard deviation (i.e. the bulk of the distribution is towards the lower load factors on the left, with a long tail towards the higher load factors on the right).

We also note that the skewness of the log-normal distribution is 0.75, which is in reasonable agreement with the data, and suggests that it is a fair descriptor. However, for the same data

set the kurtosis, the measure of the peakedness of the distribution, is 4.83, which tells a very different story.

Similarly, the normal distribution for kurtosis has a centre at 0 and standard deviation of 0.43, so the observed kurtosis is 11.2 times the standard deviation, which is large. Overall, therefore, we conclude that, strictly speaking, the achieved Load Factor data do not obey a normal or log-normal distribution.

While this is not particularly surprising the very large degree of kurtosis is so. In fact the distribution is leptokurtic, in other words it is particularly sharp-peaked compared to the normal distribution. If we chart the average LF distribution (averaged for 2006 and 2007) this is clearly apparent (Figure 4).

It should be noted that this plot includes data for all 139 sites and that the skewness is only 0.032, the low value resulting from the fact that the large positive skew of the upper cluster is cancelled by the addition of the lower cluster. However, the kurtosis is 4.59, some 11 times the standard deviation of 0.42 for the normal distribution. The log-normal distribution's kurtosis is 4.51, a value similar to that of the data, but the distribution is a poor fit.

We can further split the data into a lower installed capacity group and a higher installed capacity group, so that kurtosis of each group is smaller. For example, we can split the data at  $x$  MW and calculate the kurtosis of the lower group and upper group, and then the square sum of kurtosis. With values of  $x$  from 1 to 20 the square sum was minimised at around  $x = 3$ . With the optimised installed capacity boundary set at about 3 MW the kurtosis of load factor in each group is about 5.5 and 4.6 times larger than their standard deviations. While these values are far smaller than those noted above, they are much larger than, say, the 1.96 required for matching with the normal distribution at a 95 percent confidence level. Consequently we can conclude that grouping windfarms by their installed capacity values does not yield normal distributions for load factor.

**Figure 3: Mean Load Factor and Standard Deviation of Load Factor (LF) charted against installed capacity (IC)**

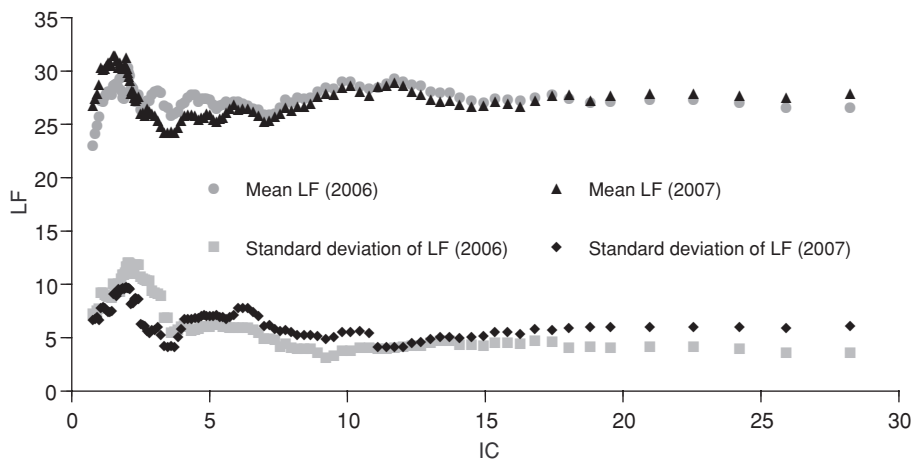
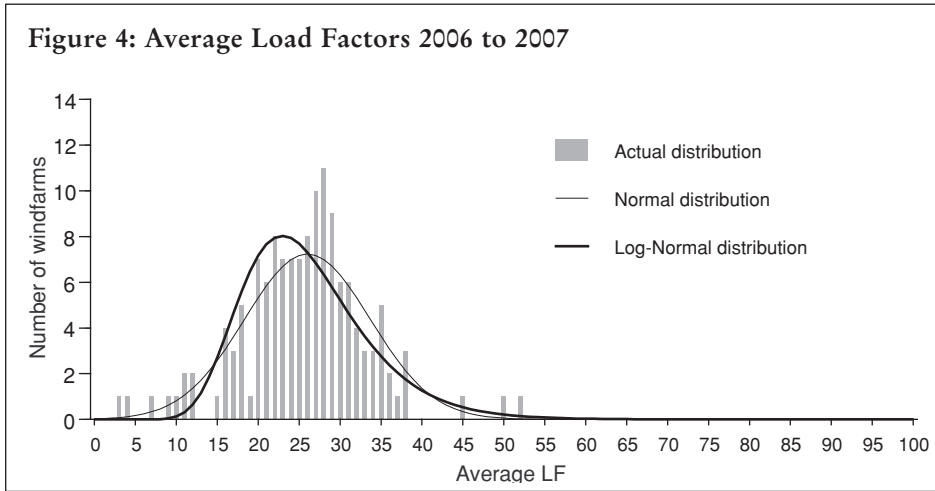


Figure 4: Average Load Factors 2006 to 2007



**Discussion: Load Factor Distribution, Standard Deviation and Subsidy**

As noted above, the Renewables Obligation entails a significant increase in prices to consumers and future iterations of this mechanism will further increase this levy, with wind power expected to be the major beneficiary. In the light of this, it is clearly a matter of concern that the funding produces optimal results, and there has been widespread concern that the system has serially rewarded the least capital-intensive technologies, initially landfill gas and latterly onshore wind, to the exclusion of others.

We acknowledge these broader concerns, but will put them aside to ask if our analysis sheds light on whether the RO is encouraging the wind sector itself to develop in an optimal fashion through the selection of high wind sites.

The reasoning behind this criterion is that the total capacities that are viable and economic in the UK in any foreseeable time frame (up to 2020 say) will be limited by system balancing problems and the costs and availability of solutions. It is therefore important to ensure that as much energy (MWh) is generated from the limited capacity (MW).

No closely reasoned estimate of the capacity limit has been offered, and it is arguably difficult in principle without further empirical experience of system behaviour. However, we venture the suggestion that the figure of approximately 10 GW is plausible

since it is just under half of minimum load in the United Kingdom (ca. 25 GW). At 27 percent load factor this would yield approximately 24 TWhs, which is about 6 percent of UK total generation. We note, as a matter of interest that Denmark and Germany combined have integrated only a little more than this, 7 percent, even with very considerable interconnection and the availability of the balancing services of Norwegian hydro.

The UK is only weakly interconnected, with a 2 GW link to France, and with a 1 GW link to the Netherlands under construction. Further connections may occur, but this will take time, and in any case study of empirical experience in Denmark suggests that the value of interconnection may be limited. It should be recalled that interconnection is a route to a balancing solution, not a balancing solution in itself.

Other measures such as demand control and storage are promising but the speed of their deployment at scale must be regarded as questionable.

Assuming that the UK’s wind capacity will be limited, it is important that the load factors of selected sites are optimised. This is in itself an argument for offshore wind, where achieved load factors at mature sites in Danish waters are approximately 40 percent. It is well known that the original design of the RO failed to encourage offshore development, and government has subsequently introduced differential rewards, ‘banding’, to address this matter.

Furthermore, the current load factor data do not suggest to us that the Renewables Obligation subsidy system is motivating the pursuit of high load factor sites onshore. Specifically, the very large magnitude of the standard deviations suggests a lack of focus on energy yield.

That is to say, if developers were prioritising wind resource when selecting a site we would expect to see distributions with smaller standard deviations, or possibly a significant general negative skewing towards higher load factors (i.e. the bulk of the distribution would be towards the right of the graph). In fact what we observe is a positive skewing (the bulk of the distribution is towards the left of the graph, with a long tail to the right).

One possible interpretation of this finding is that the RO has not motivated the selection of high wind sites. However, we note that a few very high achieving sites in Scotland and Northern Ireland are largely responsible for the observed skew; if the top six sites are removed then the skewness falls to 0.1. Even granting this, the fact remains that the distribution is not skewed towards higher load factors.

From an investor’s perspective the large standard deviations suggest that national mean or generic load factors are a poor indicator of probable site quality. Another possible inference is that either the sites and site layouts are not being selected to maximise load factors, or else many of the pre-build assessments of potential load factors are flawed. There appears to be a limited understanding of meteorology in the wind farm literature, which may result in poor decision-making in site assessment. Location-specific data and wind speed data at the appropriate height are essential when considering the value of any proposal or any existing wind farm. Lest it be thought such matters are minor considerations we note a recent investor presentation by Scottish and Southern Energy, one of the most experienced of wind farm operators in the United Kingdom, in which it is observed that a ‘10% increase in yield, ~ 1% increase in IRR’.

That is to say, even apparently small variations in load factor, two or three percentage points, can have a significant impact on project economics.

At a sophisticated level of engagement the leptokurtosis observed in the distribution is both very striking and difficult to explain. One possibility is that there is a certain amount of erroneous generation information (relating to around 10 wind farms) in the current data. We note that from the outset in 2003 the annual reports of the Office of Gas and Electricity Markets (Ofgem) concerning the Renewables Obligation have, on the basis of a handful of audited sites, expressed concern with regard to the under-reporting of input electricity, and various issues with metering quality. In the light of this, one possible interpretation of the leptokurtosis is that some wind power operators are providing estimated generation data. We have discussed this matter with Ofgem, who inform us that they consider the scale of estimates authorised due to meter failure and other problems are unlikely to be significant. We note that a comprehensive audit of wind farms might reveal other sources of error.

We have also made a brief examination of the 38 wind farms with a load factor between 26 and 30 percent to determine whether there is any common feature, such as geographical proximity, or shared technology or common ownership that might account for the leptokurtosis, but we detected nothing of apparent significance. A further possibility is that these wind farms have a particular feature of site design, layout for example, in common, and this is an area for further research.

In view of the large public subsidies for wind power, we believe it is in the public interest that more detailed performance data for existing wind farms are made available so that these issues can be studied in greater detail and future decisions based on the best available understanding.

