The Costs of Offshore Wind Power: Blindness and Insight

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The dramatically falling costs of renewables are now a political, a media, and conversational cliché. However, the claim is demonstrably false. Audited accounts show that far from getting cheaper, wind power is actually becoming more expensive. The failure of the British civil service to detect this fact and, hence, to protect the consumer and taxpayer from the consequences of the looming failure of the renewables sector raises important questions about the analytic competence of the Whitehall machine.

If we asked a random sample of broadsheet newspaper readers about the economics of offshore wind, it is practically certain that a majority of those interviewed would say they believed it was now cheap. A similar survey of investment analysts and advisors might return the same answer. Politicians and journalists would be *certain* about the matter. However, if pressed for evidence none of these groups could do much more than point to secondary sources. Some might remember that the Greenpeace sponsored an extensive advertising campaign in 2017, with full page adverts in the press. Others might point out that official bodies present offshore wind as the cheapest source of electricity. Those in financial circles might also indicate that almost every report or lengthy article on the future role of offshore wind power is accompanied by a chart which claims to show the rapid decline of costs over the last one or two decades, perhaps with forward projections to 2030 or 2040.

Incredible though it may seem, none of this is true. Neither offshore nor onshore wind has become cheaper; indeed, both have become more expensive over the last two decades.

How do we know this? Because one of us, Gordon Hughes, has compiled data from audited accounts on the capital and operating costs of 350 onshore and offshore wind farms in the United Kingdom, a set which covers the majority of the larger wind farms (> 10 MW capacity) built and commissioned between 2002 and 2019. It is the largest study of its kind to date and will be published shortly by the charity Renewable Energy Foundation, which John Constable directs.

In summary, analysis of the data reveals unequivocal findings:

1. **The actual costs of onshore and offshore wind generation have <u>not</u> fallen significantly over the last two decades and there is little prospect that they will fall in the next five or even ten years.**
2. While some of the components which feed into the calculation of costs have fallen, the overall costs have not. For example, the weighted return for investors and lenders has declined sharply, especially for offshore wind, because of a fall in *perceived* risk. In addition, the average output per MW of new capacity may have increased, particularly for offshore turbines. However, these gains have been offset by higher operating and maintenance costs (O&M).
3. **Far from falling, the actual capital costs per MW of capacity to build new wind farms *increased* substantially from 2002 to about 2015 and have, at best, remained constant since then.** Reports of the costs of building new offshore wind farms in the early 2020s imply that their costs may fall by 2025, but such reports are consistently unreliable as well as being incomplete. Final costs tend to be significantly higher, so little weight can be attached to forecasts of future costs.
4. **Far from falling, the operating costs per MW of new capacity have increased significantly for both onshore and offshore wind farms over the last two decades.** In addition, operating costs for existing wind farms tend to grow even more rapidly as they age. The increase for new capacity seems to be due to the shift to sites that are more remote or difficult to service. Much of the increase with age is due to the frequency of equipment failures and the need for preventative maintenance, both of which are strongly associated with the adoption of new generations of larger turbines – both onshore and offshore.

5. Turbine manufacturers and wind operators appear to be relying on an increase in load factors (a measure of the generator's energy productivity) via (i) an increase in hub heights to take advantage of higher wind speeds, and (ii) changes in the engineering balance between blade area and generator capacity. However, the inferior reliability of new turbine generations leads to a more rapid decline in performance with age, so that the ultimate effect on average performance over the lifetime of new turbines is not clear.
6. **The combination of increasing operating and maintenance costs with the decline in yields due to ageing means that at current market prices the expected revenues from electricity generation will be less than expected operating costs after the expiry of contracts guaranteeing above-market prices**. The length of these contracts has been reduced, implying a need to recover capital costs over a shorter economic life which pushes up the effective capital charge.

There is an important corollary to these findings. The current set of offshore projects being constructed and planned in North Western Europe are closely akin to speculative property development. They are high risk projects that will only be able to repay lenders and offer a return to equity investors if the average wholesale market prices of power rise to at least three to four times their current level throughout North West Europe. Such a price surge would require either a large and permanent increase in the market price of gas, which experience suggests is very unlikely, or carbon taxation at 8 to 10 times current levels, rising to at least €200 per tonne of carbon dioxide at 2018 prices in 2030. Such a tax would place a heavy burden on the rest of the economy.

This has consequences for financial regulation. To discharge their responsibilities financial regulators ought to impose a heavy risk weighting on loans to offshore wind farm operators, while also advising that green equity investments are too risky for pension funds and small investors. Instead, the chiefs of the European Central Bank (ECB), the Bank of England and other regulators have urged more investment in green assets without acknowledging the risks involved.

This leads to the prospect of what is not so much a car crash as a motorway pile up in the fog of ignorance. The looming crisis will require that those who finance wind power and its related ecosystem of companies are bailed out by either taxpayers or electricity consumers. The scale of the bailout would be large: about £30 billion is at risk in the UK wind sector alone, with significantly more in Germany, the Netherlands and Denmark.

Some wind industry players may be aware that specific projects are not performing in line with general expectations – there is no lack of examples reported in specialist media. However, until very recently investors have been protected by generous subsidies and operators are likely to blame project-specific factors rather than realising that the entire sector is affected. In addition, the industry in general seems believe its own propaganda, for which basic error they have only themselves to blame.

Government, we suspect, is genuinely confused. On the 24th of August while we were preparing this summary for Briefings for Britain the Department of Business, Energy and Industrial Strategy (BEIS) published its latest set of electricity generation cost estimates, *Electricity Generation Costs*.[1] It recommits BEIS to the view that the costs of wind power have fallen and that this technology is now amongst the cheapest available.

However, it is not difficult to show that the BEIS analysis is wholly, almost pitifully, inadequate and that it cannot be relied upon. We will discuss it in some detail below because the mistaken view that it gives of wind economics is important in itself. Even more, it provides a graphic illustration of the truly wretched quality of the analytical work that underpins policy decisions with vast implications for the United Kingdom and its people.

Before making more detailed observations, we note two general aspects of the BEIS study. First, it purports to provide estimates or forecasts of electricity generation costs for projects commissioning in 2025, 2030, 2035 and 2040. While costs at the nearest of these dates can be estimated rationally, costs a decade or more in the future are radically uncertain. To attempt even moderately precise costings, as BEIS does, suggests naivety or hubris. Who in 2000 – or even in 2010 – had any realistic basis for forecasting the capex and opex costs for projects that are being commissioned in 2020?

Furthermore, on examining the accompanying spreadsheet containing the Department's detailed assumptions it turns out that 94 per cent of the model parameters for the various technologies, conventional and renewable, do not change from one period to the next. This is implausible, since it must presume that there is no technological progress in those fields. Where costs do vary they are for either (a) wind and solar, or (b) a range of minor (Geothermal CHP) or novel (wave, biomass with CCS) technologies. This is unreasonable. If there are cost reductions in the renewable sector, why rule out cost reductions in the conventional sector?

Looked at in more detail this underlying bias is quite extraordinary. The rates of decline in capex and opex costs or increases in operating performance for offshore wind – now a mature technology – are greater and more sustained than the decline for CCGT+CCS – a new and potentially critical technology.

Consequently, the BEIS projections of short-term costs are almost trivial, merely generic costs for the middle of the current decade, while the estimates of relative costs of conventional and renewable generation in the medium and longer term are at best meaningless and at worst misleading.

A second general point that should be noted is that the data used in the BEIS model is almost entirely derived from work conducted by or for the department itself. With the exception of a single reference to a National Grid ESO report, all of the sources cited for the data are BEIS publications or BEIS-commissioned reports. No attempt has been made to draw upon the growing academic and policy literature on the *actual* costs of building and operating various kinds of generation. There is not even a single reference to the extensive studies undertaken by the Energy Information Agency (EIA) in the US and various of the research laboratories funded by the US Department of Energy (DoE) – for the example the Lawrence Berkeley National Laboratory (LBNL), the National Renewable Energy Laboratory (NREL) or the Oak Ridge National Laboratory (ORNL). Such a narrow focus is hard to justify, and indeed begins to look like a deliberate blindness in which all data is selected to fit with a pre-determined narrative.

And of course it is also true that BEIS has not made any effort to undertake the empirical investigation of audited accounts that forms the data behind the Hughes study summarised above.

Bearing these general remarks in mind, we will now compare some of the specific assumptions in the BEIS study with the results of the data compiled for this and other studies.

Conveniently BEIS has adopted the same base year (2018) for real prices as the one used for the Hughes database, so there is no need for adjustment. We will start by examining capex costs and then opex costs before looking at load factors and financial parameters. In all cases we will use the BEIS assumptions for projects commissioned in 2025, since, as noted above, the BEIS estimates for later dates are mere speculation. We will focus on onshore wind, offshore wind and large scale solar as those are the primary technologies for which BEIS has updated its assumptions and for which comparisons with actual data from company accounts are possible.

1. ***Capex costs***. The BEIS assumptions imply total capex costs (including capitalized interest) in 2025 of £1.30 million per MW for onshore wind, £2.16 million per MW for offshore wind (or £1.82 million excluding transmission), and £0.55 million per MW for large scale solar. Comparison with the actual costs reported in audited accounts is stark. The average value of the actual capex costs reported for onshore wind farms completed in 2016-19 was £1.61 million per MW, for offshore wind it was £4.49 million per MW (including transmission) or £3.99 million if the very expensive Hywind project is excluded. For large scale solar the average of actual costs was £0.98 million per MW. Hence, the BEIS assumptions are only 50%-80% of the actual capex costs reported in audited accounts for recently commissioned projects. Since BEIS provides no evidence of any rapid reduction in capex costs per MW of peak capacity, their assumptions reflect little more than wishful thinking. The bias is particularly egregious in the case of offshore wind as most future projects will necessarily be at greater depths and distance from shore, thus incurring significantly higher capex costs for both turbines and transmission.

2. ***Opex costs for onshore wind***. The BEIS assumptions imply opex costs for onshore wind of £47,000 per MW per year for a wind farm commissioned in 2025. Incredibly, these are assumed to be constant over an operating life of 25 years. Our study, based on audited accounts, shows that actual opex costs for a new onshore wind farm commissioned in 2016 were £77,000 per MW at age 1 and that this will increase to £114,000 at age 15, and £149,000 per MW at age 25 if it were to continue to operate that long (which is very unlikely). The analysis also shows that the *initial* opex cost for *new* wind farms has been increasing at 4.3% per year, so the expected opex cost for a wind farm commissioned in 2025 at age 1 would be £112,000 per MW, more than double the BEIS estimate. Overall, the BEIS estimates of opex costs are about one-third of the best estimate based on actual data for the last two decades.
3. ***Opex costs for offshore wind***. The BEIS assumptions imply opex costs for offshore wind of £109,000 per MW for a wind farm commissioned in 2025, constant over an operating life of 30 years. It is hard to make sense of the BEIS numbers. Their table 2.4 gives a fixed O&M cost of £36,300 per MW per year for 2025. This is implausible if it is supposed to cover Offshore Transmission Operator (OFTO) costs. Indeed, there isn't a single reference to OFTO transmission costs in the whole document, yet the methodology requires that OFTO costs must be included. Again, our analysis of audited accounts shows that actual opex costs (including OFTO costs) for a new offshore wind farm commissioned in 2018 were £184,000 per MW per year at age one, with an expectation that this will rise to £426,000 per MW per year at age fifteen. Actual offshore opex costs have been increasing at an average of 5.9% per year in real terms for the last two decades, so the lifetime average for a new wind farm commissioned in 2025 would be at least £450,000 per MW per year, or about four times the figure assumed by BEIS.
4. ***Opex costs for large solar***. The BEIS assumptions imply opex costs for large solar plants of £10,000 per MW per year, constant over an operating lifetime of 35 years. Since most large solar plants were built between 2012 and 2017 the data on lifetime opex costs is limited, but our analysis shows an average of actual operating costs of £19,000 per MW at age one rising to £33,000 per MW at age five. It is unclear whether these costs have been increasing with year of commissioning as well as age. Nonetheless, the pattern is clear. The BEIS assumptions about large solar opex costs are typically one-quarter to one-third of the actual costs incurred by real plants that are operating today.

5. ***Load factors for onshore wind***. The BEIS estimates assume constant load factors of 34% over relatively long operating lives for new plants. This is implausible, and it would be surprising if even the most committed advocates of renewable generation believed it to be correct. Even the most optimistic academic analyses imply a decline of 1.5% to 2% per year in annual output of onshore wind farms, holding wind conditions constant. Our analysis of the extensive data for Denmark, published together with the present study, shows that while the rate of decline in performance was lower for early generation turbines in the 0.5 MW to 1 MW category, which are no longer installed, the current generation of onshore turbines of greater than 2MW exhibits a rate of decline of about 3% per year. The BEIS failure to recognise any decline in performance is a serious defect in the analysis. There can be no justification for this. BEIS's own figures show that the actual load factor for onshore wind farms has been constant at about 27% over the last decade after controlling for variations in wind conditions. In practice, what has happened is that the higher load factor for larger turbines at new wind farms, which lies behind their estimate of 34%, has been offset by the decline in performance for older wind farms.
6. ***Load factors for offshore wind***. BEIS assumes a constant average lifetime load factor of 51% for conventional offshore turbines (i.e. not floating devices such as Hywind). However, for offshore turbines the rate of decline in performance is much worse than for onshore wind, a fact which underlies the rapid increase in opex costs per MW. The average load factor for offshore wind has increased, but this is purely a function of the skewed age distribution in the wind fleet. The BEIS assumption of a 51% load factor relies upon a belief that the future will be radically different from the past. That is unreasonable. The average load factors for offshore wind farms less than five years old in NW Europe mostly fall in the range 40-45%. That is the best they will achieve over their lifetimes and as they age their performance will decline. The advantages of turbine size and hub height referred to in the BEIS analysis are not remotely sufficient to account for the difference between the BEIS assumption of a constant 51%, and the reality of an initial 45% declining steadily over time.

7. ***Load factors for large solar***. Proponents of large solar generation may be somewhat aggrieved by the BEIS assumption of average lifetime load factor of 11%, which is in fact typical of recent experience. Indeed, solar developers may have a stronger case for arguing that their relatively new technology may allow higher load factors in future. This is partly a matter of definition. Peak output is rarely achieved by most solar plants, whereas wind turbines are increasingly designed to achieve rated output at lower wind speeds, by adjusting the balance of swept area to generator capacity. Nonetheless, United States Energy Information Administration (US EIA) estimates of generation costs have assumed a significant increase in solar load factors for new plants commissioned in 2023-2024 relative to those commissioned in 2019-2020, holding location and solar conditions constant. That may prove to be wrong, but BEIS's failure to note this possibility, while exaggerating the prospects for wind, brings the peculiar bias of the overall BEIS analysis into sharp focus.
8. ***Operating lifetime***. The operating lifetime of a new wind farm or solar plant is a complex economic issue and not simply a physical one, since the effect of age on operating costs and performance is critical. The BEIS assumption of an operating life of 25 years for onshore wind is optimistic but not completely outside the bounds of reason. Our analysis suggests that the upper bound with current contractual arrangements and market conditions will be no more than 20 years. On the other hand, assuming an operating life of 30 years for offshore wind – note, with a constant load factor – is completely at odds with any of the actual evidence. The same is true for the 35 year lifetime for large solar plants. After all, even mature and reliable technologies such as Combined Cycle Gas Turbines and super-critical coal plants require major refits after about 20 years.
9. ***Future market prices and lifetimes***. A possible interpretation of the implausibly long economic lifetimes projected for wind and solar is that BEIS is tacitly assuming that market power prices in the late 2030s will be 3 to 4 times their current level in real terms. Indeed, it is hard to explain the lifetime assumptions on any other basis. If that is indeed BEIS's assumption, the failure to spell this out in the analysis illustrates the lack of transparency and arbitrary nature of the whole exercise.

10. ***Hurdle rates***. The BEIS assumptions with regard to hurdle rates are based on a study by Europe Economics carried out in 2018, but only published on the 24th of August as part of the *Electricity Generation Costs* [2] Let us put aside the problem that even though the Capital Asset Pricing Model used in the study has been adopted by some economists and regulators it has, at best, only an accidental relationship to the way in which real investors determine the hurdle rate of return of investment in generation or other businesses. Still, it is surprising that BEIS appears not to have carried out any kind of sanity check on the numbers in the Europe Economics report. For example, if BEIS had examined a financial model for any of the offshore wind CfD projects in Allocation Round 2 (AR2) or Allocation Round 3 (AR3), they would have discovered that every project would be a financial disaster on the cost of capital assumptions made in the Europe Economics analysis. It would be impossible for Hornsea 2, Moray East or Triton Knoll – all AR2 projects which we have examined in detail – even to cover debt service costs on the BEIS assumptions, let alone produce a reasonable return on equity, if their CfD strike prices are taken at face value. The cost of capital for each project would have to be close to zero simply to cover the announced levels of debt that have been incurred for each project, and even that may not be possible.

Reviewing the deficiencies of the UK government's latest estimates of generation costs we are left with a puzzle. The assumptions which underpin the BEIS estimates of the cost of generation for wind and solar power are fanciful, and do not withstand even cursory scrutiny; under close analysis they disintegrate and are a disgrace to the civil service and an embarrassment to ministers. Indeed, they are so far from the *actual* costs incurred by current operators and recorded in audited accounts that they are not worth further consideration, except as evidence for fundamental civil service reform. The review preceding that reform should ask how a heavily funded and staffed government department in a major economy can have strayed so far from the real world in a matter of such importance as energy supply. What on earth is going on?

The behaviour of the commercial entities involved in the renewables sector is also puzzling. If the empirical evidence is so clear, why are large companies committing substantial capital to very large projects that are almost certain to make a loss under anything like current market conditions? There are three factors that may explain this behaviour:

- **The offshore wind sector is dominated by large companies, often state-controlled, that can deploy large cash flows from existing generation and/or network businesses and are under little pressure to cut costs for their customers or, if state entities, to return cash to their shareholders.** Three Scandinavian state-controlled companies – Equinor (formerly Statoil), Ørsted and Vattenfall – are responsible for more than half the current UK offshore wind fleet and have ambitious plans for new projects.

- **Operators expect to be able to sell on a large portion of the shares in their projects to over-optimistic investors with little appreciation of the risks involved.** In addition, projects rely heavily on debt provided by equally naïve lenders.
- **Operators and financial investors are aware of the risk but expect to be bailed out.**

Once economic reality becomes undeniable, there will be a huge lobby to pass on the full costs of offshore wind to either electricity consumers or taxpayers. The obvious instrument is carbon taxation, but the increase required would be very large, and the economic harm would be politically contentious to say the least. Vast bailouts to an industry that has misrepresented its economics, whether knowingly or not, will be extremely unpopular. A government trapped between intense political opposition and the ever-widening ramifications of the financial collapse of the offshore wind sector will behave in ways that cannot be predicted confidently, but investors in renewables should be very nervous.

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[1] BEIS, *Electricity Generation Costs* (24 August 2020). https://www.gov.uk/government/collections/energy-generation-cost-projections?utm_source=2deef6b5-8bc2-4b0b-a6a7-eecc4f289432&utm_medium=email&utm_campaign=govuk-notifications&utm_content=daily#2020

[2] https://www.gov.uk/government/publications/cost-of-capital-update-for-electricity-generation-storage-and-dsr-technologies