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Energy and Climate Change – The Connections

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Abstract

It is widely known that conventional fossil-fuel derived sources of energy contribute to climate change through the production of greenhouse gases. In an effort to slow this change, non-polluting renewable resources such as wind power, wave power and tidal power, are being more commonly exploited. However, many of these renewable energy sources depend innately on the climate itself, so it is necessary to understand how they will react to climate change and how this will impact on their viability in the short- and long-term.

Climate Change

Over the last five to ten years, global media has made climate change information readily available to the non-specialist, and the majority of people in the developed world understand that scientists attribute global warming to increasing concentrations of carbon dioxide (CO_2) in the atmosphere. The latest information from the Intergovernmental Panel on Climate Change (IPCC) confirms that fossil fuel usage is the main contributor to increasing atmospheric CO_2 levels (IPCC, 2007). Studies of historical temperature records show an increase of 0.76ºC since the late nineteenth century and the most recently published projections state that in the next 20 years we can expect increases of 0.2ºC per decade with a total temperature increase of between 1.1ºC and 6.4ºC over the next century (IPCC, 2007).

The range in projected temperatures comes from the use of a number of different climate models, each run under a number of different emissions scenarios. The emissions scenarios are used to develop a range of temperature projections for each model based on different socio-economic and technological development levels. For example, one of the higher emissions scenarios assumes continuing rapid economic growth, new technological development and low population growth, whereas a lower emissions scenario describes a world focussed on environmental sustainability and social and economic parity for the population (IPCC, 2000).

Renewable Energy

It is currently thought that climate change cannot be stopped absolutely by reducing carbon dioxide production, but that it may be slowed to a more manageable rate. To reduce CO_2 emissions requires a reduction in fossil-fuelled energy generation with renewable energy sources providing a significant part of the solution.

Figures from 2005 show that for the United Kingdom (UK) around 4% of electricity was supplied from renewable sources (DTI, 2005a). Of this the majority came from biomass and hydropower, with wind energy contributing around 17% of total renewables (DTI, 2005b). As part of attempts to lower the UK's CO_2 emissions the Government and environmental lobby are promoting rapid development of the renewable energy industry, with schemes to make it financially more attractive as well as loosening of planning restrictions. There is still some fierce opposition, mainly on grounds of visual intrusion but the aim is to grow from the current 4% of electricity generation to 20% by 2020 (DTI, 2003). Wind is expected to grow the fastest to meet this 2020 target – large offshore projects are being developed along with current onshore installations, and also by encouraging micro-generation by private homes and businesses.

Climate Change Feedback on Energy

There is, however, a feedback mechanism operating between climate and energy, wherein climate change itself may have an impact on energy supply. Thermal power plant efficiency may be adversely affected by higher temperatures in cooling media (water or air). For electricity networks, climate can affect the physical infrastructure with, for example, storms causing damage to power lines and adverse weather preventing access for maintenance. For gas networks the infrastructure is not so vulnerable, but compressors may become less efficient with rising temperatures.

Climate has a fairly obvious impact on consumer demand for energy. In a warmer climate, demand for winter heating drops whilst demand for summer cooling increases. However, if extreme climate events become more commonplace, that is, heat-waves and snowstorms, short-term demand for cooling and heating becomes an issue for suppliers.

Renewable energy sources are fundamentally dependent on the climate resource on which they are based. The operational performance of the schemes may be positively or negatively affected by climate changes, depending on the system, and will impact on the financing of the schemes. It may also affect government policy towards encouraging or providing incentives for such schemes.

Climate Change Feedback on Renewable Energy

Looking specifically at climate change feedback on renewable energy, different sources will be affected in a variety of ways. For wind power, wind strength and direction are critical to energy output thus any changes in the wind could affect financial revenue for the investors. Similarly, changes in cloud albedo will affect the energy output of a solar panel. Marine renewable sources such as wave and tidal power are vulnerable to wind changes, sea level changes and also to a higher frequency of extreme storm conditions which may cause damage. Temperature changes that cause changes in growing season length and intensity will impact on Biomass production. The type of crop that is suitable for a particular area may vary substantially with local climate. Hydropower will be affected by changes in precipitation levels and temperature which give rise to changes in runoff. The remainder of this paper is dedicated to looking in detail at climate change impacts on wind power in the UK.

Climate Change and Wind Power

The power available from a wind turbine depends on the cube of the wind speed (Manwell, 2002):

$$P = \frac{1}{2}\rho U^3$$

From this cubic relationship it is obvious that any small change in wind speed will result in a proportionately larger change in wind power output.

Wind speed is largely driven by pressure gradients in the upper atmosphere. A change in global temperature will induce changes in these pressure gradients and consequently could affect wind speeds at a surface level.

Climate Change Impacts Modelling

In order to investigate how changes in climate will occur, climatologists around the world have developed General Circulation Models, or GCMs. They model interactions between variables in the climate system over various periods of time using mass and energy transport laws as their basis. These interactions include, for example, land-surface heat exchange, the greenhouse forcing effect of CO_2 emissions and the reflective effect of snow cover.

The models solve the mass and energy transport equations through different levels in the atmosphere and ocean to model changes in greenhouse gases. On a time scale they can produce output at as low as 30 minute intervals. Their spatial resolution is around 3º latitude and longitude. This is improving with computer power and the latest models operate on grids closer to 2º.

A wind speed average for a 2-3º degree latitude/longitude area does not provide information suitable for wind generation analysis, as surface wind speeds tend to be localised and related to the terrain conditions of the area as well as the upper-level circulation. Thus, some way of interpolating or 'downscaling' the results to a higher resolution to include some local topographical effects is required. The two most commonly used downscaling methods are:

Dynamic, in which the output of the GCM is used to drive a higher resolution model nested within it (Regional Climate Model) and

Statistical, in which a large scale climate variable which is well-predicted by the GCM is statistically connected to the smaller, local variable based on historical data. The GCM output for the larger variable for future time periods is then used, via their historical relationship, to predict the local variable. In the case of wind, this would mean relating pressure levels to surface wind speeds.

Results from a Regional Climate Model

As part of an initial investigation (Harrison *et al.*, 2007) into the impacts of climate change on wind power in the UK, results of one of the downscaling methods mentioned above, Regional Climate Models, were used to map changes in wind energy output (Hulme *et al*, 2002).

The wind speed changes predicted by this RCM were converted into wind energy changes using a Rayleigh distribution based on mean wind speed values and the power curve for a standard Vestas V90 wind turbine (Vestas, 2004).

The worst-case scenario for the 2080s period under the highest predicted emissions levels is presented here to highlight the findings from this study.

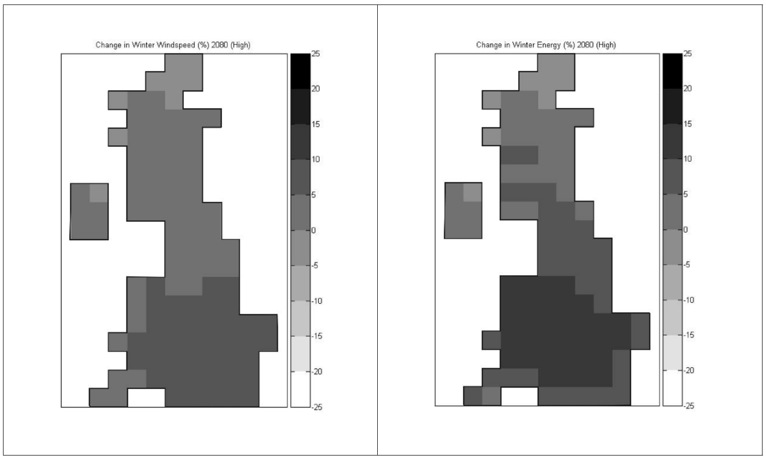

Figure 1: Winter changes (%) by 2080 in (a) mean wind speed; (b) energy production

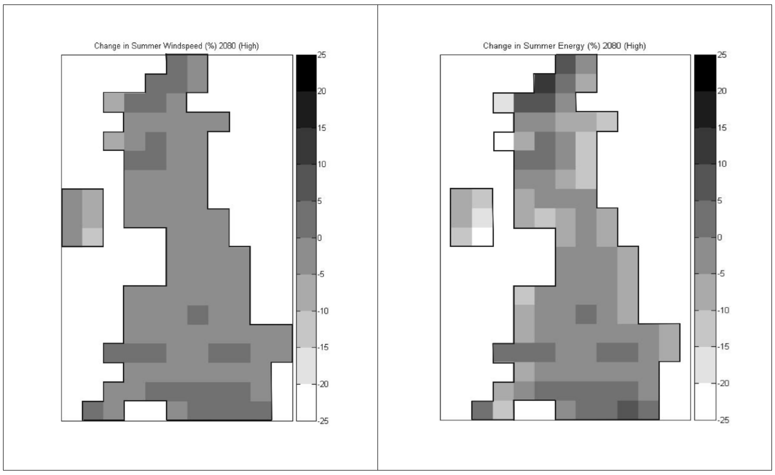

Figure 2: Summer changes (%) by 2080 in (a) mean wind speed; (b) energy production (%)

Summertime in the 2080s under conditions of 'High' emissions shows a tendency towards an overall decrease in energy production, around 5-10% in most areas. However, parts of Northern Ireland and the Western Isles of Scotland show a bigger decrease in energy output of up to 25%. Meanwhile, the north of Scotland shows an increase in production of 10-15%.

Winter energy production tends to increase, varying from 0-15% across the country. A few areas show a decrease in production however, in the North of Scotland, the Western Isles of Scotland and the North Antrim coast in Ireland. The energy output falls here by around 0 to -5%.

The overall conclusions from this particular study were that the impacts vary across the region, some are beneficial to the wind industry and some are not. However, we made several broad assumptions in the study which limit its accuracy, and whilst the resolution is higher than a GCM, it is still not reliable on a site level, only as an indication of trends in the 50 km square area covered by each grid square. (Harrison *et al*, 2007)

Conclusion

This research area is rapidly expanding – the aim of the project is to develop an understanding of the potential economic and financial issues surrounding climate change and wind power. Extensive work has been carried out for hydropower and a similar wave energy project has just begun. The answers to the questions may ultimately be useful for sculpting government policy on renewable implementation in the UK and, on a different level may help investors decide where and when to invest.

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