Wind power in West Denmark. Lessons for the UK. ©

By Dr V.C. Mason (October 2005)

***Summary**: Although one fifth of the electrical power produced annually in West Denmark is generated by its enormous capacity of wind turbines, only about 4% of the region's total power consumption is provided from this source. Most of the output of wind power is surplus to demand at the moment of generation and has to be exported at reduced prices to preserve the integrity of the domestic grid. Savings in carbon emissions are minimal. To diminish exports and lower carbon emissions, plans are now in hand to use surplus wind power for resistance heating at local combined-heat-and-power plants.*

Background

Denmark (pop. 5.4 million) operates some of the world's most efficient coal, gas and bio-fuelled CHP plants for central and local electricity production and district heating. It has also become a leading pioneer of renewable energy in an attempt to reduce its reliance on fossil fuels and imported power. In this context its Wind Turbine Industry has become an important aspect of the national economy, employing about 20,000 Danes and currently supplying about 40% of the world market (Nielsen, 2004). The country has also made considerable progress in the development of solar power and bio-fuel technologies.

Denmark's renewable energy programme is based principally on wind power. Since 1985, about 3,317 MW of mega wind turbine capacity have been installed (Bülow, 2004a), of which 420 MW are sited offshore (Nielsen, 2004). More is planned for the future (Bendtsen and Hedegaard, 2004). Until recently, these developments were heavily subsidised, directly and indirectly. They were under-pinned by a statutory obligation on Transmission System Operators (and indirectly on electricity consumers) to buy the total output of power from wind and local district heating sources at elevated prices fixed by Government. In addition, direct subsidies were paid for renewable energy produced under obligatory purchase and free market conditions. Between the end of 2000 and 2003, the associated costs were officially said to be DKK 3.40-3.85 billion per annum (Bendtsen, 2003), although some have claimed that in 2001 consumers were paying an extra DKK 8-10 billion every year in capital and operational costs for the combined conventional + renewable energy package (Krogsgaard, 2001). A serious consequence is that Danish householders pay almost double the UK price for electricity.

Since 1985, the size and number of Denmark's industrial wind turbines has grown steadily in attempts to improve their efficiency, economy and output. According to one prediction, 20MW wind turbines as high as the Eiffel Tower may be a reality by 2015 (Andersen, 2001). Towards this end, a subsidised 're-powering' scheme recently encouraged the replacement of 1,200 small turbines (< 150 kW) by 300 bigger ones (Nielsen, 2004), and under a similar arrangement a further 900 turbines of under 450 kW capacity will soon be displaced by 175 larger machines (Sandøe, 2004a). Such upgrading seems likely to continue. Most of the turbines scrapped to date operated for less than 16 years (Bülow, 2002), so it is very difficult to assess their effective lifespan or economy. Furthermore, there has been little, if any, closure of conventional power plant in response to the advent of wind power.

Western Denmark

Denmark operates two unconnected and largely autonomous grid systems, located west and east of the Great Belt, respectively. Each benefits from having large, long-established inter-connectors which facilitate the exchange of power with the bigger systems of Norway, Sweden and/or Germany. The balance of the international flow of electricity is usually in a southerly direction, although in 2003 drought conditions in Norway and Sweden encouraged a net movement northwards (Bülow, 2005a).

Wind conditions in West Denmark are comparable to those found in most of the UK (see Troen & Petersen, 1989), but are somewhat better than in the east of Denmark. Consequently, three-quarters of the country's capacity of wind turbines is found in the western region, their concentration (c. 820 MW per million of population) being amongst the highest in the world. Indeed, there are few areas in the region's rather flat or gently rolling countryside where turbines are not visible, and in particularly windy locations concentrations are high. For many residents this has seriously detracted from the former charm and beauty of their traditional, largely agricultural surroundings and coastlines, and it has also had a detrimental impact on associated wildlife habitats. A leading national newspaper has commented: "[*It is true that Denmark has placed itself in a leading position with regard to the utilisation of wind energy, but until now this has certainly occurred at great cost to nature and with considerable public subsidy*]" (Jyllands Posten, 2004).

Patterns of wind power generation

In Western Denmark (principally Jutland and Funen; pop. c. 2.9 million) electrical power is provided by about 11 primary units (3,516 MW i.c.), 558 district heating plants (1,593 MW i.c. (inc. 40 MW bio-boilers)) and 4,161 wind turbines (2,379 MW i.c.) (Eltra, 2005). Despite the high proportion of wind turbine capacity, however, the bulk of domestic electricity is still provided by central and local CHP plants on the basis of fossil fuels derived from the North Sea. This reflects unpredictable wind conditions, and an inability to assimilate widely fluctuating quantities of wind power into the domestic grid in significant amounts:

a) Despite relatively favourable wind conditions in the region, only 20-24% of the potential annual output of West Danish wind turbines has actually been achieved over the last five years. This compares with the 24.1% load or capacity factor recorded in 2003 for the much smaller number of UK onshore turbines (DTI, 2004), but is higher than the 15% calculated for Germany over the same period (see Reuters, 2004). The Union for Co-operation on Transmission of Electricity (UCTE) claims an average load factor (LF) of only 20% for its European TSO members (Refocus Weekly, 2004). Clearly, the economy of a wind turbine is greatly affected by its LF, which in turn is influenced by local wind speeds, turbulence, midge or salt accumulations on blades, and breakdowns. Serious technical problems have been recorded for the transformers of offshore wind turbines at Horns Rev (Andersen, 2004a; Renewable Energy Access, 2004) and Middelgrunden (Møller, 2005).

b) The output of wind power is highly variable and unpredictable. In strong winds, up to 2,379 MW of wind power can be generated for a domestic system in which the demand throughout the year can range between about 1,300 and 3,800 MW. In contrast, adverse conditions can greatly restrict production (Bülow, 2004a). Throughout February 2003, for example, wind speeds and the generation of wind power were very low (Bülow, 2003), while in January 2005 a hurricane forced wind turbines to shut down within hours of running at near maximum output (Andersen, 2005a). Levels of output are very sensitive to conditions. At the Horns Rev off-shore wind station, for example, an increase in wind speed from about 9 to 11.5 metres per second can double production from about 80 to 160 MW within a few minutes (Eltra, 2005).

c) Although renewable energy generation has now reached the numerically equivalent of about 26.5% of annual demand (Bülow, 2005a) and wind turbines account for about 20% of total power production (Eltra, 2005), most of the region's wind power has to be exported in order to secure stability in the domestic grid. During 2003, for example, as much as 84% of the annual supply of wind electricity was surplus to demand at its moment of generation (Sharman, 2004), and only about 4% of domestic power consumption was satisfied by wind turbines (Sharman, 2005a). In fact, close relationships exist between wind power generation and the region's net exports of electricity (see Nissen, 2004; and Sharman, 2004). Prior to 1st January 2005, surpluses were also promoted by subsidies offered for electricity produced by the independently operating district CHP plants, irrespective of the demand for power (Sandøe, 2004b). Talking to Jyllands Posten as early as 2001, a former Chairman of Eltra, stated: "[*The consequence of the many wind turbines and decentralised power stations is that during the winter there is regularly produced 1,000 to 2,000 MW more than is needed in our area. This over-production we must dispose of on the open market for considerably less than we have paid*]" (Kongstad, 2001). Recent assessments suggest that such exports cost Danish consumers about DKK 1 billion per annum (Sharman, 2004).

Balancing the grid

Balance control is a complex issue for the region's Transmission System Operator (Eltra) and has been likened to "[*having to manoeuvre a rapidly moving articulated lorry train without a steering wheel, accelerator, clutch or brakes*]" (Andersen, 2003a). Although wind turbines produce power as the wind blows, all electricity has to be sold by contract or on the open market on an hourly basis at least 16 hours before it is delivered. If the wind blows more strongly than expected for several hours, electricity delivered to the grid must be disposed of abroad at low, 'here-and-now' prices (Sandøe, 2005b).

Surges of power are transmitted abroad via AC inter-connectors big enough (c. 2,400 MW) to accommodate almost all the output of the region's expansive wind carpet. Both Norway and Sweden can absorb this power by rapidly reducing their output of hydro electricity or using power to pump water to elevated reservoirs for the later generation of electricity (White, 2004). Jutland and Germany exchange power in roughly equal quantities, but in windy conditions difficulties can be encountered with Danish exports because of direct competition from the large amounts of wind power synchronously produced on the southern side of the border (Sandøe, 2003a). This situation may worsen as Germany increases its offshore production of wind power (see Andersen, 2005b).

In becalmed periods, West Denmark can usually import hydro-, nuclear- or coal-based electrical backup from its big neighbours, though limitations in inter-connector capacity have often necessitated the purchase of balance power from Elsam, the region's biggest power company (Sandøe, 2003a). Since January 1st 2005 some of West Denmark's larger district CHP plants (> 5-10 MW) have started to supply regulating power under free market conditions (Bülow, 2004b; Bülow, 2005b), and in the near future such power will also become available from the rest of Scandinavia (Bülow, 2005c). It is interesting to note the experience of the German TSO, E.ON-Netz, that "*traditional power stations with capacities equal to 90% of the installed wind power capacity must be permanently online in order to guarantee power supply at all times*" (Teyssen & Fuchs, 2005). This emphasises the need for backup in one or other form, and may infer that savings in carbon emission are often much smaller than is often claimed.

It is hoped that the future integration of power production by West Denmark's wind turbines and CHP plants will lead to reductions in the output of surpluses and allow a more even and predictable co-production of electricity (Andersen, 2003b). To this end, the Danish Government is abandoning its obligatory purchase scheme (Andersen, 2004b), though owners of existing wind turbines and district heating plants will continue to receive subsidy (Nielsen, 2004). New legislation will also permit resistance heating (Sandøe, 2005a,b), thus allowing wind electricity to displace some of the gas currently burned at district heating facilities, particularly during winter (Sandøe, 2003b). The use of wind power to produce hydrogen for fuel cells and electricity production is also being considered (Andersen, 2004c), although the demand for enough hydrogen fuel to displace the current usage of hydrocarbons for transport vehicles would appear to require roughly nine times as much electricity as was produced by West Denmark's turbine carpet during 2003 (see Sharman, 2004). Another plan is to establish inter-connectors between West and East Denmark by 2010 (Sandøe, 2005a).

Only time will reveal the technical efficiency and economic viability of combinations of these approaches. In any event it appears likely that the aesthetic quality of West Denmark's countryside and coastal areas will continue to be eroded as the size and, perhaps, number of wind turbines and associated plant increases.

Carbon emissions

The quantitative significance of man-made carbon emissions in the process of climate change is a matter of scientific dispute and public conjecture. In 2000, Danish man-made emissions of carbon dioxide were estimated to correspond to only 0.0003% of all the carbon dioxide released annually into the atmosphere from the Earth (Jyllands Posten, 2001). Nevertheless, it makes sense for Denmark (a small, relatively lightly populated country with limited reserves of fossil fuels) to seek to improve its efficiency of power production.

Compared to the situation in many other countries, West Denmark's deployment of efficient central and local coal, gas, and bio-fuelled CHP plants represents a major advance, with considerable carbon-saving potential. In contrast, its attempts to assimilate large amounts of wind power into the domestic system have proved to be very disappointing, and have so far produced little or no reduction in carbon emissions because of the need for imported power or the less efficient production of domestic backup to protect the integrity of its grid (Sandøe, 2003a). Most of its large exports of wind power simply displace 'green' hydro or nuclear electricity produced in Norway and Sweden, helping to replenish reservoirs only in dry periods or when power is cheap. This has led a former Chairman of Eltra to ask: ["*Is it environmentally friendly to produce electricity with wind turbines if there is no-one who can use it? And is it environmentally friendly to burn natural gas in decentralised heat and power plants while dumping the over-production of Danish wind electricity in Norway, where it possibly leads to water being diverted away from the water turbines?*"] (Kongstad, 2001). Processes involved in the manufacture, excavation and/or installation of access roads, massive concrete foundations, turbine components, pylons and associated equipment also militate against the emission-saving benefits claimed for mega wind power.

As a matter of fact, despite West Denmark's massive carpet of wind turbines, its carbon emissions have recently been rising (Bruun, 2005), and a leading Elsam expert has intimated that "[*Increased development of wind turbines does not reduce Danish CO_2 emissions*]" (Nissen, 2004). The region can hope, however, that the future linking of CHP and wind power in a more flexible and co-ordinated system will improve the predictability and sustainability of power production, moderate surges and exports, and even reduce carbon emissions.

Lessons for the UK

The UK aspires to 20% renewable energy by 2020 (i.e. the level already achieved in West Denmark). This equates to about 60 - 70 TWh of renewable energy (see Sharman, 2005b). To obtain 70 TWh of production on the basis of wind turbines alone would require an installed capacity of between 23 and 40 GW, depending on the LF achieved (i.e. 35-20%). Danish experience suggests that the 40 GW estimate (equivalent to about 20,000 2MW wind turbines) would lie closest to reality, and that the UK would also need to invest heavily in local CHP plants and/or large inter-connectors for backup. Most of the associated requirement for natural gas would need to be met from vulnerable foreign sources.

The deployment of such numbers of mega turbines would have a big impact on UK land use. A widely used rule of thumb stipulates that to prevent the turbulence from adjacent turbines taking power from each other (thereby reducing the overall LF), they should be separated by 7 to 10 times their rotor diameter. Even this spacing is too close, 'shadow' effects being monitored 5 km away from wind stations (Andersen, 2005c). It thus appears that the installation of 40 GW of wind power in the UK could leave a dedicated turbine 'footprint' (i.e. a close-habitat impact zone), on land and/or at sea, equivalent in size to almost half the total land area of Wales (depending on the size, number and layout of turbines). The situation would become much worse if/when wind power is exploited to produce hydrogen as fuel. Assuming a very optimistic LF of 50% for 3MW wind turbines, a recent study (Oswald and Oswald, 2004) estimated that about 96,000 units would be required to run all British transport vehicles on hydrogen. These would occupy a dedicated area greater than that of Wales or, alternatively, a 10 km strip encircling the entire coastline of the British Isles.

The instalment of turbines and pylons in the more scenic parts of the UK would inevitably involve the clear-felling of woodland (to maximise LF) and the incidental drainage of wetland during the excavation and building of access roads and foundations. This would stimulate the oxidation of peat (releasing carbon dioxide), and impact badly on many habitats essential for the survival of particular species of wildlife. The potential danger to protected birds and bats presented by general habitat destruction and the flailing blades of wind turbines has already been illustrated in many American and European situations (e.g. see the Cefn Croes Wind Farm website, 2004, and Mason, 2004).

Conclusions

The West Danish model clearly shows that the installation of large numbers of wind turbines can lead to severe and expensive problems with power transmission, and seriously degrade wildlife habitats and the aesthetic value of land- and seascapes for little or no reduction in carbon emissions. It is therefore imperative that energy conservation schemes and alternative sources of renewable energy are more thoroughly explored before large swathes of unique UK countryside and coastal scenery are lost to industrial wind stations. Conservation measures alone could reduce UK carbon emissions by 30% (Coppinger, 2003).

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