Environmental
Change Institute
UNIVERSITY OF OXFORD

wind power and the UK

wind resource

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Wind power has emerged as a leading renewable energy technology, with projects being developed in the UK and a large number of countries around the world. This report presents an overview of the characteristics of the UK wind resource in terms of its patterns of availability and variability, and the implications of these characteristics for security of electricity supply where wind power contributes to meeting electricity demand.

Executive Summary

Overview

The importance of wind power to the United Kingdom's renewable electricity supply is predicted to increase in the coming years. Together with this greater reliance on wind power there is a greater need for understanding the characteristics of the UK's wind resource.

This report presents information on the characteristics of the UK wind resource, and some of the impacts that wind power will have on the UK electricity network.

The UK wind resource

Extensive wind speed records were used to identify patterns of wind power availability. These records show that:

- Wind power availability is greater during winter than at other times of the year, and is on average stronger during the day than overnight
- Wind power delivers around two and a half times as much electricity during periods of high electricity demand as during low demand periods;
- The recorded capacity factor for onshore wind turbines in the UK is around 27% - this is higher than that recorded in Denmark or Germany, and emphasises the need to use UK data in wind power assessments.

Extreme lows or highs in wind speed are a natural feature of the UK wind climate; however a diversified wind power system would be less affected as it is rare that these extreme events affect large areas of the country at the same time. This report found that:

- Low wind speed conditions affecting 90% or more of the UK would occur in around one hour every five years during winter;
- The chance of wind turbines shutting down due to high wind speed conditions is very rare – high winds affecting 40% or more of the UK would occur in around one hour every 10 years.

Wind power in electricity networks

Wind power developments need to be integrated in the wider electricity network – this will have impacts on the network, including that:

- The development of wind power will result in a reduced need for conventional capacity – with wind power supplying 10% of UK electricity, around 3GW of conventional plant could be retired;
- A small increase in the cost of electricity is likely to result from wind power development – this would be equal to around 2.5% of the average domestic cost of electricity with 10% wind power, and
- The cost of balancing wind power variability is expected to reduce with improvements in wind power forecasting techniques.

Introduction

Electricity is a cornerstone of the United Kingdom's economy and standard of living, and the availability of a reliable electricity supply is taken for granted in this modern economy. Traditionally, electricity has been generated by a mix of technologies, with gas and coal burning power stations, together with nuclear generators, meeting the vast bulk of the UK's electricity demand.

The UK is pursuing the development of renewable electricity generating systems in response to concerns regarding emissions from fossil fuel-based electricity generators. As a signatory to the Kyoto Protocol, the UK is obliged to meet targets set for national carbon dioxide emissions; renewable energy is one strategy to help meet this requirement, and the development of wind power has become a major component of this renewable energy strategy.

Electricity generation from wind power represents a major departure from conventional generating technologies: whereas conventional technologies consume fuel to generate electricity, the "fuel" for wind power systems is the wind itself. Since the availability of wind cannot be controlled, it is essential that the characteristics of this energy resource, and the implications of those characteristics for reliable electricity production, are understood so that the value of wind power to electricity systems can be determined.

This report

This report presents an overview of the United Kingdom wind resource, and describes the likely implications of integrating significant amounts of wind-generated electricity into the electricity supply system of the UK. This report is divided into four sections, covering:

- Wind-generated electricity: the relationship between wind speed, wind power and turbine performance;
- Characteristics of the wind resource: an assessment of the patterns of availability of wind-generated electricity, and the likelihood of extreme wind events affecting wind power generation;
- Capacity factor: the importance of this measure of wind power , and
- Wind power in electricity networks: an assessment of the availability of wind power, the impact of wind power variability on conventional generating capacity requirements, and costs.

There are a range of other issues that have been raised in relation to wind power, including planning and conservation issues – these issues are beyond the scope of this report, however there are a number of reports that address some or all of these additional issues (see Further reading).

Terminology – Intermittency or Variability?

The terms "intermittency" and "intermittent generation" are often used in relation to renewable electricity generators such as wind power, however these terms may be misleading.

Describing something as intermittent suggests an alternating presence or absence; however the pattern of electricity output of wind power is more accurately described as being *variable*, as it is the variation in output from one hour to the next that poses challenges for its integration into electricity networks.

This document uses "variable" and "variability" to refer to the changing output characteristics of wind power, and to distinguish this form of changing output from that associated with conventional generators.

UK wind data

Any assessment of the long term characteristics of the UK wind resource requires extensive records of wind speeds from a range of locations. Recordings at a single site provide information about that location, however wind characteristics differ between different sites. In addition, many wind power sites in the UK are relatively recent developments: although the variation in wind speed and power at these sites is well-known for the period of operation, these wind farm records tend to be shorter-term, and are less likely to include rare but extreme events.

The use of wind speed data has advantages over wind farm output data, including:

- A far longer period of wind observations is available from wind speed measurements than from wind farm measurements – this means that extreme events, such as very high wind speeds or large scale low wind conditions, are more likely to be included in this dataset than in shorter-term wind farm datasets;
- Wind speed measuring sites are located throughout the UK – this provides a more uniform view of wind characteristics across the UK, and allows the wind patterns of all regions to be examined (even where wind farms do not exist).

For these reasons, the information presented here is based on an extensive analysis of UK Met Office wind speed records. Average hourly wind speed data have been collected from over 60 locations throughout the United Kingdom during the period 1970 to 2003, with a minimum of 45 sites providing valid data for each hour.

Met Office wind measurements are typically recorded close to ground level, whilst wind turbines typically operate at considerable height. The height of the centre of the turbine, known as the "hub height", is typically around 80m (262ft) – at this height, wind turbines are exposed to higher wind speeds than are recorded closer to the land surface. The Met Office wind speed measurements have therefore been corrected to compensate for the height of modern wind turbines.

Generating electricity from the wind

Wind energy conversion systems, more commonly known as wind turbines, convert part of the energy content of moving air into electricity. As the wind blows air across the blades of a turbine, aerodynamic forces are generated which cause the turbine to rotate; by connecting the blades of the wind turbine to an electricity generator, the energy forcing the blades to rotate is converted into electricity, which is then fed into the electricity network.

Wind turbine power

The power output of wind turbines is dependent on a range of factors, however turbine size and wind speed are strongly related to electricity output. The rated capacity of a wind turbine represents the maximum power (watts) that each individual wind turbine can produce under suitable wind conditions. Power is generally presented as kilowatts (kW, or 1,000 watts) or megawatts (MW, or one million watts). The *energy* produced by a wind turbine is equal to the power output multiplied by time – for example, a wind turbine operating at a power output of 100kW for five hours will produce 500kWh of energy.

Modern wind turbines have increased markedly in size, and hence power output, in recent years. Current wind power developments typically use wind turbines of around 2-3MW capacity, however earlier turbines had a significantly lower rated power output.

Wind turbines have a specific wind speed range within which they operate, with wind power output dependent on the speed of the wind. Table 1 and Figure 1 show the relationship between wind speed and power output for a 2.5MW wind turbine (based on the characteristics of a Nordex N80 wind turbine). For this turbine, electricity is generated by the turbine when the wind reaches 4 metres per second (4ms^{-1}, or around 9mph), and for safety reasons they shut down in wind speeds greater than 25ms^{-1} (around 56mph).

Between 4ms^{-1} and around 14ms^{-1} (32mph) the power output of wind turbines varies in response to changes in wind speed. Between 14ms^{-1} and 25ms^{-1} the power output of wind turbines has reached a maximum and is essentially constant, irrespective of wind speed changes (Figure 1).

Calculating wind power

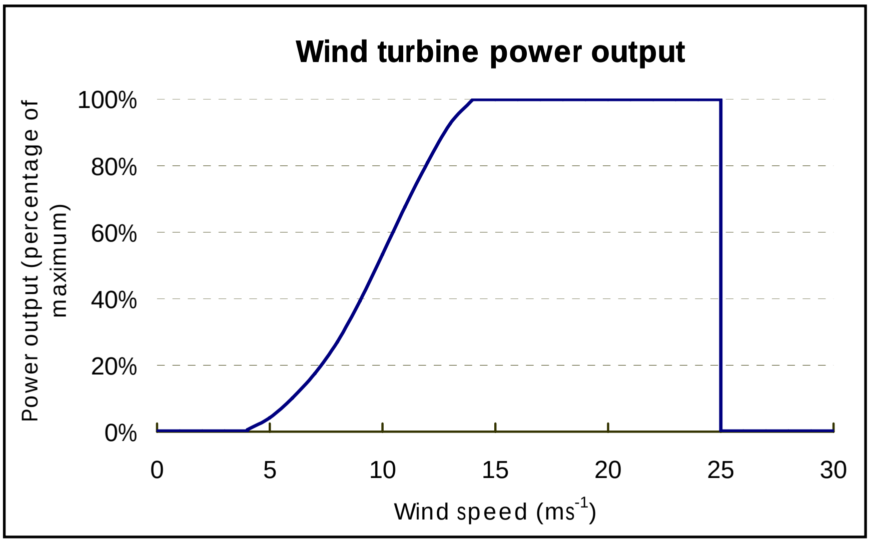
With the relationship between wind speed and power output known for a specific turbine, the wind speed measurements for the UK can then be converted into wind power output. This has been done for each hour in the study period of 1970-2003, and for each individual wind speed recording site.

Modelled wind power output can then be studied on a regional or national basis – this allows long term trends in wind power, patterns of wind power availability and extreme events in the wind climate of the UK to be examined.

Table 1 – Conversion of wind speed to power output for a 2,500kW wind turbine

Wind speed at hub height			Power output
ms^{-1}	mph	km/hr	kW
< 4	< 9	< 14	0
4	9	14	15
5	11	18	105
6	14	22	255
7	16	25	440
8	18	29	675
9	20	32	985
10	23	36	1,330
11	25	40	1,690
12	27	43	2,020
13	29	47	2,315
14	32	50	2,500
15	34	54	2,500
16	36	58	2,500
17	38	61	2,500
18	41	65	2,500
19	43	68	2,500
20	45	72	2,500
21	47	76	2,500
22	50	79	2,500
23	52	83	2,500
24	54	86	2,500
25	56	90	2,500
> 25	> 56	> 90	0

Figure 1



Characteristics of the UK wind resource

The characteristics of electricity generation from wind power in the UK are directly related to the characteristics of the wind resource. As the fuel for wind-generated electricity, the strength, presence, absence and variability of the wind determines not only how much electricity can be generated, but also how reliable electricity from the wind will be in meeting electricity demand patterns.

Wind resources vary between locations and countries; as a result, it is not possible to take the characteristics of one site in the UK and assume that it represents the overall UK wind resource. Similarly, it is not correct to assume that the characteristics of wind resources in other countries will be the same as the UK wind resource.

The information provided here is based solely on UK wind data, and therefore reflects the characteristics of the UK wind resource.

Figure 2

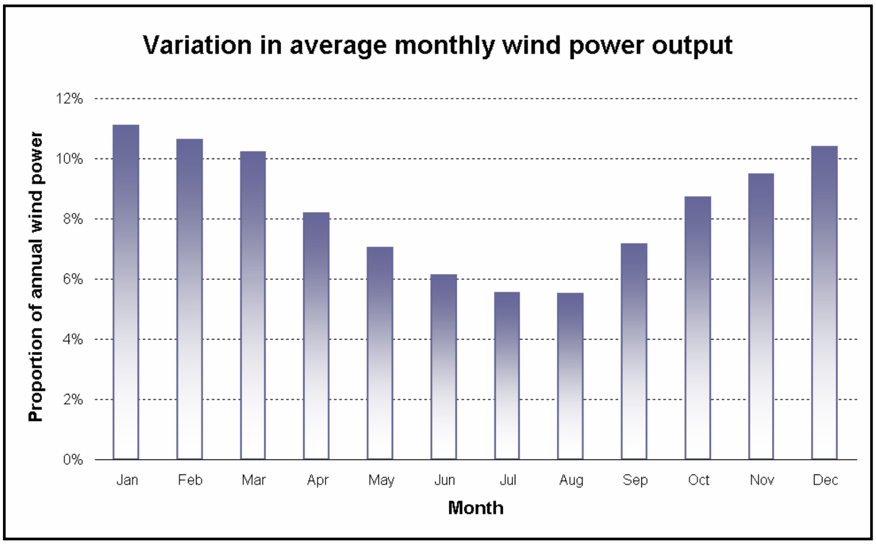
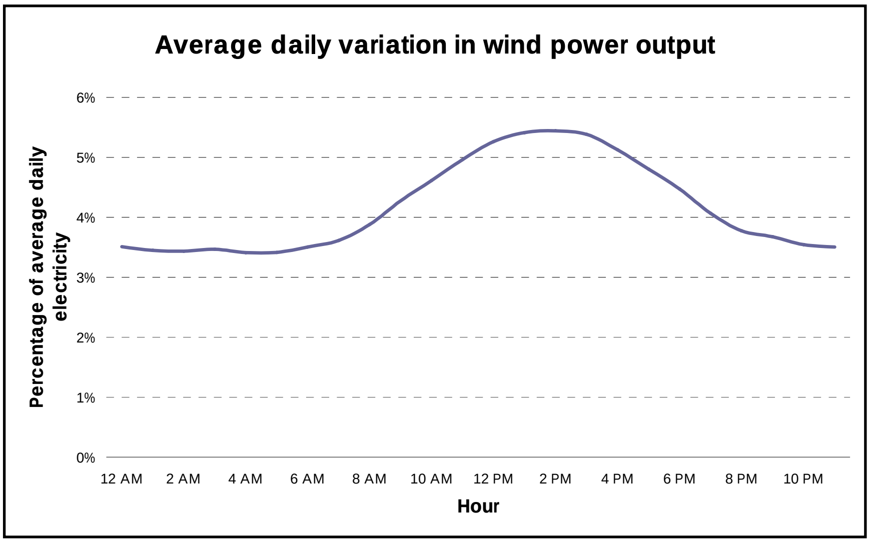


Figure 3



The importance of diversity

A diversified wind system is one where wind turbines are located in a range of locations, rather than being concentrated in one place. The advantage of a diversified system over a highly concentrated system is that the wind turbines are exposed to a range of wind conditions in different parts of the UK. For example, low wind speed conditions may be affecting Cornwall at a particular time, however strong winds may be blowing in Scotland. Unless all the UK's wind turbines are located in Cornwall, the impact of low wind speeds in this region will be smoothed by generation occurring in other regions of the UK.

Diversification does not imply that wind turbines have to be "everywhere" – the purpose of developing a diversified wind portfolio is to ensure greater reliability and lower variability in the electricity being generated by the overall system by exposing wind turbines to different regional patterns of wind variability and availability. Significant wind developments in different regions of the UK would form part of a diversified system.

The information presented here on the UK's wind resource characteristics is based on wind records from a range of sites across the UK, simulating a diversified wind power system.

Patterns of availability

The UK wind resource has strong seasonal patterns of availability, together with daily patterns of lighter and stronger winds.

Patterns of monthly wind speed create a long term pattern of wind power availability by month in the UK (Figure 2). This pattern of availability results in limited electricity production in summer and greater than average production in winter – on average, wind power delivers around twice as much electricity during the winter months of December, January and February as it does during the summer months of June, July and August.

Changes in wind power availability also occur on an hourly basis - on average, wind power is more available during the daytime than at night (Figure 3). While the average level of generation will vary by season, this trend of higher daytime power output is present irrespective of the time of year.

Whilst these patterns may initially be seen as a limitation, the availability of wind-generated electricity needs to be seen in relation to changing levels of electricity demand. The UK experiences significantly higher electricity demand during winter than in summer, while on a daily basis electricity demand is typically higher during the day and early evening than overnight and in the early hours of the morning. This broad similarity between wind power availability and electricity demand is examined further on page 6.

High and low wind events

Extreme wind events are a natural feature of the UK wind climate, and have a direct effect on the power output of wind turbines. At low wind speeds, there is insufficient energy in the wind to generate electricity, while at high wind speeds turbines will shut down as a safety measure. Given the potential impact of these events on electricity generation from wind, it is important to determine how likely these wind conditions are to occur.

Low wind speed conditions

It is common to refer to low wind speed conditions as "calm" periods but this underestimates the conditions when electricity generation will cease. Large wind turbines do not generate electricity in winds below $4ms^{-1}$, and so all hours where winds are below this speed are included in the definition of low wind speed conditions.

UK Met Office records show that whilst low wind speed conditions can be extensive, there was not a single hour during the study period where wind speeds at every location across the UK were below $4ms^{-1}$. On average there is around one hour per year when over 90% of the UK experiences low wind speed conditions (Figure 4), with these events being far more likely in summer. Low wind speed conditions extending across 90% or more of the UK during winter occur around one hour every five years.

Low wind speed conditions are far more likely to occur at individual wind sites, where they are experienced in around 15-20% of all hours. Low wind conditions are slightly more common in summer, however individual wind sites are also affected by these conditions during winter.

High wind speed conditions

Strong winds, storms and gales represent the other extreme of wind conditions, where high speed wind events result in wind turbines being shut down (and hence do not produce electricity). High speed wind conditions are those where wind speeds exceed $25ms^{-1}$.

High speed wind events are extremely rare in the UK – on average, high speed winds account for around 0.1% of hours each year at individual sites, while the single windiest site in the UK experienced high wind speeds for less than 2% of all hours. There has never been an occasion where the whole of the UK experienced high speed winds at the same time. The windiest hour in the study period affected around 43% of the UK – high wind speed conditions of a similar extent would be expected to occur around one hour every ten years.

Rate of change of output

The variability of wind power can lead to changes in power output from one hour to the next – this is known as the rate of change of output.

Changes in power output arise from changes in wind speed, however the amount of change depends on the wind speeds. For example, a change in wind speed from $14ms^{-1}$ to $18ms^{-1}$ will not alter the output of a wind turbine, however a change from $14ms^{-1}$ to $10ms^{-1}$ will cause a significant drop in electricity generation (see Table 1). The degree of diversification in the wind power system will also affect the rate of change, as power changes at one site may be offset by changes from other sites, smoothing the overall wind-generated electricity supply.

The most likely change in power output from a diversified wind power system from one hour to the next is less than ±2.5% of the total installed wind power capacity (Figure 5). Larger changes from one hour to the next do occur – a change in hourly output equal to around ±20% of the installed wind power capacity is likely to happen about once per year. Over the long term, around 99.98% of all hourly changes in wind power output from a diversified system will be less than ±20%.

Figure 4

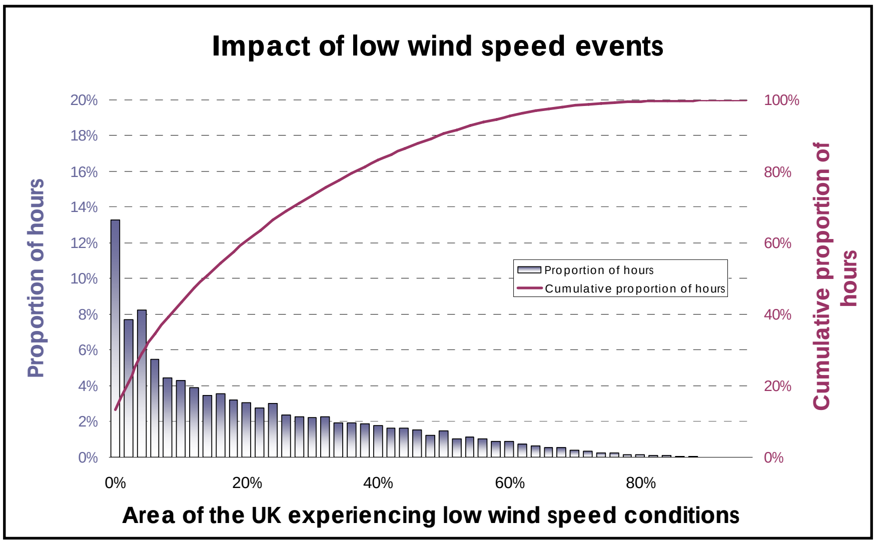
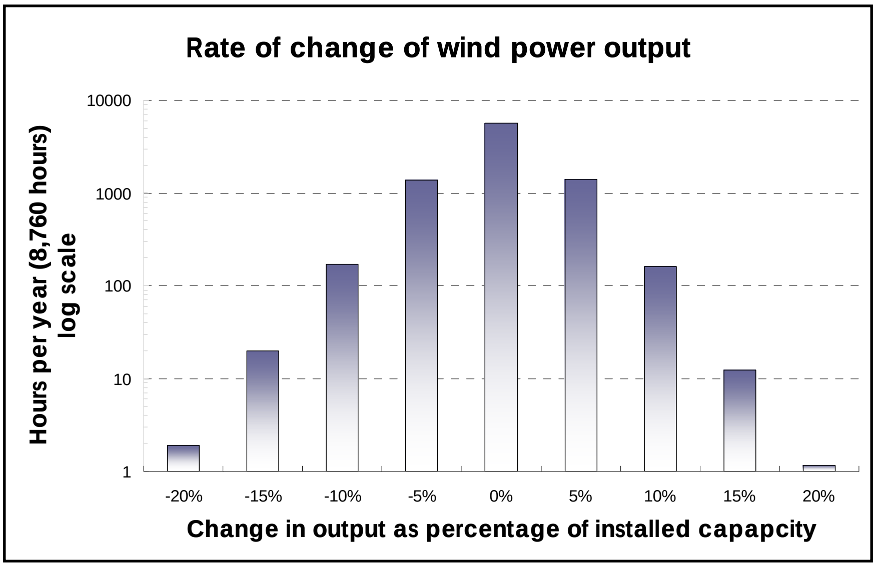


Figure 5



Wind power and capacity factor

The capacity factor (or load factor) of an electricity generator is a relative measure of the output of the device. Capacity factor expresses the output of the generator over a given time period (typically one year) as a percentage of the theoretical maximum output of the generator over the same time.

Capacity factor is often given as a "headline" statistic for wind power – while it is a useful measure of overall output, it does not represent a stand-alone measure for the success or otherwise of a generator. The usefulness of capacity factor in describing the characteristics of wind power and conventional generators is presented below.

What is capacity factor?

For conventional generators, capacity factor provides a measure of the utilisation of the generator. A high capacity factor would indicate that the generator is being used at close to its maximum theoretical output. Lower capacity figures show that the plant is operating well below its potential, however they give no information as to why this may be the case. There are many reasons why conventional plant may operate at a low capacity factor, ranging from poor operational reliability to periods required for maintenance and varying demand for electricity.

For wind power systems, capacity factor provides a measure of the amount of electricity generated by the turbines compared to the theoretical maximum output of the turbines under ideal wind conditions. Sites with a higher capacity factor will generate more electricity per turbine (or per MW of installed capacity); therefore, less installed generating capacity (or fewer turbines) is required at high capacity factor sites to generate the same amount of electricity as sites with lower capacity factors.

A high capacity factor may reduce the capital cost of a development, since more electricity will be delivered from less wind generating capacity. However, this may not always translate into lower overall costs – high capacity factor sites may be in remote or hostile locations, and the benefits need to be balanced against construction, maintenance and transmission issues.

What capacity factor is not...

Capacity factor is one measure of the overall performance and operation of generating capacity – it may be useful in terms of identifying sites or comparing output, but by itself it only describes one aspect of operation.

Capacity factor is sometimes confused with being a measure of the amount of *time* a generator runs – this is not the case. For example, a wind turbine could operate at maximum capacity for 30% of the year (and at zero for the remainder of the year), at 30% capacity for the entire year, or some combination in-between – in each cast the capacity factor would be 30%, however the number of hours of operation is different. In the UK, a typical wind turbine will generate some electricity for 80-85% of all hours in the year.

Capacity factor does not provide any information on either the *type* or *degree* of variability of a generator. It is not possible to decide that a generator with a capacity factor of 50% is twice as "good", or twice as "bad", as a generator with a capacity factor of 25% - there are many other factors that need to be taken into account.

Furthermore, it does not follow that simply because two generators have the same capacity factor they must have the same pattern of variability – for example, a generator running at 50% capacity for every hour of the year will exhibit no variability, whereas a generator with output switching from 0% to 100% each hour exhibits an extreme level of variability, yet both have a capacity factor of 50%.

Finally, capacity factor is sometimes confused with the *efficiency* of a generator – they are not the same thing. For conventional generators, efficiency is the delivered energy (electricity plus, occasionally, useful heat) expressed as a percent of the total energy input to the generator; a generator could be highly efficient at converting fuel into useful energy, but still have a very low capacity factor. For wind power, efficiency would represent the extraction of energy from the renewable resource. However, given that the fuel source is limitless and free, the "efficiency" of this conversion does not have the same meaning as the traditional concept of efficiency.

Capacity factor for the UK

Unlike conventional capacity, the capacity factor for renewable electricity generators is principally determined by the availability of the resource. For wind power, this means the wind climate at the sites where the wind turbines have been installed.

In the UK the annual capacity factor for wind power has varied from 24% to 31%, with a long term average of over 27% (DUKES, 2005) for onshore locations. These figures include periods where the wind turbines were unavailable either through planned maintenance or breakdown. The expansion of wind power to higher wind speed locations, including offshore, may result in capacity factor increasing in the future.

International comparisons

These figures reflect the wind climate of the UK, and compare favourably to the reported wind capacity factors for Denmark (around 20%) and Germany (around 15%). This variation in wind capacity factor by country reflects the wind resources of the different countries – exposure to Atlantic Ocean winds provides the UK with a more energetic wind resource (and therefore higher capacity factors) than for many other countries.

Wind power in electricity networks

The use of wind-generated electricity in electricity networks raises a number of issues related to the ability of wind to reliably contribute to meeting electricity demand.

There are a number of interlinking factors that determine the impact of wind power on electricity networks, including the availability of wind power during peak electricity demand periods, the degree to which additional backup capacity must be retained to ensure security of electricity supply, the additional reserve requirements of the network, and the implications for transmission requirements.

Wind power and electricity demand

While the focus of this report is on the properties of the UK wind resource, and in particular the variability of that resource, it must be remembered that electricity demand varies continuously. In the UK, peak electricity demand occurs during winter when dark and cold conditions drive electricity consumption higher, while electricity demand is at its lowest overnight in summer. This pattern of electricity demand has similarities with the long term average supply pattern for wind power.

By ranking each hour of the year by its electricity demand level, from lowest to highest hourly electricity demand, and determining the average contribution of wind power to demand in each hour, the long term relationship between electricity demand level and wind supply can be determined (Figure 6). This relationship demonstrates that, on average, wind power provides more electricity during times of peak electricity demand than at times of low electricity demand. The relationship also shows that the contribution of wind power during high electricity demand hours is higher than the long term average – in Figure 6, wind power has an annual average capacity factor of 28%; however, the average capacity factor during the top 10% of demand hours is over 36%.

This relationship does not mean that during every high electricity demand hour there will be high wind power output; there will be variability regarding the exact contribution that wind power will make in any hour. However, Figure 6 does demonstrate that the relationship between electricity demand and wind power availability is not random, and that there is a positive relationship between average hourly capacity factor and hourly electricity demand for the UK.

Ensuring a reliable supply

To ensure a reliable electricity supply, there must be sufficient electricity generating capacity available to meet demand. No electricity generator, whether a conventional or renewable generator, is 100% reliable. For this reason, the electricity system always has more generating capacity available than the expected demand.

Plant margin

Take the example of an electricity network with a peak demand of 70GW. To guarantee that demand will be met (to a given level of reliability), around 84GW of conventional capacity is required to be present on the network. The 14GW of "extra" generating capacity is known as the plant margin or system margin.

With 10% of the UK's electricity being generated by wind power, 13GW of wind capacity, together with around 81GW of conventional capacity, would be required to meet the same level of reliability (this assumes that wind power is the UK's sole source of variable electricity – an extremely unlikely scenario). The 81GW of conventional capacity includes the plant margin, some of which is required due to the variability of wind power.

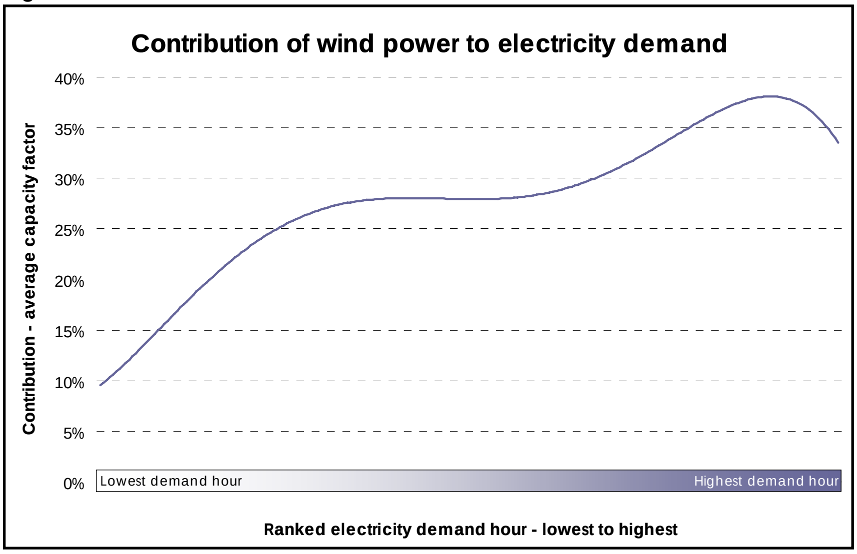
One way of viewing this change in capacity and plant margin is to determine the amount of conventional and wind power capacity required to generate 10% of annual electricity; around 5.3GW of conventional capacity generates the same amount of energy as 13GW of wind capacity (assuming a 35% capacity factor). Ideally, the wind plant would directly substitute for this conventional plant; however the variability of wind power means that not all of this conventional plant can be removed from the network.

In this example, 3GW (84GW-81GW) can be removed from the network due to the addition wind power while still meeting the reliability requirements of the network. As a result, 2.3GW (5.3GW-3GW) is retained because of wind power variability; this is equal to roughly 17% of the installed capacity of wind power.

Operating margin

The operating margin (also known as spinning reserve or backup) is the amount of extra capacity

Figure 6



that is immediately available to ensure a reliable electricity supply. The operating margin ensures that unforeseen events, such as higher than expected electricity demand or the failure of a conventional plant, do not result in the electricity network being unable to meet demand. When wind power is added to an electricity system, additional operating reserve is required because of the variability of wind power output.

The amount of operating reserve required at any one time is far less than the plant margin. It has been estimated that with 10% of UK electricity demand being met by wind power, around 700MW of additional operational reserve would be required in response to the variability of wind power – this is a little over 5% of the installed capacity of the wind plant (Milborrow, 2004).

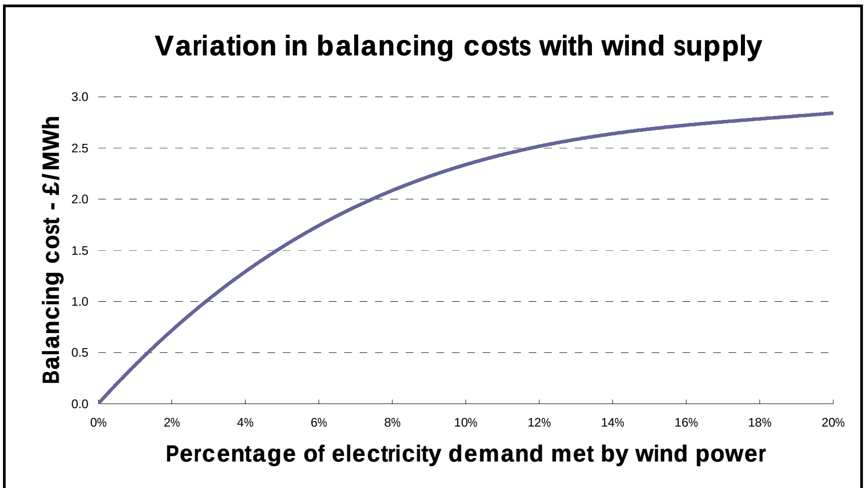
Transmission requirements

The large-scale development of wind power in the UK will require some existing transmission capacity to be upgraded, and some new transmission capacity to be added to the grid.

New wind power developments may be located some distance from existing electricity networks. In these cases, new transmission capacity will need to be installed to connect individual wind farms to the electricity network. Offshore wind developments will also require transmission capacity to bring the wind-generated electricity to shore, however this cost may in part be balanced by locating some offshore wind developments close to demand centres (eg London Array, Thames estuary).

The upgrading of transmission networks will be required where more electricity has to travel from the generating area to the demand centre. An example of this is the development of wind power sites in Scotland, with much of the electricity being consumed in England. The UK transmission network already connects Scotland and England, however this connection has a limited capacity and will not be able to accommodate the anticipated level of development in Scotland in its current form. As the amount of wind power in Scotland increases, it will be necessary to improve the north-south transmission link to ensure that flows of wind-generated electricity can be transmitted.

Figure 7



NGC data - Dale, 2002; Mott MacDonald 2003; Dale et al, 2004.
See Mott MacDonald 2003 for further information and discussion

Costs due to wind power

Wind power introduces additional costs to the electricity network. In common with all electricity generators, there are both construction and maintenance costs associated with the wind turbines; however, the variability of electricity supplied by wind power requires additional balancing on the network, and this represents an additional cost to the system. A number of studies have examined balancing costs for the UK in detail, including the System Costs of Additional Renewables report (2002), Mott MacDonald (2003), the House of Lords (2004) and Dale et al (2004) – details of these reports are included in the Further Reading section.

The most recent of these reports (Dale et al, 2004) concluded that the *total* additional costs for wind power were equal to around 5% of the standard cost of domestic electricity for a system with wind power generating 20% of all electricity. Following this analysis, the additional cost for 10% wind power is estimated to be around 2.5% of the standard cost of domestic electricity. These costs include the turbines, transmission costs and costs associated with balancing variability on the network, less the value of the saved fuel.

Balancing costs reflect the need to operate a small amount of plant to compensate for the variability of wind power. Balancing costs depend on the amount of amount of wind power connected to the network – with 10% of electricity being delivered by wind power the cost is around £2.38/MWh (0.24p/kWh) of wind-generated electricity, rising to £2.85/MWh at 20% wind power (Figure 7).

Costs and other renewable energy scenarios

The cost scenario above assumes that wind power alone provides the UK's renewable electricity supply. This is unlikely to occur in practice, as a range of renewable resources will be developed.

Some technologies, such as landfill gas or energy from waste, produce a low variability electricity supply that is not subject to additional costs such as balancing. Other energy sources such as waves and tides will show variability – however, a well-designed renewable electricity system would take advantage of the different patterns of variability to further smooth the overall supply of electricity generated from a combination of these resources.

The lower variability of a system combining different renewable energy resources would be expected to further reduce the balancing costs associated with renewable electricity systems.

Conclusion

Renewable energy represents one of a range of strategies to reduce carbon emissions of the UK. At the same time, the integration of wind power into the United Kingdom's electricity network needs to be achieved in a way that does not undermine the reliability of electricity supplies.

Understanding the characteristics of the United Kingdom's wind resource is an essential part of this goal, as the generation of electricity from wind power developments is fundamentally linked to the characteristics of the wind. This report has provided an overview of these characteristics, identifying seasonal and daily patterns of wind power availability. Within these patterns, wind power shows hour to hour variability in output, however many of these changes are small in comparison the installed capacity of wind power systems.

The occurrence of very low or very high wind conditions in the UK is limited in both duration and extent, with these conditions never affecting the whole of the UK at the same time. As a result, the development of a diversified wind power system would allow electricity generation by the wind throughout the year.

The combination of greater than average output from wind turbines during winter and higher electricity demand during winter results in wind power providing around 2½ times the amount of energy during periods of peak electricity demand compared to periods of minimum electricity demand.

Issues surrounding the capacity factor of wind power systems were discussed, in particular the limitations of this measure of generator performance. The capacity factor for wind turbines operating in the UK was found to be higher than that reported by wind operators in some other European countries.

The integration of wind power into electricity networks was discussed, including the implications of wind power for plant margin and operating margin, and the changes to transmission that may be brought about by wind developments. The reported costs related to the variability that wind power brings to the electricity network were presented, and found to be modest in comparison to current household electricity costs.

Further reading

In addition to work carried out by the Environmental Change Institute, this report has drawn on the work of other researchers and institutions, including:

Dale, L., 2002.
Neta and wind.
EPSRC "Blowing" workshop, UMIST

Dale, L., Milborrow, D., Slark, R. & Strbac, G., 2004.
Total cost estimates for large-scale wind scenarios in the UK.
Energy Policy 32.

Digest of UK Energy Statistics, 2005
Department of Trade and Industry, UK
http://www.dti.gov.uk/energy/inform/dukes/dukes2005/index.shtml

House of Lords Science and Technology Committee, 2004
Renewable Energy: Practicalities.
HL Paper 126.
http://www.publications.parliament.uk/pa/ld200304/ldselect/ldsctech/126/12602.htm

Milborrow, D., 2004
Evidence to House of Lords Science and Technolgy Committee
In: Renewable Energy: Practicalities. HL Paper 126

Mott Macdonald, 2003
Renewables Network Impact Study – Annex 4
Intermittency Literature Survey & Roadmap
http://www.thecarbontrust.co.uk/carbontrust/about/publications/Annex4.pdf

There are a number of additional reports that consider similar or related topics, including:

Carbon Trust, DTI & Mott MacDonald
Renewables Network Impact Study
http://www.thecarbontrust.co.uk/carbontrust/about/about5_3.html

Grubb, M., Butler, L. & Twomey, P., 2005
Diversity and Security in UK Electricity Generation: The Influence of Low Carbon Objectives
Energy Policy, in press

International Energy Agency
IEA Wind Energy Annual report
http://www.ieawind.org/

Ofgem
Securing Britain's Electricity Supply.
http://www.ofgem.gov.uk/temp/ofgem/cache/cmsattach/11702_soselecupdatemay05.pdf

Oxera
Results of Renewables Market Modelling.
http://www.dti.gov.uk/renewables/policy/oxeraresults.pdf

Sinden, G., 2005
Characteristics of the UK Wind Resource: Long term patterns and relationship to electricity demand.
Energy Policy, in press.

Sustainable Development Commission
Wind Power in the UK
http://www.sd-commission.org.uk/pages/media/list/wind.html

UK Energy White Paper
Department of Trade and Industry
http://www.dti.gov.uk/energy/whitepaper/index.shtml

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