Ocean-driven changes to the UK 's weather systems threaten failure of wind power generation in winter

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Summary

By 2020 the government intends that 20% of UK's electrical power derives from renewable sources, mostly wind. Projections of the power to be generated by the turbine carpet are based on wind archives and the performance of wind turbines over the past 25 years. The flaw in this approach is that the machines will depend upon *future* weather and three lines of evidence suggest the *UK is on the eve of changes in winter weather that cast serious doubt upon validity of wind power projections.*

First, last December *Nature* published a paper (Bryden et al 1038, pp 655-657) revealing that 30% of the northward flow of the warm ' Gulf Stream' - strictly the Atlantic Meridional Overturning Circulation, AMOC - has changed direction, starting around 1992. A southward-moving component of the Gulf Stream, which re-circulates warm water in the subtropical gyre has increased by half. Furthermore, half the deep current that returns the north-eastward flowing warm current from the Norwegian-Iceland Sea has gone. By 2004 about 300,000,000 MW of heating was being redirected. The ocean bordering the UK will cool: on this simple basis alone the UK should anticipate colder winters.

Second, the UK's winter weather is dominated by the North Atlantic Oscillation, NAO. When the NAO is 'positive', the UK has stormy, wet, mild winter weather. When the NAO is 'negative' we get cold, dry weather from December to March, and westerly winds are weaker or less persistent. Since 1980 the NAO has been predominantly positive: only five winters have been negative. It follows that *all the archival data on wind turbine performance are heavily skewed by positive NAO winters.* There is statistical evidence that the North Atlantic Oscillation might now be switching to 'negative', possibly as a result of the AMOC slowing.

Third, it is known that the sign of the winter NAO, positive or negative, is influenced by anomalies in the sea surface temperatures (SST) of approx.1ºCelsius across the Atlantic. The recently described changes in the AMOC will surely result in much larger anomalies in Atlantic SST and hence in the winter NAO. But exactly what will these new SST anomalies be, and how will they then influence the NAO? A reduction in SST north of Iceland and an increase in SST in the subtropical ocean would be expected to drive the NAO negative. The AMOC-SST change might be so large that there is a possibility that the NAO would cease oscillating such that all winters become 'negative'.

The impact of AMOC slowing on SST and NAO must be predicted *with precision* if the planning for wind (and wave) power is to have any validity. Precision of prediction is essential as the impact of even a small fall in mean wind speed would be amplified by the turbines: a mere 20% fall in wind speed could eliminate half the power. Any loss of higher wind speeds – those in storms- contributing to that mean would further reduce output.

The implication of this analysis is that, every winter, the wind turbine carpet might deliver several *fold* less power than currently expected. Both the DTI Energy Review, and the Welsh Affairs Committee Inquiry into Energy and Wind Power in Wales, should incorporate into their deliberations new predictions of wind resource, in which the effect of the AMOC-slowing on SSTs and NAO are fundamental. A wise government would impose a moratorium on all wind and wave power station development until it has robust predictions of the UK's wind and weather for this decade onwards.

INTRODUCTION

It is axiomatic that most forms of renewable energy are under the influence of the weather. Yet assessment of the adverse changes in the UK 's weather during the next twenty years have not informed the UK government's renewable energy strategy. The weather is a pinch-point that renders the concept of a 'mix of renewables' redundant. In particular, any diminution of the UK 's wind resource would be catastrophic: a mere 20% fall in mean wind speed would *halve* wind-turbine power output.

This briefing note outlines two weather phenomena that greatly influence winter weather in the UK and northern Europe and which show signs of change from meteorological, oceanographic and statistical studies. The two key weather phenomena are:

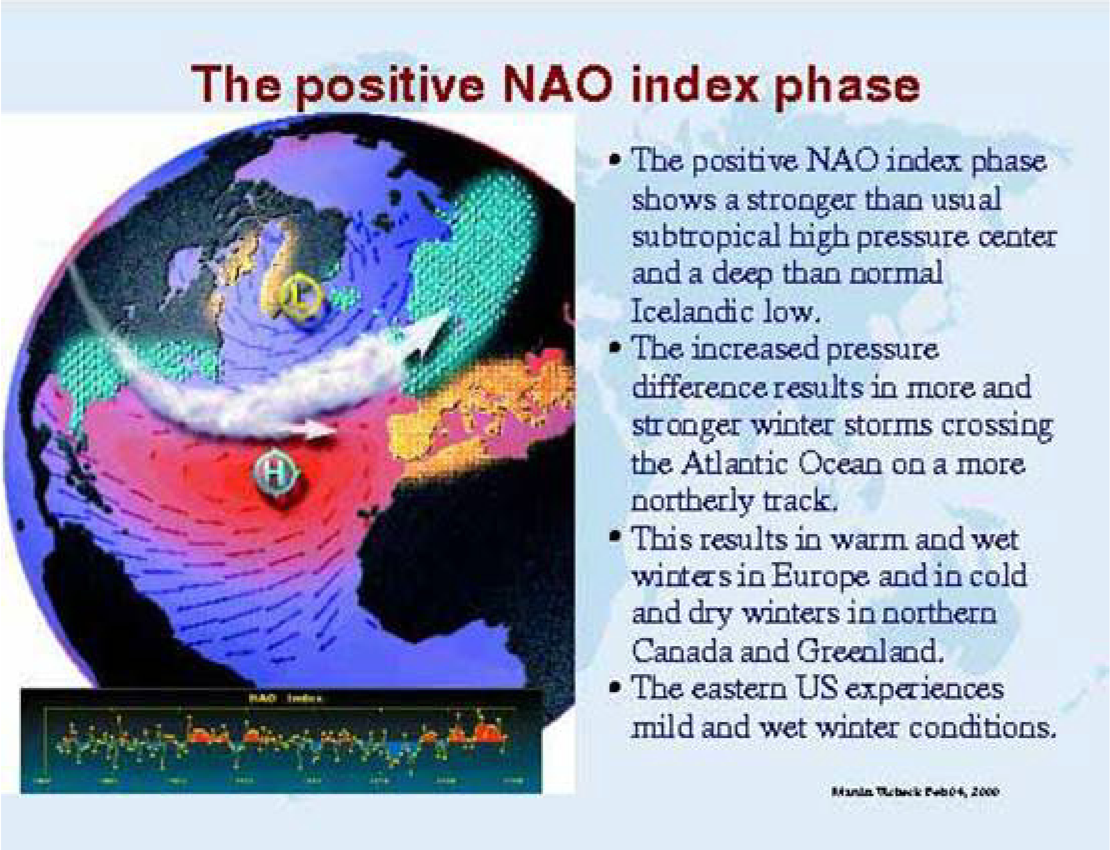
1 The North Atlantic Oscillation, NAO

2 The Gulf Stream and the Atlantic Meridional Overturning Circulation, AMOC.

The 2020 target for renewable electricity is 20% of UK demand. That the resource - windy weather - underlying much of that target has not been rigorously assessed implies a risk to the 60 million people and to UK businesses.

The North Atlantic Oscillation, NAO

The North Atlantic Oscillation (NAO) is a phenomenon associated with winter fluctuations in temperature, rainfall and storminess over much of Europe. When the NAO is 'positive', westerly winds are stronger and more persistent and northern Europe tends to be warmer and wetter than average. When the NAO is 'negative', westerly winds are weaker or less persistent and northern Europe is colder and drier. These two diagrams (from Columbia Univ.) illustrate the winter weather difference in the two states of the oscillation (fig.1; note that the red and blue colours represent high and low atmospheric pressure respectively)

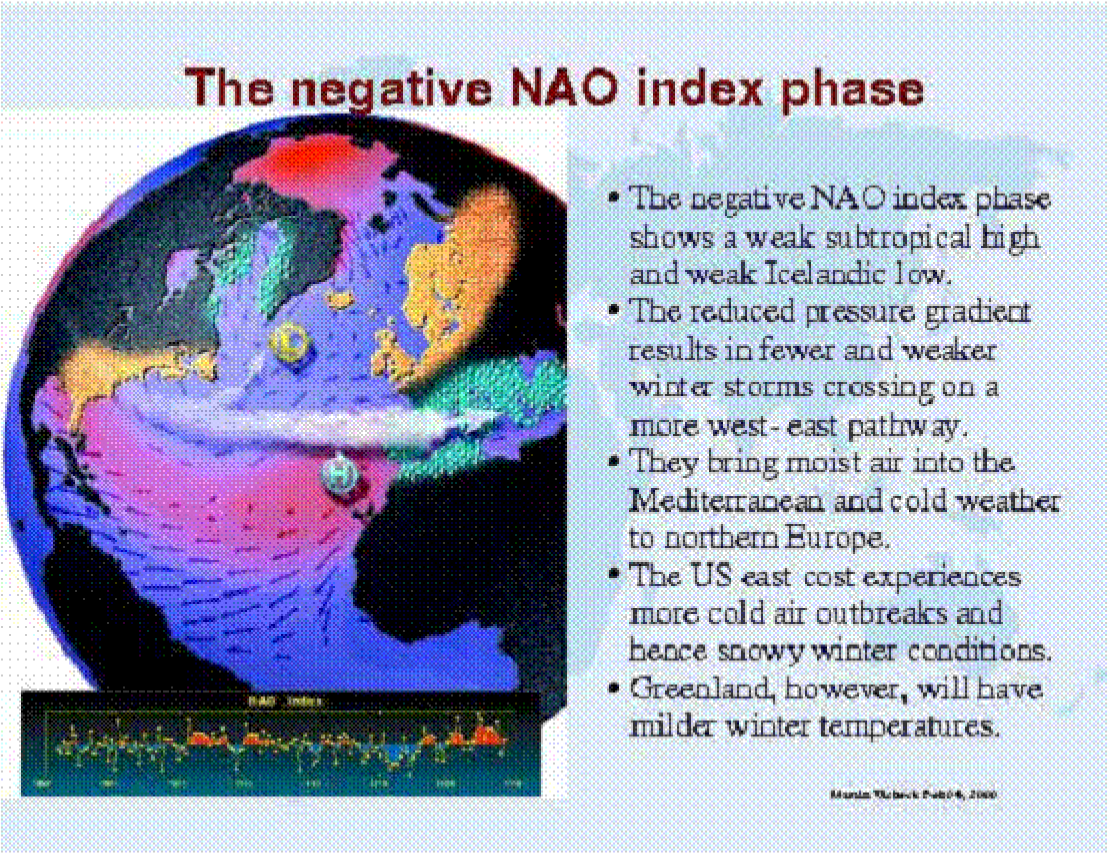


The positive NAO index phase

- The positive NAO index phase shows a stronger than usual subtropical high pressure center and a deep than normal Icelandic low.
- The increased pressure difference results in more and stronger winter storms crossing the Atlantic Ocean on a more northerly track.
- This results in warm and wet winters in Europe and in cold and dry winters in northern Canada and Greenland.
- The eastern US experiences mild and wet winter conditions.

Martin Visbeck Feb04, 2000

Fig1



The negative NAO index phase

- The negative NAO index phase shows a weak subtropical high and weak Icelandic low.
- The reduced pressure gradient results in fewer and weaker winter storms crossing on a more west- east pathway.
- They bring moist air into the Mediterranean and cold weather to northern Europe.
- The US east cost experiences more cold air outbreaks and hence snowy winter conditions.
- Greenland, however, will have milder winter temperatures.

Martin Visbeck Feb04, 2000

The NAO switches between these two states.

The NAO oscillates: it persists in, predominantly, one state for decades and then switch for decades to the other state. In figure 3 the positive states are shown in red, the negative in blue.

Note that the period of 1940 to 1980 showed an increased occurrence of negative states (blue), including the cold winters of 1947 and 1962-3. For the past 25 winters the NAO-index has been predominantly positive with just five negative winters.

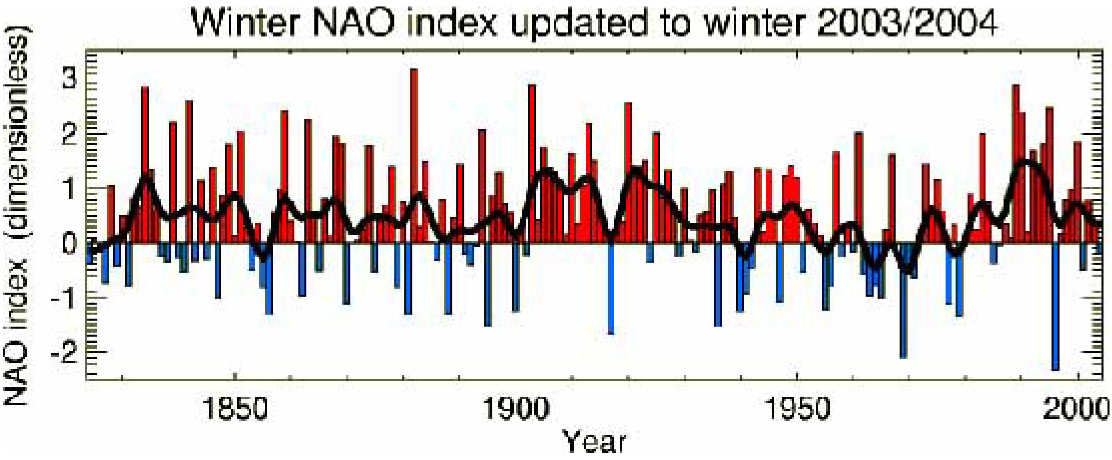


Figure 3 (from www: Dr Osborn, Univ East Anglia)

Future changes in the NAO index

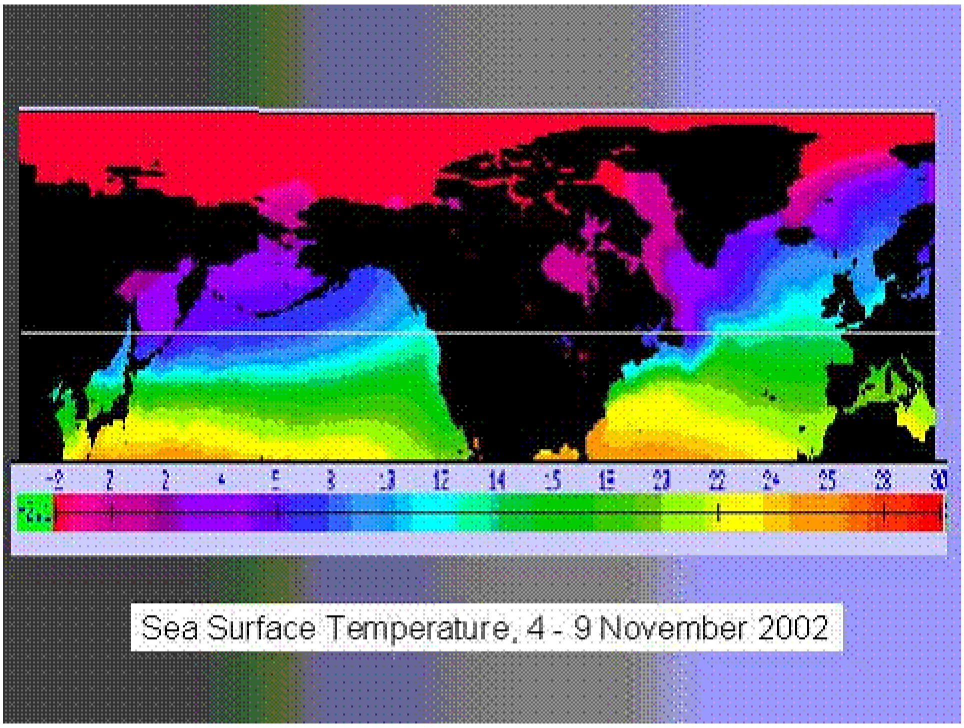
There is a possibility that the past 30 years' positive NAO is now ending and that a 20-30 year period of negative NAOs is beginning, repeating the situation found between 1940 and 1970. Sophisticated statistical techniques are being used to predict in early summer whether the following winter's NAO is likely to be positive or negative. Thus in summer 2005 the Met.Office predicted, on the basis of Atlantic sea surface temperature anomalies, that this winter's NAO would be negative (ie a cold winter). Large data sets show oscillations in the NAO going back 1000 years (eg.tree rings). The complexities in ocean/atmosphere interactions preclude any precise predictions, but the NAO will undoubtedly change at some point in the future: it might be on the cusp of going negative now. It would be unwise to formulate energy policies on the assumption that it will not change. Indeed the Atlantic Ocean may be in the process of forcing change in the NAO now: see below.

2. **The Atlantic Meridional Overturning Current, AMOC**

This AMOC is part of the global Thermohaline Conveyer and the warm surface currents within the AMOC are known as the Gulf Stream . The Gulf Stream carries vast quantities of heat north-eastwards from the Gulf of Mexico and Bahamas to northern Europe and Scandinavia . This heat flow amounts to 1.3 PetaWatts (1.3 Billion MW), equivalent to the heat generated by 1.3 million GW-sized power stations. The AMOC endows the UK , Scandinavia and N Europe with much milder winter weather than our latitude would otherwise dictate (see fig4).

Fig.4 The Gulf Stream conveys heat past UK to the Norwegian-Iceland Sea.

(from www. Dr Maroztke , NOC, Souithampton)



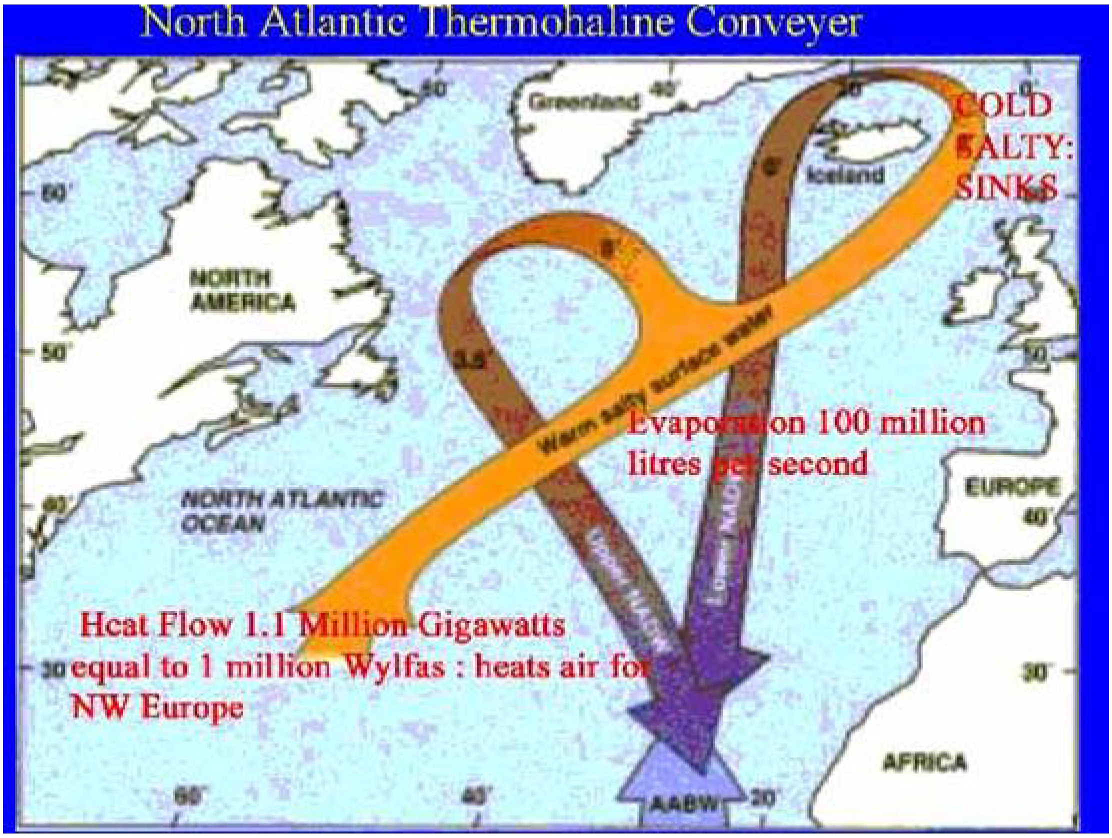
Sea Surface Temperature, 4 - 9 November 2002

Slowing of AMOC

As the Gulf Stream current flows north it evaporates water - the source of much of our rain - and cools. In the vicinity of Iceland and Greenland this cold and salty water, now denser than the local sea-water, sinks (see fig 5). The sinking current returns from the Norwegian-Iceland Sea southward at 3000-5000m depth towards the Equator, and is known as the Lower North Atlantic Deep Water Current. Freshwater flows from ‘greenhouse’-forced melting of the Greenland ice-cap and rivers from melting Siberian perma-frost, reduce the salinity of the AMOC and slow its sinking, aided by reduced formation of salty sea water under arctic sea-ice. Measurements from CEFAS, Lowestoft (Prof. RR Dickson) show a decline in the salinity of the deep-water return current in the Denmark Strait , beginning around 1970.

Three years ago, the probability of slowing of the AMOC occurring in the second half of this century was estimated at 50/50. Recently published measurements show that slowing of the AMOC is underway *now* and started no later than15 years ago (Bryden at al *Nature* 1038: 655-657; 1 Dec 2005). These oceanographic measurements show that the branch of the deep return current known as the Lower North Atlantic Deepwater (Lower NADW in figure 5) has halved between 1991 and 2004. As a result, an estimated 0.3PW of heat has already diverted in the Gulf Stream. These data from Prof H L Bryden FRS (National Oceanographic Centre, Southampton) were published in *Nature* in December 2005. An excellent over-view outlining the areas of uncertainty is here: *Nature 439 ,256-260, 19 January 2006:* ‘ *Circulation challenge’* . A simple, linear extrapolation of their data suggests that the area of the Gulf Stream which occupies the east Atlantic and which feeds the Lower NADWC could cease by 2020.

Fig 5 - Schematic diagram of the AMOC



Impacts of partial AMOC cessation

Cessation of the AMOC has not occurred for thousands of years, so UK has no experience of winters without warmth from the Gulf Stream. The impact upon energy demand in UK (and Europe and Scandinavia), especially for heating, will be considerable. The impact upon renewable energy supplies will be far-reaching. Electricity generation from wind and wave is discussed later. The cold winters will cool the soil and impair growth of crops and destroy biomass crops, such as *Miscanthus*, that are not completely freeze-hardy. Dry winters will reduce the water available for hydro-electric power (and impair refilling of aquifers for potable water). Roof-top solar photovoltaic and thermal are already relatively ineffective in winter, so the impact on these will be minor. Heat pumps relying upon surface-soil heat or bodies of water will be impaired, but borehole types should be immune. The only renewable electricity generation plant that would be immune to loss of AMOC heat are tidal-lagoons and tidal-race turbines, assuming winters will not be so cold as to promote sea-ice formation.

Interaction between NAO and AMOC

The NAO is influenced by anomalies of approx.1ºC in the Atlantic sea surface temperature (SST). [see: Rodwell at al *Nature* 398: 302-323, 1999]. They show that known decadal SST oscillations drive the NAO. This is the basis of the Met Office's experimental long-term forecasts of cold winters (i.e. prediction of negative NAO index). This relationship raises the question of how the NAO-index will be influenced by the reduction of the AMOC current. An interpretation of the Rodwell paper could be that cooling of the SST north of Iceland, and warming of the subtropical Atlantic, which are both outcomes of the AMOC slowing, will drive the NAO negative. But much more detailed, professional predictions are necessary. Specifically, how will the reduced AMOC alter the Sea Surface Temperature (SST) anomalies- by how many degrees Celsius, and when and where? Will the SST changes be so great as to abolish the decadal SST oscillations and hence cause the NAO also to cease to oscillate and to go permanently to high negative indices, *every* winter? These questions need to be posed and subjected to a risk analysis before the UK embarks upon construction of extensive renewable energy plant.

Speculation: does the trend to progressively less positive NAO indices since 1995 (see fig3) reflect the slowing of the AMOC, which began some time after 1992?

Why are predictions of the NAO and AMOC so important for wind power?

The impact of weather-related changes in wind resource upon electricity generation by wind turbines will probably be profound. Note in the diagrams above how the storm paths diverge southwards away from UK when the NAO is negative, and that the winds also weaken. These diagrams do not of course embrace the much greater southward swing in the storm belt that might be expected after slowing of the AMOC. Thus a cooling of the North East Atlantic will result in the major weather systems moving southwards to where the newly-cold northern air and air heated by the warming subtropical gyre collide. Thus the familiar concept of 'prevailing westerly winds'- which has been the predominant winter weather pattern in UK for the past two decades (fig 3) may soon be obsolete.

Wind turbines will amplify small falls in wind speed into large power falls.

How would a reduction in storminess impact upon wind power generation? To assess this we need to look into the basic characteristic of wind turbines and put numbers on the problem.

An aerofoil generator, like an aircraft wing, shows a highly non-linear relationship between wind speed and lift / torque. Thus over much of the working range of a wind turbine, a doubling of wind speed leads to an eight-fold rise in power output: a 'cube law' relationship. It follows that if the mean wind speed available to a turbine were to fall, as a result of weather changes, by just 20% the power output falls to *half* (ie by a factor of 0.8 3, or 0.51). Thus if the mean wind speed around a turbine on a Welsh hilltop is at present 8msec -1, a fall to 6.4msec -1 would halve its output. Continuing this theme, a halving of mean wind speed would result in a *eight–fold*fall in turbine power output, with the result that wind turbines that are at present delivering at 25% of their Installed Capacity would deliver just 3%. There could be no significant engineering rectification of such a situation.

So what might appear, to those uninitiated in turbine-blade characteristics, to be a rather minor reduction in wind resource will have severe effects on the real power generated. Thus the *uncertainties in the UK's future wind resource will be amplified by the turbines and precise predictions of future wind speeds are essential.*

Why has future weather and wind resource not been factored into the UK wind energy strategy?

The BWEA and wind power companies have not highlighted this problem with wind power. One reason could lie in ignorance of the relationship between the NAO and AMOC, which would be the case if they have simply dismissed the poor turbine output in negative-NAO winters as being 'anomalous' and infrequent. The second is that the change in the AMOC reported in December 2005 was unexpected, even to experts in the field. The third reason is that the impact on the wind industry's profits of those few 'anomalous' winters will not imperil their business plans because the NAO effect applies only to the winter months (i.e DJFM), and the rise in value of ROCs as result of their shortage will compensate.

Wave power.

Wave activity is secondary to wind, and is likewise exposed to uncertainty about future wind speeds. Wave generators are different from wind turbines in their dependence on wind direction (as 'fetch'). If negative-NAOs lead to changes in wind direction, with east winds coming to predominate in all winters rather than westerlies, many wave-power plant positioned to benefit from a fetch to their west, on the basis of historical wave resource, will fail to perform as predicted. The slowing of the AMOC adds uncertainty to wave power.

Wind resource data

The historical wind resource data used to predict wind turbine output by wind power companies is heavily skewed by the predominantly positive NAOs throughout the entire 30-year history of the wind power industry in Europe (see fig 3). Such data is collected by the Met.Office for sites at Bala (for Wales), Marham (for England) and Prestwick (for Scotland). These data could be used to make a rough estimate of the risk to wind generation in negative-NAO winters. But this approach cannot be used to assess AMOC-triggered changes in wind resource.

The risk in using past data from wind 'farms' to predict future power output

Wind turbines have been operating in large numbers during the past 25 years in Denmark and Germany, giving an extensive data set on performance, and providing the basis for projections of power supply. There is a fundamental risk in this approach. Figure 3 show that out of these 30 years only five, at most, have been when the NAO is negative.It follows that *ALL the audited data on wind turbine performance for Denmark and Germany have been made during winters with an overwhelmingly positive NAO index.* As a predictive tool the use of past data averaged over many years is probably useless if (when?) the NAO swings persistently negative.

“Wales has the best wind resource in Europe”

This mantra trivialises the risk: does it truly reflect the extent of weather and wind prediction by DTI and WAG?

When the NAO switches negative: “ Wales *had* the best winds in Europe.”

Conclusion

The changes in the Atlantic Ocean currents and consequent changes to the UK’s winter weather present a *high probability : high risk* scenario for the UK’s electricity supply.

Governments have a responsibility to ensure that the nation’s electrical power supply is robust and secure. The safety of the UK’s population - especially the elderly, the infirm, those in fuel poverty, and the poorly prepared - should not be put at risk by commercially-driven stakeholders and implicit assumptions that the weather will not change.

It is worth re-emphasising that the NAO is a *winter* phenomenon that threatens wind power output at the very time that the UK faces its highest demand for power and when it has the least conventional generating capacity held in reserve.

The accurate prediction of winter wind resource over the next 20 years is an absolute pre-requisite for incorporating wind and wave power into the UK’s generating capacity.

The magnitude of changes in the ocean currents and weather systems outlined above should be quantified and used to inform projections of future wind (and wave) power availability as rigorously as the science- and engineering-based planning accorded to conventional plant and fuel sources.

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