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Wind Energy Generation Costs

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By early 2011 the United Kingdom is forecast to reach 10% of its electricity consumption from renewables. The proportion is set to rise to around 30% by 2020, in line with EU 2020 targets and UK government plans on reducing carbon emissions.

In parallel, 11.4 gigawatts (GW) of the nation's coal plant will be decommissioned by 2015 and 7GW of nuclear plant by 2020, or 23% of the total generating capacity connected to the grid. It is, therefore, essential, both for the reasons of energy security and CO_2 reduction targets, that new low-carbon sources of electricity are deployed as soon as possible. But what will be the costs per megawatt hour (MWh) of electricity from these sources? This briefing sheet gives an estimate of costs of electricity generation for onshore and offshore wind compared to coal, gas and nuclear.

In the case of wind energy, **generation costs** depend on wind speed, the cost of the plant, financing terms and operating costs. No single value can be assigned, therefore, to the cost of wind energy, and comparisons with other technologies can only work if all four parameters are taken into account, as, for instance, in figure 1.

Here are some explanations of the terms used: **generation costs** are used here, in line with conventional usage. Strictly speaking, they are **generation prices. Capital costs** are primarily a function of the size of the installation (due to economies of scale), but location is also a factor, with the best sites (in terms of wind speed) often being more expensive, due to their remote locations.

Wind speed depends solely on location, and **financing terms** depend partly on the institutional framework in the country where the plant is located, and partly on the policy of the developer. There is a direct relationship between mean wind speeds at a wind farm location, and wind farm **capacity factors**, as noted in the relevant section.

Financing costs in this submission are derived using procedures that are in common use across the power industry. Real, i.e. net of inflation, interest rates (test discount rates) are used, with realistic capital repayment periods. They are therefore independent of any particular support mechanism.

Wind generation costs can be compared with those of the thermal sources of electricity generation, using similar procedures and including the **cost of the fuel** for thermal generation. There are, of course, some differences due to the natures of the technologies, which will be highlighted in the appropriate section, such as, for instance, calculating (due to convention) **operations and maintenance costs (O&M)** per MWh in the case of thermal plant and per kilowatt (kW) per year in the case of onshore and offshore wind (see table 2).

All generation costs are for new plant, built in 2010, although this does introduce a difficulty with nuclear plant, which is discussed in the relevant section.

Current costs

Onshore wind

Installed costs

Recent published installed costs for UK wind farms are in the range £1,250/kW to £1,573/kW, with a weighted mean of £1,334/kW. This suggests that Ofgem's recent estimate of £1,200/kW is on the low side.[1] The Department of Energy and Climate Change (DECC) quote from a report

they commissioned in 2009 that suggests the range is £1,172–1,329/kW.[2] A 'high' estimate of £1,600/kW has been used here and a 'low' estimate of £1,300/kW, to define the range of generating costs.

For the purpose of estimating interest during construction, a one-year build time has been assumed.

Operation and maintenance costs
Operation and maintenance costs are expressed in several ways. Several analyses express them in £/kW/yr, and reference 2 suggests a value of £40/kW/yr. This is close to the central estimate quoted by Ernst and Young (2007),[3] which gives an upper limit of £54/kW/yr. This latter value has been used here. In practice, these costs are often a mixture of "fixed" costs (£/kW) and variable costs (£/MWh).

Offshore wind

Although a number of projects were completed during 2009, there is not a large database of project costs. Recent and planned projects have been installed for between £2,000/kW and £4,000/kW. Ernst and Young (2009)[4] used a reference price of £3,200/kW and, with operating costs roughly double those of onshore wind, this suggests that generation costs will also be roughly double. There is a wider range of installed costs, compared with onshore, as there are additional variables that influence the cost, particularly water depth and distance from the shore. A range of costs from £2,500/kW to £3,600/kW encompasses the majority of recently reported costs for European wind farms.[5]

Electricity production
Although wind turbines have differing performance characteristics, the variations – taking account of size – are not that wide, and it is possible to derive a "universal" characteristic that describes the variation of output with wind speed. The "capacity factor" (average power/rated power) is the conventional term used to quantify the output. It establishes a link between wind speed and energy productivity. The data presented here assumes that the capacity factor is 19% at sites with an annual mean wind speed of 6m/s, rising to just under 40% at 9 m/s. Most UK wind farm sites have wind speeds within this range, although the resource at the upper end of the range is limited. These capacity factors include allowances for availability, inter-machine array losses, and electrical losses within the wind farm.

Generation costs of gas-fired plant

Installed and operating costs
The generation costs of combined cycle gas turbines tend to be the yardstick against which other technologies are compared. The principal uncertainty in determining these is the future cost of gas, as fuel accounts for about two-thirds of the total generation cost.

Recent reports of completed UK CCGT contracts suggests capital costs are in the range of £600–700/kW. A mid-range value of £650/kW has been used here. Build times are around two years. Estimates of operation and maintenance costs are mostly around £4/MWh.

Fuel costs
The average price paid by UK power producers for gas in 2009 was £14/MWh.[6] Assuming a build time of two years, thermal efficiency of 50% and availability of 85%, this enables generation costs to be derived. Future gas-fired generation costs are uncertain, simply because of the uncertainties in the price of gas. Modest changes in the installed costs will make very little difference to the generating cost estimates. Both Ofgem (ref 1) and the Department of Energy and Climate Change[7] suggest power producers could be paying around £20/MWh for gas by 2015; less in some scenarios, considerably more in others.

Costs of coal-fired plant

There has been little activity in the coal-fired generation market in the UK recently, but reference to the international literature suggests capital costs for coal-fired generation are mostly in the range of £1,500–1,800/kW.[8] Coal-fired plant take around four years to build, and operation and maintenance costs are in the range of £6–8/MWh. The average cost of fuel in the UK in 2009 was £7.5/MWh. As in the case of gas, future projections of fuel costs vary, but most are in the range from £7.5/MWh upwards, although DECC has one scenario in which the price falls to £5/MWh.

Nuclear costs

A number of American utilities are now seeking authorisation to build new nuclear plants. Recent data from three utilities and a UK nuclear expert are summarised in table 1. In view of the construction delays that are occurring in Finland and France, an element of uncertainty attaches to these costs. One difficulty in making comparisons is that the long lead time for nuclear construction means that, strictly speaking, costs should be projected forward to, say, 2020. Although the Florida Power and Light estimates do include an appropriate cost escalation it has not been included in the estimates in the table, so as to facilitate fair comparisons between nuclear and the other technologies. An appropriate range, excluding financing charges, appears to be £2,000–3,300/kW and that is consistent with data from the International Energy Agency (7).

Fuel costs are around £6.2/MWh, and operation and maintenance costs are in the range of £9–11/MWh, to which must be added a small amount for decommissioning costs. Comparable data for European nuclear construction are hard to come by, but it is assumed that these American costs will travel safely across the Atlantic. It should be noted that, historically, British power plant costs have tended to be higher than those in America.

Table 1. Recent estimates of capital costs for nuclear plant (£/kW)			
Source	Nuclear plant	Whole site	Including financing charges
Florida Power and Light	1,866–2,388	2,072–3,026	3,653–4,621
Progress Energy		2,310	4,223
South Carolina Electric			2,924
UK[9]		3,300	

Data Summary

Table 2. Summary of input data used to derive generating costs				
Technology	Capital cost, £/kW	O&M cost, £/kW/yr	O&M cost, £/MWh	Fuel cost, (2009 avg), £/MWh
Gas	650		4	14
Coal	1,650		7	7.5
Nuclear	2,000–3,000		9–11	6.5*
Onshore wind	1,300–1,600	54		
Offshore wind	2,500–3,600	79		
* In line with standard practice, this is the net cost to the power plant operator, not the input fuel cost, as in the case of gas and coal.				

Financial parameters

The two key financial parameters are the test discount rate and the capital recovery period. In line with most recent analyses of UK power wind plant, a 20-year capital recovery period is used, coupled with a 10% "real" test discount rate. This interest rate, alternatively known as the "Weighted Average Cost of Capital" (WACC) expresses the average rate of return on the project as a whole. For projects that are funded using the internal resources of the power company this is the interest earned on the capital invested. For projects that are financed by a mixture of debt and equity, the WACC is a weighted average of the debt interest and the anticipated equity returns. In early 2010, the weighted average cost of capital for power projects in the UK was between 7% and 11%.

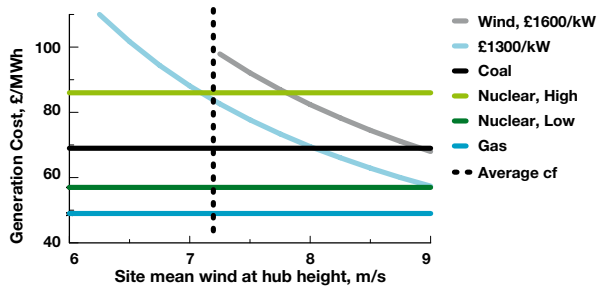
The capital recovery period is not necessarily the same as the plant lifetime. Generation costs of nuclear, for example, are often based on the assumption of a 40-year plant life. Whilst this may be realistic, it is unlikely that financing could be arranged for 40 years. The use of a 40-year life in the generating cost calculations would bring the cost of nuclear down by about 10%.

Cost of carbon

Generation cost projections for gas- and coal-fired plant need to take into account the "cost of carbon" under the European Emissions Trading Scheme. As with fossil fuel prices, there is some uncertainty over the future trajectory of carbon prices. The 2010 average is likely to be around £12/ tonne of CO_2. DECC suggests £26/tonne of CO_2 in its "Timely Investment, Moderate Demand" scenario. As two other scenarios yield higher values and only one yields a lower value, this may be taken as a conservative "high" estimate.

Generation cost comparisons

Fig 1. Generation costs of onshore wind energy, nuclear coal and gas

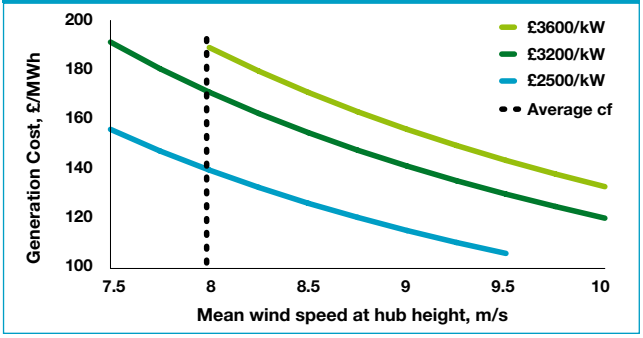


Based on the assumptions summarised above, the generation cost from onshore wind, at £1,300/kW, is just over £108/MWh at a site where the mean wind speed is 6.5m/s, falling to £67/MWh at a site where the mean wind speed is 9m/s. With a "high end" installed cost of £1,600/kW, generation costs are £104/MWh at 7.25m/s, falling to £72/MWh at 9m/s. At the average capacity factor of 29.4% recorded in 2008, generation costs – at a mid-range capital cost of £1,450/kW – would be around £90/MWh.

With the average fuel and carbon prices that prevailed in 2009, the generation cost from new gas-fired plant was around £49/MWh, whilst for coal it was around £69/MWh. Generation costs for proposed new nuclear plant are between £57/MWh and £86/MWh.

These data are assembled in figure 1 and suggest that nuclear and onshore wind prices lie within the same range. Wind is cheaper than coal at wind speeds above 8m/s (at £1,300/kW), or 9m/s (at £1,600/kW). Gas, which currently (2010) tends to set the reference price, is presently cheaper than wind.

Fig 2. Generation costs of offshore wind, for installed costs of £3,600/kW and £2,500/kW



The wind speed corresponding to the average capacity factor (cf) realised in 2008 is shown

Offshore wind generation costs are shown in figure 2. With an installed cost of £3,600/kW, these vary from just under £190/MWh with a wind speed of 8m/s, down to about £133/MWh with a wind speed of 10m/s. At £2,500/kW, generation costs vary from about £160/MWh at 7.5m/s, down to £106/MWh at 9.5m/s. At the average capacity factor of 35% recorded in 2008, generation costs, at the reference installed cost of £3,200/kW used by Ernst and Young (see reference 4), would be around £160/MWh.

Sensitivities

The principal uncertainties in these generation cost comparisons surround likely fuel prices. There is a wide range of future prices in the various scenarios examined by Ofgem in Project Discovery and by DECC in the Analytical Annex to the Renewable Energy Strategy. The possibility of coal, gas and carbon prices doubling within the next ten years is not an extreme case. If this were to happen, the cost of gas-fired generation would rise to around £81/MWh and coal would rise to around £97/MWh. The competitive position of wind would then increase significantly, although it is likely that price rises of this order would influence commodity prices and so wind plant costs would also rise – but not to the same extent.

Any increase in commodity prices would impact on nuclear costs in the same way as wind, and so the relative generation costs would probably change little. In this analysis, nuclear generation costs have been calculated using the same test discount rate as wind, whereas it is argued that the additional risks should be reflected in a higher discount rate. This would improve the competitive position of wind.

An alternative approach to modelling future electricity prices from fossil fuels, advocated in a number of papers by Awerbuch,[9] is to use a different discount rate to work out the Net Present Value of fuel costs over the life of fossil-fired power stations. This has a significant impact on the prices of coal and gas-fired generation, pushing them to levels that are higher than those shown in figure 1.

Conclusions

It may be concluded from this analysis that wind energy generation costs, although presently dearer than those of gas, could become more competitive, as there is a strong consensus that fossil fuel prices are likely to rise. Onshore wind is close to being competitive with new coal-fired plant at wind speeds above around 8.5m/s, and higher carbon prices would strengthen its position. Nuclear costs are somewhat uncertain, but it undercuts wind at most wind speeds if it can be built for £2,000/kW. At £3,300/kW, onshore wind is cheaper at wind speeds above around 7.8 m/s (approx. 31% capacity factors), but the application of a risk premium for nuclear would improve the competitive position of wind.

Offshore wind currently delivers higher generation costs than the fossil fuel sources, but that could change if installed costs fall with increasing maturity of the industry.

References

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4 Milborrow, D, 2009. "No consensus on offshore costs." Supplement to *WindPower Monthly,* September.

5 Department of Energy and Climate Change, 2010, *Quarterly Energy Prices, March.*

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7 International Energy Agency, 2010, *Projected Costs of Generating Electricity.*

8 Thomas, S., 2010, "Nuclear's cost advantage over wind is suspect", *Financial Times* letter, 28 April.

9 Awerbuch, S. and Berger, M., 2003, *Applying Portfolio Theory to EU Electricity Planning and Policy-Making*. IEA/EET Working Paper, EET/2003/03.

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