Danish Wind: Too Good to be True?

David J. White, Independent Consultant, assesses the real costs of wind energy generation in Europe

In the May issue of *The Utilities Journal*, Steffen Nielsen outlined the success of wind generation which has been developing since 1985.[1] Nearly 20% of Denmark's electricity demand is now said to be met by wind turbines. The turbine construction industry was said to be buoyant, with Denmark supplying some 40% of the world market. The implicit message is that demand for turbines remains high around the world.

While the theme may be music to the ears of the UK government and the DTI, the article tells only half the story, and omits many important aspects of the programme—particularly any reference to cost, annual availability or operability of wind generation. It does not mention Denmark's proximity to its neighbours, which holds the key to operability at the present level of capacity. There is also no mention of the fact that the wind is variable, unreliable and unpredictable, while customer demand for electricity dictates the highest degree of continuity and reliability at low cost. The experience in Denmark and other countries is beginning to raise questions about wind turbines as a means of generating power in a cost-effective way and the extent to which it reduces CO_2 emissions in the power-generating system as a whole.

If the Danish and other European wind programme data is analysed in more detail, different conclusions can be drawn. One has to question the real cost of generating electrical power from wind and whether it represents the most appropriate way to utilise a nation's capital assets. Set out below are some key elements of the Danish operating experience, along with data taken from critiques of wind power in Germany, Ireland and the UK.

Key facts omitted

Denmark has installed 3,100 MW of wind turbine capacity to date, which is in theory capable of generating 20% of the country's electricity demand. Of that capacity, 2,374 MW is located in western Denmark (Jutland and Funen). The statistic is misleading because it implies that 20% of Denmark's power is supplied continuously from its wind capacity, but the figure appears to be a promotional statistic rather than a factual representation of the supply pattern.

Jutland has cable connections to Norway, Sweden and Germany with a capacity of 2,750 MW. In other words, it has the means of exporting all of its wind production. The 2003 annual report of Eltra, the western Denmark transmission company, suggests an export figure of 84% of total wind production to these countries in 2003, with figures that ramped up rapidly over previous years as Denmark found that it could not absorb wind output into the domestic system. There is no link between east and west Denmark across the Great Belt; Zeeland has its own, but interconnected, power supply, with no connection to western Denmark.

The links between Denmark and the other countries play a vital role in system operability and they enable the output from Danish wind turbines to be accommodated whenever possible. This results from the proximity of these countries to Jutland and the nature of their power systems. Norway is almost entirely hydro, while Sweden is largely hydro and nuclear. Norway and Sweden can either take wind-derived power into their grid while reducing their hydro output, or could use the power to pump water to elevated reservoirs in order to recover power at a later date. Jutland also exchanges power with Germany in roughly equal quantities. This operational flexibility does not exist in any island power system such as in Ireland or the UK.

Electricity has become the most essential form of energy throughout the world, and there is an increasing dependency on absolute security of supply and high quality (ie, stable frequency and voltage). Too few people appreciate the fact that electric power cannot be stored (with the exception of hydro). Our power supplies result from a continuous dynamic balance between production and consumption.

In assessing the optimal way to produce power at an economic price with minimum pollution, it is important to look at all options and especially to analyse the extent to which capital assets are utilised. Wind power suffers in two ways: the capital cost per kW generated by offshore turbines is around three times the cost of CCGTs. The annual load factor from a CCGT is around 95%; the typical annual load factor from Danish wind farms is just 19–21%. The Eltra report also cites meteorological data for wind speeds being below 'normal or predicted average' for four out of the last five years—with only 73.2% 'normal' in 2003.

Reuters reports for 2003 present annual load factors of just 19% for Denmark and 18.7% for Germany.[2] An even more recent article cites the results of a study covering the German wind system for 1998–2003.[3] If the annual average load factor is back-calculated over the five-year period, it is only 14.7%. To quote the introduction:

> Germany's installed wind power capacity grew faster than the amount of electricity actually produced by wind energy plants in the last six years, the national VDEW power industry group said on Tuesday. This revealed the inefficiency of German government programmes to promote wind power and underlined that green energy can only be a supplement in the overall energy mix and not replace energy sources such as coal.
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> State subsidies have triggered a fivefold rise in installed wind power capacity between 1998–2003, while wind energy production only quadrupled.

But the law is under review because the rising costs have run into opposition from energy-intensive industries in an economic downturn.

While wind power has appeal as a source of sustainable energy, an understanding of the dynamics of power generation suggests that these low annual outputs are inevitable. Table 1 shows the relationship between wind speed and power output. It is a non-linear relationship—in fact, it is a function of the cube of the wind speed. Wind turbines are typically designed for a wind speed of around 13 metres per second (m/s) and above for maximum output. This is equivalent to about Force 7–8 on the Beaufort Scale. The turbines are designed to cut out in severe gale force winds, and require around 3 m/s wind speed to turn at all.

Table 1: Wind speed and power output

Wind speed (m/s)	% design wind speed	kW wind turbines rating	% design max. power output
13	100	1,000	100
12	92	600	60
10	77	265	27
9	69	200	20
8	62	150	15
7	54	100	10

Source: SFA Pacific.

With an output profile of this nature, it is hardly surprising to find the annual average power generation is relatively low, especially if meteorological data indicates lower than normal wind speeds. Even the UK shipping forecasts seldom report constant Force 7 winds around our coasts; there are typically 50–60 days per year when there is insufficient wind to turn a windmill. This often coincides with the coldest weather—ie, anti-cyclonic conditions which can cover the whole country.

The annual load factor will also include breakdowns, a point that has been particularly relevant to the major technical problems of the latest offshore wind farm. Such poor performance figures raise the important question of the real cost of wind-generated electricity, whether the technology achieves its goals of CO_2 saving, and whether available capital should be channelled into technology that has a far higher annual load factor. The low load factors also apply to the high-cost infrastructure needed to connect the wind farms to the power grid.

Economics of wind turbines

The power supply industry invests in generating equipment to match forecast demand and earn a return on its capital. Daily and seasonal fluctuations have to be accommodated through appropriate levels of investment. The industry clearly needs to use its capital as effectively as possible and, historically, the methods of generation offer a high level of availability year round. The capital cost of wind power and the infrastructure necessary to transmit that power to market is high but annual usage low. To date, government support has been sufficient to stimulate the development of the technology, but it is a very high cost that must be passed through to the consumer at some stage, either directly or indirectly.

While the Danish programme began in the 1980s, its real cost was not requested until 2001.[4] The overall cost has been assessed at between DKr8–10 billion (approximately £720m–£900m using a conversion rate of DKr1 = 9p as at June 28th 2004). The funds have been recovered from the market with a very high cost of electricity. Eltra indicated that the difference between the price paid to the generators under the government's terms for wind-produced electricity in 2003 exceeded the revenue from export sales by about DKr1 billion. In other words, the Danish electricity consumer is subsidising Norway and Sweden to the tune of DKr1 billion for the privilege of operating wind farms. A typical domestic price is equivalent to 14.5p/kWh, one of the highest in Europe. The current position is that 1,200 of the older, small wind turbines (which were subsidised in the first instance) have been replaced and a further 900 are to be replaced under a repowering programme also requiring subsidy.

Germany has the largest installed wind capacity in Europe. One report indicates that the cost of wind is 9c/kWh versus 3c/kWh for hydro and natural gas, 2c/kWh for nuclear, and 4.5c/kWh for hard coal.[5] The report concludes that the legally fixed permanent subsidy to compensate the power industry for wind generation is currently €1.4 billion/year. To achieve the EU objective of 10% wind input would require a permanent annual subsidy of €3.5 billion.

In the UK, public resistance and planning agreement are thwarting the development of onshore wind farms. The bulk of the new renewable capacity up to 2010 is likely to be offshore wind power where the capital cost will be of the same order of magnitude as the recent Danish offshore wind farms such as Horns Rev. (Annual load factors have not been given to date but many turbines have had to come ashore again for repair.) UK offshore turbines would have broadly similar annual availability, although this is challenged by those who want to build them. The investment needed to reach the government's 10% target of electric power (not 10% of installed capacity) by 2010 is likely to be £20–£23 billion based on the Danish experience. The recent Royal Academy of Engineering report states that the real cost of offshore wind would be 5.5p/kWh—well above the cost of totally reliable alternatives.[6] The huge expenditure has to be recovered through the price of electricity to the nation. It is becoming progressively apparent that the price will have to increase substantially to defray these costs; PowerGen has predicted a 20% increase within the next two years.[7]

Impact on CO_2 reduction

There is no CO_2 saving in Danish exchange with Norway and Sweden because wind power only displaces CO_2-free generated power. When the power is consumed in Denmark itself, fluctuations in wind output have to be managed by the operation of fossil-fired capacity below optimum efficiency in order to stabilise the grid (ie, spinning reserve). Elsam, the Jutland power generator, stated as recently as May 27th at a meeting of the Danish Wind Energy Association with the Danish government that increasing wind power does not decrease CO_2 emissions. Ireland has drawn similar conclusions based on its experience that the rate of change of wind speed can drop faster than the rate at which fossil-fuelled capacity can be started up. Hence spinning reserve is essential, although it leads to a minimal CO_2 saving on the system.[8] Innogy made the same observation about the operation of the UK system.[9]

The result is that, while wind-generated power itself is CO_2-free, the saving to the whole power system is not proportional to the amount of fossil-fuelled power that it displaces. The operation of fossil-fired capacity as spinning reserve emits more CO_2/kWh than if the use of that plant were optimised, thus offsetting much of the benefit of wind.

The Danish wind turbine industry

In his article, Mr Nielsen suggested that the turbine industry was flourishing. Vestas has taken over its rival, NEG Micon, after financial collapse; Horns Rev, the flagship offshore wind farm, has experienced major technical problems in less than two years; and Vestas faces bringing all 80 turbines ashore to modify them for the challenging conditions off the west coast of Denmark, thereby worsening its own financial position significantly. Production from Horns Rev cannot have come close to design. Vestas has the contract to supply the UK's North Hoyle site.[10]

Conclusions

Experience of wind power in Western Europe demonstrates that it is an unpredictable, unreliable and variable source of electricity for this most critical commodity for which continuity and stability are essential. The production statistics over the past five years illustrate a very low annual load factor, which represents a massive under-utilisation of high-cost assets.

Windmills do not reduce the CO_2 to the degree most people imagine when the emissions from the complete power supply system are taken into consideration. Indeed, Elsam has given a clear message about the folly of installing more windmills to reduce CO_2. Ireland has placed a moratorium on any new wind turbine connections; storage systems may be the only way to accommodate more wind into its system, adding substantially to the investment. The inevitable consequence of the current renewables policies in the EU is a substantial increase in the cost of generation that will severely penalise the economies. The UK extrapolations of cost reductions to the year 2020 that lay behind the UK Energy White Paper bear no relationship to the actual costs or investment being experienced in Denmark and Germany, or as summarised in the Royal Academy of Engineering report.

It would appear that the EU Renewables Directive and individual country targets have been driven by ideology without a thorough engineering assessment of the cost implications or CO_2-reduction benefit. While Denmark may appear to be a model that should be followed, the UK needs to learn from an objective analysis of the Danish and German experience and not from the possibly misleading claims that Denmark has already hit the 20% target that the UK hopes to achieve by 2020.

The current renewables programme is well behind schedule to meet 2010 targets and the real cost has not yet been recognised. Government support at the present level is not sustainable, as is now being reinforced by the German experience with references to the need for a permanent subsidy. The key questions are:

- can electricity be generated at lower cost by means other than renewables?
- can CO_2 be reduced at lower cost than via the use of renewable methods?

It makes no economic sense to progress an expensive and unpredictable power-generating technology in order to achieve a parallel CO_2 reduction goal when the evidence clearly indicates that the objective will not be met. Electric power is too vital a commodity to be used as a job-creation programme for the wind turbine industry. Other low-carbon technologies for power generation have to be considered if electric power is to be supplied at costs that enable European countries to compete.

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1 Nielsen, S. (2004), 'The Danish Wind Power Experience', *The Utilities Journal*, May, pp. 22–23.
2 Reuters Power News, March 24th 2004.
3 Reuters Power News, June 1st 2004.
4 Meeting of Independent Economic Council, Danish press report, May 26th 2002.
5 Professor Dr-Ing Helmut Alt (2003), 'The Economics of Wind Energy', November.
6 Royal Academy of Engineering (2004), 'The Cost of Power Generation', March.
7 The *Today* programme, BBC Radio 4, May 10th 2004.
8 Data available on www.esb.ei
9 Observation made in a paper presented by D. Tolley, Innogy, to the Institute of Mechanical Engineers, January 2003.
10 'Component Defects at Flagship North Sea Wind Power Station means all Turbines may have to Come Ashore for Repair', *Windpower Monthly*, June 2004.