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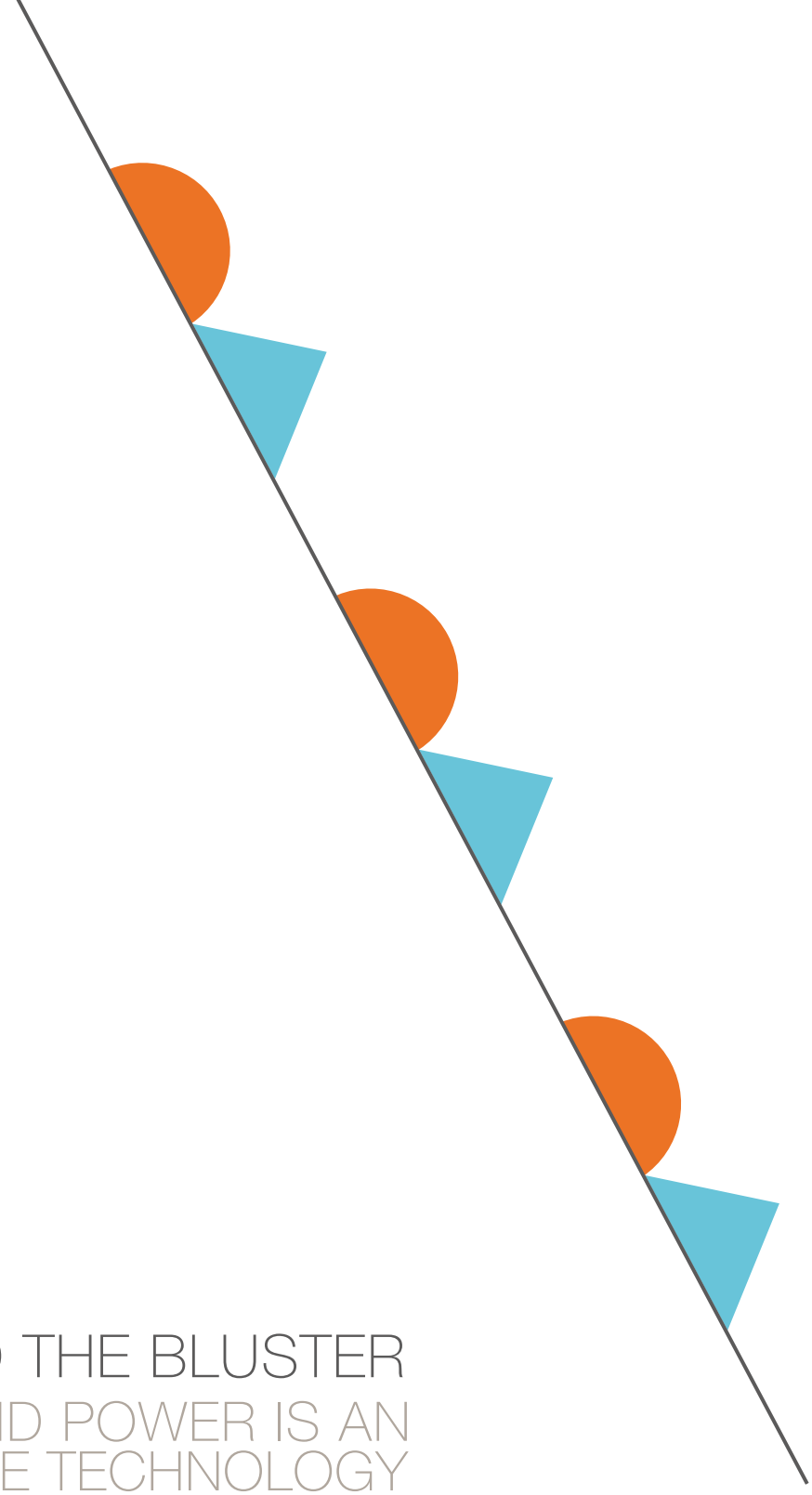

BEYOND THE BLUSTER

WHY WIND POWER IS AN EFFECTIVE TECHNOLOGY

Institute for Public Policy Research

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GETTING 'BEYOND THE BLUSTER' ON WIND POWER

FOREWORD BY REG PLATT, IPPR

The British Isles sit at Europe's windy Atlantic fringe. As a result of its exposed location, the UK has the greatest potential for wind power of any European country, both onshore and offshore (DECC 2012a). This resource, when combined with the UK's engineering heritage and the right market and policy framework, could be a source of significant economic opportunities for the UK. However, whether or not Britain should pursue an ambitious wind power strategy is hotly contested.

In February 2012 a group of more than 100 MPs sent a letter to David Cameron arguing for a cut in government support for onshore wind power.[1] Many of these MPs are based in rural constituencies where onshore wind developments may be sited. Wind farm developments are sometimes strongly opposed by people in local areas and it is right that their views are properly considered in debates about how we generate electricity. At the same time wider public opinion, which consistently and strongly supports wind power, should also be considered (see for example DECC 2012a).

Similarly, with households' budgets under pressure and energy bills at high levels, it is right that the costs of government support for wind power and other low-carbon technologies are scrutinised. However, it is important to recognise that recent increases in energy bills are far less the result of subsidies for renewable power than they are due to rises in the wholesale cost of gas. From 2004 to 2010, government support for renewables added £30 to the average energy bill while rises in the wholesale cost of gas added £290 (CCC 2011a).

Despite these legitimate concerns about local impact and cost, much opposition to wind power appears to be based on the belief that it is an ineffective technology. For example, in the letter sent to David Cameron, the technology was described as 'inefficient' and less reliable than other energy sources. This claim is untrue and it is important to get 'beyond the bluster' in assessing the effectiveness of wind power.

IPPR has worked with GL Garrad Hassan, a leading renewable energy consultancy, to produce this report, and the findings have been reviewed by a leading academic. The report addresses two commonly held misconceptions around two important, often misunderstood, questions:

- Is wind power an effective way of reducing carbon emissions?
- Is wind power a secure and reliable source of energy for the UK?

This report shows unequivocally that wind power can significantly reduce carbon emissions, is reliable, poses no threat to energy security, and is technically capable of providing a significant proportion of the UK's electricity supply with minimal impact on the existing operation of the grid. Claims to the contrary are not supported by the evidence.

1 http://www.telegraph.co.uk/earth/energy/windpower/9061554/Full-letter-from-MPs-to-David-Cameron-on-wind-power-subsidies.html

Wind power and energy policy

The government is committed to securing Britain's energy supply, keeping consumers' energy bills as low as possible, and reducing carbon emissions in line with its legal commitments. As part of this process, the government has pledged to produce 15 per cent of the country's energy and 30 per cent of the country's electricity from renewable sources by 2020. Wind power has a vital role to play in meeting these objectives.

Onshore wind is one of the most cost-effective of the low-carbon technologies and, with continuing government support, the average wind farm globally may produce power at costs that compete with fossil fuels as soon as 2016 (BNEF 2011). This means that it is an important technology for keeping down the costs of reducing emissions and meeting the 2020 renewable target. A low ambition for onshore wind would mean a greater amount of generation from other, more expensive, technologies and, therefore, higher electricity bills.

Offshore wind is more expensive than onshore wind but the cost is expected to come down rapidly (DECC 2012c). It is capable of providing huge amounts of low-carbon electricity for the UK (potentially 45 per cent of the UK's total electricity needs in 2030 (CCC 2011b)) and can make a major contribution to the 2020 renewables target. It could also generate significant benefits for the economy, with the Carbon Trust estimating it could contribute £3–10 billion annually between 2010 and 2050 (Carbon Trust 2011). The energy minister, Charles Hendry, has described offshore wind as 'an industry of strategic national importance' for the UK.

In light of these important and positive potential outcomes for the UK, wind power should be the subject of a balanced debate based on accurate evidence. False claims that influence policy outcomes and result in a low ambition for the technology could sacrifice important opportunities for the British economy. Inconsistent support from government will increase the riskiness with which businesses regard investment opportunities and increase their cost of capital. This will ultimately mean higher energy bills for consumers and businesses.

The government's recent approach to wind power is worrying. Although a decision has now been reached to reduce financial support for onshore wind by the anticipated amount of 10 per cent, rather than 25 per cent as HM Treasury had preferred, the postponement of the announcement and the decision to almost immediately conduct a further review of this support level has created widespread concerns in the industry.

It is entirely proper that subsidies for wind power are not overly generous and that local concerns are taken into account through the planning process with opportunities for local residents to share in the dividends of local development. But an ad hoc approach to policymaking based on political whims is not the right approach. The government should only alter support levels for wind power, and any other low-carbon technology, on the basis of evidence that has been published and consulted on in a timely fashion with industry.

The transition to a secure, affordable and low-carbon energy system will be extremely challenging and an important subject of debate for years to come. This report does not attempt to provide all of the answers. Nor does it aim to bring an end to the debates on wind power. Instead, we hope to show that of the many challenging issues that must be resolved, the area of wind power technology is one of the least troubling.

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TECHNICAL REPORT ON THE EFFECTIVENESS OF WIND POWER TECHNOLOGY

OSCAR FITCH-ROY AND PAUL GARDNER, GL GARRAD HASSAN

EXECUTIVE SUMMARY

This report aims to improve the quality of public debate on wind power by addressing two common misconceptions about wind power technology:

- Is wind power an effective means of reducing carbon dioxide emissions?
- Is wind power a secure and reliable source of energy for the UK?

We show that the answer to both of these questions is unequivocally 'yes'.[2]

Is switching to use more wind power an effective way of reducing carbon emissions?
Wind turbines convert wind into electrical energy without emitting polluting gases. However, the effectiveness of wind power in reducing emissions has been questioned. Using a simple model we show that every megawatt-hour (MWh) of electricity produced by wind power in Great Britain results in a minimum CO_2 saving of around 350kg. On this basis **carbon dioxide emission savings from wind energy were *at least* 5.5 million tonnes in Great Britain in 2011.** While this is a reliable minimum, there are good reasons to think that the actual figure is considerably greater (DECC 2012) and empirical examples from electricity systems in the US support this conclusion.

Is wind power a secure and reliable energy source?
Although wind is a variable energy resource, it can be easily integrated into electricity systems. Wind power output is predictable and varies at similar rates to existing electricity demand. **Our ability to 'keep the lights' on during 'cold, calm spells' is secure at the levels of wind power projected for the UK by 2020.** The experience of overseas systems such as the Iberian peninsula and island of Ireland show that the level of wind contribution expected by the government in the UK in 2020 is achievable. We show that there are several adaptations to the grid that could enable a much greater contribution from wind.

Conclusions
Wind power is a potent way of reducing carbon emissions. It is reliable, it does not threaten energy security and it is technically capable of providing a significant proportion of the UK's electricity supply with no impact on the security of the grid.

2 The contents of this technical report have been peer reviewed by Professor Nick Jenkins, institute leader at the Institute of Energy, Cardiff University.

1. IS WIND POWER AN EFFECTIVE WAY OF REDUCING CARBON EMISSIONS?

In common with all technologies that convert natural, renewable resources into useful electrical energy without combustion, wind turbines, once built, do so without emitting polluting gases of any kind. In operation, they are a near-zero-carbon technology. Conversely, the energy sources that currently supply the bulk of the UK's electricity are fossil fuels – combustion of which is a major source of CO_2 (among other pollutants). This means the question 'is wind power an effective way of reducing carbon emissions?' should be easy to answer with a simple 'yes'. Nevertheless, wind power's ability to reduce carbon emissions has recently been called into question (Lea 2012).

This section shows that not only does wind power unambiguously save a significant amount of carbon but also that analysis used to reach contrary conclusions is conceptually flawed. Below we outline and compare two methodologies for assessing the contribution of wind power to reducing carbon emissions and calculate the impact wind power had on the UK's emissions in 2011.

1.1 The marginal emissions approach to calculating emission savings: a simple 'steady-state' model

Demand for electricity at any point in time is met by a wide range of generating technologies (including wind and other renewables). A logical first step to calculating the impact on CO_2 emissions of adding wind power to the system is therefore to establish which of the many types of electricity generation this wind power will replace.

To ascertain this, we need to think about how supply adjusts to meet demand in the electricity system and use this model to tell us something about what happens when changes are made – in this case adding wind generation. To maintain the stability of the electricity system supply must equal demand at all times. However, in Great Britain's[3] electricity market, like nearly all electricity systems, supply *tends* to increase and decrease in response to changing demand, on a minute by minute basis, based on the price for which each power station is willing to supply an additional unit (a megawatt hour, MWh) of electricity. As demand increases, generation types with low marginal cost of production are selected (by the market) first. As demand for electricity increases, generation types with progressively higher marginal costs begin operating – the generation type that has the highest marginal cost being the last to start generating in response to increases in demand and the first to shut down as demand reduces. This generation type is known as the 'marginal plant'.

Electricity from renewables such as wind power has some unique economic properties. The most significant of these is the near-zero marginal cost which arises from the fact that a wind turbine does not require any economic inputs (such as fuel) to generate electricity. From this, it can be surmised that wind power will be chosen before fossil-fuelled stations,[4] since these have a higher marginal cost. Adding wind energy to electricity supply without altering demand will displace or push out an equivalent amount of supply from the marginal plant.

Having established a simple model of the electricity system, in order to estimate the carbon impact of adding wind energy we need to first establish which generation type is the 'marginal plant' and secondly how much CO_2 it emits.

In the UK there are two fossil-fuel candidates for the role of the most common 'marginal plant' – coal and gas. There is plenty of publicly available data to draw on to make an

3 The electricity system 'GB' includes England, Scotland and Wales but excludes Northern Ireland which is combined with the Irish electricity system.

4 In fact, the nature of the UK market means that wind power is almost always taken before fuelled generation.

assessment of how much CO_2 these emit. For example, the Department of Energy and Climate Change (DECC) states that coal fired power stations emit 909kg of CO_2 for every MWh produced (MacLeay et al 2011). The most fuel-efficient (and therefore carbon-efficient), widely used form of new gas-fired generation, the combined cycle gas turbine (CCGT) power station, emits 354kg per MWh (DECC 2011).

In 2011, wind power contributed approximately 15.5 terawatt hours (15.5 million MWh) to the UK's electricity generation (MacLeay et al 2012). Using the approach outlined above – if gas (CCGT) was the marginal generation type then wind power saved over 5.5 million tonnes of CO_2 from being emitted. But if coal was the marginal plant then wind power prevented the emission of over 12 million tonnes. Following this logic we can say that, using government figures about electricity generated in the UK from wind and the carbon intensity of the very best available gas technologies, the **CO_2 savings from wind energy were at least 5.5 million tonnes in 2011**. This is around 2.5 per cent of the emissions the UK is legally obliged to save annually from 2008 to 2012, as required by the Climate Change Act 2008 (CCC 2008). In reality the current impact of wind power on emissions is likely to be considerably greater than this minimum figure.

Complicating factors

The 'marginal plant' model of the carbon impact of wind is a very convenient and immediate way of understanding the effect that wind power will have on the electricity system's carbon emissions. However, it is based purely on the short-run marginal costs of generation and a number of other simplifying assumptions that introduce some uncertainty about the results. The two most significant of these are, firstly, that it assumes the marginal plant is the 'best available', newest technology and secondly, that as wind is added to the system, generating stations turn on and off in discrete blocks of capacity and without any effect on the way in which fossil-fuelled plants operate in general.

These two simplifications have opposing effects on the carbon savings estimated by the steady-state approach.

- Wind power is more likely to displace higher emitting types of generation than to replace the newest, most efficient CCGT plant: the marginal plant is unlikely to have been a brand new CCGT in 2011 when older and less efficient gas plants with higher marginal costs of production would have been withdrawn from the system before the newest stations. In fact there are good reasons to believe that the marginal emissions of the GB grid will be considerably higher than the minimum estimate some way into the future with a value of 500kg/MWh predicted in 2025 (Hawkes 2010). The assumption that the marginal plant is the newest, most efficient technology available leads the marginal emissions approach to understate carbon savings.
- Adding wind power causes dynamic changes to occur in the operation of fossil-fuelled stations which may impair their efficiency and therefore reduce carbon savings: these effects stem from the fact that not only does wind displace carbon-emitting fossil-fuelled generation, but adding wind generation also causes changes to the operational behaviour of the fossil fuel generation that remains on the system. Remaining fossil-fuelled plants may function in less efficient (and therefore more carbon intense) modes as a result of changes in electrical output from wind power in both the short and medium term.[5] Although it is difficult to estimate a precise value, the steady-state model may overestimate the carbon savings from wind power.

5 Variability effects are considered in depth in the following chapter of this report, which looks at the security and reliability of wind power.

The effects of these factors on the actual carbon saving offered by wind power are hard to determine with any certainty. One method to assess savings would be to use a computer model, but the model would need to reach a level of sophistication with a depth of data not currently available for the UK (see box 1). Another more practical solution is to physically measure the carbon intensity of the electricity system and watch what happens as wind power output fluctuates. While we do not have a rigorous, in-depth empirical study of the UK system available to us, we can look to international examples.

Box 1: Modelling carbon savings

Although it is an attractively simple alternative, a model that considers the behaviour of a single fossil-fuelled power station and its response to the variation in output from a single wind farm would be wholly inadequate for assessing the CO_2 savings of wind power.[6] The fundamental error is the assumption that the sole driver of changes to a conventional power station's output is a change in output from a particular renewable station. Significant averaging occurs as changes in electricity demand, along with variations in wind output, are balanced in aggregate by the entire electricity system. Also, as discussed elsewhere in this report, the total generation from a distributed fleet of wind farms varies less, and more slowly, than that from a single location. These factors significantly affect the estimation of fuel and emissions savings.

One way of estimating the impact of these more dynamic effects could be to create a computer model of the electricity system which is sufficiently sophisticated to capture them. The bad news about this kind of modelling is that, to be useful for our purpose, it would need to have a level of detail on the characteristics of fossil-fuelled generation that is not currently achieved, particularly on emissions, and how they are affected by varying electricity output. Commercially available electricity market modelling tools and models created by economic consultancies, universities and government can certainly be used to explore issues of system emissions but we are not aware of any modelling with the actual emissions from each type of generation on the system under all operational conditions as inputs. We would welcome the insight that would be provided by this kind of work.

1.2 An empirical approach to assessing the carbon savings from wind power

A 2011 study published by United States Association for Energy Economics (USAEE) into the performance of three (out of 10) independent electricity systems in North America looked at the measured emissions[7] of several industrial pollutants from power stations, including CO_2 (Kaffine et al 2011[8]). This study examines tens of thousands of hourly measurements which fossil-fuelled power station operators in California, Texas and the Midwest are required to take. These systems cover 60 per cent of installed wind power in the US. The results are unequivocal. The wind energy being supplied to the electricity grid in all of these regions significantly reduces the average carbon intensity, as is shown in table 1.

6 This was the basis of research that underpinned Lea 2012.

7 In the systems studies, a large majority of power stations are required by the Environmental Protection Agency to report hourly emissions: Continuous Emissions Monitoring http://www.epa.gov/ttn/emc/cem.html.

8 This paper is currently under peer review.

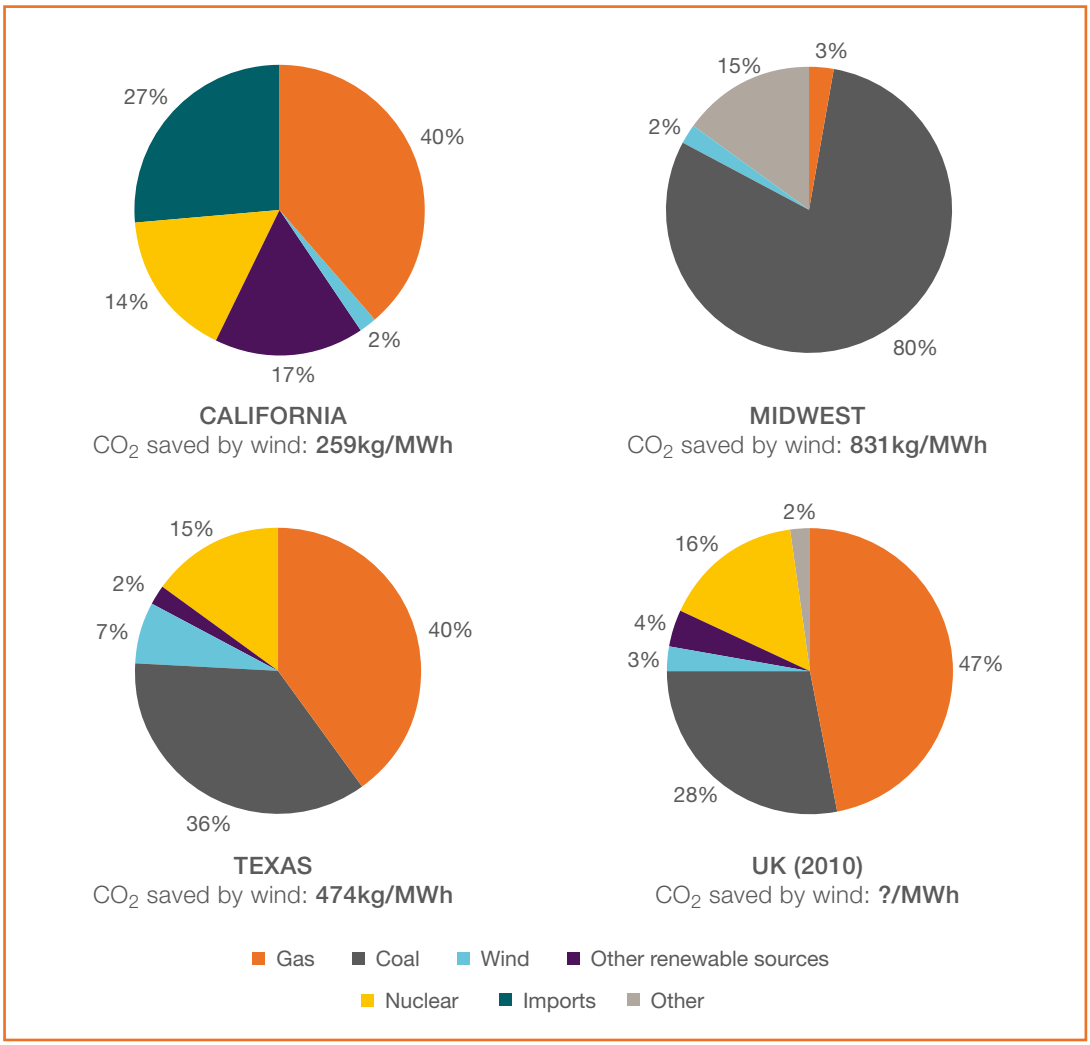
Table 1
Measured emissions reduction attributable to wind

	ERCOT (Texas)	MISO (Midwest)	CAISO (California)
Wind energy as % of total electrical energy generation	7%	2%	2%
Average carbon dioxide saving of wind energy	474kg/MWh	831kg/MWh	259kg/MWh

Source: Kaffine et al 2011

By collecting data from three regions with very different generation mixes, the study, in addition to supporting the conclusions of the steady state analysis, allows us to test some of its assumptions. Results from empirical studies such as these are highly system-specific and the actual generation mix in a particular system (as well as the behaviour of the electricity market, consumers, the wind conditions, etc.) will have a potentially large impact on the results. Nevertheless, certain cautious inferences can be made. Figure 1 shows the breakdown of electricity supply by type in terms of energy produced in 2009 in the three US regions, with the UK's current energy mix included for comparison.

Figure 1
Comparison of electricity supply mix for three US systems (2009 data) and the UK in 2010



Source: Potomac Economics 2011, CAISO 2009, RCT 2011, MacLeay et al 2010

The data clearly shows that the region with the greatest proportion of coal in the energy mix – Midwest – demonstrates the greatest saving of carbon emissions per MWh of wind generation, and the system with the lowest proportion of coal generation – California – demonstrates the lowest savings per MWh. Since the Midwest region has such a high proportion of coal, it is likely that coal is the 'marginal plant' a significant proportion of the time[9] (Potomac Economics 2011) while in California the same is likely to be true of gas (CAISO 2009). This is in line with the assumptions of the marginal emissions model of estimating carbon savings.

We can also see that the system with the most similar energy mix to the UK, Texas, sees carbon saving results of 474kg/MWh – which is consistent with the minimum estimate derived above of 350kg/MWh for the UK based on marginal emissions.

1.3 Summary

By examining two approaches to estimating carbon emissions from electricity systems and presenting the results of a study into real-world emissions we have been able to draw several conclusions.

1. **We estimate minimum carbon savings of 350kg CO_2/MWh as wind power is added to the UK's electricity system.** However, this presents an estimate based on certain simplifying assumptions rather than real-world emissions data or a fully dynamic model of the electricity system. We are not aware of any such modelling work, and can see a number of reasons why creating one with sufficient accuracy to be meaningful would be difficult.
2. Emissions data from the US provides some interesting insights into the carbon performance of different electricity systems. These empirical results confirm that wind power saves carbon emissions in systems with a diverse range of energy mixes. We can also see that **systems in which the marginal plant is more carbon intensive display greater carbon savings due to wind – validating the marginal emissions approach to estimating carbon savings.**
3. Furthermore, in a system with a fuel mix not dissimilar to that in the UK, the physical carbon saving by wind power is consistent with our estimate of a lower bound for the UK system derived using the marginal emissions approach. We acknowledge that there are uncertainties when drawing inferences from other electricity systems for the UK and believe there is value in a future study into the physical emissions from UK electricity generation.
4. It is reasonable to conclude that the marginal emissions approach to carbon savings gives a reliable minimum estimate of at least 350kg CO_2/MWh with compelling reasons to suspect that the actual figure is considerably higher. This means that **the CO_2 savings from 15.5TWh of wind energy in 2011 were *at least* 5.5 million tonnes.**

9 In fact, in 2010 coal was the marginal plant and 'set the price' 92 per cent of the time (Potomac Economics 2011).

2. IS WIND POWER A SECURE AND RELIABLE ENERGY SOURCE?

The natural variability of wind is obvious to the most casual of observers – some days are windier than others. Often this can lead to conclusions being drawn that question how reliable and secure wind power is as an energy source.[10] However the reliability and security of wind power does not depend on the variability of wind but, instead, on how well changes in wind power output can be predicted and managed.

This section demonstrates that the variability of wind power does not mean that it is either unreliable or that it is insecure. Indeed, fossil-fuelled and nuclear stations have their own challenges with intermittency (see box 2). With reference to what has already been achieved on other electricity systems, we show how the existing mechanisms for balancing supply and demand on the grid should be able to accommodate the level of wind power expected in the UK in 2020. We also describe some ways in which the grid can adapt to accommodate far higher levels of wind power (or other variable generation technologies) than is expected in 2020 while maintaining the security and reliability of power supplies.

Box 2: Variability and intermittency as terms for describing different generation technologies

The word 'intermittent' is often used to describe changes in wind power output. Intermittency can be construed as meaning that changes in wind power output are unpredictable and shift between 'on' and 'off', whereas wind power output changes over time in a predictable manner. For this reason we choose to use the term 'variable', which we believe gives a more accurate description.

In fact, the term 'intermittent' might more accurately be used to describe other types of generation. For example, in the event of a technical failure or an unplanned outage to a fossil-fuelled generation unit (depending on the number of units that the station comprises) up to 100% of the station's capacity could be suddenly and unexpectedly withdrawn from the network. Also, nuclear power stations have to be shut down completely for around one month in every 18 while maintenance work takes place (IPPR Trading Limited 2012). A similar outage to a turbine in a wind farm of a large number of individual turbines would have minimal impact on the generation capacity of the system.

2.1 Managing the variability of wind power output

The electricity system in Great Britain must accommodate a constantly varying level of demand for power. A well-known example of a dramatic change in demand that often occurs is when a popular TV programme ends and large numbers of people switch on their kettles at the same time. The electricity grid is designed to accommodate this variability and the mechanisms that enable changes in demand to be accommodated can also accommodate changes in output from variable generation sources like wind power. Before considering whether the grid can cope with the specific challenges posed by wind power variability it is first necessary to understand how variability in demand is accommodated more generally.

10 See for example terminology used in this *Telegraph* article, 'Wind power a policy spinning out of control' http://www.telegraph.co.uk/comment/telegraph-view/8771172/Wind-power-a-policy-spinning-out-of-control.html; and this letter to the prime minister from a number of MPs: http://www.telegraph.co.uk/earth/energy/windpower/9061554/Full-letter-from-MPs-to-David-Cameron-on-wind-power-subsidies.html

The level of electricity supply on the grid must at all times closely match the level of demand. Over- or under-supply risks power interruptions for energy users. There are two main means of ensuring that supply and demand remain in balance. For the most part balance is achieved through the functioning of the electricity market. If, however, supply or demand deviate from what is expected then the system operator, National Grid, has a remit to buy additional power, sell excess power or require generators to produce less power to balance the system on a half-hourly basis (Elexon 2011). Working in combination these mechanisms ensure the smooth and efficient operation of the electricity grid.

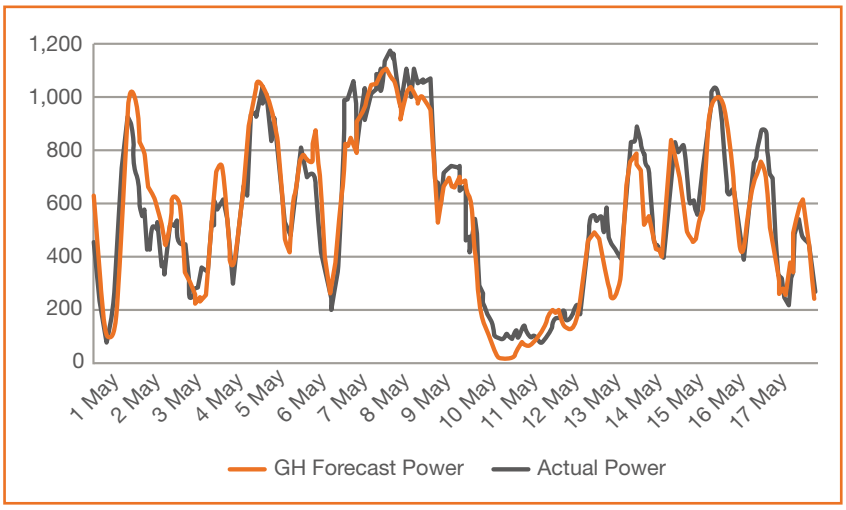
To understand whether the existing grid can cope with wind power variability we must look at the predictability of wind power and the specific types of variability that are characteristic of wind power.

The predictability of wind power

In the same way that a change in demand due to a national TV event can be predicted, so can the output from wind power – with a high degree of accuracy. Forecasting wind farm output, which is based on meteorological modelling and refined over time, is an increasingly accurate tool (Giebel et al 2007) used by electricity system operators, power asset owners and electricity traders worldwide. As one might expect, wind power forecast accuracy increases significantly as the time of energy delivery approaches. Further, the predictability of output from a portfolio of wind farms (at a national level, for example) is significantly better than from individual sites. The predictability of wind power output allows market participants and the system operator to see changes in wind coming.

The figure below is an illustration of just how accurately the output of a portfolio of wind farms can be forecast 24 hours ahead.

Figure 2
A comparison of 24-hours-ahead output forecast with actual power delivery (MW)



Source: GL Garrad Hassan

A variable resource

Variability in wind power output over minutes or hours presents very different challenges and requires different responses to variations over longer periods, such as when there is a 'long, cold, calm spell'. We address these issues in turn below.

A. Rates of change of wind power output in the short term

Although wind may seem fickle at street level, at a national or system scale, wind power production varies remarkably slowly. Due to the averaging effects that occur first as wind speed is averaged across the rotor disc of an individual turbine, then across the electrical output of a number of turbines in a wind farm and, finally, the large-scale spatial averaging that occurs across the entire dispersed wind fleet of a country, there is no significant variation of wind power output on timescales of minutes. This is illustrated in figure 3 which shows, at five-minute resolution, the output of all wind generation visible to the GB system operator, for a sample day.[11]

Statistical analyses of lengthy records of wind farm output data indicate that the most extreme variations are of the order of 20 per cent of total wind generation capacity in half an hour (GL Garrad Hassan 2011).The highest rates of change are similar to the rates of change of electricity demand already experienced by system operators. For example, between 6am and 8am on weekday mornings as people get up, make breakfast and head to work. Therefore short-term changes in the rate of wind power output are easily accommodated in the existing system.

It is of course true that, in the worst case, wind production could drop just as electricity demand is rising, thus making the system operators' job harder. However it is important to reiterate that changes in wind production are to a large degree predictable: the operators can see rapid changes coming, or at the very least, be forewarned of the risk of rapid changes. On the rare occasions when this could cause difficulty, electricity system operators can instruct the wind generation segment of the system to limit the rate at which its output increases, or to reduce its output gradually in advance of a reduction in wind speed.

Figure 3
Wind production, GB system, sample day (31 Dec 2011), five-minute averages (MW)

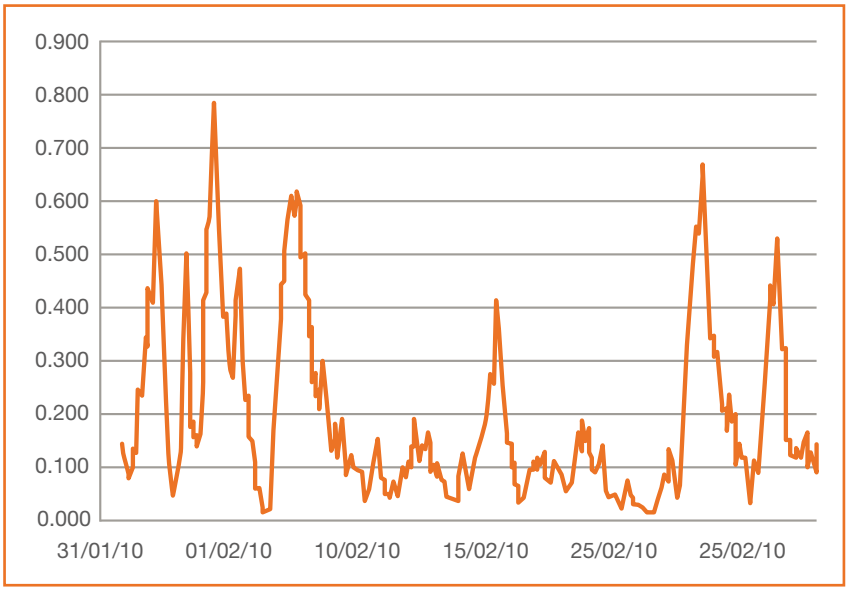
Source: Elexon 2012

11 The sample day was chosen because wind output was relatively high but below the maximum output. In this state, the wind turbines will be operating below but close to rated output, which is the region in which the power curve is steepest. In this region, variations in wind speed can be expected to produce the greatest variations in output power.

B. Secure and reliable energy during a long, cold, calm spell

While short-term variability in wind power output is fairly straightforward for the grid to manage, a more critical issue is the 'long, cold, calm spell' – an extended period of anticyclonic weather during winter, when low wind speeds, low temperatures and high electricity demand conspire to challenge the electricity system. These events do happen and figure 4 shows one such period where wind production averaged less than 15 per cent of wind capacity over a period of 14 days, from around 9–23 February 2010, in this case in Ireland – a system with far greater wind generation as a proportion of total generation than the current GB system.

Figure 4
Example of a 'long cold calm spell' in Ireland, Feb 2010 (wind energy production as a proportion of installed wind capacity)



Source: Eirgrid 2012

The extreme weather event experienced in this example did not impair the ability of the electricity system to provide secure and reliable energy supplies to homes and businesses – since it has adequate conventional capacity in reserve. Although care must be taken when comparing different systems, this should provide great confidence for the UK's electricity system. Indeed, as we show in the next section, the electricity system in Ireland already has a level of wind 'penetration' (the amount of wind energy in the electricity system) similar to that expected by the government for Great Britain in 2020.

Supply and demand still need to be balanced, despite the fact that little energy is being produced by wind in these conditions. In the case of the GB grid the current system has sufficient fossil-fuel generation in reserve to meet this requirement during a cold, calm spell. Should 20 per cent of all grid electricity be supplied from wind, which is approximately the ambition for the UK in 2020 (DECC 2010), studies suggest some additional conventional reserves will need to be available to the grid[12], given current interconnection capacity and status of electrical storage technology. Importantly, it is instructive to note that National Grid plc has stated that **should no changes be made to the way that the electricity system functions, 30GW of wind power can be accommodated** on the existing grid (ECCC 2011). This is slightly more than the 28GW

12 Determined to be around 15 per cent to 22 per cent of installed variable capacity (UKERC 2006).

that is anticipated for the UK in 2020 (DECC 2010). The government is also confident that the wind power contribution expected in 2020 can be accommodated by the existing framework (ibid). As we set out below in the section on high levels of wind penetration, there are other ways of accommodating the variability of wind power on the grid which do not involve using fossil fuel back-up generation.

2.2 International precedents for the UK's 2020 wind power ambitions

While we have shown that variability in wind power output can be predicted and managed by existing arrangements, it is reassuring to look at examples for evidence from systems with significant levels of wind power.

Wind power is not unique to the UK. Seventy-five countries have some wind power installed with 21 of these having more than 1GW of wind power capacity (GWEC 2011).

Two particularly instructive examples where a significant amount of wind power has been installed are:

1. The island of Ireland[13] (Republic of Ireland and Northern Ireland)
2. The Iberian peninsula[14] (Spain and Portugal)

Both of these electricity systems are reasonably self contained (that is, they have limited external interconnection through which they can import or export power) which validates a comparison with the British grid (see box 3). Contrastingly, the oft-cited example of a high-wind system, Denmark, is well connected to both Germany and the rest of Scandinavia[15] and has been excluded from the study for this reason.

In order to discuss the effects of wind generation on electricity systems, it is necessary to define the various ways in which we can characterise wind penetration. There are several possible definitions, but for the purposes of comparison, we use the following:

1. **Annual energy share** is the ratio, over a year, of the electrical energy produced by a particular generating source (in this case wind) to the total electrical energy consumed by customers connected to the electricity system. This definition is useful for comparison with targets for renewable energy or emissions reduction, which are typically defined on an annual basis.
2. **Capacity share** is the ratio of the total wind generating capacity connected to the electricity system, to the peak electricity demand in the year, or to the average electricity demand over the year. This definition is useful when considering the short-term issues that could arise during periods of high wind energy production.

Table 2 shows the annual energy and capacity levels and share in the UK, Ireland and Iberia in 2011, along with the projected figure for the UK in 2020. Figure 5 shows how the capacity and energy penetrations compare.

13 NI and ROI form a single interconnected system and electricity market. There is one DC connection of 500MW to Scotland, and another under construction to connect the Dublin area to NW England.

14 There are relatively weak interconnections between the Iberian peninsula and France, as well as a connection to Morocco.

15 In particular, the Scandinavian hydroelectric systems play an important role.

Box 3: Electricity system – a definition

The term 'electricity system', referred to loosely as 'the grid', is often applied at the level of nation-states (the 'national grid'), and in many cases this is adequate. However there can be strong technical advantages in at least some level of interconnection between neighbouring systems, and if the level of interconnection becomes high enough, the two systems are, in technical terms, behaving as one. For example, the electricity system in the western half of Denmark is more closely integrated with northern Germany than it is with the eastern part of Denmark.

Another example is Scotland, where until recently the connection capacity with England was of the order of 2000MW, around one-third of peak electricity demand in Scotland. However, largely as a result of the development of substantial wind generation in Scotland, the connection capacity will shortly reach 6000MW, and could reach 8000MW before 2020 with reinforcements under discussion (that is, significantly greater than Scottish peak demand).[16] At this point there is no major technical reason to consider Scotland separately from the GB system (England, Scotland and Wales).

Therefore, the level of interconnection should always be considered when evaluating wind penetration issues.

The GB system currently has relatively low interconnection capacity to Ireland, France and the Netherlands and for the purposes of this paper can be considered essentially isolated.

Table 2
Comparison of electricity systems by wind penetration: actual data and expectations for the UK in 2020

	Annual consumption (TWh)	Wind production (TWh)	Annual electricity Share	Mean demand (GW)	Wind capacity (GW)	Capacity share (ratio to mean demand)
Iberia 2011	306	50.7	16.6%	35	25	71%
Ireland 2011	35	5.2	14.7%	4	2	49%
UK 2011	371	15.5	4.2%	42	6	15%
UK 2020	377	78.3	20.8%	43	28	65%

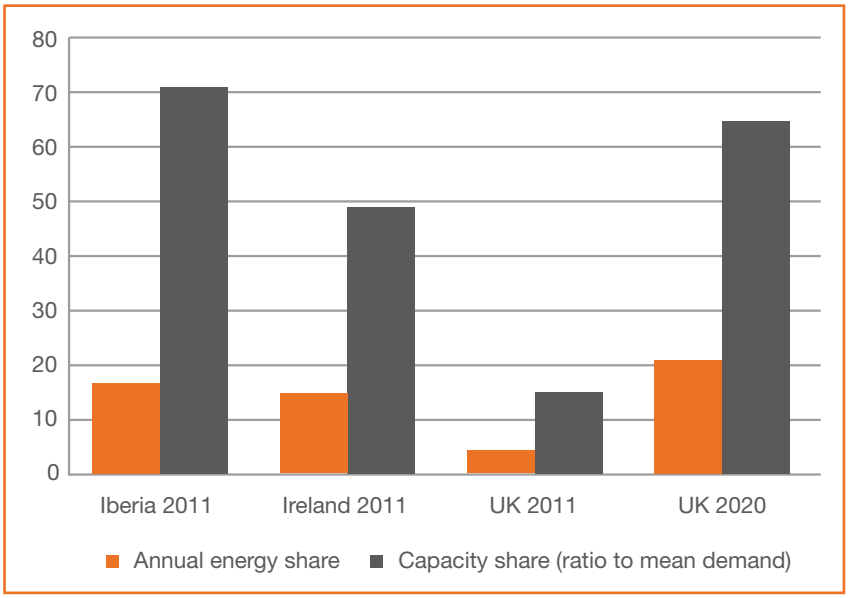
Source: Data provided by ENTSO-E and MacLeay et al 2011, DECC 2010

It can clearly be seen from table 2 and figure 5 that what is being proposed in the UK for 2020 is by no means extreme. Both Iberia and Ireland have already achieved levels of wind penetration close to that proposed in the UK for 2020 – both in the context of relatively isolated electricity systems – without jeopardising the security of their grids.[17]

16 Further equipment to deal with stability issues may need to be installed at suitable locations in Scotland, to allow full export up to these limits.

17 Security of supply was maintained – as stated in RED Electrica 2012 press release: http://www.ree.es/ingles/sala_prensa/web/notas_detalle.aspx?id_nota=232 and Eirgrid Plc annual report 2011: http://www.eirgrid.com/media/EirGrid%20Annual%20Report%202011.pdf

Figure 5
Annual energy and capacity share for Iberia and Ireland in 2011 and UK in 2011 and 2020



Source: Data provided by ENTSO-E and MacLeay et al 2011, DECC 2010

2.3 Options for adapting the grid to maintain security of supply with very high levels of wind generation

If, at a future date, market and regulatory conditions align in such a way as to increase the wind power penetration into the GB grid beyond the 28GW that is expected for 2020, it is likely the system will need to adapt in certain ways. We introduce some technical options for this adaptation to very high wind penetration levels. All of these options can be considered valuable for improving energy security, improving the cost effectiveness of power supply and managing variable and inflexible generation on Britain's electricity grid. It should be recalled, however, that both Iberia and Ireland are currently managing this level of wind power penetration without the benefit of some of the innovations described below.

The priority for a successful, sustainable and affordable power system should be to improve the efficiency of electricity used in homes and businesses – the cheapest and lowest-carbon option is simply not to use a unit of power in the first place. With measures in place to minimise demand, other options can then be considered.

The option that currently provides the greatest certainty and lowest technical risk for making up the capacity shortfall during a 'long, cold, calm spell' is to use gas. Gas generation is preferable to coal because it is emits less carbon dioxide, is likely to be cheaper under current assumptions (Parsons Brinkerhoff 2011) of fuel and carbon costs and is more flexible.[18] In the UK, the government would need to ensure the use of unabated gas generation for this purpose is consistent with hitting the emission reduction targets specified in the carbon budgets by the Committee on Climate Change.

Other measures that could play an important role after 2020 if there is more wind power are less well developed. One option is to improve interconnection between electricity systems. Interconnections could allow Britain's grid to reach 'out from under'

18 Note that thermal generation used in this way may have relatively low annual utilisation, and so technologies with relatively low capital cost (such as gas) will have a cost advantage over coal.

an anticyclonic weather system to those where there is a plentiful wind resource. They could also reach out to areas with other renewable energy sources, such as hydroelectric power. Although highly capital-intensive, as a low-carbon, very dispatchable source of electricity with low marginal costs, hydroelectricity is an ideal way to mitigate the risk of a long period of low wind output. Europe's major regions for hydroelectric generation are the Alps and Norway. Norway's hydroelectric system in particular has the potential to be a major contributor to the security of many Northern European systems. As described earlier, the UK is relatively electrically isolated – it has been observed that much greater interconnection is possible by 2030 (Poyry 2011).

Other options include improving control over patterns of energy usage by developing 'demand-side response' measures which could reduce peaks in demand, and novel ways to store energy. The deployment of smart meters, the uptake of electrical vehicles that have the ability to store power, increasing use of electrical heating through heat pumps and the ability to intelligently manage the use and storage of energy through these and other devices as part of a 'smart grid' are all areas that offer potential. As countries across the globe are undergoing major transitions with their energy systems and experiencing similar challenges to the UK these technologies would be highly exportable.

At very high wind penetrations, the mismatch between wind production and electricity demand might result in curtailment (loss of output) of wind in periods of low electricity demand and high wind production, possibly accompanied or preceded by low prices for wind production. However, analysis of this issue by GL Garrad Hassan reported in the proceedings of the European Wind Energy Association annual conference 2012 (Gardner 2012) shows that this effect is very small at the wind penetration levels expected in the UK in 2020. When wind supplies 20 per cent of GB electricity demand, results show curtailment of 4.4 per cent of wind production in the worst case, (that is, assuming the electricity system is no more flexible than at present). Under other assumptions appropriate to a more flexible system, or with greater interconnections or demand management, curtailment is effectively zero. This is not a problem that is currently experienced on the GB system – any curtailment that does occur is the result of congestion on the electricity transmission network.

It is not yet clear what the optimal mix of these tools will be or how their relative costs will develop over time. What is clear, however, is that there are many options for future adaptation and it is wrong to assume a technical ceiling to the amount of variable generation capacity that is feasible on the grid while maintaining system security.

2.4 Summary

Since electricity cannot currently be easily stored it has been asserted that the variability associated with wind power introduces unreliability which poses a threat to the UK's energy security. This chapter has shown these concerns to be unfounded. We clarify a number of issues:

- It is **inaccurate to describe the output from wind power as 'unpredictable'**. Wind power, at penetrations likely in the UK by 2020, is variable and predictable in much the same way as demand. Wind power forecasting techniques are well established and widely used and a constantly improving and essential tool for system operators and energy traders. Forecasts across the electricity system are more accurate than individual site forecasts. The aggregation of wind power output forecasts across larger geographical areas increases accuracy markedly.

- In the short term, **wind power output is remarkably stable** and increases and decreases only very slowly. In fact, rates of change in output are not dissimilar to changes in demand from power users. The current mechanisms for ensuring that supply and demand are kept in balance are perfectly adequate to maintain system security.
- **The risks associated with 'long, cold, calm spells' have been overstated.** The current electricity system is quite capable of managing these events. We highlight an extreme weather event in Ireland in 2011 (where the wind capacity is a far larger proportion of the total than in GB) which was easily dealt with without compromising system security.
- In the UK, National Grid has reported that **up to 30GW of wind power can be accommodated even if no changes are made to the way that the electricity system functions**. This is supported by empirical evidence from the Iberian peninsula and the island of Ireland. Both of these electricity systems, like the UK, are relatively isolated and have already achieved levels of wind penetration close to that proposed in the UK for 2020 without jeopardising the security of their systems.
- In the longer term **there are numerous technological options to facilitate much greater amounts of wind power** – such as improved interconnection with other countries and intelligent management of supply and demand through a 'smart grid'.

We therefore conclude that accommodating wind power at levels projected for 2020 will not demand major system adaptation and beyond this level, there are several options for further system adaptation. For this reason we believe that wind power can play a major role in a secure and reliable future electricity system.

3. CONCLUSIONS

This report has addressed two common misconceptions on wind power technology: firstly, that it is not an effective way of reducing carbon emissions; and, secondly, that wind power is too variable to be a reliable source of electricity.

We have clearly demonstrated that deriving energy from **wind power is a potent way of reducing carbon emissions and does not threaten energy security**. In the UK during 2011 wind energy reduced emissions of carbon dioxide by at least 5.5 million tonnes. Even during a prolonged period of calm, cold weather it poses no threat to the security of electricity supply.

We have also shown that **wind power is able to provide a significant proportion of the UK's electricity needs with little impact on the existing operation of the grid**. Evidence from numerous rigorous studies shows that integrating wind generation in the UK system at the levels expected in 2020 is technically feasible without major modification to the electricity system. The experience of high levels of wind power in the Iberian peninsula and the island of Ireland offer examples of where these levels of wind power have been successfully integrated.

Finally, we have outlined how **the role for variable, low-carbon generation technologies like wind power could extend significantly beyond the levels that are currently expected in the UK**. As the GB grid makes a transition to a low-carbon, secure and affordable system it will need to adapt in important ways. While the optimal mix and ultimate costs of the options remain uncertain, a range of different technologies will have a part to play in this transformed energy system.

The transition to a low-carbon, secure and affordable GB electricity system will be the subject of debate for some years to come. With this report we hope to have shown that of the many challenging issues that must resolved, the area of wind power technology is probably one of the least troubling.

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