Evidence on Wind Farm Performance Decline in the UK

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1. Onshore wind farms in the UK have aged at about the same rate as other kinds of power station. The average wind farm has an annual load factor of about 28% when first commissioned, which declines by about 0.4 percentage points per year. After 15 years, the load factor would have fallen to 23%. This ageing does not appear to have made developers replace their farms early. Forty out of the first forty-five wind farms commissioned in the UK were still operating at this age; four had been repowered. Taking this deterioration into account raises the levelised cost of electricity by around 9% over a 24-year lifespan, discounting at 10 per cent a year. This is a summary of the peer-reviewed paper "How does wind farm performance decline with age?" published in Renewable Energy, vol. 65, pp 775-786, which is available to download from http://tinyurl.com/wind-decline.

Measuring the decline in wind farm output with age

2. All machines suffer a decline in performance as they age, but there were no plausible estimates of how wind farms might age in the public domain when we began our work in January 2013. Government-sponsored reports on the cost of generating electricity include ageing effects for other technologies, but assume that wind turbines do not age. The aim of our research was to estimate the effect of varying wind speeds on the output of each of the UK's wind farms in order to reveal the underlying pattern of how output has changed over time.

3. Our wind speed data came from NASA, which publishes the MERRA database, giving estimated wind speeds for every hour on a grid of points across the globe. We used the grid surrounding each of the UK's onshore wind farms to estimate the wind speed at the location and height of each farm's turbines. We used the power curve for the specific model of turbine (which shows how much electricity it produces for a given wind speed) to estimate each farm's power output in each hour from 2001 to 2013. We had to scale those estimates to account for effects such as rough terrain upwind reducing the wind speed at the farm, or the fact that turbines downwind from others will receive less energy. We tested our technique by estimating wind speeds at the sites of UK weather stations and checking them against observations, and comparing our estimated farm outputs with those recorded by the National Grid, which are available for farms in Scotland and offshore (but not in England, Northern Ireland or Wales).

4. We took up to ten years of actual monthly output data from each of the UK's onshore wind farms from Ofgem's Renewables Register. The diamonds in Figure 1 show the monthly load factors for the Burradale 2 wind farm in Scotland, as an example. We calculated the weather-corrected load factor for each month (shown by the solid line) by subtracting the variations in our simulated load factors (from the NASA data) from these observations. This represents our best estimate of what Burradale 2 would have produced each month if it had received 'average' weather conditions. We have independent evidence that this farm was undergoing significant maintenance during the two periods with low weather corrected load factors (circled). The dotted line shows the trend in output over the entire period (including the maintenance periods) of just over -0.1 percentage points per year.

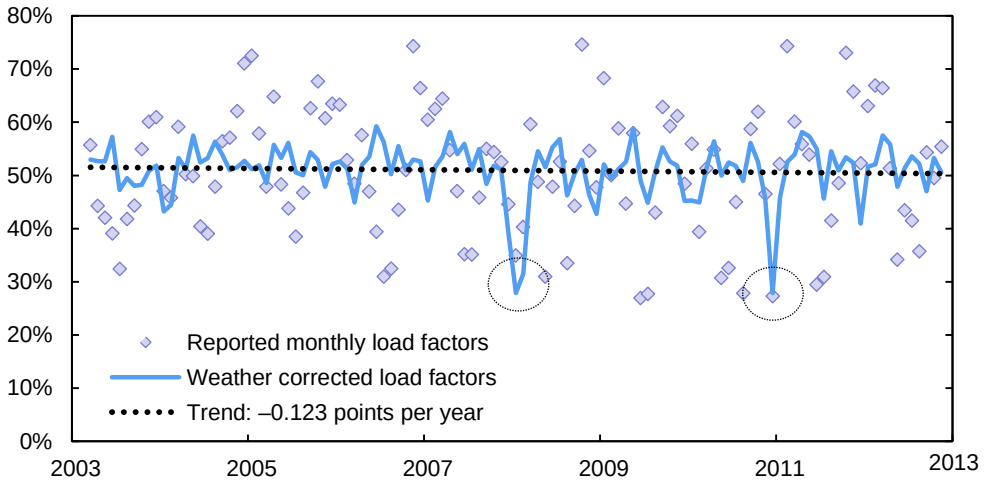

Figure 1: Actual and Weather-corrected Load Factors for Burradale 2 Wind Farm in Scotland.

5. We repeated this calculation for all the onshore wind farms in the UK. The trends are shown in Figure 2 for all the farms for which we had at least five years of data (i.e. those commissioned in 2007 or before). The vertical axis shows the date at which each farm was commissioned. The horizontal axis shows whether the trend change in output is negative (giving the ageing we would expect) or positive (as a small number of farms improved over their early years if initial commissioning problems took a long time to fix). Each circle represents our best estimate of the trend rate at which a particular farm has aged – the horizontal lines represent the standard deviation of this estimate. The size of the circle is proportional to the capacity of the farm, and it can be seen that the newer farms are generally larger than older ones. The central solid line shows how the average trend in ageing varies with the commissioning date of the farm, while those on either side give a band of plus or minus one standard deviation.

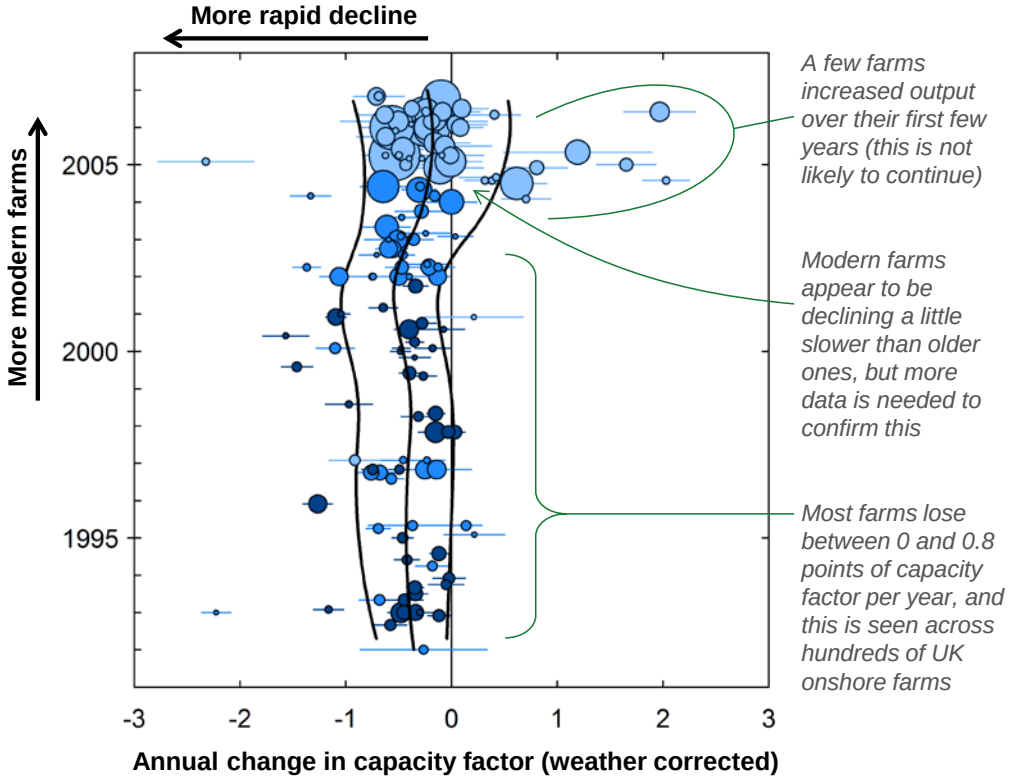

Figure 2: Estimated rates of ageing for onshore wind farms in the UK

6. The average decline rate is 0.4 percentage points of load factor per year – this is equivalent to 1.6% of the average farm's output. The average onshore wind farm in the UK has a load factor of 28% at age 1, and this will fall to 23% by age 15. There are some signs that the newer wind farms are ageing less rapidly, for our central line is closer to the vertical axis at the top, but the error band around it is wide enough for all cohorts of farms to be ageing at the same rate, on average. Other methods to estimate the rate of output decline were tested in the paper, all of which gave numbers in the range of 1.4 to 1.8% per year.

Implications of this study

7. Our estimates of ageing are in line with those for other kinds of machinery. We are unable to say whether the decline in output is due to mechanical components becoming less efficient after wear and tear, the blade surfaces becoming damaged and less aerodynamic, more time spent awaiting maintenance or some other cause. Assuming that ageing does not accelerate in the last few years of a turbine's life, most wind farms should expect to operate for the 25 years typically assumed when they were planned. Most of the farms that have been decommissioned early have been repowered with larger turbines, and it is the opportunity to increase capacity, rather than the decline in the existing farm's performance, that may have motivated the closure.

8. The ageing effects we have measured imply that the farm will produce 12.5% less output over its lifetime than if there was no ageing at all. The cost per unit of electricity will increase by less than this, however, as the worst losses occur in the future. With an interest rate of 10 per cent, this would add 9 per cent to the wind farm's levelised cost of energy – a noticeable increase, albeit one that is smaller than the difference between using a good and a bad site.

Why we undertook this study

9. The Renewable Energy Foundation published a study in 2012 that claimed the "normalised load factor for UK onshore wind farms declines from a peak of about 24% at age 1 to 15% at age 10 and 11% at age 15." A corollary was that "few wind farms will operate for more than 12–15 years." This seemed implausible, given that the actual average load factor of UK onshore wind farms was 24.4% at age 10 and 23.3% at age 15.

10. A wind farm that is ageing rapidly could produce a nearly constant output if the wind was growing continually stronger, but it is easy to check that this is not the case using the wind speed index published by the UK government. The Foundation had used a technique (regression with dummy variables to represent (1) each farm, (2) each month's average wind conditions, and (3) each age in whole years) that should have produced accurate results on average. However, given the large number of interacting dummy variables, it was vulnerable to particular combinations of data points that could lead it to produce extreme and unrealistic results. The Foundation's results were internally consistent: each farm was producing much less output as it aged; the newer farms were on worse sites than early ones (on average); but because the wind was assumed by their model to get stronger over the last decade, the average output from the fleet remained high.

11. The Foundation's results cannot be dismissed on purely statistical grounds, and even using a nationwide wind index might be misleading. We therefore undertook a detailed study of the actual wind conditions at each wind farm in the UK to infer the farm-by-farm rates of ageing described above. They are very different from those presented by the Foundation, but our results are consistent with the rates of decline seen in similar kinds of machinery and reported by some other researchers on wind ageing (including Professor David Mackay FRS). They are now being incorporated into some of DECC's energy modelling work.

Dr Iain Staffell and Professor Richard Green, 28 January 2015.