

# The case for and against onshore wind energy in the UK

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Grantham Research Institute on  
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# Summary

This policy brief aims to inform the debate about the role of onshore wind in the UK's future energy mix. The paper investigates to what extent onshore wind can contribute to future electricity generation, whether there are technological constraints, what the economic costs are, and what the environmental impacts might be.

The policy brief does not provide new empirical estimates – there are many such numbers already published. We contribute to the debate by identifying the most credible estimates available and drawing some robust policy lessons from that information.

The first such lesson concerns the unequivocal need to decarbonise the UK's electricity sector. Under the Climate Change Act (2008) and the subsequent carbon budgets, the UK is committed to cutting its annual greenhouse gas emissions by half by 2025, compared with 1990 levels. This is not achievable without a power sector that is virtually carbon-free by the middle to late 2020s. The Act has strong political support: it was passed near-unanimously by Parliament, as were the first four carbon budgets legislated under it.

Once the implications of the UK's carbon targets are recognised, the issue of onshore wind becomes a choice between this and other low-carbon energy sources. It is not a choice between onshore wind and fossil fuels. It has been argued that efficient combined cycle gas power plants may be a cheaper way of meeting our 2020 carbon reduction targets. However, it is clear that the further decarbonisation required in the 2020s cannot be achieved by heavily relying on unabated gas power stations. Rational policy-makers need to anticipate this and avoid locking in high-carbon electricity generation.

A second robust lesson is that many low-carbon technology combinations are technically feasible. Much has been made of the intermittent nature of wind and other renewables, which cannot produce electricity reliably on demand. However, the cost penalty and grid system challenges of intermittency are often exaggerated. There are several ways of compensating for this variability, such as additional capacity from fossil fuel power plants to meet balancing requirements at peak demand, bulk storage of electricity, greater interconnection, and a more diversified mix of renewable sources, as well as measures to manage demand, like smart grids and improved load management. The main concerns in choosing the best energy technology mix are not network stability, but economic costs and environmental side-effects.

The third lesson concerns the trade-off between economic costs (and, by extension, electricity bills) and environmental impacts. Onshore wind currently supplies 28 per cent of the electricity generated in the UK by renewables (DECC, 2011a). That share is likely to rise, given the abundant wind resources available in the UK, and the technological maturity of onshore wind. A key attraction of onshore wind over other low-carbon forms of electricity generation is cost. In terms of levelised cost – an economic measure which takes into account all of the costs of a technology over its lifetime – onshore wind is currently the cheapest renewable technology in the UK. It is expected that it could become fully competitive with older conventional sources of energy as early as 2016 (Bloomberg NEF, 2011a). This is an important advantage at a time of heightened sensitivity about the costs of green policies.

However, onshore wind raises potential local environmental issues, particularly through the visual impact of turbines. People value natural landscapes and are willing to pay to preserve them. This needs to be factored into the analysis. There are also wildlife effects that should be taken into account, although they are often relatively small and site-specific compared with other anthropogenic impacts.

These environmental impacts make more expensive renewable technologies – like offshore wind or solar photovoltaics – potentially more attractive. One can think of the extra cost of offshore wind as the premium society is willing to pay to avoid the local environmental cost of onshore wind.

The choice between more affordable electricity (which would favour onshore wind) and local environmental protection (which may favour other low-carbon technologies) is ultimately a political one. However, given the economic and environmental trade-offs, technological uncertainty, and the absence of one clearly superior solution, the best approach seems to be a portfolio of different energy technologies to balance the cost to consumers and environmental concerns. Onshore wind has a role in that mix.

The final lesson concerns the role of policy in ensuring a rational approach to onshore wind. This policy brief does not review the regulatory environment, but it is clear that adequate policies can make onshore wind less risky and more attractive to investors and local communities alike. There are a number of regulatory measures that can help to encourage onshore wind developments where they make sense and prevent them from happening where they do not. These include:

- A clear price on carbon that underlines the relative merit of wind (and other low-carbon forms of power production) vis-à-vis hydrocarbon-based fuels.
- A planning system that (i) reduces the costs and uncertainties to project developers, thus making project development more efficient; (ii) factors in local environmental concerns and prevents developments in important environmental areas; and (iii) ensures appropriate benefit-sharing (compensation) in areas where local impacts are acceptable.
- Flanking measures to ensure that the electricity system can cope with intermittent resources, including adequate and sufficiently smart transmission and distribution systems, interconnection to other energy markets, energy storage, load management and flexible demand measures, as well as an appropriate combination of fossil fuel (ultimately linked with carbon capture and storage) and renewable sources to ensure balancing and the ability to meet peak demand.

# 1. Introduction – the issue at stake

There is a lively ongoing public debate about the role of onshore wind energy in meeting the UK's future electricity needs and environmental targets. Notably, in January 2012, more than 100 Members of Parliament expressed their concerns over onshore wind subsidies in a letter to the Prime Minister.<sup>1</sup> He responded by defending the role of the renewable technology as a key part of the UK's future mix of energy sources.<sup>2</sup>

The background to this debate is the UK's twin commitment to reduce greenhouse gas emissions and to increase the proportion of energy generated by renewable sources, such as wind and solar. The Climate Change Act (Her Majesty's Government, 2008) commits the UK to reducing its annual greenhouse gas emissions by at least 80 per cent by 2050 compared with 1990 levels. The initial four carbon budgets set by the Government, and passed by Parliament, require emissions to be cut<sup>3</sup> by 34 per cent by 2020 and by 50 per cent by 2025. At the same time, the European Union Directive on Renewable Energy (2009/28/EC) requires the UK to obtain at least 15 per cent of its gross final consumption of energy<sup>4</sup> from renewable sources by 2020.

In order to achieve these objectives and move towards a low-carbon economy, the UK must undertake a shift in its energy supply towards much less carbon-intensive sources. Renewable energy, such as onshore wind, is central to this ambition.

However, there are several forms of low-carbon energy, and it is not trivial to determine the right combination of renewable sources and other low-carbon technologies. Several environmental, economic and social considerations need to be carefully taken into account in order to identify the most desirable energy mix.

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

2 See: <http://www.scribd.com/doc/82548604/David-Cameron-wind-letter>

3 Compared to 1990 emission levels.

4 Gross final consumption of energy refers to the total energy consumed by end users, as well as by the energy sector for electricity and heat production, including losses of electricity and heat in distribution and transmission.

The aim of this policy brief is to inform the debate about the role of onshore wind energy in meeting the UK's future electricity needs and achieving its environmental objectives. The brief does not provide new empirical estimates – there are many such numbers already published. We contribute to the debate by identifying the most credible estimates available and drawing some key policy lessons from that information. Some robust conclusions can indeed be drawn, but this does not mean the evidence base is perfect. Data on energy technologies and their future development are subject to uncertainty and may change over time, so we recommend that this issue continues to be monitored and investigated in future research.

The brief is structured around four key questions:

- How much might onshore wind contribute to the UK energy mix over the next few decades?
- What is the impact of intermittent wind power generation at a large scale on the stability and reliability of the UK's electric power system?
- What is the economic cost of onshore wind and how does it compare with other forms of low-carbon energy?
- What are the environmental side-effects of onshore wind on the UK's landscapes and ecosystems?

We conclude by suggesting how the acceptability of onshore wind may be enhanced through changes in the policy environment.



## 2. How much might onshore wind contribute to the UK's energy mix?

Wind turbines, located on land (onshore) or in sea or freshwater (offshore), harness the energy of moving air, primarily to generate electricity. The UK has excellent opportunities for onshore turbines, with particularly good wind speeds in Scotland, Northern Ireland and Wales (DECC, 2011a). According to the European Environment Agency, the onshore locations in the UK offer about 11 per cent of the total generation potential of wind energy in the European Union (EEA, 2009).

Besides onshore and offshore wind, the UK uses a range of other renewable sources to generate electricity and heat, and for transport fuels. These include solar heating and photovoltaics, small-scale and large-scale hydropower, biomass (such as landfill gas, sewage sludge digestion and wood combustion), geothermal aquifers, heat pumps and transport biofuels (bioethanol and biodiesel).

Overall, in 2010, renewable sources of energy met about 7.4 per cent of the UK's electricity needs and 3.3 per cent of gross final energy consumption<sup>5</sup> (DECC, 2011a; see Figure 1). Under existing European Union commitments, renewable energy generation is meant to grow to supply about 15 per cent of total gross final energy consumption by 2020 in the UK.

The government's Renewable Energy Strategy (Her Majesty's Government, 2009) suggests that one way to deliver the 2020 target would be to supply around 30 per cent of electricity, 12 per cent of heat and 10 per cent of the energy required by motorised transport from renewable sources.

### Box 1. Note on terminology

Since onshore wind is used primarily for electricity generation, in this report we refer to its contribution to both electricity and total energy supply. It is important, however, to keep in mind that renewable electricity is but a subset of the overall energy supply.

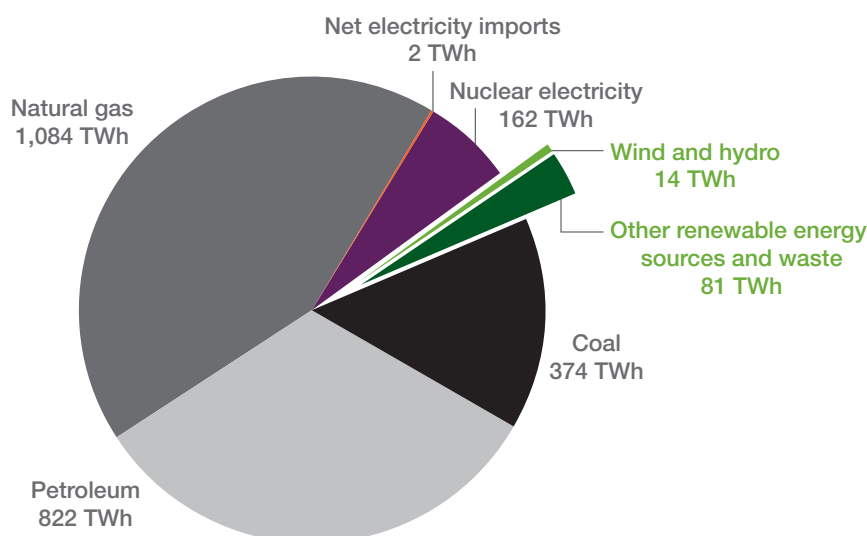
Also, we describe energy sources both in terms of their 'capacity' and 'generation'. The capacity of an (energy) installation is the maximum power; that is, the maximum quantity of energy delivered per unit of time (IPCC, 2012), and is expressed in watts (W) and its multiples.<sup>6</sup> Generation (or 'output') instead refers to the amount of electric energy produced in a given period, typically an hour, and is expressed in watthours (Wh) and its multiples.<sup>7</sup>

5 In line with the criteria set out in the EU Renewable Energy Directive (2009/29/EC), which include a cap on energy consumption from air transport. See also footnote 4 for a definition of 'gross final energy consumption'.

6 1,000,000,000 Watt (W) = 1,000,000 kilowatt (kW) = 1,000 megawatt (MW) = 1 gigawatt (GW) = 0.001 terawatt (TW).

7 1,000,000,000 watt-hour = 1,000,000 kilowatt-hour (kWh) = 1,000 megawatt-hour (MWh) = 1 gigawatt-hour (GWh) = 0.001 terawatt-hour (TWh).

Figure 1. Inland energy consumption by primary fuel input<sup>8</sup>, 2010



Source: Calculations based on DECC (2011a).

Onshore wind is one of the most technologically mature renewables and, as such, currently plays a leading role in the generation of renewable electricity in the UK. In 2010, the UK had more than 4,000 megawatts (MW) of onshore wind capacity (Figure 2), and reached almost 4,800 MW in early 2012 (DECC, 2012a). The most recent generation data shows that onshore wind supplied 7.1 terawatt hours (TWh) of electricity in 2010, equivalent to about 28 per cent of the renewable electricity output during the year (DECC, 2011a; Figure 3) and just under 2 per cent of the total electricity generated in the UK. Assuming an average household electricity consumption of 3,300 kWh per year (as in Ofgem, 2011), this is equivalent to the electricity used by about 2 million homes.<sup>9</sup>

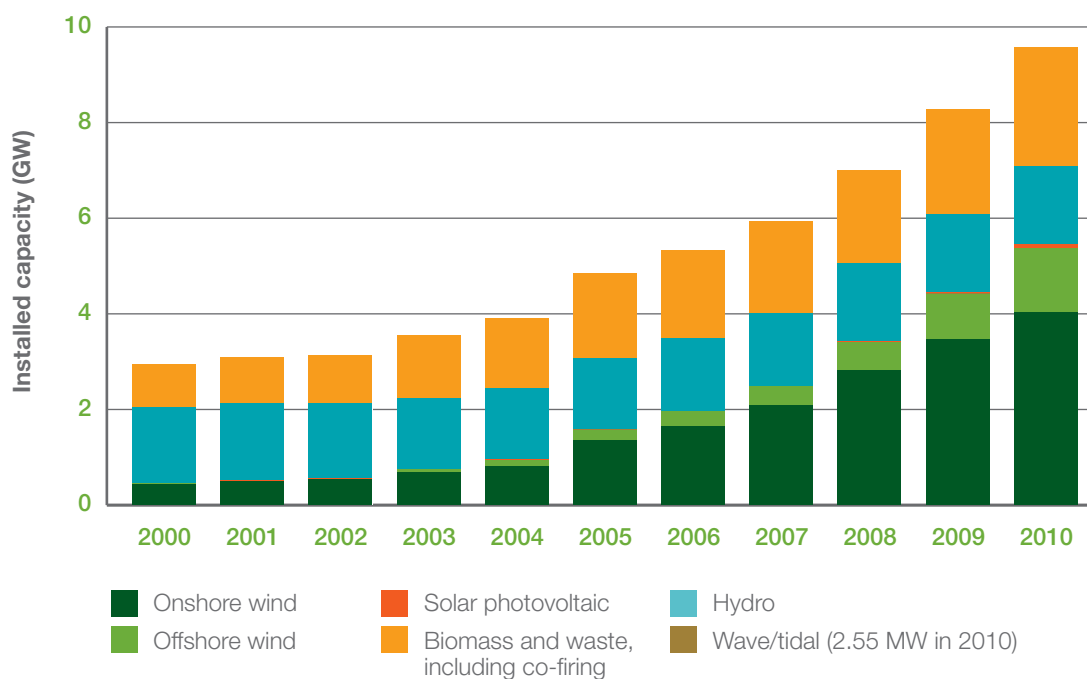
Several assessments have been carried out to estimate the future capacity and generation potential of onshore wind in the near- (2020) and mid-term future (2030) (e.g. Her Majesty's Government, 2010a; CCC, 2010).

For the period to 2020, the most up-to-date analysis has been conducted by the Electricity Networks Strategy Group (ENSG, 2012), a team of network operators, utilities and other stakeholders reporting to the Department of Energy and Climate Change and Ofgem. In their 'Gone Green' scenario, they estimated that, to meet the 15 per cent renewable energy target, renewable electricity capacity should reach 35,600 MW, generating about 113 TWh by 2020. In this scenario, onshore wind should increase from the current 4,800 MW to about 9,000 MW, which, assuming an average turbine capacity of 2.5 MW, would imply the construction of approximately 1,700 new turbines. It is estimated that such capacity will generate up to 30 TWh of electricity annually (ENSG, 2012). This is also consistent with the 'central' scenario of the Renewable Energy Roadmap produced by the Department of Energy and Climate Change, which expects onshore wind to generate between 24 and 32 TWh each year by 2020 (DECC, 2011c).

<sup>8</sup> Inland energy consumption refers to the energy used in the country. It includes primary energy production less exports, energy imports and changes in stock (positive or negative), and excludes energy used in marine bunkers (i.e. fuels supplied to ships engaged in international transport).

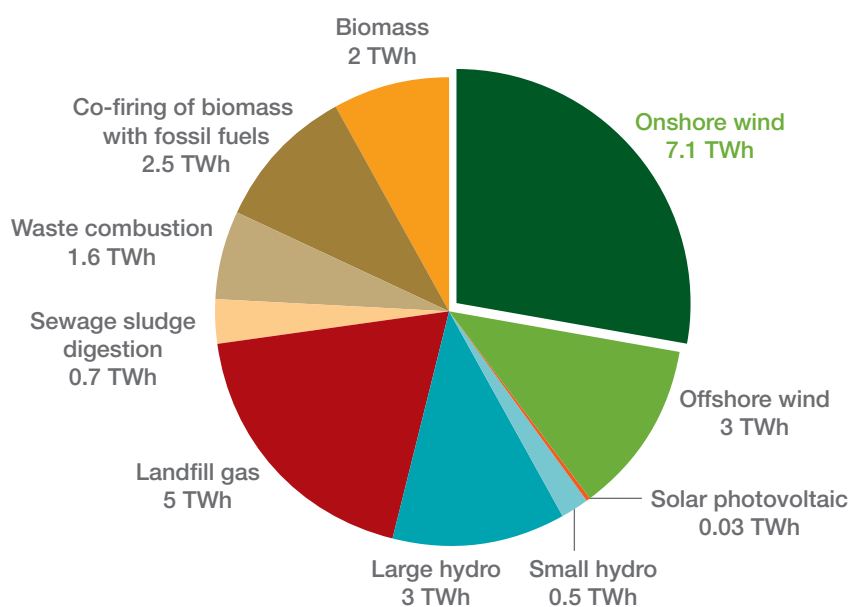
<sup>9</sup> It should be noted that, given its intermittent nature, onshore wind will not be sufficient to power households without the support of other energy sources. This figure is provided for comparison purposes only.

Figure 2. Total installed capacity of renewable energy sources in the UK, from 2000 to 2010



Source: Based on Her Majesty's Government (2011a).

Figure 3. Electricity generation from renewable energy sources in the UK, 2010



Source: Calculations based on DECC (2011a).

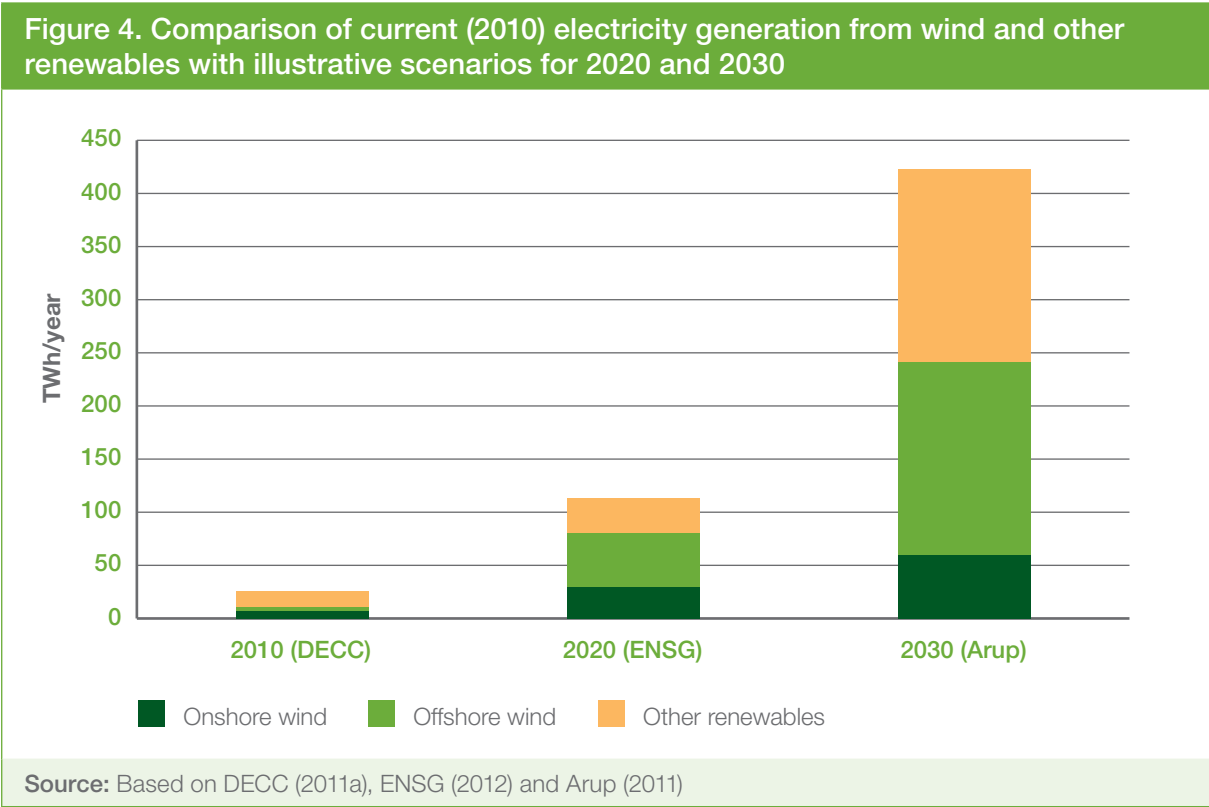
The UK government has also estimated that renewable electricity capacity will be between 35,000 and 50,000 MW by 2030, providing over 40 per cent of electricity output (Her Majesty's Government, 2011a).

2. How much might onshore wind contribute to the UK's energy mix?

As for the specific role of onshore wind, the most recent analysis was carried out by Arup (2011) for the Department of Energy and Climate Change. The study indicates that onshore wind capacity could range between 15,000 and 25,000 MW, generating 37 to 60 TWh per year by 2030. Assuming an average turbine capacity of 2.5 MW, this would require the construction of approximately 4,000 to 8,000 new turbines, in addition to the existing stock.

Possible future electricity generation from wind and other renewables is shown in Figure 4 for the 2020 'Gone Green' scenario published by the Electricity Networks Strategy Group and Arup's 2030 'High' scenario.

In practice, as of April 2012, approval has been given for the construction of new wind farms to provide an additional generation capacity of almost 6,500 MW in the UK, while a further 6,500 MW of onshore wind capacity is awaiting approval (DECC, 2012a). Should all these installations be developed in the next decade, the future capacity of onshore wind farms could reach almost 18,000 MW by 2020, including the existing 4,800 MW already in operation. Such capacity could generate more than 42 TWh, which is comparable to the electricity consumed by almost 13 million homes in a year.<sup>10</sup> This would be above the 2020 estimates given elsewhere in this section (ENSG, 2012). It is unlikely, however, that all these installations will be built. Approval rates were, on average, only 69 per cent between 2004 and 2009 (Her Majesty's Government, 2010). However, output could be higher in the long term, should new wind farms be proposed and approved and/or technology efficiency improved. More capacity, in addition to the turbines already planned, might be needed in the future to meet the carbon reduction targets for 2030 and beyond.



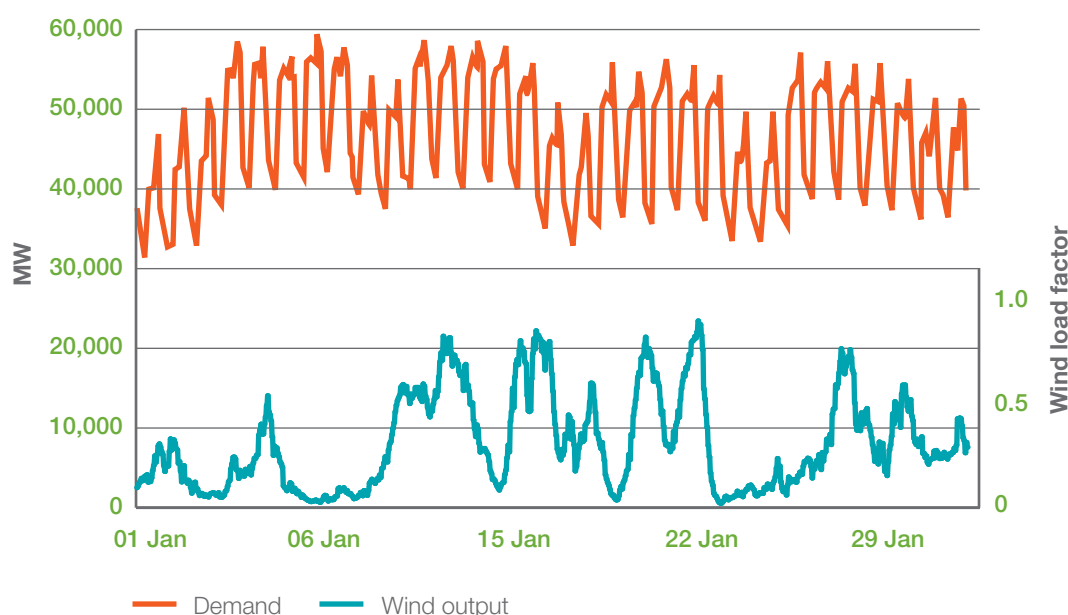
10 Assuming a load factor of 28 per cent and an average electricity consumption of 3,300 kWh per household per year (as in Ofgem, 2011). It should be acknowledged that onshore load factors, which express the average hourly quantity of electricity generated as a percentage of the average capacity at the beginning and end of a year, depend crucially on wind farms' locations and weather conditions. We use here the most recent average load factor adopted in a report by Arup (2011) for the Department of Energy and Climate Change. It is slightly conservative compared with the 30 per cent load factor used in the earlier '2050 Pathway' report (Her Majesty's Government, 2010). See also footnote 9.

### 3. What is the impact of onshore wind intermittency on the electricity system?

The demand for electricity varies throughout the day, week and season. As electricity is hard to store, supply must also vary to meet this demand, which is achieved by turning power stations on and off, or by operating them below full load. This is a particular challenge for some renewable technologies such as wind turbines, solar panels, or wave power generators, since the electricity they supply is variable or 'intermittent': it depends, for instance, on when the sun shines or the wind blows.

Wind electricity output, from both onshore and offshore sources, can vary greatly, not only across seasons but also during the day. This implies that wind output can be as high at times of low demand (e.g. overnight) as at times of high demand – see, for example, Figure 5. However, there is some evidence that, in the UK, wind power is, on average, more available during daytime and in the winter season, when electricity demand is higher (Sinden, 2007; CCC, 2011a). Also, as wind blows at different speeds in different areas, having wind farms located in areas that are far apart from each other can reduce the variability of average wind power output. But even so, the capability of wind to provide an adequate amount of electricity 'on demand' on its own remains limited.

Figure 5. Electricity demand and wind generation profile in January 2010



**Note:** The figure shows Great Britain's demand profile (red line) for January 2010, together with a scaled January 2010 wind generation profile (blue line) that reflects the estimated wind capacity in January 2021 – i.e. 26,700 MW of offshore and onshore wind capacity (of which 9,000 MW onshore), in line with the 2020 'Gone Green' scenario developed by the Electricity Networks Strategy Group (ENSG, 2009). Overall, it shows how the estimated future onshore wind generation can contribute to a demand profile similar to our current (2010) needs.

**Source:** National Grid (2011).

### 3. What is the impact of onshore wind intermittency on the electricity system?

The intermittent nature of renewable sources has two main impacts on the electricity system. First, it affects the system's 'balancing'; that is, the relatively rapid short-term adjustments needed to manage electricity fluctuations over a short time period, (i.e. from minutes to hours). Second, it affects the system's 'reliability'; that is, the need to ensure that sufficient output is available to meet peak demand.

Several solutions are available to tackle this issue. These include the use of additional fossil fuel plant capacity to meet balancing requirements and peak demand, the increase of interconnections and storage, the introduction of smart grids, and the improvement of load management.

Additional generation capacity, typically from fossil fuel power plants, can operate when there is a major surge in demand or when wind and other intermittent renewables are not generating power. This is usually referred to as 'back-up capacity'<sup>11</sup>, when it is designed to maintain a given level of reliability, and 'balancing reserves', when used for balancing. As conventional power stations also face changes in demand, experience failures or are temporarily unavailable (e.g. due to planned maintenance), arrangements for balancing and reliability are already in place. The current level of wind power capacity has had little impact on existing arrangements so far. However, a higher share of intermittent renewable sources is expected to require additional fossil fuel-fired generation capacity.

According to the UK Energy Research Centre (Gross et al., 2006), should 20 per cent of electricity be supplied by wind power (or other intermittent renewable energy sources) by 2020, the additional back-up capacity and system balancing reserves needed would be equivalent to about 20-32 per cent of the renewable capacity. So for example, assuming an onshore and offshore wind installed capacity of 26,700 MW by 2020 (as estimated by ENSG, 2012), an additional 5,300 to 8,500 MW of fossil fuel-fired generation capacity would be required.

Extra capacity from fossil fuel plants is helpful to counterbalance the intermittency of some renewable sources, but has the disadvantage of generating greenhouse gas emissions. As these plants are usually kept part-loaded so that they can be switched on and off quickly, they are less efficient, thus creating more greenhouse gas emissions per unit of electricity (Centre for Sustainable Energy, 2011), and lead to potentially higher capital costs per unit of electricity.

The need for additional fossil fuel generating capacity can be reduced, however, through other 'non-generation' measures, such as interconnection with other electricity markets, energy storage and load management. Non-generation technologies are indeed fully recognised as a central element of the UK future energy policy in the Government's White Paper on electricity market reform (DECC, 2011d).

Interconnections are physical links between the national grid and other networks, which allow electricity to be imported and exported (DECC, 2011d). They can offer significant flexibility to overcome the issue of intermittency. For example, Denmark, which meets 20 per cent of total electricity demand from wind energy, has strong transmission interconnections with its neighbouring countries, relying in particular on flexible hydropower sources in the Nordic system (IPCC, 2011). Great Britain has 3,500 MW interconnection capacity at the moment (DECC, 2011d). National Grid (2011) has forecast that interconnector capacity could reach 5,700 MW by 2020, while a study for the Committee on Climate Change (Pöyry, 2011) estimated that interconnections between the UK and Ireland, north-west Europe and Norway could provide between 10,000 and 16,000 MW of back-up capacity by 2030.

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11 Sometimes it is also referred to as 'stand-by capacity' or 'system reserves' (Gross et al., 2006).

The issue of intermittency can also be addressed by increasing energy storage. This involves converting electricity into another form of energy when supply outstrips demand, and converting it back when the system requires it (DECC, 2011d). Currently, installed storage capacity is quite low (under 3,000 MW in Great Britain) and largely consists of pumped storage<sup>12</sup> (DECC, 2011d). Future technology developments are expected to allow for increasing energy storage, for example through batteries, flywheels and additional pumped storage systems. Pöyry (2011) suggested that bulk storage could provide between 2,800 and 4,000 MW of capacity by 2030.

Furthermore, the stand-by generators of commercial energy users, such as supermarkets, which are currently only used in emergencies, could also be made available in order to meet peak demand, in coordination with energy suppliers. Although there are no official data on the amount of existing stand-by capacity which is currently available, estimates suggest that the UK capacity of emergency diesel generation is about 20,000 MW. Of this, about 5,000 MW may be suitable for remote control by the system operator by 2020 (npower, 2011).

In addition, a diversification of the renewables mix to include less variable sources (such as biomass) and more predictable sources (such as tidal), as well as improved forecasting and planning of the use of intermittent sources (such as wind and sun), can contribute to smoothing of the overall variability of electricity supply.

On the demand side, changes in patterns of electricity use may put additional pressure on supply systems, as well as helping to reduce the challenges of system balancing and maintaining system reliability.

On the one hand, the potential electrification of heating, transport and industrial processes could lead average electricity demand to rise by 30 to 60 per cent by 2050 (Her Majesty's Government, 2011a). On the other hand, demand-side measures are expected to help manage electricity more effectively. For example, an increased use of electric cars could help store electricity when supply exceeds demand. A 'smart grid' (i.e. an electricity network making extensive use of information and communications technology) is expected to enable more dynamic real-time flows of information and more interaction between suppliers and consumers (CCC, 2010). By allowing greater flexibility of demand, it could enable variable supply to be more easily accommodated. For instance, it could help to manage electric vehicle charging and other energy use, according to the electricity available in the system. Improved communications and control systems could also make it possible for an energy supplier to 'buy' capacity from electricity users through 'load shifts'. This might mean, for example, an energy supplier pays a supermarket chain to turn all of its refrigerators off briefly (while maintaining a safe temperature margin) to balance out the grid at times of high demand. National Grid has estimated that up to around 5,500 MW of load could be time-shifted in this way by 2020 (npower et al., 2011).

It is not easy to estimate the net effect of all of the measures to manage supply and demand which could ensure the efficient functioning of the electricity system, once a larger amount of renewable energy is deployed. However, it is clear that several options are available. Besides holding gas-fired power stations in reserve, which has the disadvantage of leading to additional emissions when they are used, it is possible to rely also on interconnection, load-shifts, stand-by generators, smart grids and other measures that can create significant additional flexibility for the system.

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12 A technology which stores energy in the form of water, pumped from a lower elevation reservoir to a higher elevation when electricity supply outstrips demand. During periods of high electrical demand, the stored water is released through turbines (CCC, 2012).



# 4. What is the cost of onshore wind?

A concern sometimes expressed about onshore wind, and other low-carbon energy sources, is that they are more expensive than fossil fuels for generating electricity, and that the additional cost burden will raise electricity bills for households and businesses. To make an informed judgment about the cost of onshore wind, a number of factors need to be considered.

The first factor is the cost of climate change, which is real and needs to be added to the cost of technologies that emit greenhouse gases, in the form of an appropriate price for carbon (Bowen, 2011). Second, the comparison needs to take into account the actual and future prices of energy technologies, including the expected price of fossil fuels and cost reductions for low-carbon technologies due to learning and economies of scale. Third, onshore wind should be compared not just with fossil-fuel based power, but also with other sources of low-carbon energy.

To understand the cost of different energy technologies, a useful first comparison is to consider their levelised costs. These take into account investment, fuel, and operation and maintenance costs, and relate them to total energy supply over the assumed economic life of a power plant. Levelised costs are calculated by dividing the total lifetime cost of a power source by the total value of electricity generation, both discounted through time<sup>13</sup>, and are usually expressed in units of currency per kWh or MWh (e.g. p/kWh or £/MWh).

Several assessments of levelised costs exist. In this policy brief, we rely on the estimates by the Committee on Climate Change (CCC, 2011b), as these are among the most recent and reliable data available and those most tailored to the UK. According to these estimates, the levelised costs for onshore wind ranged between 6.6 and 9.3 pence per kilowatt-hour (p/kWh) in 2011 (see Figure 6).

By comparison, data from Bloomberg New Energy Finance (2011b) put the figure slightly lower, at around US\$60-100 per megawatt-hour in 2010 (i.e. approximately 4-6.5p/kWh<sup>14</sup>). Estimates vary because different assumptions can be made about uncertain parameters, such as the discount rate (i.e. the cost of capital through time), the effect of the exchange rate, commodity prices (e.g. for steel) and the cost of complying with national legislation. But, despite some differences due to these assumptions, costs tend to be of the same order of magnitude. Overall, onshore wind appears likely to be one of the cheapest energy technologies available in 2030.

Figure 6 shows the estimated levelised costs for onshore wind and for other technologies of relevance for the UK energy mix. The cost range takes into account high and low real discount rates (respectively 10 and 3.5 per cent) in 2011 and in 2030. According to the Committee on Climate Change, all 'clean' energy sources are estimated to be cheaper in 2030 thanks to technological improvements. By contrast, while unabated gas<sup>15</sup> had the lowest levelised cost in 2010 (between 3.6 and 7 p/kWh), this is expected to increase in the future given expected higher fossil fuel and carbon prices. Future gas prices, of course, are uncertain; we rely here

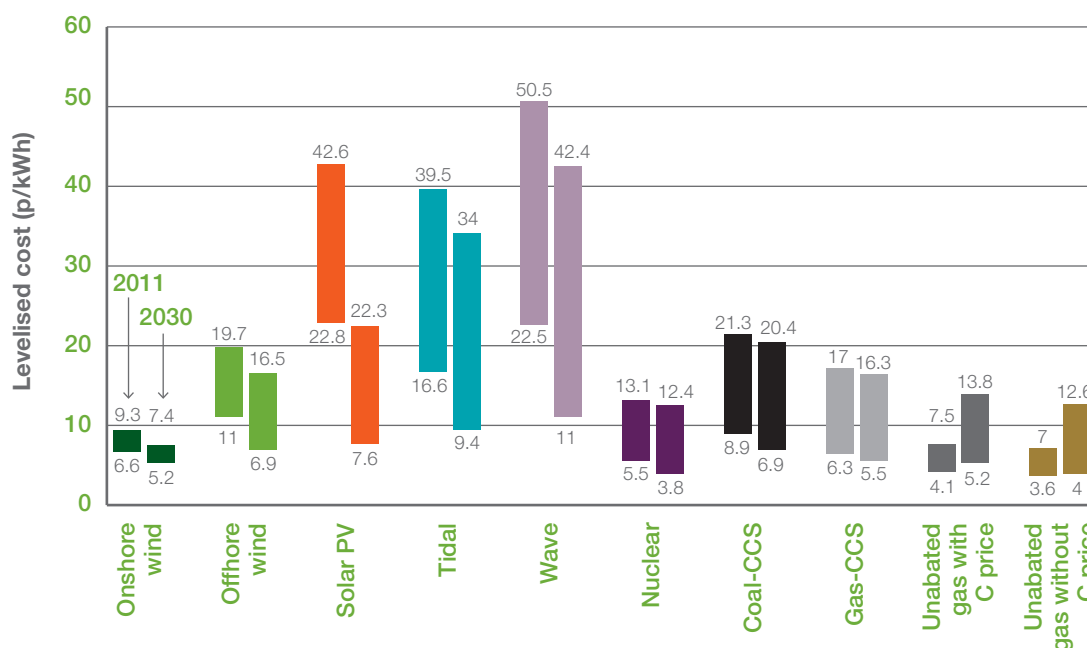
13 Discounting is applied to future cash flows (e.g. future costs and revenues) to identify their net present value.

14 Conversion units: US\$100 per MWh = 10 cents per kWh = 6.5 pence per kWh. Average exchange rate in third quarter of 2010: US\$1.00 = £0.646. Source: <http://www.oanda.com/currency/average>

15 Gas power plants not retrofitted with carbon capture and storage.



**Figure 6. Levelised costs of energy for different sources in 2011 and 2030 (3.5 to 10 per cent discount rate) (p/kWh)**



**Note:** The first column of each technology refers to 2011, the second to 2030

**Source:** Calculations based on CCC (2011b).

on estimates by the Department of Energy and Climate Change, which are broadly consistent with forecasts by the International Energy Agency.<sup>16</sup>

We have also included, as a hypothetical yardstick, an estimate for the levelised cost of unabated gas without the embedded carbon price (see the last two columns to the right in Figure 6). The Committee on Climate Change expects the carbon price to rise from £14 per tonne in 2010 to £30 per tonne in 2020 and £70 per tonne in 2030. This is estimated to account for between 7 and 23 per cent of the total cost of unabated gas. Excluding the price of carbon is wrong analytically, as emissions are a real cost to the economy. But even if carbon costs were ignored (that is, if gas were to continue to enjoy a ‘carbon subsidy’), the lowest projected cost of gas in 2030 would be only about 20 per cent cheaper than onshore wind. Furthermore, although it has been argued that prioritising efficient combined cycle gas power plants rather than wind energy may be a cheaper way of decarbonising the UK’s energy sector (e.g. Hughes, 2012), this risks higher costs and higher emissions in the long run as high-carbon technologies are locked in.

It is important to recognise, however, that levelised costs are but one part of the overall picture. There are other costs incurred in managing an electricity system with increasing levels of renewable energy generation which also need to be taken into account.

<sup>16</sup> Despite the advent of shale gas, the price of gas is expected to rise from 41 p/therm to 77 p/therm in 2030 according to the central scenario developed by the Committee on Climate Change (ranging from 37 p/therm in the low scenario to 124 p/therm in the high scenario). These were based on assumptions from the Department of Energy and Climate Change, updated for 2010 prices. By comparison, recent forecasts by the International Energy Agency (2012) indicate that European gas import prices will range between 10.1 and 12.9 US\$ per million British thermal units (MBtu) in 2030 (in 2009 terms) – i.e. about 65 – 83 p/therm.

In particular, it is necessary to connect the new renewable generation sources, some of which may be far from the residential and industrial areas where energy is needed (e.g. some onshore wind turbines and offshore wind), to the grid and to allow for sufficient flexibility to address the issue of intermittency. Hence investments will be needed in transmission and distribution networks, interconnections, back-up capacity and balancing reserves, energy storage and smart grid infrastructure.

Estimating the transmission and distribution costs related to renewables is not a simple task, because some of the future investments in grid upgrading can be attributed not only to renewable sources, but also to a range of other causes such as the replacement of old infrastructure, demographic and demand shifts, and connections from fossil fuel plants and nuclear power stations (Gross, 2012).

The most recent official assessment of transmission requirements associated with renewables has been carried out by the Electricity Network Strategy Group. The total investment cost of transmission consistent with the provision of 30 per cent of electricity from renewable sources by 2020 (including about 32,000 MW from onshore and offshore wind) was estimated to be £8.8 billion (ENSG, 2012), or roughly £1 billion as an annual average if costs are spread evenly each year from now to 2020. As the benefits of the investment will accrue over the lifetime of the assets, which will be several decades, it makes sense to annuitise it over a longer period. This has been done by the Committee on Climate Change (2011b), which estimated that transmission costs will be around 20 per cent of the total annualised costs of accommodating 30 to 64 per cent of electricity from renewable sources by 2030.

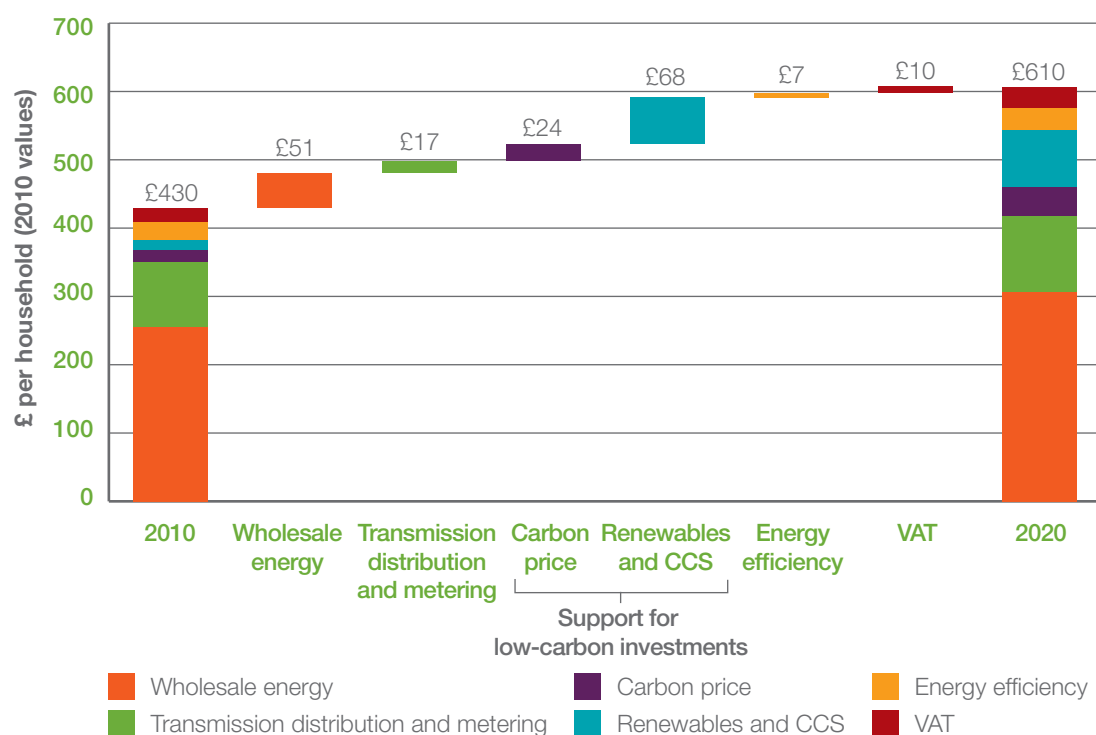
Besides transmission, the costs related to the increased intermittency of electricity sources also need to be taken into account. These include the costs of distribution interconnection, bulk storage, smart grids and additional conventional generation (to ensure balancing and reliability). Overall, the Committee on Climate Change estimated that the combined costs of transmission upgrades and other flexibility measures related to a 30 to 64 per cent share of electricity from renewables by 2030 would be between £5 and £5.9 billion per year (CCC, 2011b; Pöyry, 2011).

But how much will this affect individual households' electricity bills? This was recently assessed by the Committee on Climate Change, in its analysis of the impact of meeting the 15 per cent renewable energy target by 2020 (CCC, 2011c). Should energy consumption remain the same<sup>17</sup>, electricity bills are estimated to rise from £430 in 2010 to £610 in 2020, i.e. by £180 per household on average. Of this, about £20 would be due to upgrades in transmission, distribution and metering, £90 would be due to support for renewables and carbon capture and storage, and £10 would be due to funding for energy efficiency measures. The rest would be related to increases in wholesale energy prices and VAT, which together would be about £60 – a third of the estimated increase (Figure 7).

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17 i.e. around 3,400 kWh per household, according to the Committee on Climate Change (2011c). This is also broadly in line with the most recent estimate by Ofgem (2011) used elsewhere in this policy brief, which is 3,300 kWh per household in 2011.

Figure 7. Projected increase in households' electricity bill, 2010-2020



Source: Own calculations based on CCC (2011c)

Future electricity bills, however, could be lower, depending on the effect of energy efficiency policies on households' consumption. Whether the full potential of these measures will be fully realised is still uncertain, but it is estimated that these could lead to a reduction in electricity consumption of up to 19 per cent by 2020. In such a case, the electricity bill of an average household is expected to increase by only £65, rather than £180 (CCC, 2011c).

By looking at the impact of renewable energy policies on households' bills, it is also possible to estimate the specific contribution of onshore wind to current and future bills.

The impact of renewables is embedded in the cost of the Renewables Obligation, the main subsidy mechanism for renewable energy (see Box 2). According to the Department of Energy and Climate Change, the contribution of the Renewables Obligation to an average household's electricity bill was about 0.5 p/kWh in 2011, and will rise to 1.1 p/kWh in 2020 (DECC, 2011b).

### Box 2. The UK Renewables Obligation

The Renewables Obligation (RO) was introduced in 2002 as a mechanism to incentivise large-scale (>5 MW) renewable electricity generation in the UK. The RO requires electricity end-suppliers to purchase a specific fraction of their annual electricity supply from producers using specific renewable technologies. The end-suppliers receive tradable Renewables Obligation Certificates (ROCs) for doing so. One ROC per MWh of renewable output is the default.

Currently, onshore wind installations receive 1 ROC per MWh, offshore wind installations receive 2 ROCs per MWh, and sewage gas-fired plants receive 0.5 ROC per MWh. The supplier can also 'buy out' the obligation by paying a set price per MWh, currently £38.69. The buy-out revenue is recycled to participating suppliers in proportion to their ROCs. Combined with the buy-out payments, the extra revenue from ROC sales effectively doubles the income for renewables generators. Together with annual increases in the RO target (12.4 per cent of supply in 2011/12, up from 11.1 in 2010/11), this drives investment in new renewables capacity. The cost of the RO is ultimately borne by energy users, as it is recouped by suppliers via higher energy prices.

The UK Government is currently reviewing the amount of support provided to different technologies through the scheme, and is due to announce the revised bands in summer 2012. The support for onshore wind is expected to be reduced from 1 to 0.9 ROCs per MWh from 2013.

From 2017 onwards, the RO will be gradually phased out (it will close completely in 2037) and will be replaced with a Feed-in Tariff with Contracts for Difference. These consist of long-term contracts between the Government and large-scale (above 5 MW) low-carbon generators. Feed-in tariffs are a key element of the Government's ongoing process of electricity market reform (DECC, 2011d). According to these contracts, when the generators sell electricity to the market, they either receive or make a payment based on the difference between the average market price and the tariff agreed in their contract.

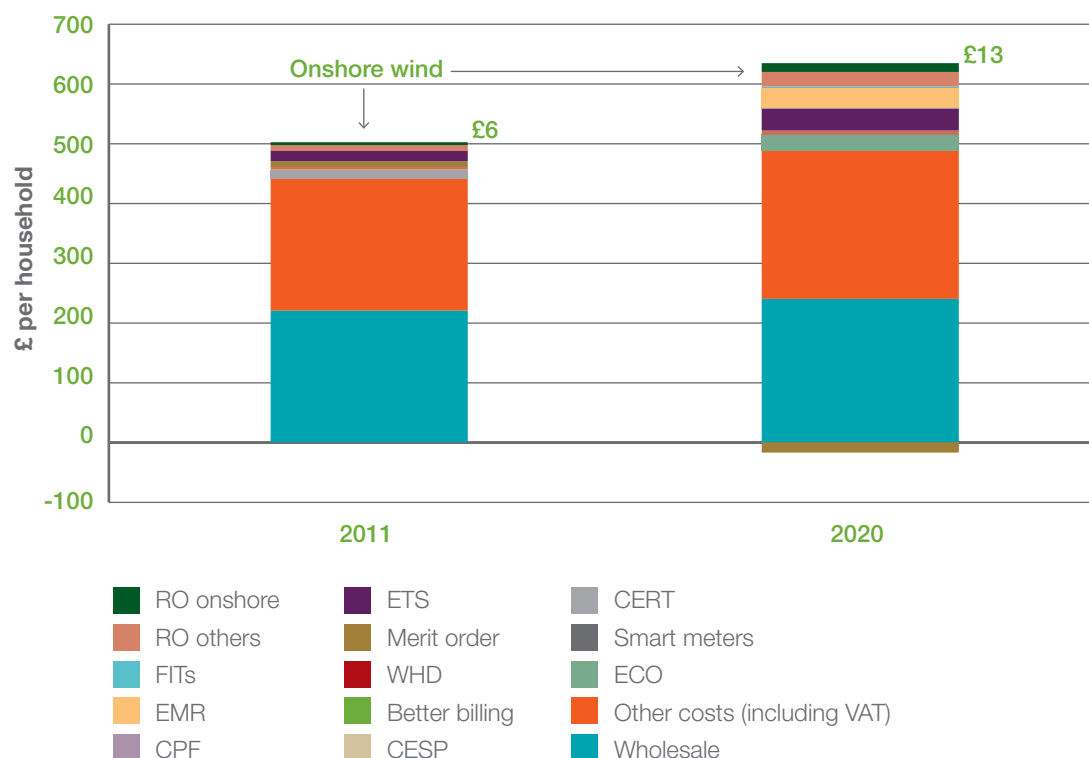
Using official estimates of future electricity consumption and generation capacity (DECC, 2011a; CCC, 2011a), and assuming an average ROC price of £45 per MWh, it is possible to obtain an indicative value for the contribution of onshore wind to the overall bill. This would be about 0.18p/kWh in 2011 and 0.37p/kWh in 2020. Assuming the average household consumption of electricity will remain unchanged at 3,400 kWh per year<sup>18</sup>, this would imply an additional annual cost of £6 in 2010 and £13 in 2020 (Figure 8).

Although this is only meant to provide an order of magnitude estimate (it does not take into account future contributions from feed-in tariffs for example), it can be inferred that onshore wind is but a small component of current and future electricity bills (1 per cent in 2011 and 2 per cent in 2020). If subsidies for onshore wind were reduced or removed (e.g. by reducing RO contributions for onshore wind to zero), as recently suggested<sup>19</sup>, the likely impact on household bills would be negligible. Conversely, electricity bills would go up if electricity generation from onshore wind was to be replaced by more heavily subsidised renewables.

18 The Department of Energy and Climate Change uses instead a higher estimate of 4,000 kWh. For consistency we adopt here an assumption used by the Committee on Climate Change (2011c). This is also more consistent with Ofgem's estimates – see footnote 17.

19 See for example: <http://www.telegraph.co.uk/earth/energy/windpower/9061554/Full-letter-from-MPs-to-David-Cameron-on-wind-power-subsidies.html>

Figure 8. Estimated impact of onshore wind and other energy and climate change policies on an average household electricity bill, 2011 and 2020



**Key:** RO onshore = Renewables Obligation for onshore wind; RO others = Renewables Obligation for other renewable technologies, including offshore wind, hydro, biomass, landfill gas etc.; FITs = Feed-in Tariffs; EMR = Electricity Market Reform; WHD = Warm Home Discount; CESP = Community Energy Saving Programme; CERT = Carbon Emission Reduction Target; ECO = Energy Company Obligation. Other costs include transmission, distribution and metering, and other supplier costs and margin.

**Note:** The total annual electricity bill is slightly higher than in Figure 7 (based on CCC, 2011c), because of different assumptions used in DECC (2011b).

**Source:** Calculation based on DECC (2011b).

If subsidies for onshore wind were reduced or removed [...] the likely impact on household bills would be negligible.

# 5. What are the environmental impacts of onshore wind?

An important objection to onshore wind developments has been their local environmental impact. This is a valid concern. The local environmental costs of energy production are as relevant to an economic evaluation as its global environmental costs (reflected in the price of carbon) and investment, maintenance and fuel costs. They need to be taken into account to understand fully the net impact of harnessing onshore wind power.

All forms of energy production have environmental side-effects. In the case of fossil fuel-based electricity, the main concerns, besides carbon emissions, are air pollution, water demand for cooling and the environmental effects of fuel production upstream (e.g. related to fracking for shale gas, coal mining or oil spills). Nuclear energy's impacts relate to radioactive waste and the risk of an accident. Hydro-electricity can have detrimental side-effects on water flows and the natural environment.

Most of these side-effects are absent from wind power developments. Unlike other generation sources, wind does not require significant amounts of water, produces little waste and requires no mining or drilling to obtain fuel (IPCC, 2011). It is true that, from a life-cycle perspective, wind energy is not entirely a zero-carbon technology, as some greenhouse gas emissions are generated during the manufacturing, transport, installation, operation and decommissioning of turbines. These, however, are considered to be very limited. Global estimates by the Intergovernmental Panel on Climate Change (IPCC, 2011) indicate that these are of the order of 8 to 20 gCO<sub>2</sub>/kWh. By comparison, the average emissions from power generation in the UK were around 540 gCO<sub>2</sub>/kWh in 2008 (CCC, 2010). In accordance with current accounting conventions, these emissions are measured and assigned to the activities where they occur (such as transport or steel production).

It has been argued that the emissions of a system strongly relying on intermittent renewables can be as high, or higher than those of a system running only on efficient gas turbines (e.g. as in Hughes, 2012; Lea, 2012). This claim is based on the assumption that wind power intermittency is managed entirely through back-up from part-loaded fossil fuel power stations which work less efficiently than gas turbines running alone (see Section 3). However, a study by Dale et al. (2003), for instance, calculated that if wind power supplied 20 per cent of electricity in 2020, the reduced efficiency of the gas back-up would only cut the emissions savings by 1 per cent.

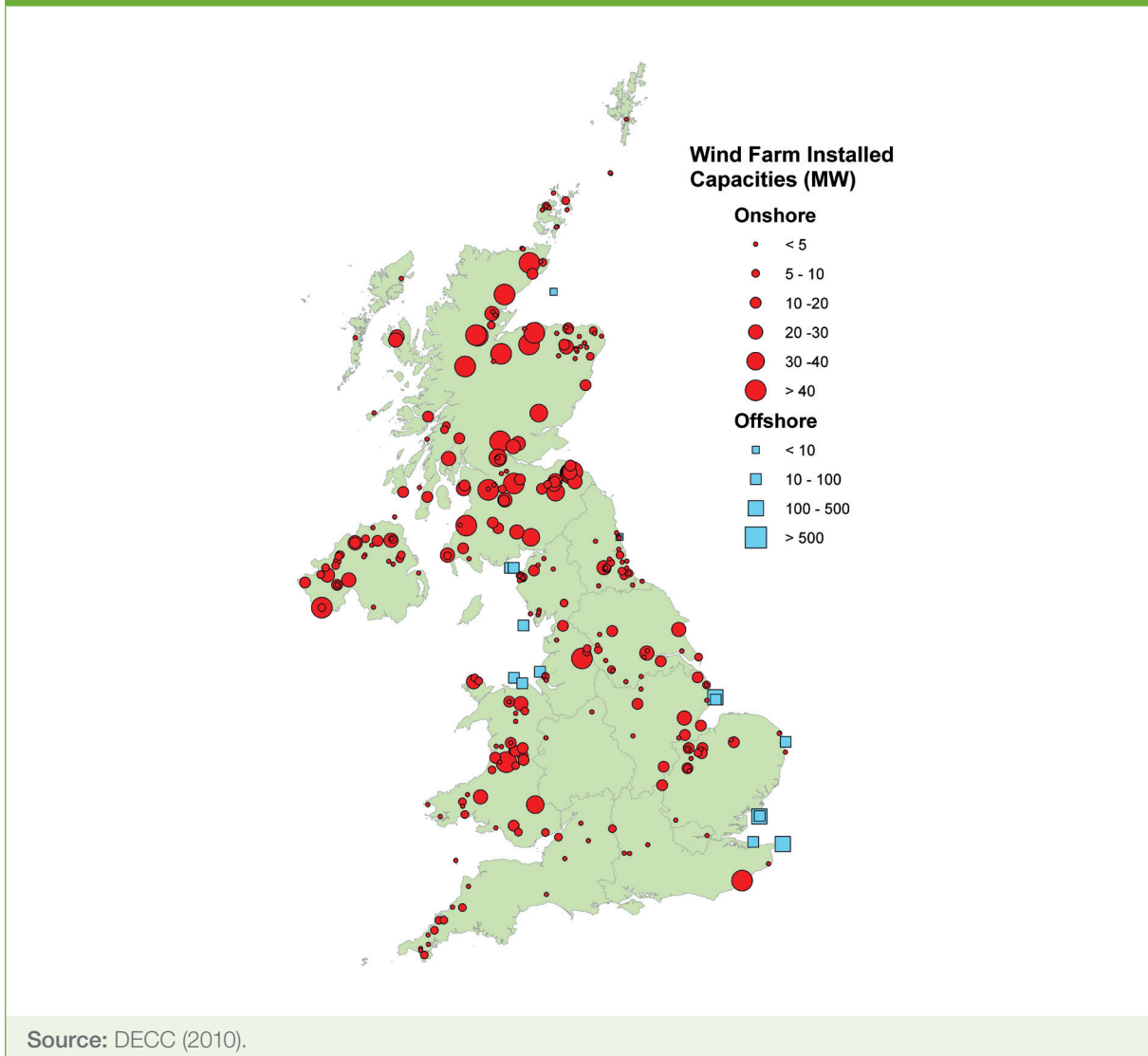
Estimates by Pöyry (2011) for the Committee on Climate Change show that, once the inefficiency of back-up capacity is taken into account, as well as other available measures to address intermittency<sup>20</sup>, a system in which 30 to 64 per cent of electricity is generated by renewable sources can still emit less than 50g of CO<sub>2</sub> per kWh in 2030. This is significantly less emissions-intensive than the most efficient gas combined-cycle turbines, which produce around 350 gCO<sub>2</sub> per kWh.

Nevertheless, the construction of wind turbines, their operation, and, importantly, their location, can have non-negligible impacts on the environment. Depending on their location (Figure 9), construction and operation, wind energy developments, both onshore and offshore, can affect landscapes, impact wildlife and lead to habitat and ecosystem modification.

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20 Assuming a 15 per cent flexible demand, 10 to 16 GW of interconnection and between 2.8 and 4 GW of bulk storage (Pöyry, 2011).

Figure 9. The location of onshore and offshore wind farms in the UK, December 2010



Visual impacts on land- and seascapes are perhaps the most important environmental cost of wind developments, and can affect large areas. This is not a feature of wind turbines only, as most large infrastructure projects, such as fossil fuel and nuclear power stations, can also have significant impacts on the landscape. Power stations, however, are usually more spatially contained, while onshore wind farms tend to be more spread out, running the risk of affecting a larger share of the population, especially in rural areas. The problem is also exacerbated by the fact that the areas with the best wind resources tend to include coastal and upland areas, many of which are of high aesthetic value.

The Sustainable Development Commission (SDC, 2005) highlighted how the visual impacts of wind installations are highly dependent on the areas from which the structures are seen (extent of visibility) and how they appear within these views (nature of visibility). For example, a development that is grouped into a tightly clustered array is usually visually more acceptable in open, undeveloped land. But in agricultural landscapes, rows of turbines may be visually acceptable where formal field boundaries are used as an existing feature. It is generally considered that fewer and larger turbines have a lower visual impact than a greater number of smaller turbines (Tucker et al., 2008).



Several studies have attempted to quantify the visual impact of wind energy and how this affects the value people attach to a landscape. According to one estimate, Norwegian households would be willing to pay up to £75-88 (€110-130) per year to replace wind power with hydropower (Navrud, 2004). Swedish households would be willing to pay £8 (€12) per year to move an onshore wind farm from mountains to lowland areas, and £18 (€29) per year to have it in an offshore location (Ek, 2002). In Spain, the impacts on flora, fauna and landscape associated with wind turbines were valued respectively at £13.4, £23.6 and £24.2 (€22, €37 and €38) per household per year (Alvarez-Farizo and Hanley, 2002). A study in Scotland estimated that households would be willing to pay £14 (€20) per year to reduce air pollution, £8 (€12) to reduce landscape impacts, and £4 (€6) to reduce impacts on wildlife (Bergmann et al., 2006)<sup>21</sup>.

These estimates are hard to generalise. They vary substantially according to the site considered (e.g. depending on the perceived biodiversity value), the valuation method used (e.g. stated or revealed preferences) and the development alternatives taken into account (e.g. expanding the capacity of existing hydro, building turbines offshore rather than onshore, or building new fossil fuel power plants). Further assumptions are also needed to translate estimates of negative impacts per affected households into costs per kWh of output.

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... people do attribute a value to nature and landscapes [...]. It is important that such values and preferences are taken into account in planning decisions.

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A simple estimate based on the figures cited here indicates that the willingness to pay could range from 0.3 to 4 p/kWh, depending on factors such as population density, the size of the area where wind turbines are a concern, the proximity to wind turbines, wind farm size and their output.<sup>22</sup> This would add between 3 and 60 per cent to the current levelised cost of onshore wind (which is 6.6 to 9.3 p/kWh, as in Figure 6). Environmental costs at the lower end of the range are unlikely to affect planning decisions, but at the upper end projects may be harder to justify. Although these are but indicative figures, it is clear that people do attribute a value to nature and landscapes, but that this varies substantially depending on local conditions. It is important that such values and preferences are taken into account in planning decisions.

Experience from Germany and Denmark, which have relatively large wind capacities (respectively 27,000 MW and 3,700 MW) compared with their overall electricity generation capacity, confirms that the involvement of local communities is crucial when developing new wind installations. Unlike the UK, where the majority of onshore wind projects are developed and owned by commercial companies, the majority of projects in Germany and Denmark (up to 80 per cent in Denmark) are characterised by a 'community ownership' model, where local communities pool resources to finance the purchasing, installation and maintenance of projects, and individuals are entitled to a share of the annual revenue that is proportional to their initial investment (CCC, 2011a).

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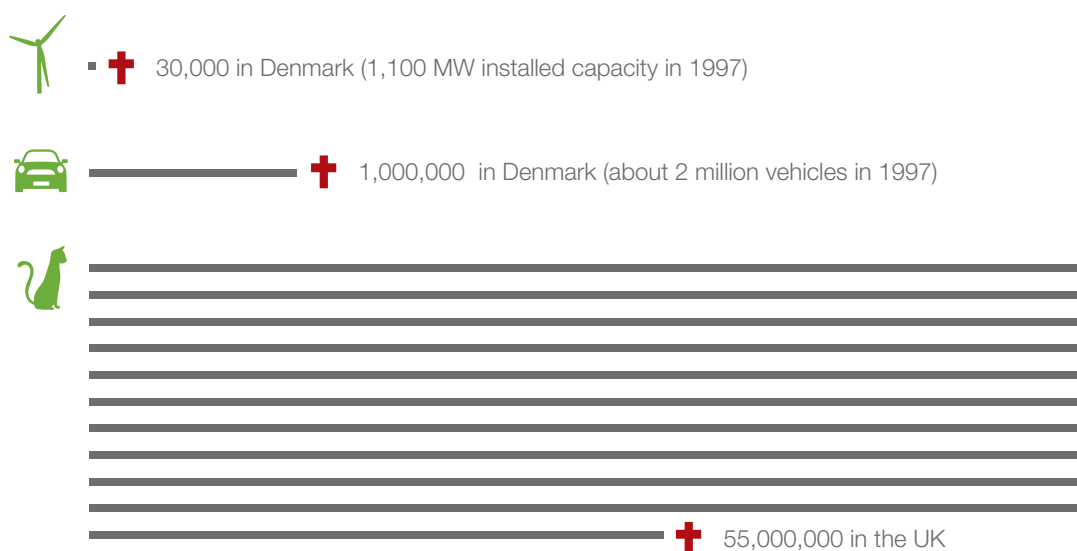
21 All values in € as in Ladenburg (2009). Annual average exchange rate €/£ used from <http://www.oanda.com/currency/average>

22 The main assumptions are as follows. If the population density in the affected area is 80-120 persons per km<sup>2</sup> and the development affects people within a 15-20 km radius, 14,000 – 38,000 households (of four persons each) are affected. The annual compensation per household is £24-75, according to the studies cited here (excluding outliers). In the case of a 30-50 MW development this can be spread over an annual output of 70-120 GWh.



In addition to landscape impacts, biodiversity and habitat impacts are also often quoted as a matter of concern, particularly bird fatalities due to collisions with wind turbines. The evidence, however, shows that these are quite low. Worldwide avian fatalities have been reported at between 0.95 and 11.67 per MW per year, and bat fatalities range from 0.2 to 53.2 per MW per year (IPCC, 2011). Assuming that the UK's onshore wind capacity will rise to 9,100 MW by 2020 (as in ENSG, 2012) bird fatalities could be between 9,600 and 106,000 per year. Although clearly undesirable, this is orders of magnitude lower than other anthropogenic causes of bird deaths. For example, 55 million birds are killed by domestic cats in the UK each year (McKay, 2008). In Denmark, about 30,000 birds were killed by wind turbines in 1997, while 1 million birds were killed by traffic (Andersen, 1998; see Figure 10). It should be noted that Denmark, at the time, had only about one fourth of the UK onshore wind capacity today – about 1,100 MW (Eurostat, 2012) versus 4,800 MW in the UK – and less than one-fifteenth of the vehicles – about 2 million in 1997 versus almost 32 million in the UK in 2008 (Eurostat, 2012). Although it is difficult to extrapolate from these data what the effects would be in the UK, it is clear that there is a significant difference in scale between the impact of wind turbines and of traffic on birds and that, if anything, in the UK this ratio might be even higher.

**Figure 10. Annual bird deaths in Denmark caused by wind turbines and cars and annual bird deaths in Britain caused by cats.**



Source: McKay (2008).

While collision mortality rates per turbine are relatively low, this does not mean that wildlife mortality is not important. It is indeed undesirable, especially when it affects rare and endangered species. And collision rates can also be much higher in poorly sited wind farms. Minimising risks through appropriate siting and avoiding habitats that are vulnerable or of high conservation importance should therefore be an important consideration in any planning decision.

A study investigating UK, Danish and German experiences confirms that, to create an effective planning system that respects concerns about nature conservation, whilst securing rapid onshore wind development, a number of requirements must be met. These include early engagement of stakeholders, clarity over nature conservation concerns and high quality environmental impact assessments (Bowyer et al., 2009). It is advisable that such elements are taken into account within the UK planning framework.

## 6. Conclusions: how onshore wind compares with other energy sources

When debating the merits and shortcomings of onshore wind power, it is important to remember the policy context within which these investments are considered. The UK has statutory commitments that require the rapid decarbonisation of electricity generation. Once this is recognised, the question of onshore wind becomes a choice between this and other low-carbon solutions. It is not a choice between onshore wind and fossil fuels. By the 2020s, even efficient unabated gas can play no more than a niche role in power generation.

Under the Climate Change Act (Her Majesty's Government, 2008), the UK is committed to reducing annual greenhouse gas emissions by 34 per cent by 2020 and 50 per cent by 2025, compared with 1990 levels. The Act has strong political support: it was passed near-unanimously by Parliament, as were the first four carbon budgets legislated under it. The Act and its provisions make environmental and economic sense. They put the UK on a sensible path towards a low-carbon economy.

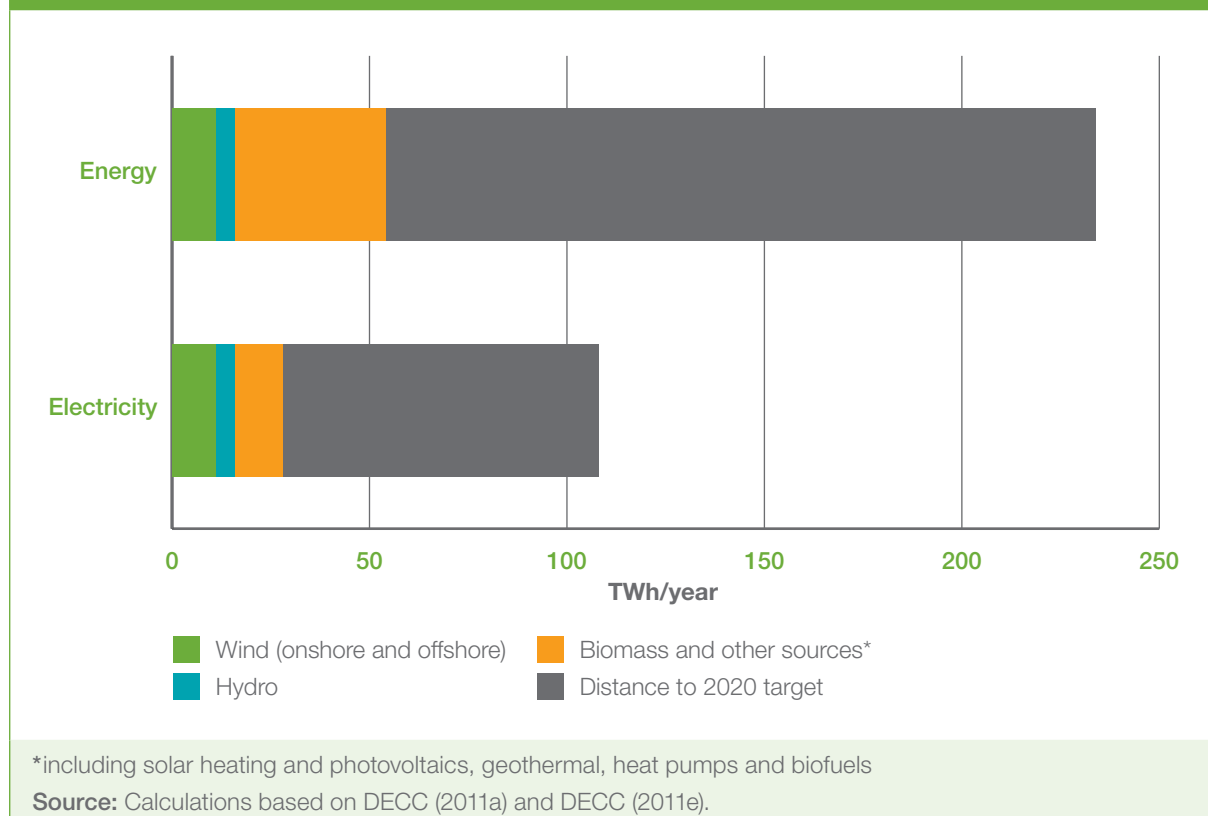
There is wide agreement that the long-term objectives of the Act cannot be met without the rapid decarbonisation of electricity generation. This in turn requires a significant increase in the uptake of low-carbon energy sources such as onshore wind and other renewables. The 2025 target (as per the fourth carbon budget) in particular would be out of reach with a power sector that is dominated by unabated gas (CCC 2010). It has been argued that efficient combined cycle gas power plants may be a cheaper way of meeting our 2020 carbon reduction targets (e.g. Hughes, 2012). However, the further decarbonisation required in the 2020s – when the carbon intensity of power generation has to fall to about 50 gCO<sub>2</sub>/kWh – cannot be achieved by a heavy reliance on unabated gas. The most efficient combined-cycle turbines emit about 350 gCO<sub>2</sub>/kWh. Evidence from the International Energy Agency (2011) shows that an increased share of natural gas in the global energy mix alone will not put the world on a greenhouse gas emissions path consistent with avoiding a rise in global average temperature of more than 2°C. Rational policy-makers need to anticipate this and avoid locking in high-carbon electricity generation over the coming years.

Taking a long-term view to 2025 can be difficult for policy-makers. However, over the medium term, the case for renewables is reinforced by another commitment. Under the EU Renewable Energy Directive (2009/29/EC), the UK has to increase the share of energy from renewables from currently 3.3 per cent (in 2010) to 15 per cent by 2020. The electricity sector is expected to play a significant role in this. By 2020 at least 30 per cent of electricity should be generated from renewable sources, and by 2050 the power sector will need to be almost completely decarbonised (Her Majesty's Government, 2011a).

In terms of absolute numbers, the UK Government estimates that, to meet the 2020 target, 234 TWh should come from a combination of renewable energy sources for electricity, heat and transport. Of this, 108 TWh should be accounted for by large-scale renewable electricity (DECC, 2011e). In 2010, renewable energy and electricity output were about 54 TWh and 28 TWh respectively (DECC, 2011a). It is therefore apparent that there is still a wide gap between the current situation and future objectives, as shown in Figure 11.

The choice between onshore wind and other forms of low-carbon electricity is more difficult to make. Many low-carbon technology combinations are conceivable, featuring different amounts of onshore wind, offshore wind, nuclear energy and, in the longer term, carbon capture and storage, wave and tidal energy or solar panels.

**Figure 11. Electricity and energy generation from renewable energy sources, 2010 levels and distance to the 2020 targets**



Much has been made of the intermittent nature of wind (and other renewables), which cannot produce electricity reliably on demand. However, the cost penalty and grid system challenges of intermittency are often exaggerated (e.g. in Hughes, 2012). The Committee on Climate Change has found that even very high levels of renewable energy penetration are technologically feasible and at a cost that will be lower than for other renewables and, likely, competitive with fossil fuel prices within a few years (CCC 2011a). A combination of smart transmission and distribution systems, interconnection to other energy markets, energy storage, load management and flexible demand measures can address the problem. The main concerns in choosing the best energy technology mix are not network stability, but economic costs and environmental side-effects.

The key advantage of onshore wind over other low-carbon forms of electricity generation is cost. Onshore wind is much cheaper than offshore wind and other renewables, and will remain so for some time. Onshore wind already supplies 28 per cent of the electricity generated by renewables (DECC, 2011a). Given the abundant wind resources available in the UK, and the technological maturity of onshore wind technology, onshore wind represents an economically attractive option for the transition towards a low-carbon future and would put less pressure on fuel bills. This is important at a time of heightened sensitivity about the cost of green policies and their impact on fuel poverty.

However, onshore wind raises potential local environmental issues, particularly through its visual impact. People value natural landscapes and are willing to pay to preserve them, even if the impact of wind farms on wildlife are sometimes exaggerated. Reducing the amenity value of nature (a measure of the associated benefits of living in or near to desirable natural areas or resources), constitutes a real economic cost that needs to be taken into account. There are environmental limits to onshore wind development. Turbines should not be allowed in areas of outstanding natural beauty or high ecological value, or, more generally, in any area where the full economic value of the local environment is very high.

There will also be cases where local populations object to a development not because its environmental costs are too high, but because they are not sufficiently compensated. In a typical UK wind project, the benefits accrue nationwide (to a project developer and ultimately electricity consumers), while the environmental side-effects are borne locally. In these circumstances local opposition should not come as a surprise, and the response should be appropriate benefit-sharing, rather than outright rejection. Such local environmental constraints can make more expensive renewable technologies – such as offshore wind or solar photovoltaics – potentially attractive. One can think of the extra cost of offshore wind as the premium society is willing to pay to avoid the local environmental cost of onshore wind.

However, when making technology choices it is important to factor in the environmental and social impacts of all of the alternatives considered. Most energy sources have environmental side-effects, including, for instance, land use and habitat change (e.g. by open cast coal mining, tidal barrages, biomass and biofuels), visual impacts (e.g. to coastal landscapes, caused by offshore wind farms), disturbance (e.g. related to seismic surveys for oil and gas production), infrastructure construction (such as new power plants and transmission systems), air and water pollution (e.g. from oil spills, acid mine drainage from coal pits, biofuels and eutrophication impacts from nitrogen oxides from coal power stations), and the accidental killing of wildlife (e.g. by power lines and tidal barrages) (Tucker et al., 2008).

Given the economic and environmental trade-offs, technological uncertainty, and the absence of one clearly superior solution, the best approach seems to be a portfolio of different energy technologies to balance the cost to consumers and environmental concerns. Onshore wind has a role in that mix, even though the local environmental issues are ultimately a constraint.

This policy brief has not reviewed the regulatory environment, but it is clear that adequate policies can make onshore wind less risky and more attractive to investors and local communities alike. There are a number of regulatory measures that can help to encourage onshore wind developments where they make sense and prevent them from happening where they do not. These include:

- A clear price on carbon that underlines the relative merit of wind (and other low-carbon forms of power production) vis-à-vis hydrocarbon-based fuels.
- A planning system that (i) reduces the costs and uncertainties to project developers, thus making project development more efficient; (ii) factors in local environmental concerns and prevents developments in important environmental areas; and (iii) ensures appropriate benefit-sharing (compensation) in areas where local impacts are acceptable.
- Flanking measures to ensure that the electricity system can cope with intermittent resources, including adequate and sufficiently smart transmission and distribution systems, interconnection to other energy markets, energy storage, load management and flexible demand measures, as well as an adequate combination of fossil fuel (ultimately with carbon capture and storage) and renewable sources to ensure balancing and the ability to meet peak demand.

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# Glossary

Term	Definition
<b>Annuitise</b>	To convert the capital cost of an investment (e.g. the cost of building a wind farm) into an equivalent stream of annual costs, spread over the lifetime of the investment.
<b>Back-up capacity</b>	A back-up reserve of electricity used when there is a major surge in demand and/or when electricity from intermittent renewable sources such as wind and solar are not in sufficient supply. This is usually referred to as 'back-up capacity' (or 'stand-by capacity' or 'system reserves') when designed to maintain a given level of reliability, and 'balancing reserves' when used for ensuring system balancing. It is typically provided by gas-fuelled power stations whose electricity output can be increased and decreased relatively quickly in response to demand.
<b>Balancing supply impacts</b>	The rapid adjustments needed to manage electricity fluctuations over a short time period, so that demand and supply are in balance.
<b>Bulk storage</b>	Converting electrical energy into another form of energy when demand is lower than supply, and converting it back to electricity when the system requires it. In the UK, storage capacity is currently largely made up of pumped storage (based on water reservoirs). In the longer term, new storage opportunities are expected to emerge, such as compressed air and heat storage in molten salts.
<b>Carbon budget</b>	<p>A legally-binding limit on greenhouse gas emissions in the UK for a five-year period. Each carbon budget provides a total cap on emissions, which should not be exceeded in order to meet the UK's emissions reduction commitments under the 2008 Climate Change Act.</p> <p>The fourth carbon budget, developed by the Committee on Climate Change, was set in law in June 2011 to cover the period 2023-7 (DECC, 2012b). It commits the UK to a 50 per cent reduction in annual greenhouse gas emissions, compared with the 1990 baseline for each year that is covered by the fourth carbon budget (Her Majesty's Government, 2011b). This equates to 1950 million tonnes of carbon dioxide equivalent for 2023-2027 (Her Majesty's Government, 2011b).</p>
<b>Carbon price</b>	A cost applied to carbon pollution. Essentially a 'damage cost' applied to goods and services which produce greenhouse gases – the impacts and costs of which will be felt by future generations. Can be administered through a carbon tax or cap and trade system (Bowen, 2011).
<b>Discounting</b>	Discounting is the process of determining the present value (i.e. the value today) of future financial flows (costs, benefits). The discount rate reflects the social preferences for current as compared with future uses. In a simple economic model it also equals the opportunity cost of capital, i.e. the alternative return an investment might earn. For example, if capital can earn a return of 10 per cent per annum, a future revenue of £110 in a year's time is equivalent to £100 today.

Term	Definition
<b>Gross final energy demand</b>	The total energy consumed by end-users, such as households, industry and agriculture, as well as the consumption of electricity, and heat used by the energy sector for electricity and heat production. Also includes losses of electricity and heat in distribution and transmission.
<b>Intermittent supply</b>	Refers to the variability in supply of electricity from some renewable technologies such as wind turbines, where the ability to reliably produce electricity varies depending on external conditions over which the operator has no control – such as wind speed (for wind energy) or amount of sunlight (for solar energy).
<b>Levelised costs</b>	<p>The average cost of producing electricity over the lifetime of a generation plant, and therefore the price at which electricity must be sold to consumers for the supplier to break-even (excluding taxes and subsidies).</p> <p>It is calculated by dividing the lifetime capital and operational costs of a power source by the total value of the electricity it generates, both discounted through time. It is usually expressed in units of currency per kWh or MWh, for example p/kWh or £/MWh.</p>
<b>Load factor</b>	The average hourly quantity of electricity generated as a percentage of the average capacity of an installation at the beginning and end of a year.
<b>Load management</b>	The active control of electricity users' load, i.e. the amount of energy they require, in response to power market conditions. For example, suppliers can influence electricity use through electricity prices (e.g. imposing higher prices during high demand periods), or can be given a degree of remote control over some users' facilities (e.g. industrial refrigeration).
<b>Pumped storage</b>	Where water is pumped from low to high elevation reservoirs in order to store energy. When energy supply is needed, water is released through turbines which produce electricity (CCC, 2012).
<b>Onshore wind</b>	A renewable energy technology, where wind turbines are located on land to harness the energy of moving air, to generate electricity.
<b>Offshore wind</b>	A renewable energy technology, where wind turbines are located out at sea or in freshwater to harness the energy of moving air, to generate electricity.
<b>Reliability impacts</b>	The extent to which an electric system is able to provide sufficient output to meet peak demand.
<b>Renewables obligation</b>	Introduced in 2002 by the UK government to incentivise renewable energy technology deployment. It requires electricity companies to source a proportion of their commercial supply from renewable sources – via the setting of annual obligation targets, which rise year on year. Where annual targets are not met, companies are fined accordingly – also referred to as the buy-out price (DECC, 2012c).
<b>Smart grid</b>	A future version of our current electricity grid system, which aims to enable more efficient and cost-effective delivery of electricity, by applying information and communications technologies (ICT) to the electricity system. Such technologies enable suppliers to gather real-time data on power generation and demand and to adjust the system accordingly (DECC, 2009).
<b>Unabated gas</b>	Gas from power plants built without carbon capture and storage, a technology which captures carbon dioxide emitted from fossil fuel plants.

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